

FACULTY OF ENGINEERING AND TECHNOLOGY.

DEPARTMENT OF AGRICULTURAL MECHANIZATION AND IRRIGATION

ENGINEERING.

**DEVELOPMENT OF AN INTEGRATED RAINFALL PREDICTION
AND WATER ALLOCATION MODEL FOR IMPROVED RUNOFF
DAM MANAGEMENT.**

CASE STUDY: MOROTO, UGANDA

BY

NYAMWENGE SAMANTHA G.

BU/UP/2021/0263

This final year project report is submitted to the Department of Agricultural Mechanization and Irrigation Engineering as a partial fulfillment of the requirements for the award of Bachelor of Science in Agricultural Mechanization and Irrigation Engineering.

MAY, 2025

ABSTRACT.

Water scarcity is a persistent challenge in semi-arid regions like Karamoja in northeastern Uganda, where effective water resource management is critical for agricultural sustainability. This study presents a decision-support model for the Kobebe Dam catchment that integrates rainfall prediction, runoff estimation, and dynamic water allocation to optimize water availability and usage. A machine learning approach was employed to forecast rainfall using 33 years of historical weather data from NOAA and NASA, including variables such as temperature, humidity, wind speed, and pressure. Among the three models tested Random Forest, XGBoost, and Linear Regression the Random Forest Regressor demonstrated superior performance, achieving an RMSE of 0.00575 mm, MAE of 0.00244 mm, and an R^2 of 0.99998. Its high accuracy provided reliable monthly rainfall forecasts, including a predicted 35 mm for May 2025. Using the Soil Conservation Service Curve Number (SCS-CN) method, rainfall predictions were converted into runoff estimates. Soil and land use data sourced from FAO and local hydrological assessments produced a weighted average Curve Number of 69.33. For May 2025, the runoff depth was estimated at 0.89 mm, corresponding to a total runoff volume of approximately 9.72 million litres flowing into Kobebe Dam—highlighting its potential for meaningful rainwater harvesting. A flexible water allocation algorithm was then applied to simulate various distribution strategies based on available runoff, crop water requirements, and management priorities. Initial tests used demonstration ratios of 80%, 15%, and 5% to validate the algorithm's capacity to model diverse allocation scenarios. These ratios are not fixed but are intended to explore “what-if” situations, allowing iterative evaluation of water distribution outcomes under changing conditions. This adaptability supports the identification of optimal allocation strategies that ensure sustainable water use and continuous crop production, ultimately enhancing water security in the region.

DECLARATION

I, NYAMWENGE SAMANTHA G., declare that this research proposal report was originally written and organized by me and has not been previously published or submitted to any institution of higher learning for any academic award.

Date

Signature.....

ACKNOWLEDGEMENT

I take this opportunity to thank the almighty God for the good health and the ability to research and gather information in this report. I thank my supervisor for the time, support, and advice provided to me during this development stage.

DEDICATION

I dedicate this report to my beloved parents as an appreciation for the love and care provided up to this point in my academics.

APPROVAL

I NYAMWENGE SAMANTHA G, submit this report of my final year project proposal to the faculty of engineering and technology in the department of Agricultural Mechanization and Irrigation engineering for the examinations with approval of my supervisor.

Miss. NABUNYA VICTO



Date: 30/05/2025

TABLE OF CONTENT.

ABSTRACT.....	ii
DECLARATION	iii
ACKNOWLEDGEMENT	iv
DEDICATION.....	v
APPROVAL	vi
LIST OF FIGURES.	ix
LIST OF TABLES.....	x
LIST OF ACRONYMS.	xi
CHAPTER ONE: INTRODUCTION.....	1
1.1: BACKGROUND.	1
1.2: PROBLEM STATEMENT.....	2
1.3: JUSTIFICATION.	3
1.4: OBJECTIVES.....	4
1.4.1: Main objective.	4
1.5: SIGNIFICANCE OF THE STUDY.....	4
1.6 SCOPE OF THE STUDY.....	5
1.7.1: Conceptual scope.	5
1.7.2: Time scope.....	5
1.7.3: Geographical scope.....	5
1.8: LIMITATIONS OF THE STUDY.....	5
CHAPTER TWO: LITERATURE REVIEW.....	6
2.0. Introduction.....	6
2.1. Machine Learning.....	6
2.1.1. How machine learning algorithms work.....	6
2.2. Climate predictions.	10
2.2.1. Rainfall Prediction Machine learning models are to be trained in this study.....	11
2.2.2. Multivariate linear regression (MLR).	11
2.2.3. Random forest (RF).	12
2.2.4. XGBoost gradient descent.	13
2.3. Climate variability and climate change.....	13
2.3.1. Climate Variability.....	13
2.3.2. Climate Change.....	14
2.3.3. Rainfall Variability.	15
2.4. Rainwater harvesting.	17
2.4.1. Benefits of harvesting rainwater.	17

2.4.2. Ways to Harvest Rainwater.....	18
2.5. Use of Open Weather API in Rainfall Prediction and Water Resource Management.	19
2.6. Runoff Estimation Methods.	20
CHAPTER THREE: METHODOLOGY.	22
3.0. Introduction to the study area.....	22
3.1. METHODOLOGY TO OBJECTIVE ONE.....	23
3.1.1. Data Collection	23
3.1.2. Data Preprocessing.....	24
3.1.3. Data analysis and visualization.	25
3.1.4. Data Splitting.	25
3.1.5. Machine learning models’ development.	26
3.2. METHODOLOGY FOR OBJECTIVE TWO.	28
3.2.1. Determining the CN.	29
3.2.2. Determining the runoff depth.....	29
3.2.3. Aggregate Runoff Volume for the Catchment.	30
3.3. METHODOLOGY FOR OBJECTIVE THREE.....	30
3.3.0. Steps in the algorithm formation.....	30
3.3.1. Problem definition.	30
3.3.2. Data collection.	30
3.3.3. Identifying water demands for algorithm design.	30
3.3.4. Develop the Allocation Algorithm.....	33
3.3.5. Tool implementation.....	33
CHAPTER FOUR: RESULTS AND DISCUSSION.	34
4.1.1: Data Description and Preprocessing Outcomes	34
4.1.2: Model Training and Performance Comparison.....	39
4.2.1: Determining the curve number.	41
CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS.	46
5.1: CONCLUSION.....	46
5.2: RECOMMENDATIONS.....	47
APPENDIX.....	48
References.....	50

LIST OF FIGURES.

Figure 1:Machine learning process training flow diagram.	28
Figure 2:Missing data heatmap.	35
Figure 3:Imputed data	35
Figure 4:Daily temperature trend.	37
Figure 5:Daily precipitation trend.....	37
Figure 6:Pair plot of the metrological data	38
Figure 7:Ranking of metrological features that affect rainfall.	39
Figure 8:Map of Moroto showing the different soil codes.	42
Figure 9:Map of Moroto showing the different HSG.	42
Figure 10:Curve number map of Moroto.....	43
Figure 11. Image showing the water distribution percentages and output.....	44

LIST OF TABLES.

Table 1. Data sources.....	22
Table 2:Kc values from FAO.	32
Table 3: Estimated number of days for each crop stage.	32
Table 4. Comparison of model performance in predicting rainfall.....	39
Table 5:ETc of crops for an entire crop season.....	43

LIST OF ACRONYMS.

ML...Machine Learning.

IWRM...Integrated Water Resource Management.

SVM...Support Vector Machine.

SNN...Simulated Neural Networks.

ANN...Artificial Neural Networks.

KNN...K-nearest neighbor.

GCM...Global Climate Models.

RCM...Regional Climate Models.

RWH...Rainwater harvesting.

WFP...World Food Program.

LULC...Land Use and Land Cover.

FAO...Food and Agricultural Organization.

SCS...Soil conservation service.

CV...Curve number.

References.

- Breiman, L. (2001). *Random Forests. Machine Learning*.
- Chen, T. &. (2016). XGBoost: A Scalable Tree Boosting System. *Conference proceedings* (pp. 785–794). (KDD 2016).
- Tripathi, A. S. (2020). Rainfall Prediction Using Machine Learning Techniques: A Comparative Study. *Journal of Hydrology*.
- International Journal of Latest Research In Engineering and Computing (IJLREC). (2024). *RAINFALL PREDICTION SYSTEM USING ML, Volume 11*(,Issue 1, Page No.100-106).
- (Eng), M. M. (2024). *AMI 3203 IRRIGATION AGRONOMY*.
- Abraham, M., & .Priyadarshini, B. (2024). *Rainwater harvesting for sustainable water management*.
- agency, U. K. (2023). Moroto pastrolists ccryout as kobebe dam dries up.
- Ahrens, C. (2019). Meteorology Today. *An introduction to weather, climate and environment*.
- Avery, E. S. (2014). Water development an dirrigation in karamoja, uganda.
- Barakagira, A., & Ndungo, I. (2023). Watershed management and climate change adaptation mechanisms used by people.
- Bruggen, V. k. (2018). Effects of Climate Change on Water Savings and Water Security from Rainwater Harvesting .
- council, W. w. (2023). world water council.
- Daily., P. (2019). <https://www.pmldaily.com/features/2019/10/erratic-rainfalls-indicate-tragic-reality-of-climate-change.html>.
- Domingos, P. (2012). A paper summarizing practical insights and challenges in machine learning applications. (Communications of the ACM). *A Few Useful Things to Know About Machine Learning*.
- Durodolaa, O. S., & Joash Bwambalea, c. a. (2020). Using every drop: rainwater harvesting for food security in Mbale, Uganda. *Water Practice & Technology Vol 15 No 2*.
- FAO. (2015).
- FAO. (2020). The state of food and agriculture, rome.
- Harris, S. A. (2023). *Comparison of Recently Proposed Causes of Climate Change*.

hhryu. (2023). *rt*.

Juan F. Velasco-Muñoz 1ORCID, J. A.-S. (2019). Rainwater Harvesting for Agricultural Irrigation: An Analysis of Global Research.

Kisakye, V., Akuru, M., & Bruggen, B. V. (n.d.). Effect of climate change on reliability of rainwater harvesting systems for kabarole district,Uganda. *Effect of climate change on reliability of rainwater harvesting systems for kabarole district,Uganda*.

Machine Learning-Based Rainfall Prediction: Unveiling Insights and Forecasting for Improved Preparedness. (2023). *IEEE Journals & Magazine, IEEE Xplore*(<https://ieeexplore.ieee.org/document/10320349>).

Ministry of finance, p. a. (2022). Water for Production in Uganda. Progress and constraints in reducing the.

Ogwang, B. A. (2023). Characteristics of extreme rainfall events over Uganda during September to November rainfall season.

Rahul Grover, S. S. (2024). Analysis on temporal variability of monsoon rainfall using ARIMA Model and ANN-LSTM.

Sindrella, A. (2023). *Identification of rainwater harvesting areas for development of irrigation water resources in uganda*.

Uganda Bureau of statistics. (2021). *Nation service Delivery survey*.

Umar, D. A., Ramli, M. F., Aris, A. Z., Jamil, N. R., & Aderemi, A. A. (2019). Atmospheric Research. *Evidence of climate variability from rainfall and temperature fluctuations in semi-arid region of the tropics*, Volume 224, 1 August 2019, Pages 52-64.

Vartan, S. (2024). *A Beginner's Guide to Rainwater Harvesting*.

Varun Kumar P, M. M. (2023). *Real Time Rainfall Prediction For Indian States Using XGBoost And Random Forest Approach, IJCRT | Volume 11*(, Issue 4 April 2023 | ISSN: 2320-2882).

Varun Kumar P, M. M. (2023). *Real Time Rainfall Prediction For Indian States Using XGBoost And Random Forest Approach, Volume 11*(Issue 4 April 2023 | ISSN: 2320-2882).

(2023). *World Water Council. (2023). Opening Up Integrated Water Resource Management*. https://www.worldwatercouncil.org/sites/default/files/2023-09/REPORT_IWRM_2023_WEB.pdf.

- Campisano, A., Butler, D., Ward, S., Burns, M. J., Friedler, E., DeBusk, K., ... & Han, M. (2017). Urban rainwater harvesting systems: Research, implementation and future perspectives. *Water Research*, 115, 195–209. <https://doi.org/10.1016/j.watres.2017.02.056>
- Fletcher, T. D., Shuster, W., Hunt, W. F., Ashley, R., Butler, D., Arthur, S., ... & Dagenais, D. (2015). SUDS, LID, BMPs, WSUD and more – The evolution and application of terminology surrounding urban drainage. *Urban Water Journal*, 12(7), 525–542. <https://doi.org/10.1080/1573062X.2014.916314>
- Gyamfi, C. A., Kabo-Bah, A. T., Owusu, P. A., & Akpoti, K. (2020). Rainwater harvesting for sustainable agricultural water management in Ghana. *Sustainable Water Resources Management*, 6, 52. <https://doi.org/10.1007/s40899-020-00411-3>
- Jayarathna, L., Manatunge, J., & Herath, G. (2021). Economic feasibility of rainwater harvesting systems: A case study from Sri Lanka. *Sustainable Cities and Society*, 69, 102844. <https://doi.org/10.1016/j.scs.2021.102844>
- Mekonnen, D. K., Demlie, M. B., & Belete, M. A. (2022). The role of rainwater harvesting in enhancing soil moisture and agricultural productivity in Ethiopia. *Heliyon*, 8(12), e12587. <https://doi.org/10.1016/j.heliyon.2022.e12587>
- Otoo, M., Drechsel, P., & Gordon, C. (2021). Nature-based solutions for stormwater management and water quality: The role of rainwater harvesting. *Environmental Science & Policy*, 118, 78–88. <https://doi.org/10.1016/j.envsci.2021.01.009>
- United Nations Environment Programme (UNEP). (2021). *Rainwater harvesting: A nature-based solution for water security*. Nairobi: UNEP. <https://www.unep.org/resources/report/rainwater-harvesting-nature-based-solution-water-security>
- Vartan, S. (2024). Rainwater harvesting benefits around the world. *Treehugger*. Retrieved from <https://www.treehugger.com>
- Aloysius, N., Gebremicael, T. G., & Tadesse, T. (2016). Climate variability and its impact on rainfall patterns in East Africa. *Climate*, 4(4), 60. <https://doi.org/10.3390/cli4040060>
- IPCC. (2021). *Climate change 2021: The physical science basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press.
- Nkiaka, E., Taylor, A., & Dougill, A. J. (2020). Analysis of rainfall variability and trends in semi-arid regions of Africa. *International Journal of Climatology*, 40(5), 2448–2462. <https://doi.org/10.1002/joc.6343>
- Gebrechorkos, S. H., Hülsmann, S., & Bernhofer, C. (2019). *Regional climate projections for impact assessment studies in East Africa*. Environmental Research Letters, 14(4), 044031. <https://doi.org/10.1088/1748-9326/ab055a>

Nabakooza, I., Nakileza, B., & Lwasa, S. (2022). *Impacts of climate variability on rain-fed agriculture in Uganda: A case of the cattle corridor*. Weather and Climate Extremes, 35, 100413. <https://doi.org/10.1016/j.wace.2022.100413>