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RESEARCH ARTICLE

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EMPIRICAL MODELLING OF GREEN WATER: A CASE OF WAMI RUVU BASIN, TANZANIA

Benson H.M. Lazaro[1]*, Martine M. Hagai[1] and Rubhera R.A.M. Mato[2]

[1]School of Earth Sciences, Real Estate, Business Studies and Informatics, Department of Geospatial Sciences and Technology, Ardhi University, P.O. Box 35176, Dar es salaam, Tanzania
[2]School of Engineering and Environmental Studies; Department of Environmental Science and Management; Ardhi University, P. O. Box 35176, Dar es Salaam, Tanzania

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****Corresponding author:***
Benson H.M. Lazaro

ABSTRACT

Green water supports the entire terrestrial environment, ensuring human survival and access to food. Overuse and loss of natural resources have led to a decline in green water throughout the time. The postulated causative factors of green water availability are precipitation, temperature, land cover changes, human population increase, relative humidity and sunshine intensity. Interrelationships between them at the local and global level is unknown. The study was done based on in-situ data observation from 1990 to 2020 in Wami/Ruvu Basin, and Linear Multiple Regression Model and SWAT Model were developed and applied to estimate and project green water availability in the basin by 2035. The study findings was that green water will be accessible in the basin for its sustainable management, and temperature has a comparatively greater impact in green water availability. Given that, temperature rise is mostly unchecked and is projected to climb over normal international standards, it is recommended to invest in the use of green water resources to ensure food security because a spike in temperature also results in an increase in green water.

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INTRODUCTION

To maintain their health through residential, agricultural, industrial, transportation, and recreational use, humans are dependent on a steady supply of clean water. Increased strain is placed on the world's water resources by growing water demand for agriculture, industry, home use, and ecosystems (Rockström *et al.*, 2014). The freshwater cycle is composed of ''green'' and ''blue'' water in accordance with the hydrological processes and quantity. Water that flows through or below the ground surface and is stored in aquifers, lakes, and reservoirs is referred to as "bluewater", on the other hand, Green water refers to the portion of precipitation that infiltrates to become soil moisture or remains temporarily on top of the soil or vegetation, then eventually returns to the atmosphere via transpiration and evaporation (Falkenmark *et al.*, 2006; Rockström *et al.*, 2014). The availability of blue water has been sufficiently reported in the literature; it is thought to hold close to one-third of all freshwater resources (Falkenmark *et al.*, 2006).

The remaining 2/3 of the total freshwater is Green Water (GW), which is rather invisible, as such, it has attracted less attention in research and literature. The primary supply of water for the whole terrestrial ecosystem, including crops, grasslands, and forests, is green water, which also ensures the local communities' access to food. Green water is necessary for between 60% and 80% of the world's food production, as well as for forest grasslands and nearly all meat products produced through animal husbandry and forestry (Liu *et al.*, 2009a, b). According to Hoekstra (2012), in the period 1996–2005, 74% of the average yearly freshwater use on the planet was from green water sources. Zhao *et al.* (2016) show that whereas green water makes up more than 30% of all water resources in humid places, it makes up more than 80% of all water resources in arid locations. Due to its high demand, green water is a precious resource that needs further consideration in terms of sustainability, usage, and conservation. Despite its significance, the literature has given the implementation of green water distribution very little consideration (Schyns *et al.*, 2015; Schyns *et al.*, 2019; Hoekstra *et al.*, 2012; Mao *et al.*, 2019).

According to Konar *et al.* (2012) and Yang *et al.* (2006), the absence of competitive uses for green water in other industries and home settings may be the reason why green water receives so little attention in literature. However, some research has been done on green water, and in recent years, interest in green water resources has grown because of its importance for climate change mitigation, food security, and environmental preservation (Lyu *et al.,* 2019; Farsani *et al.,* 2019). A common statistical technique for forecasting variable values based on two or more related variables is the study of multiple linear regression (MLR) model (Mohd *et al.*, 2020). Correlation analysis serves as the foundation for multiple regression analysis, which uses both correlation and regression to do multivariate studies (Sukran *et al.*, 2014; Yusof *et al.*, 2012). According to Patel *et al.* (2016), the Regression-based analysis model is one of the effective statistical tool for resources management e.g. in data consolidation, prediction etc. Both locally and globally, the causes of green water and the interactions between them remain unknown. This study used multiple linear regression analysis and the SWAT Model in Tanzania's Wami/Ruvu Basin to empirically model green water in watershed ecosystems. On the basis of in-situ observations of observable phenomena throughout time, the created model forecasts green water for its sustainable management in the basin. The major goal of this study was to forecast the availability of green water in the Wami Ruvu basin by 2035 using multiple linear regression analysis.

METHODS AND MATERIALS

Description of the Study Area: WRB, one of Tanzania's nine water basins, is situated in the nation's east-central region. It has an area of around 66,899 km^2. According to Figure 1, It is located between latitude 4^{o}54′29″ and 7^{o}38′10″ South, and longitude 35^{o}38′22″ and 39^{o}16′22″ East.

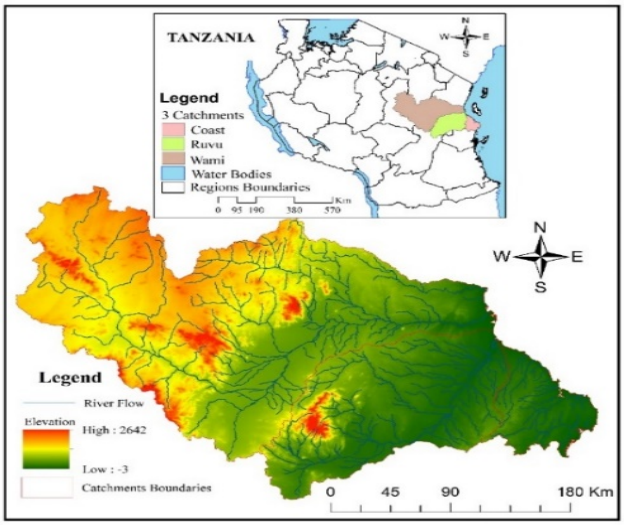


Figure 1. Location of Wami Ruvu basin on Map of Tanzania

The Eastern Arc Mountains, which extend from southern Kenya to Tanzania, include the catchment forests of the Wami and Ruvu subbasins. Numerous thousands of species of plants and animals may be found in the Eastern Arc Mountains, which also contains some of the highest levels of endemism on the planet (Burgess *et al.,* 2007). The basin empties into the Wami and Ruvu, two significant rivers that empty into the Indian Ocean. The WRB's climate is influenced by the Equatorial Convergence Zone. From forests in the uplands to mixed-type subsistent agriculture in the mid to lowland regions, there are several forms of land use and land cover. The basin is divided into the Wami, Ruvu, and Coast subbasins. WRB is divided into three catchments namely: Wami, Ruvu and Coast. Wami catchment comprises; Kinyasungwe, Mkondoa and Wami sub-catchments. Ruvu comprises; Upper Ruvu, Ngerengere and Lower Ruvu sub-catchments while Coast catchment itself stand alone, as shown in Figure 2.

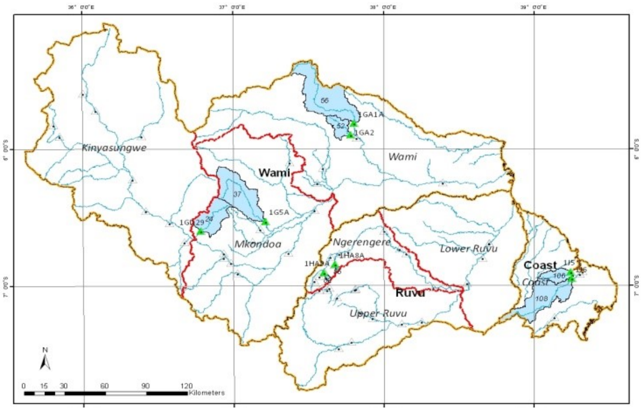


Figure 2. Sub-basins of WRB

The basin is characterized by a variety of soil types including Red soils predominately in the Kinyasungwe Catchment and eastern portions of the Mkondoa Catchments, sandy soils mostly in coastal regions, and vertisol, also known as mbuga black soil, that is distributed over the majority of the basin (URT. 2019). There are two rainfall regions in the basin. These are the unimodal rainfall region, which covers the western and southwestern parts with one wet period ranging from November to April and the bimodal rainfall region which covers the eastern and northeastern part of the basin with two wet periods, one ranging from October to December and the second period from March to May. Six areas of Tanzania are intersected by the basin: Dar es Salaam, Pwani, Morogoro, Tanga, Manyara, and Dodoma.

Materials and Methods: The digital elevation model (DEM), land cover data, and soil data entered into SWAT, the Soil and Water Assessment Tool, were all used in this study. The research also involved the published Monthly in-situ data of crop water need and their statistical analysis. Precipitation (mm), temperature (^{o}C), sunlight intensity (Hours), relative humidity (%), land cover (km^2), population (capita), soil texture (%), and soil group were the eight key characteristics that were predicted to contribute to green water.

Creation of SWAT Model
Evapotranspiration (Green Water Flow)
Determination of Green Water
Soil Water (Green Water Quantity)
Model Calibration and Validation
Predict Green Water
Model Validation
Testing the Influence of Variables on GW
Multiple Regression Modelling

Based on in-situ data observation from 1990 to 2020. of causative factors of green water, a linear multiple regression model was developed and applied to estimate and project green water availability in the Basin by 2035. The entire research methods applied in this research are as articulated in the research flow diagram as indicated in Figure 3 below. The general water balance equation in the SWAT model (equation 1) was used to quantify the amount of GW and BW in the study area.

$$SW_t = SW_0 + \sum_{t=i}^{t}\left(R_{day} + Q_{SURF} - E_a - w_{seep} - Q_{gw}\right) \tag{1}$$

Where: SW_t is the final content of soil water (mm), SW_0 is the initial content of soil water on a day i (mm), t is the time taken in days, R_{day} is the precipitation amount on a day i (mm), Q_{surf} is the surface runoff amount on a day i (mm), E_a is the evapotranspiration amaount on a day i (mm), w_{seep} is seepage and bypass water amount from the soil profile on a day i (mm), and Q_{gw} is the return flow amount on a day i (mm). Figure 2 demonstrates a flowchart for the SWAT model's evaluation of the distribution of GW and BW. Equation (1) can also be re-written as shown in Equation (2) in terms of blue and green water (Farsani *et al.,* 2019).

$$Rainfall = Evapotranspiration + Water\ Yield + \blacktriangle(Soil\ Storage) + \blacktriangle(Ground\ Water\ Stirage) + Losses \quad (2)$$

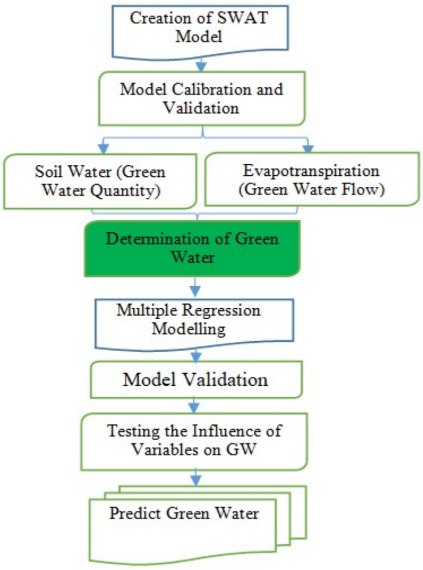


Figure 3. Reasearch Flow Diagram

The general Multiple Linear Regression model according to Golfinopoulos and Arhonditsis (2002) is hereby stated as:

$$y_i = \beta_0 + \beta_1 x_{1i} + \beta_2 x_{2i} + \cdots + \beta_q x_{qi} + s_i, \quad (3)$$

where y_i is the dependent variable observed values; $i = 1, \ldots, n$; n is the sample size and $x_1, x_2, \ldots, x_q$ are the explanatory or independent variables; $x_{1i}, x_{2i}, \ldots, x_{qi}$ are the descriptors of observed values; s_i is the residual or error for individual i; β_0 is a constant; and $\beta_1, \beta_2 \ldots, \beta q$ are the coefficients of regression. The following unique regression model for WRWB was developed to associate the quantity of green water with its impacts, taking into account the eight factors that have been identified as being highly important on green water:

$$y = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4 + b_5x_5 + \ldots.. + b_8x_8 \quad (4)$$

where, y_i is a dependent variable, green water in Wami Ruvu Basin (mm/year), x_1 is the independent variable, precipitation (mm), x_2 describes the independent variable,temperature (°C/year), x_3 is the independent variable, sun shine (Hours), x_4 is the independent variable, relative humidity (%), x_5 describes the independent variable, land cover (km^2), x_6 denotes the independent variable, population (capita), x_{7-} is the independent variable,soil texture (%) and $x_{8-}$is the independent variable,oil group (%). b_0 is the regression constant, b_1 to b_8 are regression coefficients for x_1 to x_8 respectively. The Integrated Water Management and Development Plan for WRB (IWMDP) project was the basis for the time period used in the multiple linear regression analysis, which ran from 1990 to 2020 (URT, 2019). The F-statistic was used to test each variable's significance at a predetermined level (mean square for the model divided by the mean square for error) in order to determine the most appropriate subset of predictors (McCuen *et al.*, 1996). The significance threshold in this study was set at 0.05, and the multiple regression analysis included a p-value test for each regression element. The p-value shows the chance of inadvertently ruling out a null hypothesis. It is given as a percentage and ranges from 0 to 1. The significance threshold, which is typically 5% ($p>0.05$), is denoted by the symbol "α_{crit}t." The stepwise procedure was used to evaluate all of the variables already included in the model after each variable was added, and any variable that did not generate F-statistical significance at the chosen confidence level was removed from the model. The regression analysis was redone after the predictor with the highest p-value, larger than crit, was eliminated (Golfinopoulos *et al.*, 2002). To accomplish this, a stepwise elimination method was applied within the EXCEL statistical package program to specify which predictor variables were to be included in the regression equation. The variable was deemed significant if the p-value was less than 5%; else, it was insignificant. The process was done until all p-values were lower than αcrit (Table 1), then after, the final model was established (Eq. (5)).

Estimation of Regression Model parameters: The final model consists of only three independent variables that were proved to be significant which are precipitation, temperature, and sunshine intensity. The rest of the independent variables, were filtered out since they did not satisfy the significance level described by critical value (α_{crit}).

$$y = -7727.060 - 1.524x_1 + 115.916x_2 + 702.601x_3 \quad (5)$$

The constant term indicates the calculation of the amount of green water if there were no precipitation, no change in temperature, and no increase in sunlight intensity. This estimate is overly optimistic because such a situation is improbable. The second, third, and fourth terms, respectively, describe the estimation of green water amount owing to precipitation, temperature, and solar intensity. Monthly and yearly green water amount were simulated and forecasted (Figs. 4 and 5) based on the developed final regression function (Eq. (5)).

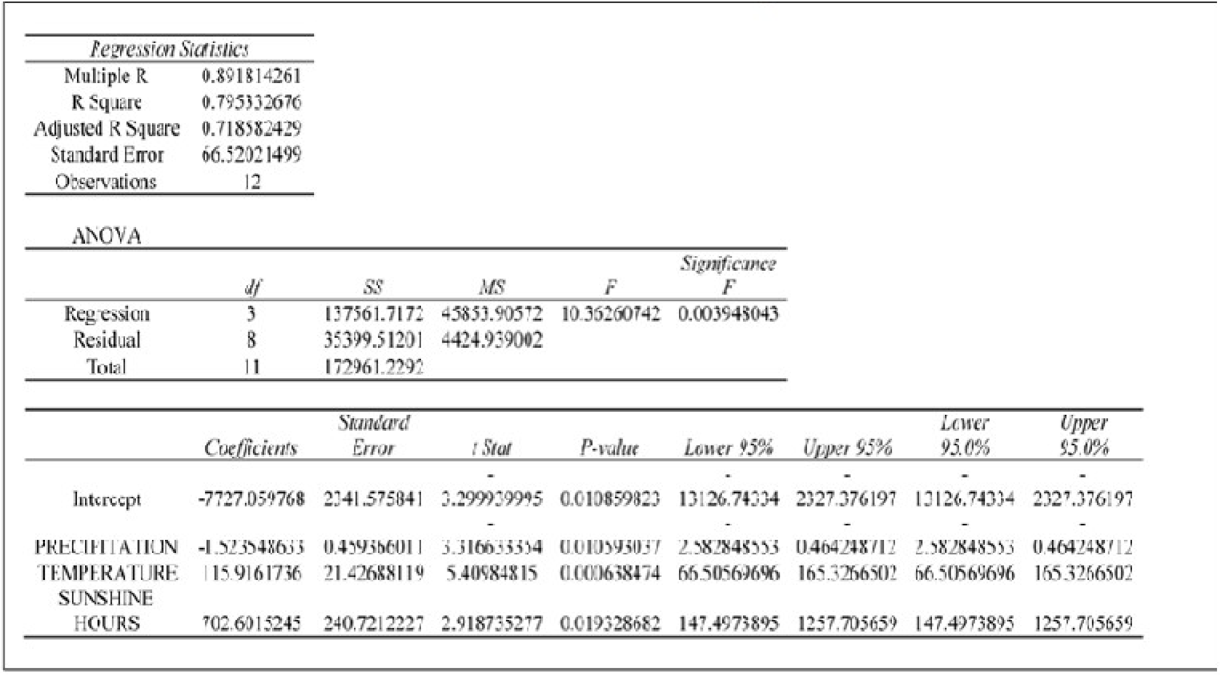
RESULTS

From Table 1, the correlation coefficient, which gauges how strongly two variables are correlated linearly R was determined to be 0.892, more than 0.7, indicating a strong positive relationship between the predictors and response variables (Rahman *et al.*, 2018; Mohd *et al.*, 2020). This agrees with the assumption that there is a relationship between green water quantity, precipitation, temperature, and sunshine intensity. Additionally, the F-Test, which assesses the model's overall quality and significance based on the null hypothesis, was discovered to be larger than the threshold significance level value ($p>5\%$) (ibid). The coefficient of determination (R^2) was appropriately interpreted because the significance of F (p-value for the F-Test) was only 3.95% as compared to a threshold ($p>5\%$) (ibid). The variables x_1, x_2, and x_3 have p-values of 1.06%, 0.06%, and 1.93%, respectively. Precipitation, temperature, and sunlight intensity are all significant factors in characterizing the target variable in both situations since the p-value was smaller than the critical value ($\alpha_{crit}=5\%$).

DISCUSSION

The final regression model's R^2 value of 0.80 indicates that fluctuations in precipitation, temperature, and sunlight intensity accounted for 80.0% of the variance in the study of green water amount, making this model's linear approximation acceptable. The final regression model's adjusted R^2 (0.719) was compared to the initial regression model's adjusted R^2 (0.827). The outcome demonstrated that the stepwise elimination procedure only marginally lowered the adjusted R^2, indicating that the removal of the five irrelevant variables had little impact on the regression equation's ability to fit the data. Because the deleted factors had little to no impact on the regression model, the model was deemed significant. According to the results, precipitation, temperature, and sunlight intensity have the greatest influence on the amount of green water in WRB and have been growing at rates of $R^2=0.005$, 0.74, and 0.0002 correspondingly from 1990 to 2020 (Figure 6). Temperature being the most influential amongst the three. The regression analysis based on regression function for the period year 1990-2035 (Figure 5) shows that GW will continue increasing due to temperature increase. The shown GW increasing trend corresponds to Zhang (2020) and USAID (2018) who together concluded that higher temperatures lead to increased evaporation and thus, GW. This result is supported by Luhunga *et al.* (2016) and Luhunga (2017) who predicted the temperature to range from 1.1 °C to 2 °C in the study area for the years 2010-2040. Wambura *et al.*, (2017) research on evaluating spatiotemporal patterns of remotely observed evapotranspiration to infer knowledge about hydrological behavior supports the findings as they pointed out that the Wami sub basin has extended high evapotranspiration at the end of the dry season i.e June–September periods.

Table 1. MLR Model Perfrmance and Green Water Storage Estimation Parameters



Regression Statistics	
Multiple R	0.891814261
R Square	0.795332676
Adjusted R Square	0.718582429
Standard Error	66.52021499
Observations	12

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	137561.7172	45853.90572	10.36260742	0.003948043
Residual	8	35399.51201	4424.939002		
Total	11	172961.2292			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-7727.059768	2341.575841	-3.299939995	0.010859823	-13126.74334	-2327.376197	-13126.74334	-2327.376197
PRECIPITATION	-1.523548633	0.459366011	-3.316633354	0.010593037	-2.582848553	-0.464248712	-2.582848553	-0.464248712
TEMPERATURE	115.9161736	21.42688119	5.40984815	0.000638474	66.50569696	165.3266502	66.50569696	165.3266502
SUNSHINE HOURS	702.6015245	240.7212227	2.918735277	0.019328682	147.4973895	1257.705659	147.4973895	1257.705659

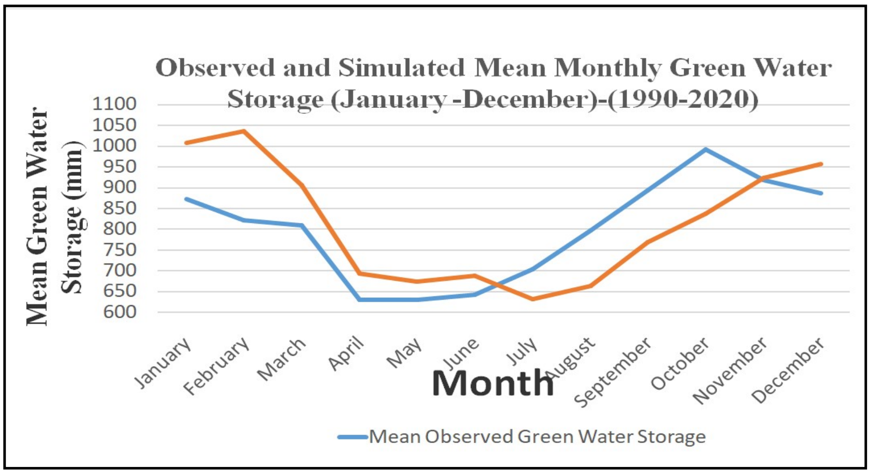


Figure 4. Observed and Simulated Mean Monthly Green Water Quantity (January-December) -(1990-2020)

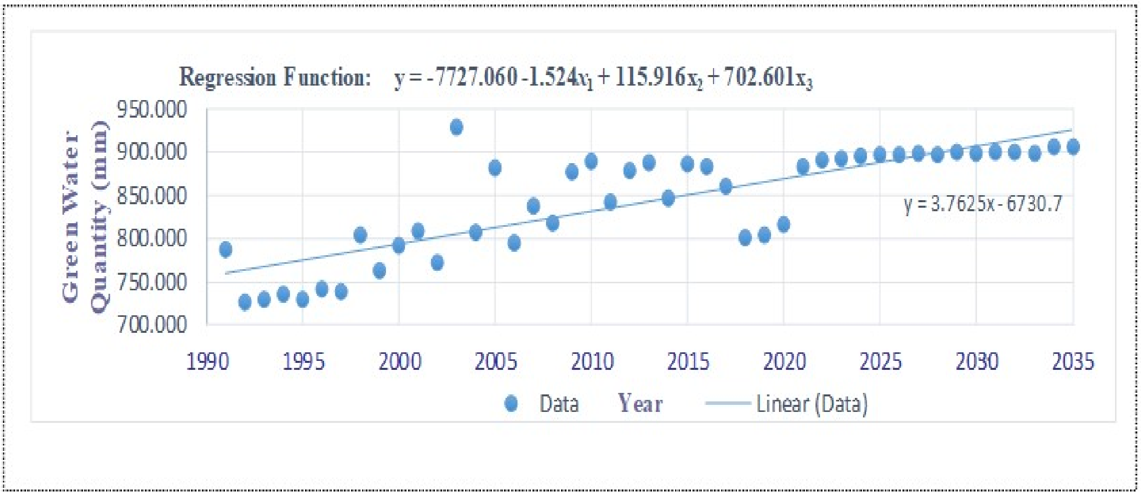
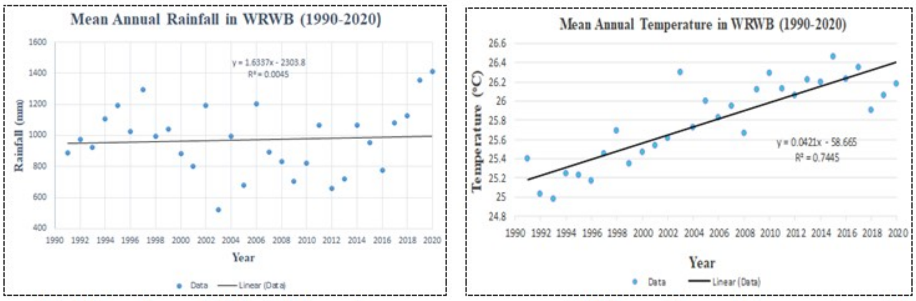
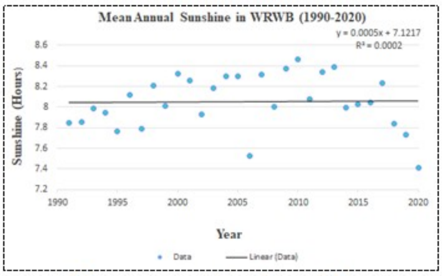


Figure 5. Regression Analysis of Green Water Quantity (mm) Based on Regression Function for Epoch (1990-2035)



(a) Mean Annual Rainfall (mm) (b) Mean Annual Temperature (°C)



(c)Mean Annual Sunshine (Hours)

Figure 6. Regression Analysis of Causative Factors on Green Water Quantity of WRWB (1990-2020): (a) Mean annual Rainfall, (b) Mean Temperature, and (c) Mean Annual Sunshine intensity

CONCLUSION

The constructed Multiple Linear Regression model, which used precipitation, temperature, and sunlight intensity to forecast the amount of green water in the Wami Ruvu Water Basin, met all the criteria for a recognized model. The historical (1990–2020) data-derived regression coefficients and constants were suitable for the model. The results of the variance analysis, including the R, R^2, F-test, and residual analysis p-value test, showed that the final model and its independent variables should be regarded as significant and ideal for estimating and analyzing the quantity of green water in the WRB. Given that temperature rise is mostly unchecked and is projected to climb over normal international standards, the government and the general public should try investing in the use of green water resources because a spike in temperature also results in an increase in green water. It is recommended to carry out further study in the WRB, considering the proper utilization of green water resources.

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