Tanzania Journal of Science 49(1): 250-262, 2023
ISSN 0856-1761, e-ISSN 2507-7961

Effects of Climate Change, Land Use and Land Cover Variability on Green and Blue Water in Wami/Ruvu Basin, Tanzania

Benson HM Lazaro[1*], Martine M Hagai[1] and Rubhera RAM 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 Environmental Science and Technology, Department of Environmental Engineering Ardhi University, P.O. Box 35176, Dar es Salaam, Tanzania.
**Corresponding author, email: lazabenm@gmail.com*
Received 19 Jul 2022, Revised 28 Mar 2023, Accepted 30 Mar 2023 Published Mar 2023
DOI: https://dx.doi.org/10.4314/tjs.v49i1.22

Abstract

Water basins are the primary food sources, giving green water and blue water worldwide. Despite the basins' potential, information on the periodical variations in blue water and green water is sparse, particularly in developing countries. The study specifically evaluated the changes in land use and land cover variability (LULCV), effects of land use and land cover variability on green water and blue water variations, and effects of climatic changes on green water and blue water. The evaluation involved the Enhanced Thematic Mapper and Operational Land Imager satellite images of 1990, 2000, 2010 and 2020. Image processing utilized the Soil and Water Assessment Tool (SWAT) in ArcGIS software. The land use and land cover variabilities indicated that land use supporting social-economic activities increased, while natural land cover decreased. Proportionally, blue water per annum was decreasing due to declining natural vegetation, enhanced by the increased socio-economic activities. Whereas, the increase in green water per annum was due to the increased temperatures, boosted by climate changes. Since the temperature rise is mainly uncontrolled, greenhouse farming should be encouraged for making green water more productive in agriculture and communities should be encouraged to practice environmentally friendly anthropogenic activities for sustainable green water and blue water management.

Keywords: Basin, Green water, Blue water, SWAT model, Climate change.

Introduction

The evaluation of land use, land cover, and climate changes has become a central component in current approaches to managing natural resources, especially fresh water in river basins. The freshwater cycle in the river basin may be partitioned into ''green water'' and ''blue water" following the hydrological processes and the storage type involved. The term "green water" refers to the percentage of precipitation that penetrates the soil to become soil moisture or temporarily remains on top of the soil or vegetation before finally evaporating and transpiring back into the atmosphere (Rockström et al. 2009). Green water is the most important water source for food production globally (ibid). The water that flows through either on or below the land surface and is stored in aquifers, lakes, and reservoirs is referred to as "blue water" (Falkenmark and Rockström 2006, Hoekstra et al. 2011). Blue water is used for domestic use such as drinking, and industrial uses including manufacturing of beverages and irrigation agriculture (Zisopoulou and

Panagoulia 2021). The sustainability of both green water and blue water is currently threatened by land usage, losses in land cover and climate changes. The hydrological cycle of green water and blue water in the basin is greatly influenced by climatic variability and land use changes (Lyu et al. 2019). Consequently, climate changes have threatened human survival due to significant impacts on the weather, crop production, water resources, and livestock production (Araya et al. 2015). Besides, according to the Conference of the Parties [COP26] (2021), effects of climate changes have already resulted in significant financial losses.

In Tanzania, the Wami/Ruvu basin is one among nine river basins available in the country. The basin is located in the east-central area of Tanzania, covering an area approximately 66,899 km^2. The basin is under overwhelming pressure due to land uses, land cover and climate variabilities. Such pressure comes from harnessing about 35% of the national economy (United Republic of Tanzania [URT] 2021). The basin intersects six regions: Dar es Salaam, Pwani, Morogoro, Tanga, Manyara and Dodoma, the latter being the capital of Tanzania. The Wami/Ruvu basin intersection with those major regions results in over-dependence by about 10 million people, estimated at 12.58 million by 2035 (Japan International Cooperation Agency [JICA] 2013). Such rapid population is also linked to increased socio-economic activities, including farming, livestock herding and industrialisation, leading to increasing water demand, posing a challenge for sustainable water resource management within the basin. Despite the potential of the Wami/Ruvu basin and the existing pressure, particularly in providing the blue water and green water in Tanzania, many studies have focused on hydrology and the potential of biodiversity within the basin (Burgess 2007, Twisa and Buchroithner 2019, Ngondo et al. 2022). Wambura et al. (2015) assessed the changing discharge patterns of the Wami/Ruvu basin under high-end climate change scenarios and reported a decrease in the base flow of the Wami river water basin. Global Water for Sustainability Program [GLOWS] (2014) report showed an average annual temperature over the Wami/Ruvu basin for historical period (1925–2002) and predicts high rise of temperature during 2003–2099.

The studies investigating the impacts of land use, land cover, and climate variability in the Wami/Ruvu basin are limited. In addition, studies utilising remotely sensed data to facilitate the synoptic analyses in periodic changes in land cover, land use, and climate change impacts in the Wami/Ruvu basin are narrow. Therefore, there was a need to investigate the effects of climate change, land use, and land cover variability aiming at improving water resources and environmental management in the Wami/Ruvu basin. This study investigated the effects of climate changes, land use, and land cover variability on green water and blue water in the Wami/Ruvu basin using remotely sensed data. Specifically, the study evaluated the aspects of changes in land use and land cover variability (LULCV), the effects of land use and land cover variability on green water and blue water variations, and the effects of climatic changes on green water and blue water.

Materials and Methods

An overview of the study area

Tanzania is divided into nine hydrological zones or river basins, including Pangani, Wami/Ruvu, Rufiji and Ruvuma, which drain their water into the Indian Ocean. Other basins are Lake Nyasa, Lake Rukwa, Lake Tanganyika, Lake Victoria, and the Internal drainage. The Wami/Ruvu basin is located in the east-central area of Tanzania, approximately 66,899 km^2. It is located between latitudes 4°54′29″ and 7°38′10″ South, and longitudes 35°38′22″ and 39°16′22″ East (Figure 1).

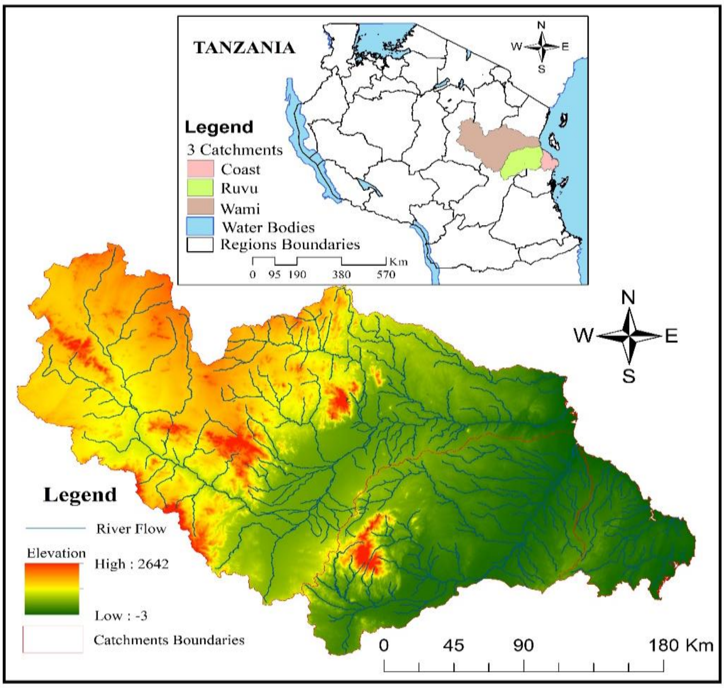

Figure 1: Location of Wami/Ruvu basin on map of Tanzania (Source: URT, 2019).

The basin consists of three sub-basins of Wami, Ruvu and Coast. In addition, the basin comprises seven catchments, namely Kinyasungwe, Mkondoa, Wami, Upper Ruvu, Ngerengere, Lower Ruvu and Coast (Figure 2).

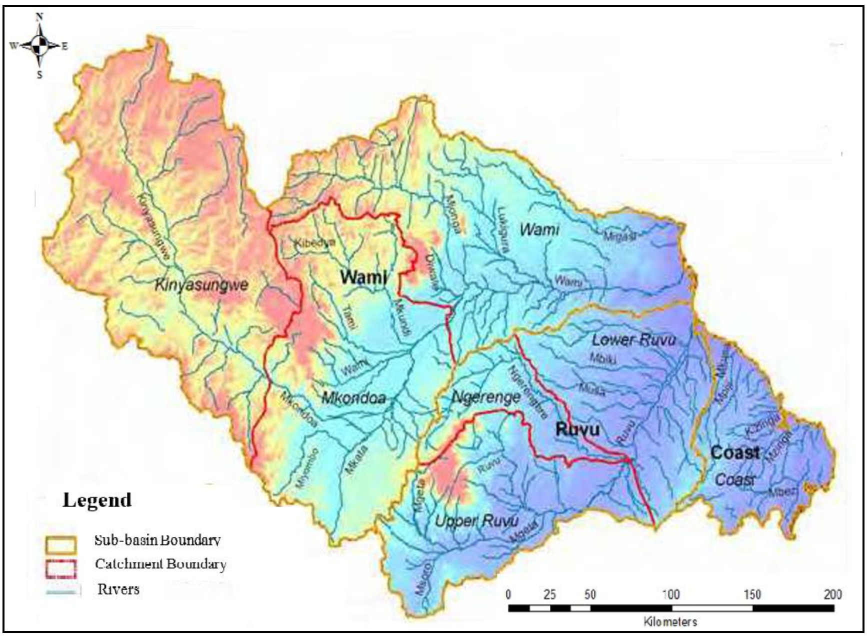

Figure 2: Sub-basins of Wami/Ruvu basin (Source: URT 2019).

The basin experiences two rainfall regions: the first is the unimodal rainfall region that covers the western and southwestern parts with one wet period ranging from November to April. The second is the bimodal rainfall region that covers the eastern and northeastern parts of the basin with two wet periods; one goes from October to December and the other from March to May (Burgess 2007).

General methodological approach

LULC data

Satellite images freely downloaded from the United States Geological Survey (USGS) Earth Explorer Database (https://earthexplorer.usgs.gov/distribution) were used in this study. This source was chosen because it has enough temporal satellite imagery data to cover the three-epoch analysis intended in this study, i.e., 1990–2000, 2000–2010 and 2010–2020. Therefore, sets of temporal Landsat satellite images, including Enhanced Thematic Mapper (ETM) and Operational Land Imager (OLI/TIRS) of 1990, 2000, 2010 and 2020 (Table 1) were used to investigate land cover changes in the study area from 1990 to 2020. The images were selected to calculate land cover changes approximately every ten (10) years.

Mapping of land use/land cover

Landsat imagery was subjected to visual inspection and interpretation. Image Classification was performed using the ArcGIS platform. Arc GIS platform was applied because it effectively extracted the land use/land cover layer from satellite imageries (Prakasam 2010, Tiwari and Khanduri 2011). Digital land use/land cover classification was deployed through the supervised classification method using ground truth data collected by hand-held GPS. The maximum likelihood technique was selected as an image classifier during the supervised classification.

Table 1: Characteristics of satellite imagery data used in this study
DEM–Digital Elevation Model

Path/ rows	Landsat type	Sensor	Acquisition date	Spatial resolution (m)	Source
168/65	Landsat 8	OLIS/TIRS C1 Level-1	1990-07-11		
	Landsat 7	ETM + C1 Level-1	2000-10-10	30	USGS
	Landsat 4-5	ETM C1 Level-1	2010-10-14		
168/64	Landsat 8	OLIS/TIRS C1 Level-1	1990-07-11		
	Landsat 7	ETM + C1 Level-1	2000-07-06	30	USGS
	Landsat 4-5	ETM C1 Level-1	2010-09-28		
167/65	Landsat 8	OLIS/TIRS C1 Level-1	1991-06-05		
	Landsat 7	ETM + C1 Level-1	2000-07-07	30	USGS
	Landsat 4-5	ETM C1 Level-1	2010-10-07		
167/64	Landsat 8	OLIS/TIRS C1 Level-1	1990-02-11		
	Landsat 7	ETM + C1 Level-1	2000-07-07	30	USGS
	Landsat 4-5	ETM C1 Level-1	2010-10-07		
166/65	Landsat 8	OLIS/TIRS C1 Level-1	1991-06-14		
	Landsat 7	ETM + C1 Level-1	2000-06-30	30	USGS
	Landsat 4-5	ETM C1 Level-1	2010-05-17		
166/64	Landsat 8	OLIS/TIRS C1 Level-1	1990-02-11		
	Landsat 7	ETM + C1 Level-1	1998-03-29	30	USGS
	Landsat 4-5	ETM C1 Level-1	2010-01-17		
DEM	SRTM 1arc-second global			30	USGS

Image processing utilised the Soil and Water Assessment Tool (SWAT) in ArcGIS software.

Quantification of green water and blue water

The quantities of green water and blue water were evaluated using SWAT model one among many hydrological modelling software. The SWAT is a continuous-time and spatially distributed basin-scale model in which hydrological processes on the surface and sub-surface are coupled to simulate the impacts of changes in management practices (Wang et al. 2017). As a built-in program, SWAT stands for the Soil and Water Assessment Tool in a computing environment that uses a water balance equation. Other hydrological models include Water Evaluation and Planning (WEAP), Soil Water Atmosphere Plant (SWAP), Spatial Processes in Hydrology (SPHY), European Hydrological System (MIKE SHE), and many others. SWAT takes different forms of naming/extension depending on the key GIS software installed with it, e.g. ArcSWAT for the ArcGIS software, MSWAT for Map window software, and QSWAT for QGIS software (Ngondo et al. 2022).

Fakhri et al. (2014), who reviewed 72 hydrological models, subscribe that the soil and water assessment tool (SWAT) model is one of the most efficient in watershed modelling in both arid and semi-arid regions. This is the reason for deploying SWAT model in this research, whereby ArcSWAT was deployed based on the water balance equation, which according to Falkenmark and Rockström (2006), is given as:

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

Notes: SW_t is the final soil water content (mm), SW_0 is the initial soil water content on a day i (mm), t is the time in days, R_{day} is the amount of precipitation on a day I (mm), Q_{surf} is the amount of surface runoff on a day i (mm), E_a is the amount of evapotranspiration on a day i (mm), w_{seep} is the amount of seepage and bypass water from the soil profile on a day i (mm), and Q_{gw} is the amount of return flow on a day i (mm).

The major input data for SWAT includes DEM, LULC, soil properties, and daily weather data such as precipitation, maximum and minimum air temperature, relative humidity, wind speed and solar radiation. Green water was calculated by summing the interception and soil moisture recharge simulated by the model. The amount of blue water was calculated by adding the model-simulated surface runoff, subsurface runoff and groundwater recharge.

Results

The results of this research are presented in two components: one for the Land Use Land Cover (LULC) variability and the other for hydrological model components in the SWAT model.

Land Use Land Cover (LULC) variability

Six LULC types were obtained from land cover classification: built-up, agriculture, water, bare land and woodland/forest (Figures 3 and 4).

Tables 2 and 3 summarise the temporal trends of the LULC variability analysis from 1990 to 2020 based on six targeted LULC types. Three land covers dominated in 1990 were woodland, wetland and agriculture, which covered 57.4%, 21.1% and 11.0% of the basin, respectively. However, woodland areas increased tremendously in 2000 but declined tremendously in the following years. In 2000, the same three land covers dominated the basin; woodland which occupied 63%, agriculture 15% and wetland 10%. In the year 2010, woodland covered (55%), wetland (18%) and agriculture (13%), while in 2020, the basin was dominated by four land covers, woodland (41%), wetland (22%), agriculture (17%) and built-up (15%) as shown in Table 2. Wetland and water as natural areas increased from 22% in 1990 to 22.7% in 2020, while woodland decreased from 57.4% in 1990 to 41.4% in 2020 (Table 2).

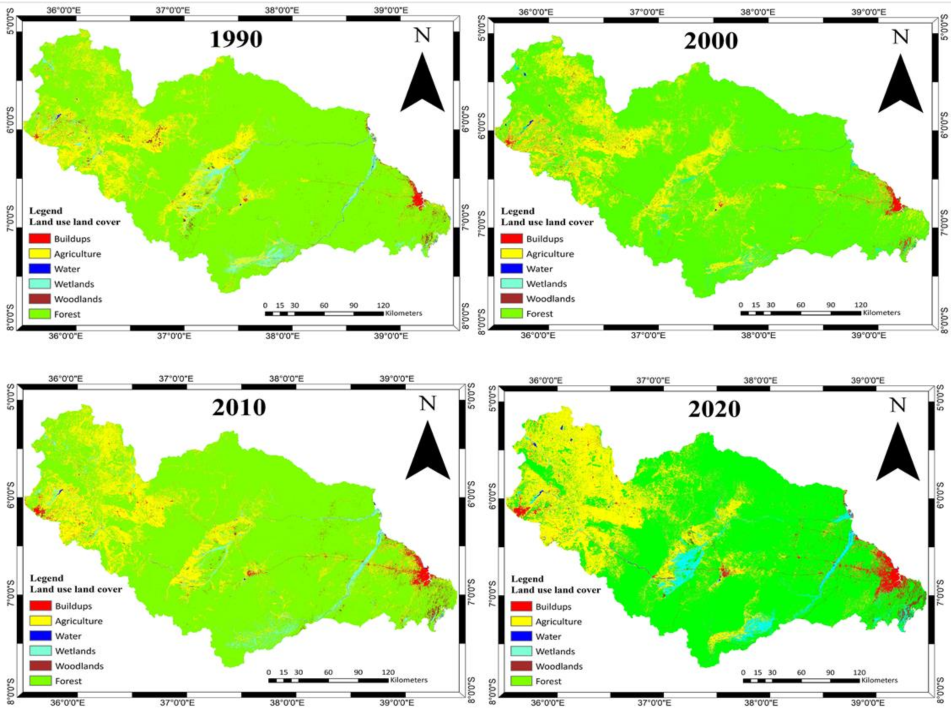

Figure 3: Land use/land cover maps of the study area for the year 2020.

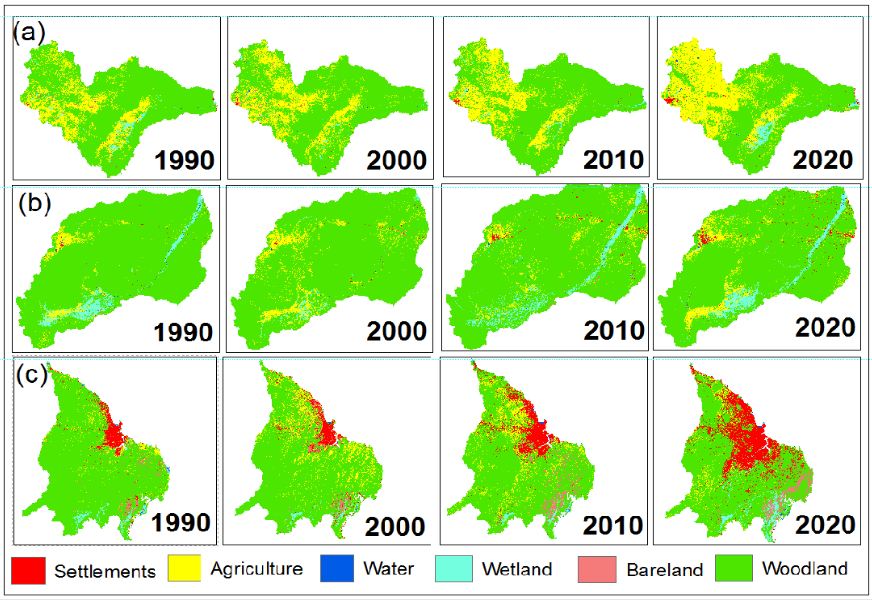

Figure 4: Land use/land cover map of the study area in a study period for each sub-basin (a) Wami, (b) Ruvu, and (c) Coast.

Generally, the results for the study period (1990–2020) on six types of LULC in the basin indicate that the land uses supporting economic activities and population development increased, as demonstrated by agriculture and built-up areas (Figures 3 and 4, and Tables 2 and 3). Built-up is the LULC with the highest gain (11.4%), and woodland is the LULC with the highest loss (16.0%) over the yearly intervals from 1990 to 2020 (Table 3). This is associated with the increase of anthropogenic activities that are not friendly to the environment. These LULC results agree with the results of previous studies by Ngondo et al. (2022), who studied the implications of LULC changes on Coastal Water Resource Management and, Twisa and Buchroithner (2019), who used a section of the Wami sub-basin to study the effects of LULC changes on hydrology.

Table 2: Overall areas (km^2) of individual LULC classification in the years 1990, 2000, 2010 and 2020 in the Wami/Ruvu Basin

LULC Types	1990 km^2	1990 %	2000 km^2	2000 %	2010 km^2	2010 %	2020 km^2	2020 %
Built-up	2,559	3.8	3,087	4.6	5,829	8.7	10,156	15.2
Agriculture	7,355	11.0	10,202	15.3	8,764	13.1	11,363	17.0
Water	589	0.9	578	0.9	467	0.7	755	1.1
Wetland	14,113	21.1	6,355	9.5	11,949	17.9	14,470	21.6
Bareland	3,863	5.8	4,335	6.5	3,307	4.9	2,443	3.7
Woodland	38,419	57.4	42,341	63.3	36,583	54.7	27,712	41.4
Total	**66,899**	**100**	**66,899**	**100**	**66,899**	**100**	**66,899**	**100**

Table 3: Yearly interval results of the LULC classification images for 1990–2000, 2000–2010, 2010–2020, and 1990–2020, showing area change (+Gain and -Loss) in (km^2) and (%) in the Wami/Ruvu Basin

LULC types	1990–2000 km^2	1990–2000 %	2000–2010 km^2	2000–2010 %	2010–2020 km^2	2010–2020 %	1990–2020 km^2	1990–2020 %
Built-up	528	0.8	2742	4.1	4327	6.5	7596	11.4
Agriculture	2847	4.3	-1438	-2.1	2599	3.9	4008	6.0
Water	-11	0.0	-111	-0.2	288	0.4	166	0.2
Wetland	-7758	-11.6	5594	8.4	2521	3.8	357	0.5
Bareland	472	0.7	-1028	-1.5	-864	-1.3	-1420	-2.1
Woodland	3922	5.9	-5758	-8.6	-8872	-13.3	-10708	-16.0

Accuracy assessment

The 1990, 2000 and 2010 image classifications had overall accuracy of 75%, 71% and 77% and kappa statistics of 0.73, 0.75 and 0.70, respectively, while the 2020 image classification had 76% overall accuracy and kappa statistic of 0.72. The image classification accuracy for each land cover class is listed in Table 4, with an average kappa index of 0.7. Therefore, as Tewabe and Fentahum (2020) observed, the classification is sufficient to produce a good and acceptable map.

Table 4: Overall classification accuracy and Kappa (K^) index statistics

Land cover class	Land cover validation accuracy			
	1990	2000	2010	2020
Built-up	75.02	69.46	31.61	70.51
Agriculture	68.35	76.85	86.30	93.63
Water	82.62	44.78	83.01	90.71
Wetland	80.43	81.03	95.66	67.85
Bareland	61.91	86.81	82.03	63.38
Woodland/Forest	78.72	65.26	81.82	70.74
Overall accuracy (%)	**74.51**	**70.70**	**76.74**	**76.14**
Kappa Index	**0.73**	**0.75**	**0.70**	**0.72**

Temperature and precipitation trends

The temperature and precipitation studies for the Wami/Ruvu basin showed an increase in temperature and a decrease in precipitation (Figures 5 and 6). On average, the temperature across the basin varied between 25 °C and 26 °C. The Wami sub-basin temperature varied between 25 °C and 26.7 °C from the 1990s to 2020. The Ruvu sub-basin increased from 24.6 °C to 26.2 °C, and Coast sub-basin increased from 25.3 °C to 27 °C. The temperature variations in these sub-basins of the Wami/Ruvu basin demonstrate temperature increased by approximately 1 °C from the 1990s to 2020 (Figure 5). Luhunga et al. (2016) predicts the increased maximum temperature in Wami/Ruvu basin from 2011 to 2040, to range from 1 °C to 1.2 °C. However, there was a sharp precipitation decrease for both sub-basins during the first and second epochs of the study. In the third epoch, specifically from 2016 to the end of the study period, there was an increasing trend in precipitation (Figure 6). This is associated with the improved environment through tree cropping and land use planning strategies implemented in Wami/Ruvu basin under securing watershed services project (Ministry of Water and Irrigation [MoWI] 2018).

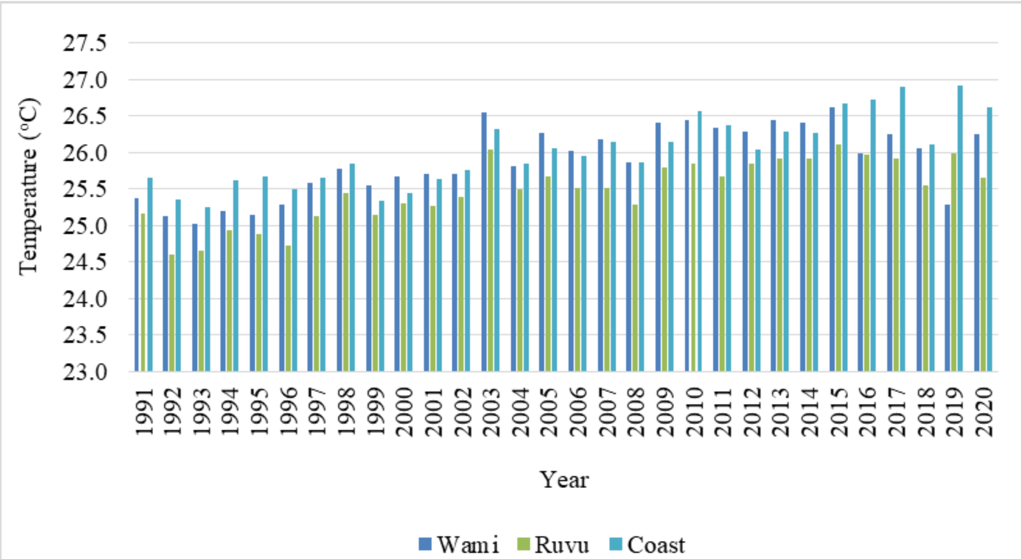

Figure 5: Annual temperature for the Sub-basins of Wami/Ruvu Basin.

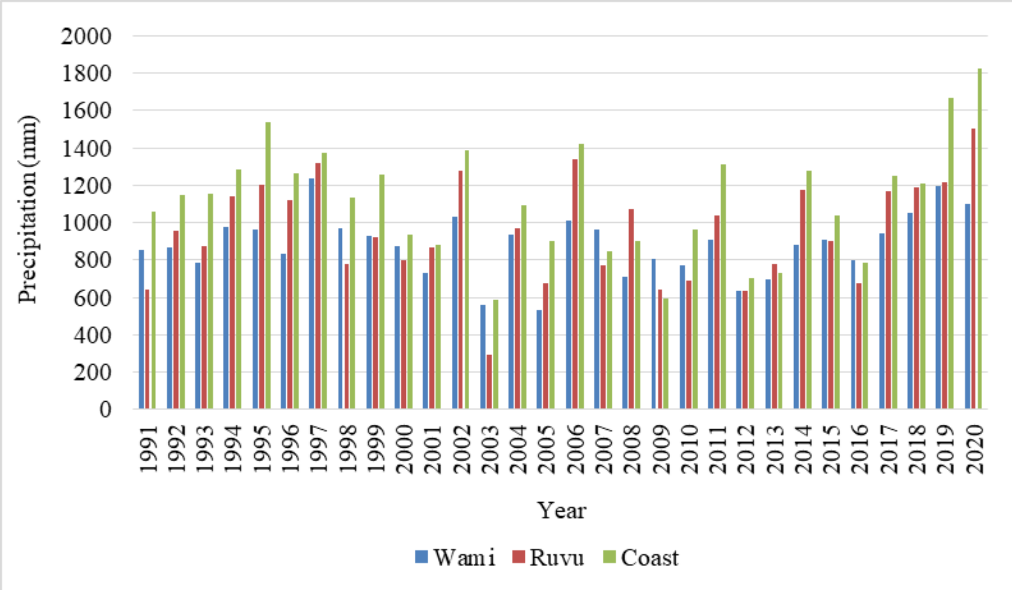

Figure 6: Annual precipitation for the Sub-basins of Wami/Ruvu Basin.

Spatial-temporal green water and blue water distribution

The green water and blue water distribution results vary between the three decades (Figure 7). The result indicated the increasing trend in green water from 320 mm per annum in 1990 to 354 mm in 2020 as opposed to blue water, which decreased from 111 mm per annum in 1990 to 97 mm in 2020). Across sub-basins, the green water variation trend was maintained whereby the Coastal had a higher amount of green water, followed by Ruvu and Wami for all the three decades. However, the amount of blue water kept on changing: in epoch one, the years 1990–2000, Ruvu had a higher amount of blue water, followed by the Coastal sub-basin. In the epoch followed the year 2000–2020, the Coastal sub-basin had a higher amount of blue water followed by Ruvu. In epoch three of the study, 2000–2010, all three sub-basins had insignificance differences in the amounts of blue water due to increased land uses supporting economic activities, i.e., agriculture and built-up areas (Figure 4). This was due to fact that the anthropogenic activities in all three sub-basins were similar. The blue water results agree with the results of previous studies by Ngondo et al. (2022), who studied the implications of LULC changes on Coastal Water Resource Management, and Twisa and Buchroithner (2019), who used a section of the Wami sub-basin to study the effects of LULC changes on hydrology.

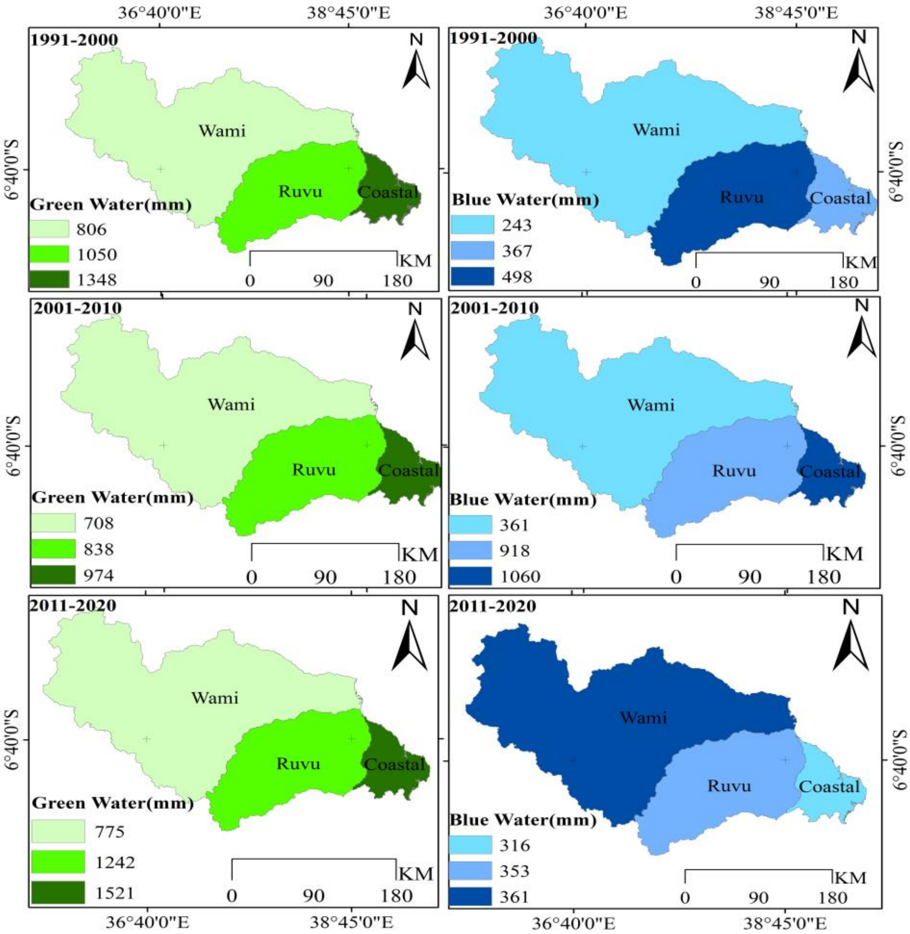

Figure 7: Spatial green water and blue water distribution in the Wami/Ruvu basin for three epochs (1990–2000, 2000–2010 and 2010–2020).

Discussions

The results for the studied years (1990, 2000, 2010, and 2020) on the different types of LULC indicated that different land cover classes were converted from one class to other classes in both epochs of the study. Most of the Wami/Ruvu basin natural areas were intensively converted into agricultural and built-up areas which are land uses supporting socio-economic activities, while natural land cover such as woodland, wetland, and water decreased. The observed land use pattern agrees with other studies conducted in different catchment areas in Tanzania, such as Malagarasi and Ruvu, where settlements and cultivation expansions were expanding rapidly (Yanda and Mushi 2007, Kashaigili and Majaliwa 2010, Mbungu 2016). This land use change pattern reflects the influence of the population on land cover due to deforestation of native vegetation, which in return affects surface runoff (Wang et al. 2017), streamflow (Zhang and Schilling 2006, Aboelnour et al. 2021), and river discharge (Costa et al. 2003) thus affecting blue water. Therefore, blue water indicated decreasing trend from 111 mm per annum in 1990 to 97 mm per annum in 2020. The observed blue water declining pattern within the Wami/Ruvu basin due to declining of natural vegetation is as established in Zhang et al. (2020). The increased population from 3.5 million in the 1990s to about 10 million people in 2020 is expected to increase to 12.58 million by 2035, forestall the increase in agricultural land and built-up areas and reducing woodland, water, and wetlands follow the current LULC trend in the study area. If this trend continues without remedial measures, its impacts on the blue and green water components will increase considerably in the future.

The increase in temperature for the studied period by 1 °C from the 1990s to 2020 was the same as the one reported in previous research by Ngondo et al. (2022), who studied the implications of LULC changes on coastal water resource management by considering Wami and Ruvu sub-basins. The alterations of precipitation trends are associated with environmental management strategies and implementation carried out by the Wami/Ruvu basin management under securing watershed services project (Ministry of Water and Irrigation [MoWI] 2018). The project improved environments by promoting income-generating activities, tree cropping, land use planning and construction of cattle troughs.

The decreasing trend of blue water during the study period was associated with a natural land cover decrease, which affects the hydrological cycle, as reported by Twisa and Buchroithner (2019) and Ngondo et al. (2022). Green water increased from 320 mm per annum in 1990 to 354 mm per annum in 2020 as opposed to blue water (Figure 7). This trend is due to the increased temperatures by 1 °C for the three decades from 1990 to 2020. Zhang et al. (2020) supports these results from his climate and land use change study that impacts blue water and green water at the Upper Ganjiang River Basin in China. Higher temperatures lead to increased evaporation and a corresponding reduction in blue water flow (ibid). According to Luhunga et al. (2016), the increased maximum temperature in 2011–2040 is projected to range from 1 °C to 1.2 °C. Furthermore, Luhunga et al. (2017) predicts temperature at the Upper Ruvu and Mkondoa catchments to range from 1.3 °C to 2.0 °C, followed by the Coast, Lower Ruvu and Wami catchments, whose temperatures will range from 1.1 °C to 1.3 °C in the years 2010–2039. The present study anticipates using the expected availability of green water for better livelihood of Wami/Ruvu dwellers.

Conclusion and Recommendations

This study assessed the effects of land use and land cover variabilities on green and blue water in the Wami/Ruvu basin over 30 years (1990 to 2020) using SWAT in ArcGIS software. Landsat data were used to acquire land use and land cover variability and, together with hydro-meteorological, topological and soil data, to model the Wami/Ruvu basin hydrology. The decrease in blue water per annum is due to declining natural vegetation. Natural land cover areas are converted into agriculture, and socio-economic activities enhance the built-up areas. On the other hand, the increase in green water per annum is due to the increased temperatures of 1 °C in three decades. These results provide important insights into the effects of changes in specific land use types and climatic factors on the hydrological characteristics. The increasing trend in temperature equally causes the increase of green water. Bearing in mind that temperature rise is mainly uncontrolled; it is likely to rise to above standard international levels, thus, detrimental to the environment.

Following observations and examinations of land use and land cover variabilities in the study area, the Wami/Ruvu Board's strategies for environmental management of the basin are highly supported. Possible mitigation measures that may be taken to improve the basin's current conditions are advised for the basin's protection. The Government and community should endeavour to invest in greenhouse farming to sustain food security. Moreover, local communities should be encouraged to practice environmentally friendly anthropogenic activities for sustainable green water and blue water management. It is recommended to carry out further studies in the Wami/Ruvu Basin, considering other key drivers of changes besides LULCVs. Furthermore, it is recommended to study blue water and green water in the rest of the eight (8) water basins since this study provides a valuable direction for studying blue water and green water in other basins in Tanzania.

Funding
This work was supported by the Research and Consultancy Unit of the Ardhi Institute Morogoro, Tanzania.

Declaration of competing for interest: The authors have no competing interests.

Acknowledgements
The authors acknowledge the financial support of the Ardhi Institute (Morogoro) through the Research and Consultancy Unit of the Institute. The authors also recognise and extend generous gratitude to the Wami/Ruvu basin Water Board and the Basin Meteorological Agency management for their cooperation and delivery of valuable information for this study.

References

Aboelnour MA, Engel BA, Frisbee MD, Gitau MW and Flanagan DC 2021 Impacts of watershed physical properties and land use on base flow at regional scales. *J. Hydrol. Reg. Stud.* 35: 100810.

Araya A, Girma A and Getachew F 2015 Exploring impacts of climate change on maize yield in two contrasting agro-ecologies of Ethiopia. *Asian J. Appl. Sci. Eng*. 4: 27–37.

Burgess ND, Butynski TM, Cordeiro NJ, Doggartg NH, Fjeldså J, Howell KM, Kilahama FB, Loader SP, Lovett JC, Mbilinyi R, Menegon M, Moyer DC, Nashanda E, Perkin A, Rovero F, Stanley WT and Stuart SN 2007 The biological importance of the Eastern Arc Mountains of Tanzania and Kenya. *Biol. Conserv*. 134(2): 209–231.

COP26 (Conference of the Parties) 2021 Uniting the World to Tackle Climate Change. UN Climate Change Conference Report in Glasgow, UK, 31 October–13 November 2021. https://ukcop26.org/the-conference. Accessed on 10th December 2021.

Costa MH, Botta A and Cardille JA 2003 Effects of large-scale changes in land cover on the discharge of the Tocantins River, Southeastern Amazonia. *J. Hydrol.* 283: 206–217.

Fakhri M, Dokouhaki H, Eslamian SS, Fazeli FI and Farzaneh MR 2014 Flow and sediment transport modeling in rivers. In: Eslamian SS (ed) Handbook of Engineering Hydrology, Ch. 13, Vol. 2: modeling, climate change, and variability. Taylor and Francis: CRC Press, Boca Raton, pp 233–267.

Falkenmark M and Rockström J 2006 The new blue and green water paradigm: breaking new ground for water resources planning and management. *J. Wat. Res. Plan. Manage.* 132 (3): 129–132.

Global Water for Sustainability Program (GLOWS) 2014 Report on Climate, forest cover and water resources vulnerability, Wami/Ruvu Basin, Tanzania. Available online: http://dpanther.fiu.edu/sobek/FI14103145/00001. Accessed on 20th January 2022.

Hoekstra AY, Chapagain AK, Mekonnen M and Aldaya MM 2011 The Water Footprint Assessment Manual: Setting the Global Standard (1st ed), London, UK, Earthscan.

Japan International Cooperation Agency (JICA) 2013 The Study on Water Resources Management and Development in Wami/Ruvu basin in the United Republic of Tanzania. Available online: https://www.jica.go.jp/tanzania/english/index.html
Accessed on 17th December2021.

Kashaigili JJ and Majaliwa AM 2010 Integrated assessment of land use and cover changes in the Malagarasi river catchment in Tanzania. *Phys. Chem. Earth Parts A B C.* 35: 730–741.

Luhunga MP 2016 *Evaluation of climate change impacts on rain-fed crop production in the Wami-Ruvu Basin of Tanzania*. PhD thesis, University of Pretoria, South Africa.

Luhunga P, Chang'a L and Djolov G 2017 Assessment of the impacts of climate change on maize production in the Wami Ruvu Basin of Tanzania. *J. Water Climate Change* 8(1): 142-164.

Lyu L, Wang X, Sun C, Ren T and Zheng D 2019 Quantifying the effect of land use change and climate variability on green water resources in the Xihe River Basin, Northeast China. *Sustainability* 11: 338.

Mbungu WB 2017 *Impacts of land use and land cover changes, and climate variability on hydrology and soil erosion in the Upper Ruvu Watershed, Tanzania*. PhD thesis, Virginia Tech: Blacksburg, Virginia.

Ministry of Water and Irrigation (MoWI), United Republic of Tanzania 2018 Securing Watershed Services Through SLM in the Ruvu and Zigi Catchments (Eastern Arc Region), Tanzania. UNDP GEF PIMS 5077/GEF ID 5436; Atlas Award 00086631/Atlas Project ID 00093855. Project Report. GEF, United Republic of Tanzania and UNDP.

Ngondo J, Mango J, Nobert J, Alfonse D, Li X and Cheng H 2022 Hydrological response of the Wami–Ruvu Basin to land use and land cover changes and its impacts in the future. *Water* 14: 184.

Prakasam C 2010 Land use and land cover change detection through remote sensing approach: A case study of Kodaikanal Taluk, Tamil Nadu. *Int. J. Geomat. Geosci.* 1(2): 150–158.

Rockström, J, Falkenmark M, Karlberg L, Hoff H, Rost S and Gerten D 2009 Future water availability for global food production: The potential of green water for increasing resilience to global change. *Water Resour. Res.* 45(7): W00A12.

Tewabe D and Fentahun T 2020 Assessing land use and land cover change detection using remote sensing in the Lake Tana Basin, Northwest Ethiopia. *Cogent Environ. Sci.* 6(1): 1778998.

Tiwari K and Khanduri K 2011 Land use/land cover change detection in Doon Valley (Dehradun Tehsil), Uttarakhand: using GIS & Remote Sensing Technique. *Int. J. Geomat. Geosci.* 2(1): 34-41.

Twisa S and Buchroithner MF 2019 Land use and land cover change detection in Wami River Basin, Tanzania. *Land* 8: 136.

United Republic of Tanzania (URT) 2019 The study on integrated water management and development plan for Wami/RuvuBasin (IWRMDP); Project: Report Ministry of Water, Comprehensive review of existing water resources assessment: YEKOM Consulting engineers. Dodoma, Tanzania.

United Republic of Tanzania (URT) 2021 Tanzania in Figures, National Bureau of Statistics, Ministry of Finance and Planning. Dodoma, Tanzania.

Wambura FJ, Ndomba PM, Kongo V and Tumbo SD 2015 Uncertainty of runoff projections under changing climate in Wami River sub-basin. *J. Hydrol. Region. Studies* 4: 333–348.

Wang F, Ge Q, Yu Q, Wang H and Xu X 2017 Impacts of land use and land cover changes on river runoff in Yellow River Basin for period of 1956–2012. *Chin. Geogr. Sci*. 27: 13–24.

Yanda PZ and Munishi P 2007 Hydrologic and land use/cover change analysis for the Ruvu River (Uluguru) and Sigi River (East Usambara) watersheds. For WWF/CARE Dar es Salaam; Tanzania. Available online: https://citeseerx.ist.psu.edu/document?repre=rep1&type=pdf&doi=71008399b49c99f2e1790689532d553a0b9719c8 Accessed on 19 August 2021.

Zhang Y, Tang C, Ye A, Zheng T, Nie X, Tu A, Zhu H and Zhan S 2020 Impacts of climate and land use change on blue and green water: A case study of the Upper Ganjiang River Basin, China. *Water* 12(10): 2661.

Zhang YK and Schilling KE 2006 Increasing stream flow and base flow in Mississippi River since the 1940s: Effect of land use change. *J. Hydrol*. 324: 412–422.

Zisopoulou K and Panagoulia D 2021 An in-depth analysis of physical blue and greenwater scarcity in agriculture in terms of causes and events and perceived amenability to economic interpretation. *Water* 13(12): 1693.