



**BUSITEMA
UNIVERSITY**
Pursuing Excellence



**BUSITEMA UNIVERSITY
FACULTY OF ENGINEERING
DEPARTMENT OF AGRICULTURAL MECHANIZATION AND IRRIGATION
ENGINEERING
FINAL YEAR DISSERTATION
APPLICATION OF SWAT MODEL IN WATER RESOURCES ASSESSMENT TO
GUIDE IRRIGATION DEVELOPMENT IN MALABA SUB CATCHMENT, UGANDA.**

BY

NAME: **ADONGO OWORA LEO**

REG NO: **BU/GS16/MID/1**

ADVISORS

Dr. MUSINGUZI WILSON BABU

Dr. SAMSON RWAHWIRE

This master's thesis is submitted to the Directorate of Graduate School in partial fulfillment of the requirements for the award of the Degree of Master of Science in Irrigation and Drainage Engineering (MID) of Busitema University

September 2019.

ADONGO OWORA LEO BU/GS16/MID/1

ABSTRACT

Human population increase, economic development, climate change and other drivers alter water resources availability and use resulting in increased risks of extreme low and high flows, drastically altered flow regimes, threats to water quality and water demands surpassing renewable supply.

In this research, water resources assessment of river Malaba sub-catchment was carried out using SWAT model, Irrigation Water requirement of rice crop determined using the CROPWAT 8.0 software, border strip irrigation design carried out accompanied with a simulation of border strip irrigation hydraulics using WinSRFR 4.1.3 software and the suitable sites for location of valley tanks executed using Multi criteria decision analysis in GIS environment. A sensitivity analysis was done in SWATCUP using observed data for 497 simulations. The 10 most sensitive parameters were used for calibration and validation of the model in SWAT-CUP using SUFI-2. SWAT model performance was based on the R^2 and NSI values of both calibration and validation. The R^2 value of 0.93 and 0.90 for calibration and validation respectively were obtained. The NSI of 0.90 and 0.89 for calibration and validation respectively were also obtained.

The crop water requirements were determined using 15year climatic data using CROPWAT 8.0, A gross irrigation requirement (GIR) of 29.76mm was obtained and IWR of each command area. A border strip irrigation system for the rice crop was designed and simulated using WinSRFR 4.1.3 software and an economical and hydraulically efficient trapezoidal channel was designed. Application efficiency of 59% and percentage runoff of 32% were generated from WinSRFR 4.1.3.

The suitable sites for location of valley tanks was done using a multi criteria decision analysis and pairwise comparison made for each criterion considered. These suitable sites were Kisoko, Ongere, Nawire, Nakwiga and Paya villages in Tororo district, Buyunda and Bugalama in Busia district and Butema, Namukonge and Bugalama in Bugiri districts.

Different blocks of irrigation command areas were delineated in arc GIS 10.1 using a multi criteria decision analysis and pairwise comparison made for each criterion considered. The delineated command area blocks were 5 having a total area of 7,835 hectares. 2 blocks can be irrigated by direct abstraction from river Malaba by gravity flow. 3 blocks can be irrigated by using valley tanks.

DECLARATION

I **ADONGO OWORA LEO**, declare that this dissertation is my own, original piece of work and has never been presented in any University/institution for an award. I further attest that the research carried out is unique and has never been conducted in the same area in Uganda.

NAME: **ADONGO OWORA LEO**

REG NO.: **BU/GS16/MID/1**

SIGNATURE: 

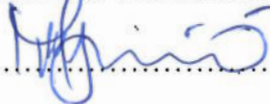
DATE: **11/9/2019**



APPROVAL

This is to certify that this dissertation was written by my own efforts under the guidance of advisors on the topic “**Application of The Soil and Water Assessment Tool (SWAT) Model in Water Resources Assessment to Guide Irrigation Development in Malaba Sub Catchment, Uganda.**” and is now ready for submission to the Department of Agricultural Mechanization and Irrigation of Busitema University.

Dr. MUSINGUZI WILSON BABU

Sign: 

DATE: 12/09/2019

Dr. SAMSON RWAHWIRE

Sign: 

DATE: 12/09/2019

ACKNOWLEDGEMENT

I appreciate the Ministry of Water and Environment for the scholarship to study this Master's Degree under the capacity Building programme. I thank the management and staff of the department of Agricultural Mechanization and Irrigation Engineering of Busitema University for the adequate support to the programme. Special thanks to my advisors Dr. Musinguzi Wilson Babu, Dr. Samson Rwahwire and Eng. Mohamed Badaza for guidance during this research.

DEDICATION

This dissertation is dedicated to my children (Gloria, Michelle and Francis) and their beloved Mom Wafula Bilha.

ABBREVIATIONS AND ACRONYMS

ARS	Agricultural research service
CWR	Crop water requirement
DEM	Digital Elevation Model
DSS	Decision Support System
EPA	Environmental Protection Agency
FAO	Food and Agricultural Organization
GIS	Geographic/Geospatial Information Systems
GoU	Government of Uganda
HRUs	Hydrologic Response Units
IDP	Internally Displaced Persons
IFAD	International fund for Agricultural development
ILO	International Labor Organization
NARO	National Agricultural Research Organization
NDP	National Development Plan
NSI	Nash – Sutcliffe Index
NUARP	Northern Uganda Agricultural Recovery programme
QGIS	Quantum geographical information system
QSWAT	Quantum soil and water assessment tool
RALNUC	Restoration of Agricultural Livelihood in Northern Uganda
RAM	Readily Available Moisture
SCS-CN	Soil conservation service- Curve number
SCS-CN	Soil Conservation Service Curve Number
SDGs	Sustainable Development Goals
SDSS	Spatial decision Support System
SMCE	Spatial Multiple Criteria Evaluation
SMDA	Spatial Multiple Decision Analysis
SMM	Sio-Malaba-Malakisi

SNHT	Standard Normal Homogeneity Test
SUFI-2	Sequential Uncertainty Fitting
SWAT	Soil and water assessment tool
SWAT-CUP	SWAT Calibration Uncertainty Procedure
TFR	Total fertility rate.
UKAID	United Kingdom Agency for International Development
UN	United Nations
USAID	United States Agency for International Development
USDA	United states department of agriculture
WEAP	Water Evaluation and planning system
WLC	Weighted Linear Combination.

LIST OF FIGURES

Figure 2.1: Program structure for Climwat and Cropwat software	24
Figure 3.1: Rainfall and evapotranspiration.....	39
Figure 3.2: Double mass curve for rainfall	44
Figure 3.3: Double mass curve for flow	45
Figure 3.4: Graph of Pettitt's homogeneity test for rainfall	48
Figure 3.5; Graph of SNHT for rainfall.....	51
Figure 3.6: Rainfall Distribution.....	59
Figure 3.7: Flow diagram for hydrological assessment of the sub- catchment using SWAT model	61
Figure 3.8: Conceptual diagram for evaluating the SWAT model.....	70
Figure 3.9: Conceptual Flow chart of designing border strip irrigation using WinSRFR software and GIS	75
Figure 3.10: Conceptual diagram for sites location of valley tank.....	82
Figure 4.1 : Patterns of rainfall for Tororo station.....	89
Figure 4.2 : Annual Flows of Malaba River.	90
Figure 4.3 : Representation of water balance of the sub catchment	91
Figure 4.4: Average annual precipitation from 1982 to 2013.....	92
Figure 4.5: Average annual runoff from 1982 to 2013	93
Figure 4.6: River Malaba sub-catchment Calibration output.....	96
Figure 4.7: River Malaba Sub-Catchment Validation output.....	96
Figure 4.8: Average monthly-flows against irrigation water requirement.....	102
Figure 4.9: Average monthly flows against irrigation water requirement for total command area	103
Figure 4.10: Flow duration curve for Malaba river	103
Figure 4.11: Slope of block 5 at the command area.	104
Figure 4.12: Summary of border strip irrigation design outputs from WinSRFR software.	107
Figure 4.13: Border strip irrigation hydraulics	108
Figure 4.14: Schematic drawing of the trapezoidal channel.....	111
Figure 4.15: Layout of the border strip irrigation scheme.....	111
Figure 4.16: Water Abstraction points from R. Malaba	118
Figure 4.17: Conceptual diagram of valley tank and irrigation system	120
Figure 4.18: Plan Layout of Valley Tank and related components at Block 5.....	121
Figure 4.19: Spillway cross-section at Block 5	121
Figure 4.20: Longitudinal section through the tank at Block5	122
Figure 4.21: Plan for masonry steps	122
Figure 4.22: Fence gate plan drawing and dimension	122
Figure 4.23: Pump house plan	123
Figure 4.24: Pump curve for grundfos SQF 8A-5 pump	125

LIST OF TABLES

Table 2.1: Comparison of the three semi- distributed models.....	8
Table 2.2: Cropwat inputs and outputs	25
Table 2.3: Commonly used values of manning's coefficient, n in surface irrigation.	28
Table 2.4: Area and hydraulic radius calculations for the three channel types.	29
Table 2.5: Typical border strip dimensions in meters as related to soil type, slope, irrigation depth and stream size.	30
Table 3.1: SWAT model data inputs and their respective outcomes.	43
Table 3.2: Statistical summary for rainfall data.....	47
Table 3.3: Monte Carlo simulation results of Pettitt's test for rainfall data.....	47
Table 3.4: Monte Carlo simulation results of SNHT for rainfall data.....	48
Table 3.5: SNHT output of rainfall data for Malaba sub-catchment from 1979 to 2013.....	50
Table 3.6: Statistical summary for temperature data.....	51
Table 3.7: Monte Carlo simulation results of Pettitt's test for temperature data.....	52
Table 3.8: Monte Carlo simulation results of SNHT for temperature data.....	52
Table 3.9: Statistical summary of relative humidity data.....	53
Table 3.10: Monte Carlo simulation results of Pettitt's test for relative humidity data.....	53
Table 3.11: Monte Carlo simulation results of SNHT test for relative humidity data.....	54
Table 3.12: Statistical summary for solar radiation data.....	55
Table 3.13: Monte Carlo simulation results of Pettitt's test for solar radiation data.....	55
Table 3.14: Monte Carlo simulation results of SNHT for solar radiation data.....	56
Table 3.15: Statistical summary for wind speed data.....	57
Table 3.16: Monte Carlo simulation results of Pettitt's test for wind speed data.....	57
Table 3.17: Monte Carlo simulation results of SNHT for wind speed data.....	58
Table 3.18: Criteria used in the valley tank site selection, buffer zone and classes.....	77
Table 3.19: Irrigation Command area blocks and their respective sizes.....	83
Table 4.1: Parameters from sensitivity analysis and their ranks.....	94
Table 4.2: Monthly ETo from CROPWAT 8.0.....	97
Table 4.3: Monthly rain from CROPWAT 8.0.....	98
Table 4.4: Kc for rice from CROPWAT 8.0.....	98
Table 4.5: Soils data from CROPWAT 8.0.....	99
Table 4.6: Crop water requirement.....	99
Table 4.7: Rice irrigation schedule.....	100
Table 4.8: Irrigation water requirements for different blocks of irrigable land.....	101
Table 4.9: Values of the pairwise comparison matrix.....	112
Table 4.10: Weighted values of the pairwise criteria and their influence.....	113
Table 4.11: Values of the pairwise comparison matrix for command area location.....	115
Table 4.12: Weighted values of the pairwise criteria and their influence for command area location.....	116
Table 4.13: Command area acreage and their centroid coordinates.....	116

Table 4.14: Abstraction points from river Malaba and blocks to irrigate..... 118
Table 4.15: Water demands to be stored..... 119
Table 4.16: Dimensions of various components of the valley tank at block 5 119

LIST OF MAPS

Map 3.1: showing the districts within which R. Malaba sub-catchment is located.....	36
Map 3.2: Rivers in the districts within which Malaba sub-catchment is located.	37
Map 3.3 Malaba-sub catchment and the district within which it's found.....	38
Map 3.4 : DEM for districts within Malaba sub-catchment	63
Map 3.5 : Delineated Malaba sub catchment.....	64
Map 3.6: Land use map of the districts within Malaba sub-catchment.	66
Map 3.7: Soils in the districts within Malaba sub-catchment.....	67
Map 3.8: Irrigation Command area blocks	84
Map 4.1 : Showing the delineated sub catchment sub basins and stream network	90
Map 4.2: Soil type at the command areas in the sub catchment.....	105
Map 4.3: Showing suitable sites for location of valley tanks	114
Map 4.4: Potential Irrigation Command Areas in Malaba Sub Catchment.....	117

TABLE OF CONTENTS

ABSTRACT	i
DECLARATION	ii
APPROVAL.....	iii
ACKNOWLEDGEMENT	iv
DEDICATION	v
ABBREVIATIONS AND ACRONYMS.....	vi
LIST OF FIGURES.....	viii
LIST OF TABLES.....	ix
LIST OF MAPS	xi
TABLE OF CONTENTS	xii
CHAPTER ONE: INTRODUCTION.....	1
1.1 Background.....	1
1.2 Problem statement.....	2
1.3 Main Objective.....	2
1.3.1 Specific Objectives.....	2
1.4 Research questions	2
1.5 Significance of the study.....	3
1.6 Scope of the study:	3
CHAPTER TWO: LITERATURE REVIEW.....	4
2.1 Surface water resources assessment.....	4
2.2.1 Approach to Assessment	4
2.2.2 Water resources assessments for irrigation projects:	4
2.3 Water resources assessment models.....	7
2.3.1 Hydrological Model Selection	7
2.3.2 Soil and water assessment tool (SWAT) Model.	8
2.3.3 Sensitivity analysis of swat model parameters.....	9
2.3.4 Calibration of SWAT Model.....	10
2.3.5 Validation of SWAT model	11
2.4 The drainage network patterns of Malaba sub-catchment	12

2.5 Hydrological Data Preparation and Processing.....	12
2.5.1 The Double-Mass Curve	12
2.5.2 Application to Hydrologic Data	13
2.5.3 Checking Consistency of hydrological data.....	13
2.6 Homogeneity Testing of Datasets	13
2.6.1 Alexanderson's Standard Normal Homogeneity Tests (SNHT).....	13
2.6.1.1 Application of SNHT in the production of homogeneous data sets.....	15
2.6.2 Pettitt's test.....	16
2.6.3 Buishand's test	17
2.6.4 Von Neumann's Ratio Test	19
2.7 Irrigation.....	20
2.7.1 Irrigation Requirement	21
2.7.1.1 Net Irrigation Requirement	21
2.7.2 CROPWAT	22
2.8 Irrigation System Design.....	26
2.8.1 Design of surface irrigation system.	27
2.8.1.1 Design of Border strip irrigation.	31
2.9 Introduction to valley tanks.....	32
2.9.1 Site location Selection of valley tanks	34
CHAPTER THREE: MATERIALS AND METHODS	36
3.1 Description of the study area.....	36
3.1.1 Location.....	36
3.1.2 Physical characteristics	39
3.1.2.1 Topography and climate.....	39
3.1.2.2 Geology and Soils	40
3.1.2.3 Water resources systems	41
3.1.3 Socio-Economic conditions of the sub catchment	42
3.1.3.1 Demography.....	42
3.1.3.2 Major economic activities in the sub catchment	42
3.2 Research methods.....	42
3.2.1 Data Collection.....	42

3.2.2 Data preparation and processing	44
3.2.2.1 Consistence Check for Climatic Data	44
3.3 Homogeneity Test for Climatic Data	47
3.3.1 Homogeneity test for rainfall	47
3.3.2 Homogeneity test for Temperature	51
3.3.3 Homogeneity test for relative humidity	53
3.3.4 Homogeneity test for solar radiation	54
3.3.5 Homogeneity test for wind speed	56
3.3.6 Gap filling in stream flow data.....	59
3.4 Materials.....	60
3.4.1 GIS for watershed modelling.....	60
3.4.2 SWAT Model Setup.....	62
3.4.3 Model Calibration	68
3.4.4 Validation of SWAT model	68
3.4.5 Collating and evaluating the model outputs.....	69
3.3.5.1 SWAT model performance evaluation.....	69
3.4.6 Determination of Irrigation Water Requirement.....	70
3.5 Irrigation system design	73
3.5.1 Design of border strip irrigation system.....	73
3.5.1.1 Design of the irrigation channel (Trapezoidal channel).....	75
3.6 Determining the most suitable site for Valley tanks as storage infrastructure.....	76
3.6.1 Selection of valley tank site Criteria	76
3.6.2 Deriving Dataset and Attributes and Standardization.....	78
3.6.3 Assignment of Weight.....	79
3.6.4 Overlaying of Weighted Criteria to Develop Suitability Index.....	80
3.6.5 Selecting the Best Site.....	81
3.6.6 Delineation of irrigation command areas.....	83
3.7 Designing the Valley Tank and Related Components	85
3.7.1 Reservoir Capacity and Dimensions.....	85
3.7.2 Sedimentation tank/ Silt trap.....	86
3.7.3 Spillway.....	86

3.7.4 Water abstraction facilities.....	86
3.7.5 Fencing	87
3.7.6 Estimation of the Water Losses from the Reservoir.	87
3.7.7 Freeboard.....	87
3.7.8 Valley tank slopes.	88
CHAPTER FOUR: RESULTS AND DISCUSSIONS.....	89
4.1 Introduction.....	89
4.2 Rainfall Seasonality Analysis.....	89
4.3 Stream flow	90
4.4 SWAT Modelling.....	90
4.4.1 Hydrological analysis of the catchment	91
4.5 SWATCUP work.....	93
4.5.1 Sensitivity Analysis.....	93
4.5.2 Model Calibration	95
4.5.3 Validation of SWAT model	96
4.5.4 Collating the Model Outputs.....	97
4.6 Irrigation Requirement Using Cropwat 8.0.....	97
4.6.1 Irrigation water requirement determination	100
4.7 Designing the border strip irrigation system.....	104
4.7.1 Determining WinSRFR 4.1.3 input parameters:	105
4.7.2 Results from WinSRFR 4.1.3 (border strip irrigation).....	106
4.7.3 Design of the conveyance channel.....	109
4.8 Locating the Most Suitable Site for valley tank Using GIS and Google Maps.	112
4.8.1 Delineation of Irrigation Command Areas.....	115
4.9 Reservoir capacity and dimensions.....	119
CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS.	127
5.1 Conclusion.....	127
5.2 Recommendations	127
REFERENCES.....	128

CHAPTER ONE: INTRODUCTION

1.1 Background

Water is essential for human, animal and plant life. It supports all aspects of human livelihood. The past two decades have witnessed increasing global concern about the need for sustainable water and land management in an era of rapid change in land and water resources, and persistent water and food insecurity (Pahl-wostl *et al.*, 2013). Human population increase, economic development, climate change and other drivers alter water resources availability and use resulting in increased risks of extreme low and high flows, drastically altered flow regimes, threats to water quality, water demands surpassing renewable supply and famine that has become a common problem for the communities.

The quantity, quality and timing of water flows required to sustain ecosystems and the valuable services they provide are referred to as environmental flows (Securing Water for Ecosystems and Human Well-being: The Importance of Environmental Flows, 2006). For river and wetland ecosystems, the flow regime is the most important determinant of ecosystem function and services provided by these functions. Flow features are determined by river size, geology, climate variation, topography and vegetation cover. The different components of an environmental flow regime contribute to different ecological processes. For instance, base flows help maintain water table levels in the flood plain and soil moisture for plants, high pulse flows shape the character of river channels and large floodplain aquifers. The water resources availability assessment requires detailed analysis of these hydrological processes.

An appropriate valley tank site location for storage of runoff from the sub-catchment for irrigation is fundamental. A suitable valley tank site location involves sensible decision making process comprising of various considerations of factors and criteria (Stemn and Kumi-boateng, 2016). It's evident that the factors considered for the valley tank site selection and also the physical appearances of the area are fundamentally geospatial in nature. This necessitates the use of GIS tools, concepts and technology in managing this data (Stemn and Kumi-boateng, 2016).

In this study, GIS, a Multi Criteria Decision Analysis (MCDA) technique has been preferred as a possible way of making optimal decisions in selecting a suitable site for valley tank location and SWAT tool has been used to assess the amount of runoff generated that can fill the identified valley tank sites.

REFERENCES

- Alexandersson, H. and Moberg, A. (1997) 'HOMOGENIZATION OF SWEDISH TEMPERATURE DATA . PART I : HOMOGENEITY TEST FOR LINEAR TRENDS', 17, pp. 25–34.
- Arnold, J. G. *et al.* (2012) 'SWAT : Model use , calibration , and validation'.
- Baker, Tracy J and Miller, S. N. (2013) 'Using the Soil and Water Assessment Tool (.SWAT) to assess land use impact on water resources in an East African watershed', 486, pp. 100–111.
- Baker, T. J. and Miller, S. N. (2013) 'Using the Soil and Water Assessment Tool (SWAT) to assess land use impact on water resources in an East African watershed', *Journal of Hydrology*, 486, pp. 100–111. doi: 10.1016/j.jhydrol.2013.01.041.
- Beven, K. (2012) 'Hydrological Similarity, Distribution Functions and Semi-Distributed Rainfall–Runoff Models', *Rainfall-Runoff Modelling*, pp. 185–229. doi: 10.1002/9781119951001.ch6.
- Beven, K. J. (2000) 'On the future of distributed modelling in hydrology.', *Hydrological Processes*, 14(16–17), pp. 3183–3184. doi: 10.1002/hyp.325.
- Beven, K. J. (2012) *Rainfall-runoff modelling: the primer*, *Rainfall-Runoff Modelling: The Primer: Second Edition*. doi: 10.1002/9781119951001.
- Building, C. *et al.* (2002) *of Irrigated Agriculture*. Available at: http://www.iwmi.cgiar.org/Publications/Working_Papers/working/WOR16.pdf.
- Chai, S. G., Yoon, K. S. and Han, K. H. (2011) 'Estimation of SCS Runoff Curve Number for Agricultural Reservoir Watershed by Analysis of Reservoir Operation Record ESTIMATION DU NOMBRE DE LA COURBE DE RUISSELLEMENT SCS DES BASSINS VERSANTS AGRICOLES PAR L ' ANALYSE DU DOSSIER D ' EXPOITATION DU RESERV', pp. 287–295.
- Chai, T. and Draxler, R. R. (2014) 'Root mean square error (RMSE) or mean absolute error (MAE)? -Arguments against avoiding RMSE in the literature', *Geoscientific Model Development*, 7(3), pp. 1247–1250. doi: 10.5194/gmd-7-1247-2014.
- Cristina, A. and Amílcar, C. (2009) 'Homogenization of Climate Data : Review and New Perspectives Using Geostatistics', pp. 291–305. doi: 10.1007/s11004-008-9203-3.
- Dai, X. (2016) 'Dam site selection using an integrated method of AHP and GIS for decision making support in Dam site selection using an integrated method of AHP and GIS for decision

- making support in Bortala , Northwest China By', (14).
- Edges, F. *et al.* (no date) 'Frustum', pp. 1–4.
- Fukunaga, D. C. *et al.* (2015) 'Application of the SWAT hydrologic model to a tropical watershed at Brazil', *Catena*, 125, pp. 206–213. doi: 10.1016/j.catena.2014.10.032.
- 'General Design and Construction Considerations for Earth and Rock-Fill Dams' (2004), (July).
- 'GIS multi-criteria decision analysis for assessment and mapping of neotectonic landscape deformation: A case study from Crete. Athanasios V. Argyriou' (no date), pp. 1–47.
- Google Maps (2017) 'Google Maps - Αϊτή', p. 94030. Available at: <https://www.google.gr/maps/@18.8615636,-71.1855958,7z?hl=en>.
- Gupta, H. V. and Kling, H. (2011) 'On typical range, sensitivity, and normalization of Mean Squared Error and Nash-Sutcliffe Efficiency type metrics', *Water Resources Research*, 47(10). doi: 10.1029/2011WR010962.
- Issue, V. *et al.* (2015) 'Assessment of Drinking Water Quality from the Malakisi River in Western Kenya Abstract ', 4(4), pp. 154–161.
- Jokiel, C. (2000) 'An Innovative Sediment Removal Solution Application and Project Experiences', (Figure 1).
- Kang, H. M. and Yusof, F. (2012) 'Homogeneity Tests on Daily Rainfall Series in Peninsular Malaysia', 7(1), pp. 9–22.
- Kangume, C. (2016) 'Assessing the impact of climate change on stream flow in Malaba river'.
- Khaliq, M. N. and Ouarda, T. B. M. J. (2007) 'Short Communication On the critical values of the standard normal homogeneity test (SNHT)', 687(November 2006), pp. 681–687. doi: 10.1002/joc.
- 'Lake Kyoga - Wikipedia' (2017), (February), p. 2017.
- Lindeboom, R. (2011) 'The Science of Surface and Ground Water Lesson Geomorphology of Rivers'.
- Liu, Y. and Gupta, H. V. (2007) 'Uncertainty in hydrologic modeling: Toward an integrated data assimilation framework', *Water Resources Research*. doi: 10.1029/2006WR005756.
- Van Loon, A. F. and Van Lanen, H. A. J. (2012) 'A process-based typology of hydrological drought', *Hydrology and Earth System Sciences*, 16(7), pp. 1915–1946. doi: 10.5194/hess-16-1915-2012.
- Maidment, D. R. and Mays, L. W. (no date) *APPLIED*.

- Moberg, A. and Alexandersson, H. (1997) 'HOMOGENIZED GRIDDED AIR TEMPERATURE COMPARED WITH A SUBSET OF GLOBAL GRIDDED AIR TEMPERATURE SINCE 1861', 17, pp. 35–54.
- NARITA, K. (2000) 'Design and Construction of Embankment Dams', pp. 0–17.
- Neitsch, S. L. *et al.* (2005) 'Soil and Water Assessment Tool User's Manual Version 2005.', *Diffuse Pollution Conference Dublin*, p. 494.
- Nissen-petersen, E. (2006) 'Water from Small Dams'.
- Njiru, F. M. (2017) 'University of Nairobi', (August).
'Page 1' (2013), (May).
- Pahl-wostl, C. *et al.* (2013) 'Environmental flows and water governance : managing sustainable water uses', pp. 1–11.
- Prairie Farm Rehabilitation Administration (1992) 'Small dam design and construction manual'.
- Project, S. R. B. (2010) '(NELSAP) Sio-Malaba-Malakisi River Basin Project PRE-FEASIBILITY STUDIES FOR THE DEVELOPMENT OF MULTI-PURPOSE STORAGE RESERVOIRS SIO-MALABA-MALAKISI RIVER CATCHMENT Volume I : Main Report', I(September).
- Pyrcie, R. (2004) 'Hydrological low flow indices and their uses', *Watershed science center. Trent University*, 67(1–2), pp. 139–156. doi: 10.1016/j.earscirev.2004.03.003.
- Qiang, C. *et al.* (2010) 'Analysis of SWAT 2005 Parameter Sensitivity with LH-OAT Method', *HKIE Transactions Hong Kong Institution of Engineers*, 17(3), pp. 1–7. doi: 10.1080/1023697X.2010.10668197.
- Republic, T. H. E. and Water, M. O. F. (2013) 'THE REPUBLIC OF UGANDA A MINISTRY OF WATER AND ENVIRONMENT THE REPUBLIC OF UGANDA MINISTRY OF WATER AND ENVIRONMENT WATER SUPPLY DESIGN MANUAL'.
- Schuol, J. and Abbaspour, K. C. (2007) 'Using monthly weather statistics to generate daily data in a SWAT model application to West Africa', *Ecological Modelling*, 201(3–4), pp. 301–311. doi: 10.1016/j.ecolmodel.2006.09.028.
- Scott, E. M. (1996) 'Uncertainty and sensitivity studies of models of environmental systems', *Proceedings of the 28th conference on winter simulation*, (January 1996), pp. 255–259. doi: 10.1145/256562.256618.
- Securing Water for Ecosystems and Human Well-being : The Importance of Environmental*

Flows (no date).

Sellami, H. *et al.* (2013) 'Parameter and rating curve uncertainty propagation analysis of the SWAT model for two small Mediterranean catchments', *Hydrological Sciences Journal*, 58(8), pp. 1635–1657. doi: 10.1080/02626667.2013.837222.

Sharma, S. K. (1997) 'APPLICATION OF GIS AND REMOTE SENSING DATA IN SELECTING ALTERNATE HABITABLE SITE IN OUTER HIMALAYA , INDIA', pp. 1–2.

Srinivasan, R. *et al.* (2012) 'Swat: m', 55(4), pp. 1491–1508.

Stemn, E. and Kumi-boateng, B. (2016) 'Multi-Criteria-GIS Based Site Selection for Irrigational Reservoir – A Case Multi-Criteria-GIS Based Site Selection for Irrigational Reservoir – A Case Study', (March). doi: 10.17830/j.eaj.2016.03.001.

Stephens, T. and FAO (2010) *Manual on small earth dams, A guide to siting, design and construction, FAO drainage and irrigation paper, Number 64.*

Suliman, A. H. A. *et al.* (2015) 'Comparison of Semi-Distributed, GIS-Based Hydrological Models for the Prediction of Streamflow in a Large Catchment', *Water Resources Management*, 29(9), pp. 3095–3110. doi: 10.1007/s11269-015-0984-0.

Survsy, A. L. (no date) 'Double-Mass Curves Double-Mass Curves'.

Tuomenvirta, H. (2001) 'HOMOGENEITY ADJUSTMENTS OF TEMPERATURE AND PRECIPITATION SERIES — FINNISH AND NORDIC DATA', 506, pp. 495–506.

Tuomenvirta, H. (2002) 'Homogeneity Testing and Adjustment of Climatic Time Series in', 38, pp. 15–41.

Vatankhah, A. R., Ghafari, S. and Mahdavi Mazdeh, A. (2015) 'New and improved hydraulic radius for channels of the second kind', *Ain Shams Engineering Journal*. Faculty of Engineering, Ain Shams University, 6(3), pp. 767–773. doi: 10.1016/j.asej.2015.02.003.

Vi, V. (no date) 'FAO-UNESCO soil map of the world, 1:5000000. Vol. 6: Africa', VI.

Yang, J. *et al.* (2008) 'Comparing uncertainty analysis techniques for a SWAT application to the Chaohé Basin in China', *Journal of Hydrology*, 358(1–2), pp. 1–23. doi: 10.1016/j.jhydrol.2008.05.012.

Zhang, D. *et al.* (2015) 'Improved calibration scheme of SWAT by separating wet and dry seasons', *Ecological Modelling*, 301, pp. 54–61. doi: 10.1016/j.ecolmodel.2015.01.018.