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# Modelling the Impacts of Climate Change on Water Level Fluctuations in Water Resources in Tanzania: A Case Study of Mtera Dam

Filimon Abel Mgandu<sup>a</sup>, Mashaka Mkandawile<sup>b</sup>, Mohamed Rashid<sup>b</sup>

<sup>a</sup> College of Business Education, P. O. Box 2077, Dodoma, Tanzania.

<sup>b</sup> University of Dar es salaam, P. O. Box 35091, Dar es salaam, Tanzania.

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## Abstract

This study presents the modelling of impacts of climate change on water resources. Mtera dam in Tanzania was taken as a case study. Data for climate variables on four stations were obtained from Tanzania Meteorological Agency (TMA) while data for water level were obtained from Rufiji Basin Development Authority (RUBADA). The study aimed at doing regression analysis on all stations to analyze the impacts of change in climate variables on water level. Results show that rainfall was significant predictor of water level at Iringa and Dodoma while temperature and sunshine were significant at Mbeya station. Change in climate variables accounted for 37% of the fluctuations of water level in the dam. It was recommended that TANESCO should construct small dams on upper side of Mtera dam to harvest rain water during rainy season. In long run TANESCO should invest into alternative sources of energy.

**Index Terms:** Climate change, Water level, Mtera dam, Regression Analysis.

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## **1. Introduction**

### *1.1 Background Information*

Water resource refers to the surface water or groundwater available in a given area [17]. Some sources of water include rivers, reservoirs, lakes and groundwater. Although the role of water in human development is important, observed trends and climate forecasting provides evidence that water resources are vulnerable and will be strongly affected by climate change and industrialization which place key challenges to their existence [3]. Intergovernmental Panel on Climate Change (IPCC) refer to climate change as any change in average weather conditions over a long period of time as a result of natural factors or human activities [6]. On contrary, the United Nations Framework Convention on Climate Change (UNFCCC) refers to climate change as change in average weather conditions over a long period of time that is caused directly or indirectly by human activities [4].

Global climate change is the main cause of frequent droughts and floods events and their profound impacts are huge particularly on water resources. According to [6], the frequencies of floods and droughts are certain to increase in many parts of the world a fact that call for a long-term strategic planning of water resources and water utilization. In the same context, [1] suggested that quantification of the impacts of climate change on water resources is important as it provide useful input data for planning and management of water resources.

According to [16], around 1,800 million people will be living in places with total water scarcity and two-thirds of the world population could be under water stress situations by year 2025 developing countries being most affected. For the case of African continent, about 25% of her population is suffering water scarcity situation [3]. It is predicted that about 65% of the African population will experience water stress condition by the year 2025 which demand more strategies to overcome the situation [2]. Tanzania in particular, has observed a number of climate associated disasters including floods, droughts, failure of agricultural production in some years and increase of climate related diseases like malaria and others [11]. Study by [18] reported that in East African, Tanzania has been severely impacted by climate change where decreasing water quantity in water resources has been observed and more effort is required to quantify the impacts of climate change on water resources and appropriate strategies be taken.

Global climate changes and increasing demands of water resource as a result of population increase have forced water level regimes of lakes and reservoirs to change [6]. Study by [20] indicated that man-made reservoirs tend to experience greater water level fluctuations than natural lakes causing annual water level fluctuations of tens of meters in electricity generating dams. It is important to understand the impacts of climate change in Tanzanian's hydropower dams to prepare appropriate measures.

Water resources and water volumes are critical inputs to Tanzania major socio-economic activities including food security through irrigation agricultural sector performance, water for industries, water for people (clean and safe water for good health workforce). Furthermore, water in rivers and reservoirs is pivotal to electric powering industrial and household activities [10]. Therefore, changes in water flow affects Tanzania Electric Supply Company (TANESCO) capacity to produce and supply electricity hence hinders Tanzania government machineries capacity to support socio-economic activities of her fast-growing populations [15]. This study quantifies the impacts of climate change on water level in Mtera dam in Tanzania.

### *1.2 Statement of the problem*

Water resources in Tanzania are earmarked to face non-uniform climate change impacts that will lead to fluctuations water levels in most basins [12]. Increasing river flow in some basins, drying - up of some water bodies and intrusion of sea water into fresh water bodies including groundwater are expected [15]. In the recent past, two - thirds of rivers in Tanzania experienced reduced water volume due to decreased rainfall and increased temperature, which are key indicative parameters in climate change.

Different researches have been done on assessing the impacts of climate change on the fluctuation of water level in water resources for example; [5,7,8,9,13,14,19,21]. [9] studied the hydrological flow change of Usangu-Mtera ecosystem and how it links to changes in rainfall variability. However, the study focused on the variation of rainfall only leaving out other climatic elements like temperature, sunshine and humidity which might have influence on water level. Therefore, the aim of this study was to model the impacts of climatic changes on water level fluctuations in Mtera dam. Regression model considered water level fluctuations as a function of change in climate variables; temperature, rainfall, sunshine and humidity.

### *1.3 Related studies*

Impacts of climate change on fluctuations of water level in water resources have been widely assessed in different geographical areas. The study by [19] investigated failure of Mtera and Kidatu dam's system in the early 1990s by studying some causes like unexpected reduction in inflows, abrupt rise in losses, abrupt growth in hydropower generation or leaks or combination of these. It was found that uncontrolled leakage was the main cause. However, the study didn't investigate the fluctuations of water levels due to climate change in the dam.

The study by [9] investigated the water resource change of Usangu-Mtera ecosystem and how it was associated to changes in rainfall variability. It was found that variations in the amounts of rainfall accounted for 64.2% of the variations in annual water levels in Mtera dam which indicate that climate change has strong impacts on the fluctuation of water level in Usangu-Mtera ecosystem. However, the study focused on the variation of rainfall only leaving out other climatic variables like temperature, sunshine and humidity which might have influence on water level.

[21] studied how changes in climatic factors (that is temperature and rainfall) affect the amount of water resources in Huai River basin. Regression analysis was employed to understand the relationship between water resources quantity and climatic factors in order to explain how water resources in the basin were affected by climate change. Findings from this study indicated that there was a trend of slow decrease in the amount of the basin's water resources with falling rainfall and increasing air temperature for the period under study. However, the study considered only two climate factors that is temperature and rainfall leaving out others climate factors which might have effects on the amount of water in the basin.

This study employed regression model to evaluate impacts of climatic changes on water level fluctuations in Mtera dam. Water level fluctuations was considered as a function of change in climate variables; temperature, rainfall, sunshine and humidity.

## **2. Data and Research Methodology.**

### *2.1 Data sources*

Data for water level in Mtera dam were obtained from the Rufiji Basin Development Authority (RUBADA). Water levels were measured in meter above sea level (m.a.s.l). Data for rainfall, temperature, humidity and sunshine on Rufiji basin were obtained from Tanzania Meteorological Agency (TMA) where four stations were considered; Iringa, Mbeya, Dodoma and Singida. Rainfall was measured in millimetre (mm), temperature in centigrade (0C), humidity in percent (%) while sunshine was measured in Hours (hr). All data have passed strict quality checks. Some missing data have been interpolated using the mean values of the measured data for the same period.

## 2.2 Methodology

Regression model was employed in this study to establish relationship between water level in Mtera dam denoted by  $y$  and climate variables namely rainfall denoted by  $x_1$ , temperature denoted by  $x_2$ , humidity denoted by  $x_3$  and sunshine denoted by  $x_4$  and they are related as shown in equation 1. Regression analysis is a widely used statistical technique to understand relationship between variables.

$$y = \beta_0 + \beta_1x_1 + \beta_2x_2 + \beta_3x_3 + \beta_4x_4 + \varepsilon \quad (1)$$

where  $\beta_0$  is the constant term,  $\beta_j$  for  $(j=1, \dots, 4)$  are the regression coefficients relating the climate variables to the water level and  $\varepsilon$  is an error term. The aim is to estimate  $\beta_j$  for  $(j=0, \dots, 4)$  coefficients from the data. At each station, a regression model was developed to establish the relationship between water level and climate variables. The coefficient of determination  $R^2$  and the adjusted coefficient of determination  $\bar{R}^2$  were used to examine the goodness of fit of each regression model.

The coefficient of determination  $R^2$  and the adjusted coefficient of determination  $\bar{R}^2$  are calculated as shown in equation 2 and 3:

$$R^2 = 1 - \frac{SSE}{SST} = 1 - \frac{\sum_{i=1}^n (y_i - \hat{y}_i)^2}{\sum_{i=1}^n (y_i - \bar{y})^2} \quad (2)$$

$$\bar{R}^2 = 1 - \left[ (1 - R^2) \cdot \frac{n-1}{n-k-1} \right] \quad (3)$$

Where SSE is the sum of squares error, SST is the sum of squares total and the ratio of SSE and SST is the unexplained variation of water level by the model,  $y_i$  is the water level from the actual data,  $\bar{y}$  is the mean water level,  $\hat{y}_i$  is the predicted water level,  $(n-k-1)$  is a degree of freedom,  $n$  is the sample size and  $k$  is the number of independent variables.

## 3. Results

R statistical software was used to implement ordinary least square procedures. At each station Rh denotes relative humidity, R denotes rainfall, S denotes sunshine and T denotes temperature. The values of  $\beta_j$ 's in the regression model quantify the change in water level as a result of unit change in one climate variable provided others climate variable are constant.  $\beta_0$  is the intercept and is obtained when all climate variables are zero.

### 3.1 Assumptions of regression analysis

The regression analysis has assumptions to be satisfied before it can be used. The assumptions include; linear relationship, independence of errors, homoscedasticity (constant variance), normality and little or no multicollinearity. All assumptions of linear regression were checked and results shows that they were satisfied. Some of the assumptions are explained below.

The assumption of independence of errors was checked by Durbin-Watson statistic which ranges from 0 to 4. The values between 1.5 and 2.5 mean that the errors are independent of one another. Values approaching 0 indicates strong positive correlation and values approaching 4 indicates strong negative correlations. Table 1 show that Durbin-Watson statistic were between 1.5 and 2.5. It can be concluded that errors were independent.

Table 1: Durbin-Watson statistics

Station	Durbin-Watson
Iringa	1.568
Mbeya	1.503
Dodoma	1.652
Singida	1.932

Variance inflation factor (VIF) was used to check multicollinearity between explanatory variables. The explanatory variables with VIF between 1 to 10 has no symptoms of multicollinearity while those with VIF above 10 can be removed from the model since their effects can be explained by another explanatory variable. The results from Table 2 shows that VIF values were between 1 to 10. It can be concluded that there was no multicollinearity symptoms.

Table 2: VIF statistics for multicollinearity test

Variable	Iringa		Mbeya		Dodoma		Singida	
	Tolerance	VIF	Tolerance	VIF	Tolerance	VIF	Tolerance	VIF
Rh	0.891	1.123	0.797	1.255	0.936	1.068	0.841	1.189
Rainfall	0.961	1.041	0.88	1.126	0.944	1.059	0.978	1.023
Sunshine	0.88	1.126	0.960	1.041	1.025	0.883	0.976	1.133
Temperature	0.823	1.215	0.779	1.284	0.884	1.131	0.944	1.059

### 3.2 Mbeya station

Table 3 presents results of regression coefficients for climate variables influencing water level in Mtera dam at Mbeya station.

Table 3: Regression coefficients for Mbeya station.

Model	Unstandardized Coefficients		Std. Coefficients	t- value	p- value
	B	Std. Error	Beta		
(Constant)	706.491	10.080		12.214	0.039
Rh	0.093	0.135	0.137	0.689	0.499
Rainfall	0.001	0.003	0.080	0.424	0.676
Sunshine	1.851	0.715	0.468	2.587	0.018
Temperature	-2.615	1.183	-0.444	-2.211	0.039

The unstandardized coefficients from Table 3 are the  $\beta_j$ 's and can be inserted in equation (1) to produce the following regression model:

$$Water\ level = 706.49 + 0.093 Rh + 0.001 R + 1.85 S - 2.62 T \tag{4}$$

Table 4 shows the analysis of variance for the test of goodness of fit of the regression model 4.

Table 3: ANOVA table for Mbeya station

Model	Sum of Squares	df	Mean Square	F-test	p-value	R	R Square	Adjusted R Square
Regression	52.358	4	13.089	2.972	0.045	0.611	0.373	0.247
Residual	88.091	24	4.405					
Total	140.448	28						

The overall regression model equation 4 is significant and appropriate for predicting the water level in Mtera dam, since  $F(4, 20) = 2.972$  and  $p \leq 0.05$  indicating a significant relationship between water level and climate variables. Table 4 shows that adjusted R squared  $\bar{R}^2=0.247$  implying that 24.7% of variation of water level is described by the regression model 4. On the other hand, R square  $R^2 = 0.373$  indicates that 37.3% of variation in water level can be explained by climate variables. The remaining percentage of the fluctuation of water level was described by other factors.

### 3.3 Iringa station

Table 5 presents results of regression coefficients for climate variables influencing water level in Mtera dam at Iringa station.

Table 4:Regression coefficients for Iringa station

Model	Unstandardized Coefficients		Std. Coefficients	t- value	p- value
	B	Std. Error	Beta		
(Constant)	708.968	12.178		58.217	0.000
Rh	-0.284	0.172	-0.282	-1.653	0.111
Rainfall	0.010	0.003	0.480	2.924	0.007
Sunshine	-0.824	0.463	-0.305	-1.782	0.087
Temperature&	-0.098	0.150	-0.116	0.654	0.520

The unstandardized coefficients from Table 5 are the  $\beta_j$ 's and can be inserted in equation (1) to produce the following regression model:

$$\text{Water level} = 708.97 - 0.284 Rh + 0.01 R - 0.824 S - 0.098 \tag{1}$$

Table 6 shows the analysis of variance for the test of goodness of fit of the regression model 5.

Table 5: ANOVA table for Iringa station

Model	Sum of Squares	df	Mean Square	F-test	p-value	R	R Square	Adjusted R Square
Regression	101.970	4	25.492	3.638	0.019	0.611	0.373	0.247
Residual	168.188	24	7.008					
Total	270.157	28						

The overall regression model equation 5 is significant and appropriate for predicting the water level in Mtera dam, since  $F(4, 24) = 3.638$  and  $p \leq 0.05$  indicating a significant relationship between water level and climate variables as shown in Table 6. Table 6 shows that the value of adjusted coefficient of determination (Adjusted R squared)  $R^2 = 0.274$  implying that 27.4% of variation of water level is explained by the regression equation 5. Also the value of R square  $R^2 = 0.377$  implies that 37.7% of variance in water level can be predicted by explanatory variables. The remaining percentage of the fluctuation of water level was explained by other factors.

### 3.4 Dodoma station

Table 7 presents results of regression coefficients for climate variables influencing water level in Mtera dam at Dodoma station.

Table 6: Regression coefficients for Dodoma station

Model	Unstandardized Coefficients		Std. Coefficients	t- value	p- value
	B	Std. Error	Beta		
(Constant)	683.864	45.422		15.056	0.000
Rh	0.451	0.271	0.277	1.662	0.110
Rainfall	0.018	0.006	0.509	3.070	0.005
Sunshine	-0.535	1.683	-0.052	-0.318	0.753
Temperature&	-1.347	1.774	-0.130	-0.760	0.455

The unstandardized coefficients from Table 3.7 are the  $\beta_j$ 's and can be inserted in equation (1) to produce the following regression model:

$$\text{Water level} = 683.86 + 0.451 Rh + 0.02 R - 0.535 S - 1.347 T \tag{2}$$

Table 8 shows the analysis of variance for the test of goodness of fit of the regression model 6.

Table 7: ANOVA table for Dodoma station

Model	Sum of Squares	df	Mean Square	F-test	p-value	R	R Square	Adjusted R Square
Regression	310.577	4	77.644	3.618	0.019	0.613	0.376	0.272
Residual	515.023	24	21.459					
Total	825.600	28						

The overall regression model equation 6 is significant and appropriate for predicting the water level in Mtera dam, since  $F(4, 24) = 3.618$  and  $p \leq 0.05$  indicating a significant relationship between water level and climate variables as shown in Table 8. Table 3.8 shows that adjusted R squared  $\bar{R}^2 = 0.272$  implying that 27.2% of variation of water level is described by the regression model 6. On the other hand, R square  $R^2 = 0.376$  indicates that 37.6% of variation in water level can be explained by climate variables. The remaining percentage of the fluctuation of water level was described by other factors.

### 3.5 Singida station

Table 9 shows the analysis of variance for the test of goodness of fit of the regression model at Singida station.

Table 8: ANOVA table for Singida station Model	Sum of Squares	df	Mean Square	F-test	p-value	R	R Square	Adjusted R Square
Regression	19.147	4	4.787	0.868	0.509	0.613	0.376	0.272
Residual	71.665	13	5.513					
Total	90.813	17						

Table 9 shows that the model is not suitable for predicting the water level in Mtera dam, since  $F(4, 17) = 3.618$  and  $p \geq 0.05$  is not statistically significant, indicating that there is no significant association between water level and climate variables at Singida station.

## 4. Discussion

Results from regression analysis shows that rainfall is significant predictor of water level at Iringa and Dodoma stations while temperature and sunshine were significant at Mbeya station. These results are in line with the study by [9] which indicated that, 64% of growing variation in rainfall over years in the Usangu-Mtera basin explained decreasing water levels in Mtera dam.

It was observed that change in climate variables at Mbeya, Iringa and Dodoma stations explain about 37% of the fluctuation of water level in Mtera dam. This means that climate change accounted for only 37% of fluctuations of water level in Mtera dam. The remaining percent of fluctuations of water level in Mtera dam was explained by other factors such as impact of social, economic and ecosystem changes which are not related to climate change.

The observed regression models (equation 4, 5, and 6) were statistically significant at 95% level of significance indicating that models are adequate and they can be useful. Therefore equation 4, 5 and 6 can be used to explain relationship between water level and climate variables at Mbeya, Iringa and Dodoma stations respectively. At each station the contribution of each climate variable to water level can be obtained by

assuming that the remaining factors were all zero then water level will increase or decrease by its coefficient,  $\beta_j$ .

## **5. Conclusions and Recommendations**

The aim of this study was to fit a regression model to analyze the impacts of climate change on fluctuation of water level in Mtera dam. Results indicates that rainfall is significant predictor of water level at Iringa and Dodoma stations while temperature and sunshine are significant at Mbeya station. Change in climate variables accounted for 37% of fluctuation of water level in Mtera dam. The remaining percent of fluctuation of water level in Mtera dam was explained by other factors such as impact of social, economic and ecosystem changes.

The study recommends that; Small dams should be constructed on the upper side of Mtera dam on the Great Ruaha river to harvest rain water when the main dam is at its maximum level (698 m.a.s.l). The stored water will be used to fill the main dam when its approaching its minimum level (690 m.a.s.l). In long run, TANESCO should invest on alternative source of energy such as thermal, gas and coal power rather than depending on hydropower which is affected by climate change.

The conclusion reached should be considered as preliminary and it is reflecting the impact of temperature, rainfall, sunshine and relative humidity changes on water level fluctuations under current conditions. It is still necessary to conduct more research on the combined impacts of climate change and human activities on water resources in Rufiji basin for more complete results.

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## Authors' Profiles



**Filimon Abel Mgandu** works at College of Business Education (CBE)- Department of ICT and Mathematics. He was awarded Bsc. With Education (Informatics and Mathematics) in 2016 from Sokoine University of Agriculture and MSc in Mathematical Modelling in 2019 from University of Dar es salaam. His research area includes Statistics, Data science and Computer programming.



**Dr. Mashaka Mkandawile** works at the University of Dar es Salaam as a Lecturer and Coordinator of Actuarial Science Programme, Department of Mathematics, College of Natural and Applied Sciences (CONAS). He obtained his PhD in Operations Research in 2015 at the University of Dar es Salaam with research work and licentiate at Umea University in Sweden. His research area includes Actuarial Science, Statistics and Probability Theories, Numerical Optimization, Graph Theory and Computer Programming.



**Dr. Mohamed Rashid** works at the University of Dar es Salaam as a Lecturer, Department of Mathematics, College of Natural and Applied Sciences (CONAS). He has Masters and PhD both obtained at the University of Dar es Salaam. His research area includes Statistics and Probability Theories and Numerical Optimization.

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