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Impact of climate change on groundwater recharge in the lake Manyara catchment, Tanzania

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ABSTRACT

Groundwater account for about 60 to 80% of water supply to the population of Tanzania's semi-arid regions for domestic and agriculture uses. Despite the importance of groundwater resource in semi-arid areas, limited information exists on the recharge amount and potential recharge zones in Tanzania in the context of climate change which could result in unsustainable withdrawals. This study aimed to estimate the potential impact of climate change on groundwater recharge and identify potential recharge zones in the Lake Manyara catchment using Water and Energy Transfer between Soil, Plants and Atmosphere under the quasi-steady State (WetSpass) model. The WetSpass model was setup and calibrated using hydro-meteorological data (rainfall, temperature, wind speed, potential evapotranspiration, and groundwater depth) and biophysical data (soil, land use, topography, and slope). Simulated rainfall, temperature and potential evapotranspiration from an ensemble of four CORDEX-Africa regional climate models for the period 2021–2050 under the Representative Concentration Pathway (RCP 8.5) scenario (hereafter referred as business-as-usual scenario) were used as input in the WetSpass model for the climate change impact assessment. WetSpass model calibration using the water balance equation showed a coefficient of determination (R^2) value of 0.9 and Root-Mean-Square Error (RMSE) of 0.49 mm/yr between the simulated and calculated recharge. It was determined that the mean annual recharge of 53.9 mm/year (149 MCM/year) for the period 1989–2018 would increase by 7.9% in the future (2021–2050) under the business-as-usual climate scenario, due to the increase in rainfall. Seasonality and spatial differences in recharge amount were observed, with recharge projected to increase in the dry season and at areas that receive high amount of rainfall. Potential recharge zones in the catchment were found mostly around the northern part near Ngorongoro, the south-western part, and around Mbulu region. Findings from this study would help policymakers, and local stakeholders in planning and management of the groundwater resources for sustainable development.

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Introduction

Water, as the backbone and most important element of life on the global scale, must be available in adequate quantity and quality to meet the growing demand for domestic, agricultural, and industrial processing operations. However, due to its natural distribution on the earth's surface, its availability is limited [23]. Basically, global water contains 97.5% by volume that is held in the oceans as saltwater and only 2.5% as freshwater; 68.7% of the freshwater is encased in glaciers, while 30.1% and 0.9% represent groundwater and surface freshwater, respectively [23, 27, 29].Increase in population and economic activities intensifies water demand whereas climate change and variability influence the distribution of water around the world. According to Intergovernmental Panel on Climate Change (IPCC) (2013), climate change has the potential to degrade groundwater availability, water quality, and water supplies [9, 13]. The majority of current studies concentrate on surface water resources focusing water quality [30] and quantity. However, the analysis of groundwater resource is much more needed especially amidst the presence of climate change and variability in order to sustainably balance the recharge and abstraction of the available groundwater resource.

In Sub-Saharan Africa, a large population lacks the accessibility to clean water and is more vulnerable to the anticipated changes and variability in climate [4]. For rural populations and many growing cities, groundwater is the primary supply of clean drinking water, and often the only source of water in dry lands [15]. Groundwater resource exploration is rising quickly in Africa and is obviously featured in national development plans, particularly to meet the demand for improved access to safe water and agricultural intensification in the face of fast-growing populations and economic development. Therefore, proper planning of such a scarce water resources in terms of storage, allocation, return flow and environmental services are vital for optimization of the resource.

The mean values of climatic variables have been projected to change, especially temperature increase in the dry areas and decrease in wet areas [19]. These have implications on both groundwater quality and quantity. In recent times, groundwater resources have more competitive advantages than other water resources because in most of the areas, groundwater resource is used as adaptation measures to climate variability and change. Additionally, groundwater has sustainability potential over surface water due to its relatively lower exposure to pollution and in most cases complex reservoir can exist throughout the year. In a similar vein, the impact of climate change on groundwater has been observed in the resident time of the groundwater recharge, which ranges from days to tens of thousands of years. [1]. The prolonged resident time delays and disperses the effects of climate and challenges efforts to detect responses in the groundwater to climate variability and change [14]. However, renewable groundwater is directly tied to near-surface hydrologic processes; the hydrologic cycle could be directly affected by climatic change.

In Tanzania, heterogeneous climate condition is experienced due to the complicated topography, numerous inland water bodies, variation in vegetation types and land-ocean contrasts (Kijazi & Reason, 2009). This complexity leads to a variety of climate among different areas even within a relatively small distance, depending on the sensitivity of the hydrological response and processes towards the different geophysical feature of the area [16]. The country's populace relies on both surface water and groundwater resources for water supply. However, in semi-arid locations, groundwater is the primary source of water due to the limited availability of surface water. In these areas, groundwater account for about 60 to 80% of water supply to the population for domestic and agriculture uses. Despite the importance of groundwater resource in semi-arid areas, limited information is available on the recharge amount and potential recharge zones. This presents substantial challenge in the management of the groundwater resource.

Lake Manyara catchment is one of the important catchments in Tanzania for agriculture and tourism which employs and provides income for the population. Irrigated agriculture, livestock holding, and wildlife protection are all supported by the catchment. The increased freshwater demand and temporal variability of surface water flow, increased human activities and intensification of climate variability and change have put stress on the water supply in the Lake Manyara catchment. This has led to water related conflicts between pastoralist and farmers in some communities within the catchment [24]. The situation has become critical in the context of climate change. However, few studies have been done [8, 10, 17, 22] on groundwater quality and other parameters. Little information is known in terms of the quantity of historical and future groundwater recharge in the Lake Manyara catchment. Therefore, the aim of this study was to assess the impact of climate change on groundwater recharge at the Lake Manyara catchment using Water and Energy Transfer between Soil, Plants and Atmosphere under quasi-steady State (WetSpass) model and identify potential recharge zones. This study is not only crucial for water resource managers but also to improve our understanding of hydrological processes in this catchment. As far as the authors are aware, no such comprehensive methodological approach used by the present study examined the groundwater resources of the catchment.

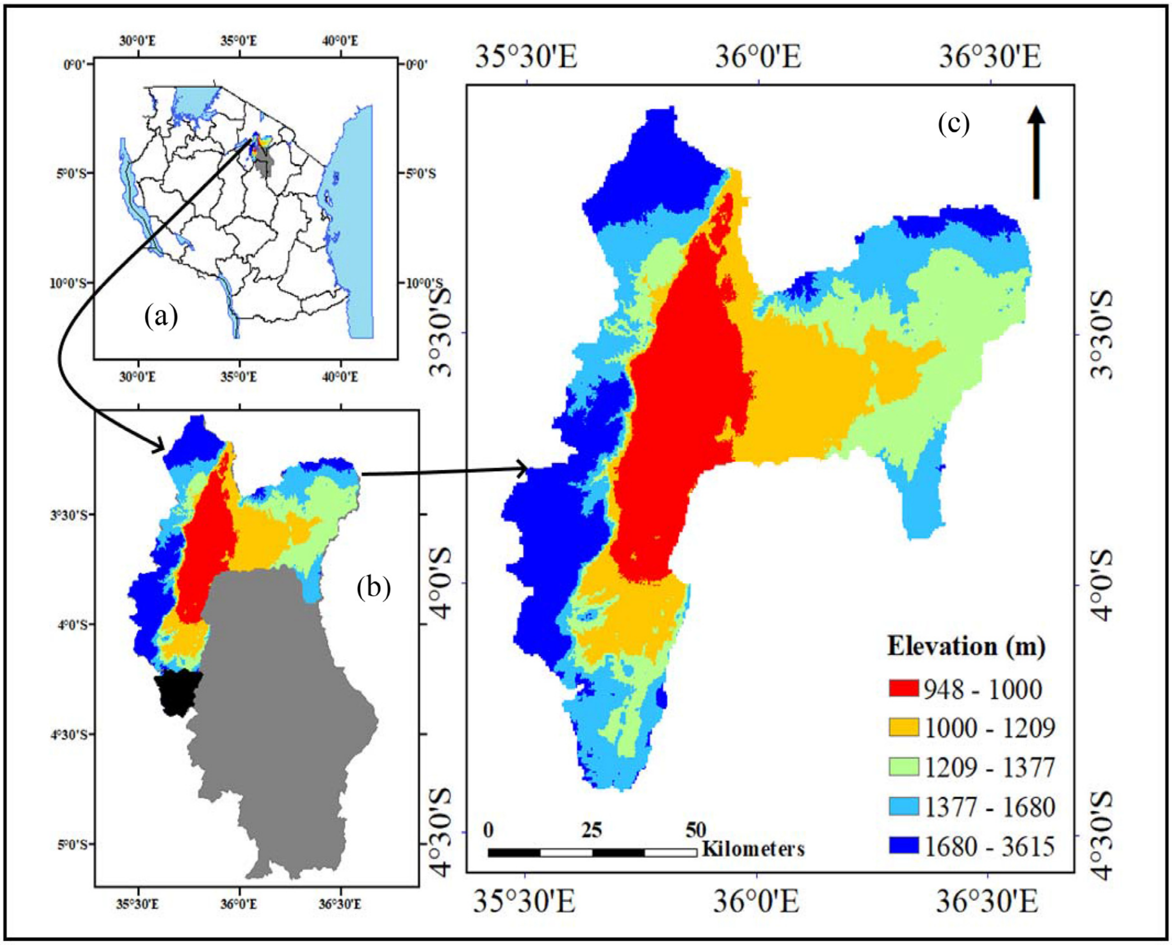

Fig. 1. Location of Lake Manyara catchment: (a) within Tanzania (b) Lake Manyara basin (c) showing elevation of the Lake Manyara catchment.

The article has the following structure: Section two presents the description of materials and methods which include the study area, data used, climate analysis, model description and hydrological modeling. The section three presents the results and discussion, whilst section four presents the conclusion of the research.

Materials and methods

Study area

Lake Manyara catchment is situated in the north-eastern part of Tanzania within Arusha and Manyara regions (Fig. 1). Specifically, it is situated in the geographical location of latitude 3°00′ S to 5°30′ S, and longitude 35°30′ E to 37°00′ E, within an estimated area of about 7920 km^2 [28]. The climate of the catchment is characterized by bimodal rainy seasons. The major (longer) rainy season is between March and May, and the minor (shorter) rainy season is from October to December. The mean annual rainfall in the catchment is about 780 mm. The mean maximum and minimum temperatures are around 27.8 °C and 15.0 °C, respectively [25]. The dominant land use/land cover types in the catchment include grassland, shrub cover and cultivated land [21]. During the dry season, the area experiences crowds of livestock migrations from Serengeti to Ngorongoro [28], which increases pressure on available water resources in the catchment. The frequently cultivated crops in the area include bananas, maize, rice and vegetables. Most of these crops have high water demand (FAO, 2007). Hydrologically, both perennial and non-perennial rivers cover the area and feed water to the lake. Mto wa Mbu, Mto wa Simba, and the Kirurumu River are the catchment's major tributaries.

WetSpass model description

The WetSpass is a physically-based model used to estimate the spatial patterns of the water balance components (i.e. groundwater recharge, surface runoff and evapotranspiration) by using physical and empirical relationships [5]. The model was selected due to its ability to simulate groundwater recharge in areas of scarce data availability such as this catchment [6]. Compared with most traditional hydrological models, the WetSpass model is user friendly and is more preferable for Lake Manyara catchment where hydro-meteorological data is a challenge. In addition, the model has been applied in different countries mostly in the tropics for annual and seasonal groundwater spatial variation estimation and the obtained results have strong relationship with other traditional hydrological model results simulated in the same area [23]. However, like other models, WetSpass has several uncertainties, even though the results from it are valid for groundwater resources management plans and policy formulations. The spatial patterns of the water balance components are obtained by summing up the individual water balance raster cells Eq. (1) to (3) which according to Batelaan and De Smedt [6] are defined as:

$$ET_C = a_v ET_v + a_s E_s + a_o E_O + a_i E_i \tag{1}$$

$$S_C = a_v S_v + a_s S_s + a_o S_O + a_i S_i \tag{2}$$

$$R_C = a_v R_v + a_s R_s + a_o R_o + a_i R_i \tag{3}$$

where, ET_c, S_c and R_c are the total evapotranspiration, surface run-off, and groundwater recharge of a raster cell, respectively. The indices s, o and i stand for the bare area, open water area and impervious surfaces, respectively. While S_s, S_o and S_i; E_s, E_o and E_i; and R_v, R_s, R_o and R_i are the surface run-offs, evaporations and groundwater recharge in the bare area, open water area and impervious surface, respectively.

The groundwater recharge (R_v) is calculated as shown in Eq. (4).

$$R_v = P - S_v + ET_v + I \tag{4}$$

where P is the average seasonal precipitation, ET_v is the actual evapotranspiration [$LT^{-}1$] (per liter), S_v is the surface runoff over the land surface beneath the vegetation, and I is the interception by vegetation, all variables have the unit of $LT^{-}1$.

WetSpass model input data

The essential inputs required by the WetSpass model are hydro-meteorological parameters, and biophysical parameters (i.e. Digital Elevation Model (DEM), Land use/cover and soil data) which are spatialized [7]. Input data were prepared as grid maps using ArcGIS 10.5 as required by the WetSpass model [23].

Hydro-meteorological data

The hydro-meteorological parameters were prepared based on the seasonal climatic conditions (dry and rainy seasons) identified in the region. The parameters used in this study include rainfall, temperature (mean, maximum and minimum), potential evapotranspiration (PET), and wind speed for the period 1989–2018 and groundwater levels for the period 2010–2015. The rainfall data was obtained from the Climate Hazards Group Infrared Precipitation with Station data (CHIRPS) which is at 5 km spatial resolution [11]. The temperature and wind speed datasets were obtained from the National Aeronautics and Space Administration Prediction of Worldwide Energy Resource (NASA POWER) project (https://www.power.larc.nasa.gov/data-access-viewer). Data on groundwater level was collected from the Internal Drainage Basin (IDB) in Tanzania. The PET (mm/day) was calculated using the Hargreaves method as shown in Eq. (5) [2].

$$\mathrm{PET} = 0.00023(\mathrm{Tmean} + 17.8)(\mathrm{Tmax} - \mathrm{Tmin})\mathrm{x}0.5\mathrm{Ra} \tag{5}$$

where Tmean is the mean temperature; Tmax and Tmin are the maximum and minimum temperature (°C) values, respectively; and Ra is extraterrestrial radiation (mm/day).

The long-term spatial distribution pattern of the mean annual rainfall, temperature, wind speed (Appendix 1), and that of potential evapotranspiration and 1989–2018 and 2010–2015 for ground water levels (Appendix 2) for the rainy and dry seasons were analyzed using the Inverse Distance Weighs (IDW) method. High rainfall amount is received in the western-north and the southern part of the catchment while the lowest rainfall amount is received at the eastern part of the catchment in the rainy season. Spatial distribution of temperature is opposite or contrary to that of rainfall (Appendix 2a and 2c). During the dry season, rainfall in the northern part of the catchment is generally higher than in the southern part. In the case of temperature, an opposite situation is noticed. The southern part rather experiences higher temperature compared to the northern part of the catchment. The spatial distribution of future rainfall, temperature and evapotranspiration under the RCP 8.5 emission scenario are presented in Appendix 3.

Biophysical parameters

Digital elevation model. The data from Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) DEM at 30 m spatial resolution was used in this study. The slope map of the catchment which was derived from the DEM using the 'slope' module in ArcGIS 10.5, ranges from 0.0 to 47% (Appendix. 4a), and the elevation of the catchment ranges from 948 m to 3615 m (Appendix. 4b).

Land-use/ land-cover. The land use/land cover (LULC) map of 2016 at 20 m resolution was obtained from the Sentinel 2A prototype land cover under the ESA Climate Change Initiative (CCI) (http://2016africalandcover20m.esrin.esa.int/download.php). The extracted LULC data for the catchment (Appendix. 4c) was reclassified using the ArcGIS into similar land use/ cover classes defined in the WetSpass model for the Lake Manyara catchment. The LULC data was then converted from raster to ASCII format, acceptable format as input data for WetSpass. Grassland (39.6%) was identified as the most dominant LULC type, flowed by shrub cover (26.6%), agriculture (18.8%), mixed forest (6.9%), Water (6.7%) and the rest (1.3%) as shown in Appendix 5a. In view of the negligible change in land-use between wet and dry season in the same year, only the available LULC which was for the year 2016 was used for both seasons.

Soil map. The spatial soil map used was based on the soil texture classification scheme developed by the United States Department of Agriculture (USDA) [12]. Appendix 5b shows that the dominant soil textures of the catchment are silt (46%), sandy loam (19%), loamy sand (13.8%), and sand (13.6%). The silt soil has high water retention capacity and porosity, which makes the area not much conducive for recharge capability.

WetSpass model setup, calibration and performance evaluation

Long-term average climatic data for the period 1989–2018 together with topography, potential evapotranspiration, LULC and soil map were used to set up the WetSpass model [5]. The grids of potential runoff coefficient and depression storage capacity of the catchment by means of attribute lookup tables was obtained from topography, LULC and soil map (Kahsay et al. 2017). The instantaneous unit hydrograph (IUH), travel time to the basin outlet, grids of flow velocity and standard deviation were generated at the final time step. The model was calibrated for the period 2010–2015 using a repeated trial and error method and fine-tuning the global parameters within the range (Kahsay et al. 2017). The simulated recharge was compared with the water balance equation calculated recharge. This approach of WetSpass model calibration by comparing the model simulated recharge with calculated recharge has also been used by Kubicz et al. [18]. A detailed description of the water balance equation procedure used in the manual recharge calculation can be found in Armanuos et al. [3]. The main WetSpa model calibration parameters and its common threshold values used in this study are shown in Appendix 6. Due to the limited or few parameters of the model, model sensitivity analysis was not performed with the assumption that each parameter will affects the model results (Liu and De Smedt, 2004). The WetSpass model performance after calibration was evaluated using the scatter plot, coefficient of determination (R^2) and Root-Mean-Square Error (RMSE). The R^2 is one of the important criteria which expresses the model confidence when evaluating continuous model simulation. The R^2 is considered acceptable when greater than 0.5 (Santhi et al., 2001). After the calibration of the WetSpass model, the groundwater recharge was estimated based on the measured input parameters to the model.

Identification of the recharge zones

Recharge zones were identified from the recharge output maps obtained from the WetSpass model. From the recharge output maps, the recharge computation showed the places with high recharge amount (best recharge points/locations). Three points/locations were selected and ranked into three categories (high, medium and low recharge areas) during the computation analysis of the recharge point. The rechargeability of the identified zones was performed using the ArcGIS software by computing the recharge amount for each cell over the recharge area.

Climate change data and impact assessment

The study assessed climate change impact (i.e. changes in rainfall, temperature and PET) on groundwater recharge by assuming that land use and other biophysical factors will remain constant in future. Future climatic data (rainfall and temperature) at daily scale used in this study was obtained from the multi-model ensemble (MME) of four Coordinated Regional Climate Downscaling Experiment (CORDEX) Africa regional climate models (RCMs) at 44 km spatial resolution. The RCMs used are dynamically downscaled from Coupled Model Inter-Comparison Project Phase 5 (CMIP5) of IPCC fifth assessment report. These four RCMs were selected due to their capabilities to reproduce the observed rainfall and temperature at the study region [20]. The characteristics of the CORDEX-Africa RCMs are shown in Table 1. MME is recommended for impact assessment because of it better performance when considering all aspects of the predictions and it reduce uncertainties [20]. The RCP 8.5 which indicates business- as -usual emission scenario was chosen to determine the possible worse situation for ground water recharge in the study area if mitigation and adaptation strategies are not implemented immediately. The RCP 8.5 was chosen because many previous climate change analysis studies and the recent IPCC Sixth Assessment Report (AR6) attest to the fact that the world has still not achieved the anticipated change from the business-as-usual way of mitigating climate change, and the future possible global efforts to technically limit forcing from RCP 8.5 to lower levels are very uncertain.

The future (2021–2050) potential evapotranspiration (PET) data was computed from the future temperature data using the Hargraves method. The spatial distribution of future rainfall, temperature and PET for the rainy and dry seasons (Appendix 3) were analyzed using the IDW technique. The obtained simulated rainfall, temperature and PET data under RCP 8.5 scenario were used as inputs to the WetSpass model to estimate the future groundwater recharge of the Lake Manyara catchment as illustrated by Fig. 2 below.

Table 1
Characteristics of the CORDEX-Africa models used [20].

RCMs	Institution	Short name of RCM	GCM
CLM com COSMO–CLM (CCLM4)	Climate Limited- Area Modelling (CLM) Community	CCLM4	MPI- ICHEC CNRM
DMI HIRHAMS	Darmarks Meteorologiske	HIRHAMS	
	Instut (DMI)		
	Danmark		ICHEC
SMHI Rossby	Sveriges Meteorologiske		
Atmosheric Climate	Och Hydrologisks		
Model (RCA4)	Instut (SMHI)		MPI-ICHEC
	Sweden	RCA4	CNRM
KNMI	Konkinklijk		
Atmospheric Climate	Nederland	RACMO2.2T	ICHEC
Models, version 2.2	Instituut (KNMI)		
(RACMO2.2T)	Netherlands		

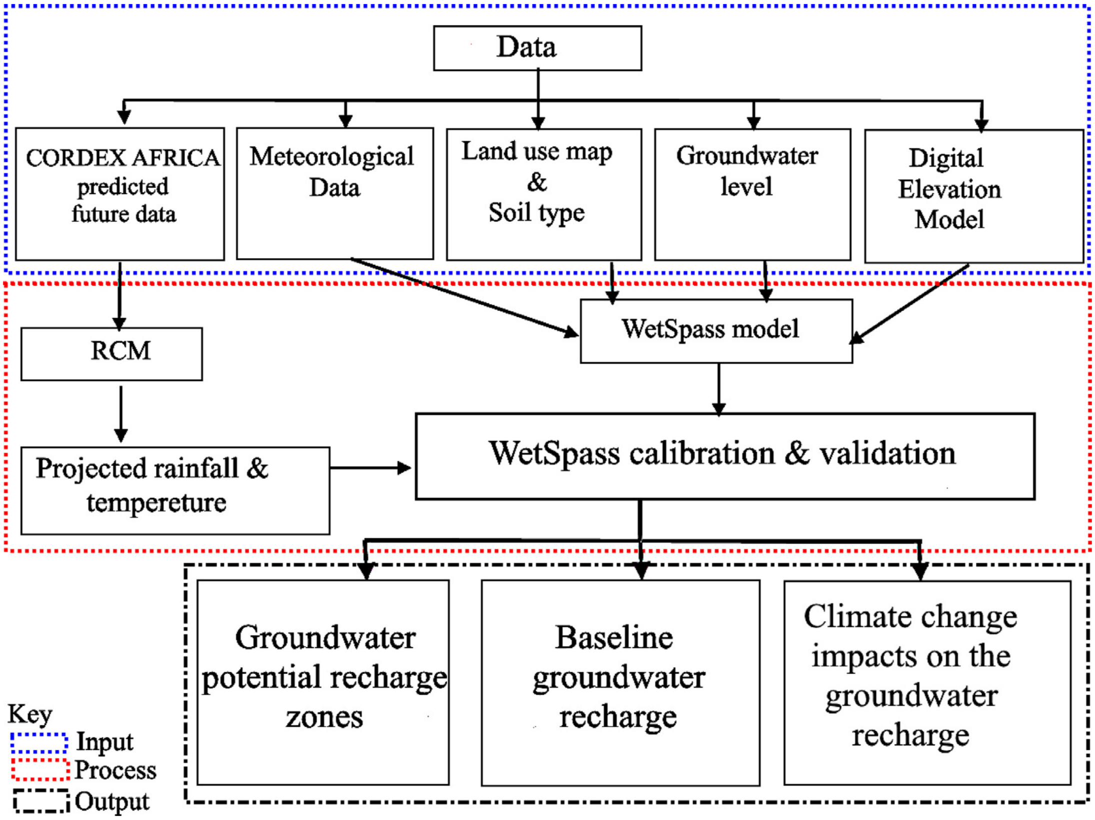

Fig. 2. Methodological framework.

Results and discussion

WetSpass model performance evaluation

Presented in Appendix 7 are the global model parameters and calibration results for the Lake Manyara catchment. The statistical modeling results from 2010 to 2015 indicate a good agreement between the simulated and calculated groundwater recharge in the Lake Manyara catchment (Fig. 3). A high correlation coefficient of determination (R^2) of 0.9 and Root-Mean-Square Error (RMSE) of 0.49 mm/yr were found during the calibration process. The obtained calibration results of the WetSpass model shows its skills in simulating the hydrological components of the Lake Manyara catchment. This statistical model results are in agreement with Yenehun et al. (2017) and Kahsay et al. (2017) where WetSpass model model was calibrated and used to estimate groundwater recharge.

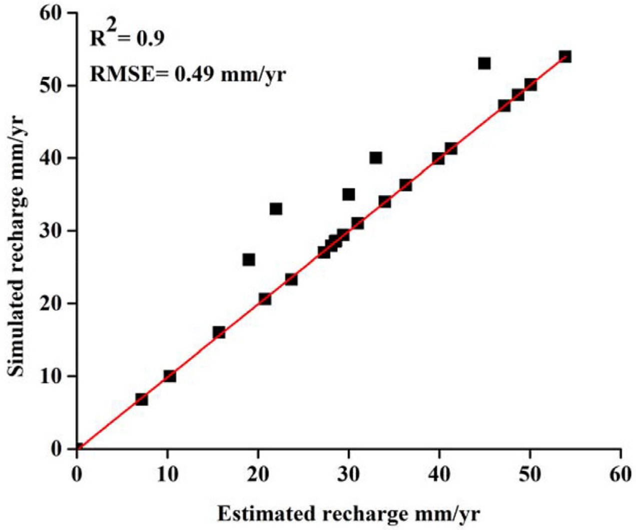

Fig. 3. Scatter plot of simulated recharge calculated using the water balance equation model and estimated using WetSpass model in the Lake Manyara catchment from 2010 to 2015.

Recharge estimation under historical and future climate

Recharge under historical period

During the historical (1989–2018) period, the average annual long-term groundwater recharge from infiltrated rainfall into the aquifer was simulated to be 53 mm/ year (6.7% of the mean annual rainfall), corresponding to 149 MCM/year. The spatial distribution of the annual average value of simulated groundwater recharge for the 30-year period (1989 to 2018) shows seasonality differences in recharge amount (Fig. 4). In the historical period, high recharge at the catchment was mostly found to be located at the northern and western parts. The areas that showed the highest recharge were areas that receive a high amount of rainfall. The areas were also forested and the soil type was sandy with high porosity to allow the recorded amount of groundwater recharge. Similarly, places with low recharge mostly receive less rainfall, and had silt soil type and shrub land cover. Sandy soils have higher water infiltration rates compared with clayey and silty soils, notwithstanding the fact that the presence of a closed forest canopy also influences the varying groundwater recharge over the study area. This result indicates the influence of land use land cover and soil type in groundwater recharge, apart from the climate. Minimum recharge amounts of approximately zero were observed especially in the dry season and mostly found in the eastern and southern parts of the catchment where temperature was mostly high (Fig. 4b). Seasonal variation showed more recharge in the rainy season than the dry season. The result shows that evapotranspiration process occur faster in the catchment thereby hindering the possibility of groundwater recharge from a rainfall events especially during the dry season when rainfall is significantly low [18] and temperatures are high. It implies that, the continuous abstraction and decline in groundwater levels in most areas in the catchment would take a longer period to be recharged or may not be recharged at all. This condition will lead to water scarcity over the area for both surface and groundwater and thereby limits accessibility of water for domestic use, livestock keeping and agriculture activities around the area especially during drought years.

Future projections of climate and recharge under RCP 8.5 scenario

Analysis of the multi-model mean of the RCMs for rainfall and temperature in the 2021–2050 period under RCP8.5 scenario showed an increase in the mean annual rainfall and temperature by 8% and 0.3 °C respectively relative to the 1989–2018 period. At the seasonal scale, the spatial distribution of rainfall ranged from 532.3 to 654.5 mm in the rainy season and from 18.5 to 140.1 mm in the dry season during the historical period (Appendix 3). Rainfall was projected to increase from 323.2 to 761.8 mm in the rainy season and from 38.9 to 502 mm during the dry season. The spatial distribution of future temperature showed an increase from 19.7 to 22.3 °C during the dry season and a decrease from 22.3 to 22.1 °C during the rainy season (Appendix 3).

The results for the spatial distribution of the groundwater recharge for the period 2021–2050 for both the rainy and dry season under the RCP 8.5 scenario are shown in Fig. 5. The groundwater recharge is projected to increase in the current defined rainy season at the entire catchment. The mean annual recharge shows an increase of 6.7% due to the increase in the amount of rainfall in the future. The projected increase in recharge due to the projected increase in rainfall found in this study agrees with the findings of Meresa and Taye [23] for Birki watershed in the eastern zone of Tigray, Northern Ethiopia. According to Meresa and Taye [23], the Birki watershed showed a related climatic pattern to the conditions in the Lake Manyara catchment. Similary, Gizaw et al. (2017) have also reported that the projected mean annual precipitation may increase by about 6% in the 2050s which led to an increase in recharge by about 3% in the major Ethiopian river

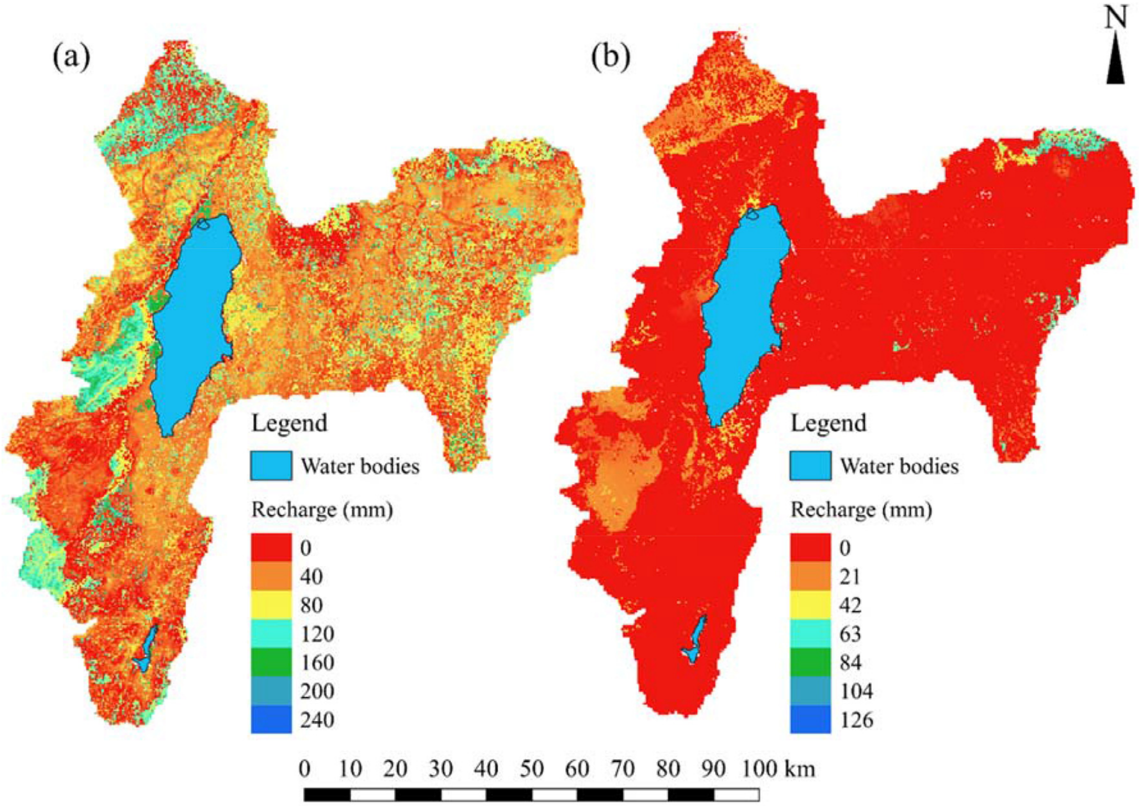

Fig. 4. Spatial distribution of groundwater recharge for the period 1989–2018 during the (a) rainy and (b) dry seasons.

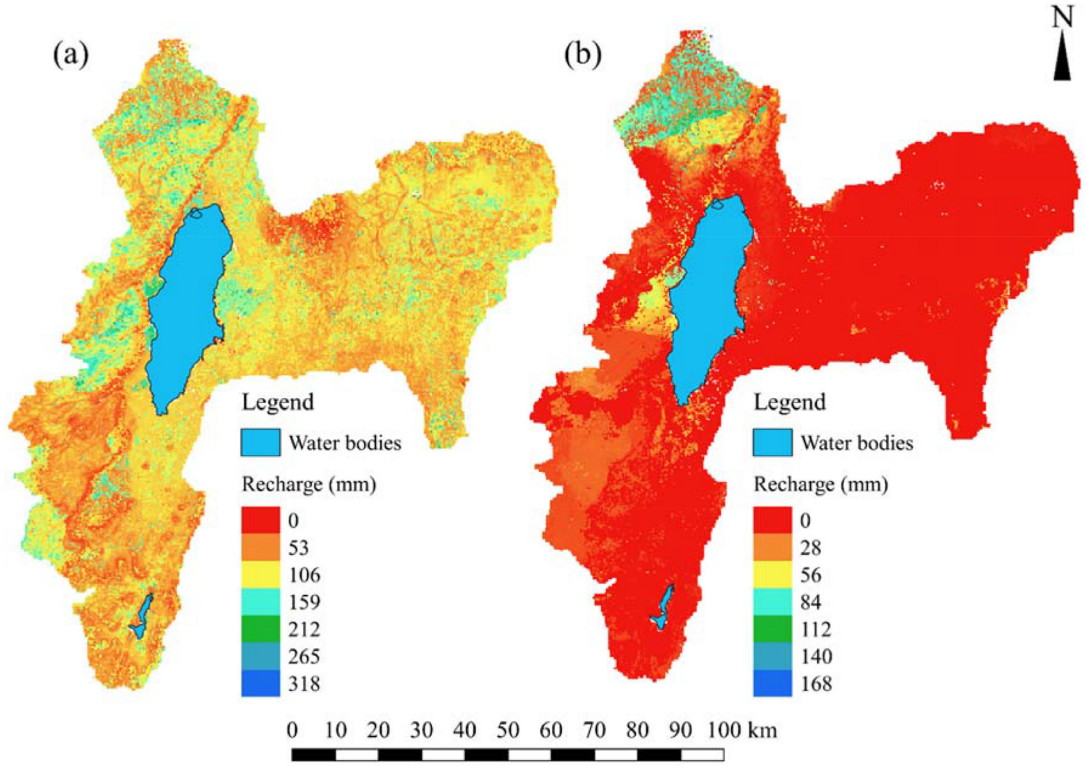

Fig. 5. Spatial distribution of future (2021 – 2050) groundwater recharge at the Lake Manyara catchment for during the (a) rainy and (b) dry season.

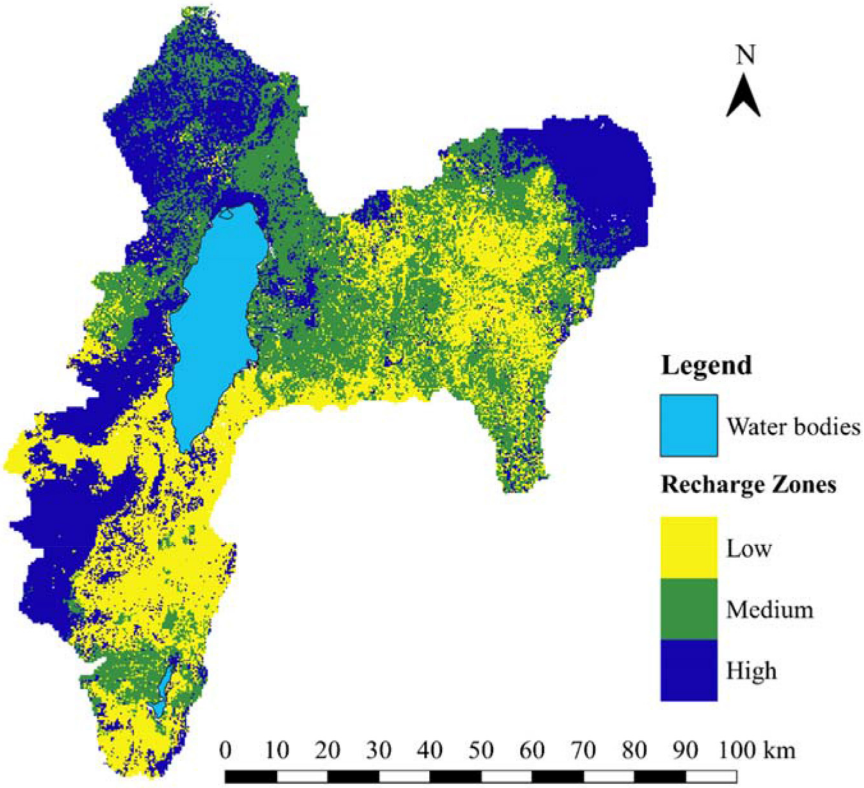

Fig. 6. Groundwater potential recharge zones in the Lake Manyara catchment as simulated by the averaged hydro-meteorological parameters from 1989 to 2018.

basins including Tekeze Rivers under RCP 8.5 scenario. The increase in groundwater recharge, will enhance the groundwater availability around lake Manyara catchment for the future (2021–2050).

Projected increase in groundwater recharge can provide various benefits to communities in the catchment and surrounding areas. The study area is dominated by agricultural and pastoral activities, therefore projected increase in groundwater could favor cultivation of bananas, maize, rice and vegetables. Furthermore, more wells could be constructed to supply water for wildlife, livestock and other domestic activities. In addition, understanding groundwater recharge is vital for effective water resource management and subsurface fluid and pollutant transport studies in Lake Manyara and other areas with similar geographical characteristics. In maximizing the benefit of increasing groundwater recharge for present and future generation, efficient management measures need to be in place, bearing in mind that population and economic activities will increase with time. For example, the communities should minimize application of chemicals so as to minimize pollution to groundwater.

Groundwater potential recharge zones

According to the simulated averaged hydro-meteorological parameters from 1989 to 2018, the results indicate three zones of potential groundwater recharge in the catchment which were categorized into low, medium and high recharge zones (Fig. 6). The potential groundwater recharge zones in Lake Manyara catchment were found in the northern part near Ngorongoro, the south-western part, Buger ward and around Mbulu region in the south part of the catchment.

Variations in potential recharge zones were due to various factors. For example, areas characterized by sandy soil with tree cover showed more rechargeability compared to other types of soil. This study concurs with finding from Ouyang et al. [26], where they showed that in Mississippi River basin, recharge was higher in forest land than agricultural land. High runoff in agricultural land reduced the amount of percolation whereas forest land with low runoff allows more time for water to percolate.

The total potential recharge (high recharge zones) area in the Lake Manyara catchment was about 23%. This finding is key to inform sustainable utilization and management of groundwater resources especially the specific locations that needs regular monitoring to prevent total withdrawal. Furthermore, the distribution of the potential recharge zones would serve as a guide for the development of water resources programs (e.g. drilling boreholes and designing hand dug wells and springs), since groundwater is the major water source for both domestic and economic activities in the basin. Strategic policies and plans for sustainable management and use of groundwater resources considering the limited area with high recharge potential (Fig. 6).

Conclusion

The impact of climate change on groundwater recharge of the Lake Manyara catchment under the Representative Concentration Pathway (RCP 8.5) was assessed using the WetSpass model. Simulated rainfall, temperature and PET from an ensemble mean of four RCMs for the period 2021–2050 were used as input in the WetSpass model for the climate change impact assessment. Model calibration using the water balance equation model revealed a high level of agreement between the WetSpass simulated and calculated recharge by water balance equation with R^2 and RMSE of 0.9 and 0.49 mm/yr, respectively. The WetSpass model result indicates groundwater recharge of 53.9 mm/year (6.7% of mean annual rainfall) with a potential groundwater recharge of 149 MCM during the historical (1989–2018) period. The mean annual groundwater recharge under the RCP 8.5 scenario of climate change is projected to increase by 88.5 mm/year with a potential recharge of 421 MCM relative to the baseline period.

The projected increased in groundwater recharge together with implementation of suitable water resources management measures could possibly support economic activities including agriculture and livestock in the future. The increase in recharge in the northern and south-western part of the catchment may be attributed to the presence of forest land and sandy soil. Furthermore, the WetSpass model results showed that the spatial and temporal rainfall and temperature distribution have impact on groundwater recharge. The outcome of this study serves as empirical evidence of the expected status of groundwater availability in the catchment and provide a foundation for further research to improve groundwater resources in regions and catchments with similar hydro-meteorological characteristics. Assessment of the impact of climate change and other human activities on groundwater quality would be essential for wholistic development of sustainable adaptation strategies to improve the groundwater resources in the study area. Based on the findings, it is suggested that rainwater collection structures and artificial aquifer recharge schemes be developed as an adaptation strategy in the Lake Manyara catchment to increase groundwater recharging potential and reduce the negative impacts of climate change.

Credit author statement

Latifa Nyembo: Conceptualization, Methodology, Writing- original draft.
Isaac Larbi: Data curation, Visualization, Investigation.
Juma Rajab: Supervision.
Enoch Bessah: Validation.
Mohammed Mwabumba: Methodology, Writting-review & editing.
Sam-Quarcoo Dotse: Writting-review & editing.
Andrew Manoba Limantol: Writting-review & editing.

Declaration of Competing Interest

The authors declare that no established personal conflict or financial interests that could have influenced the work presented in this paper.

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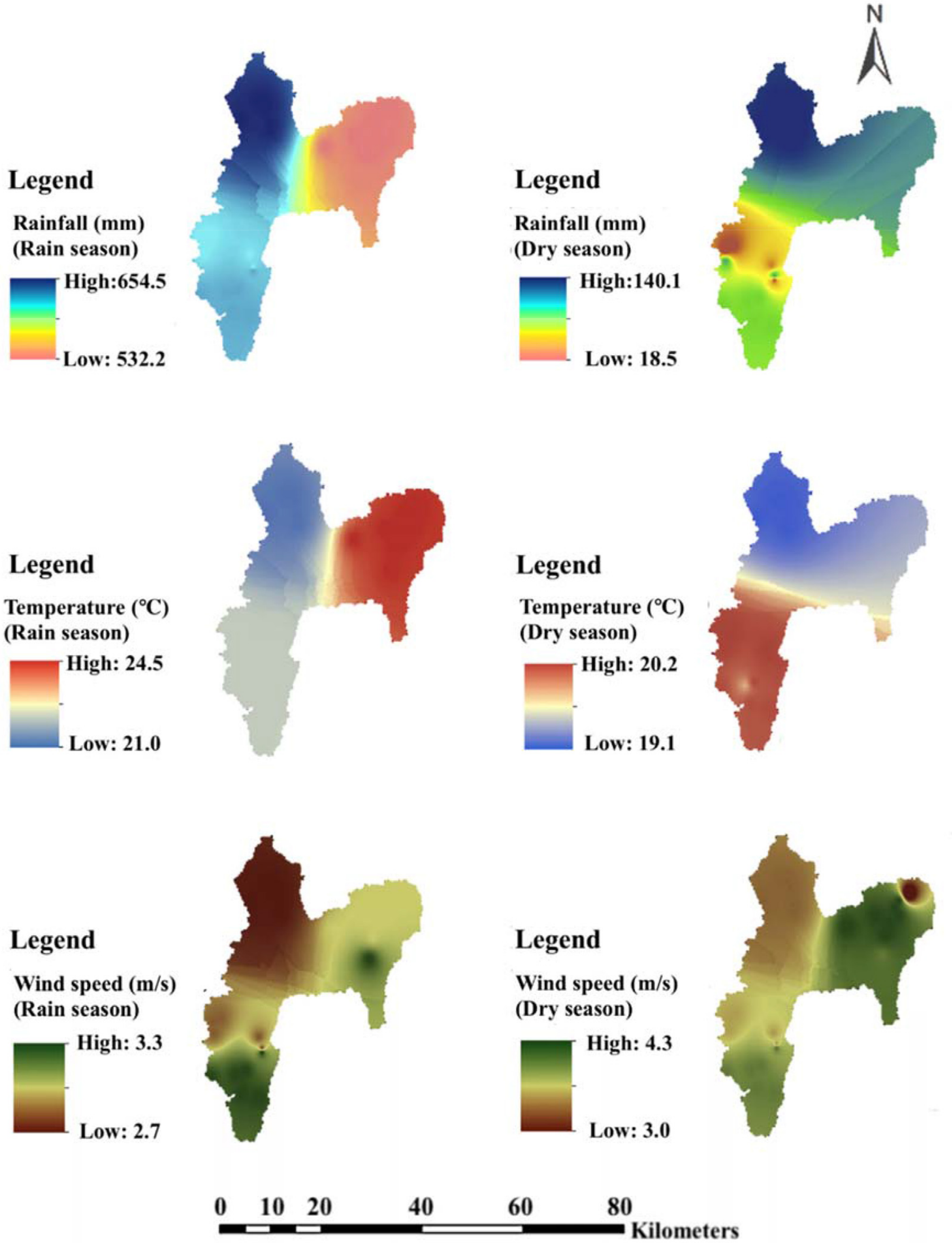
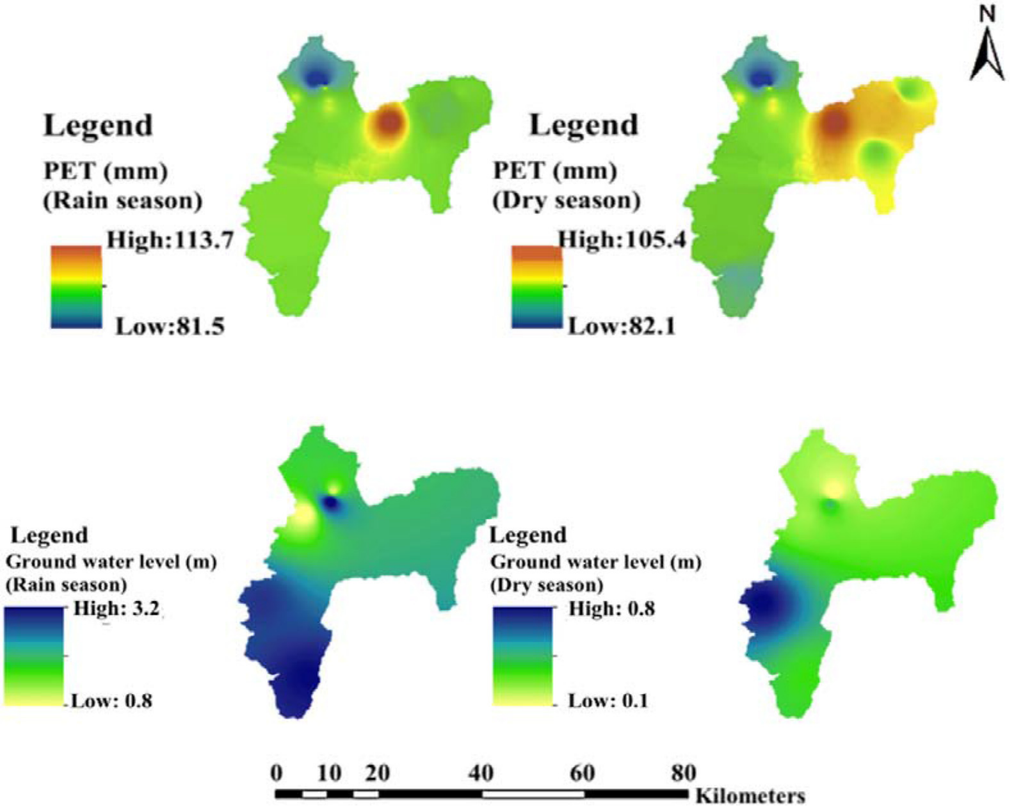
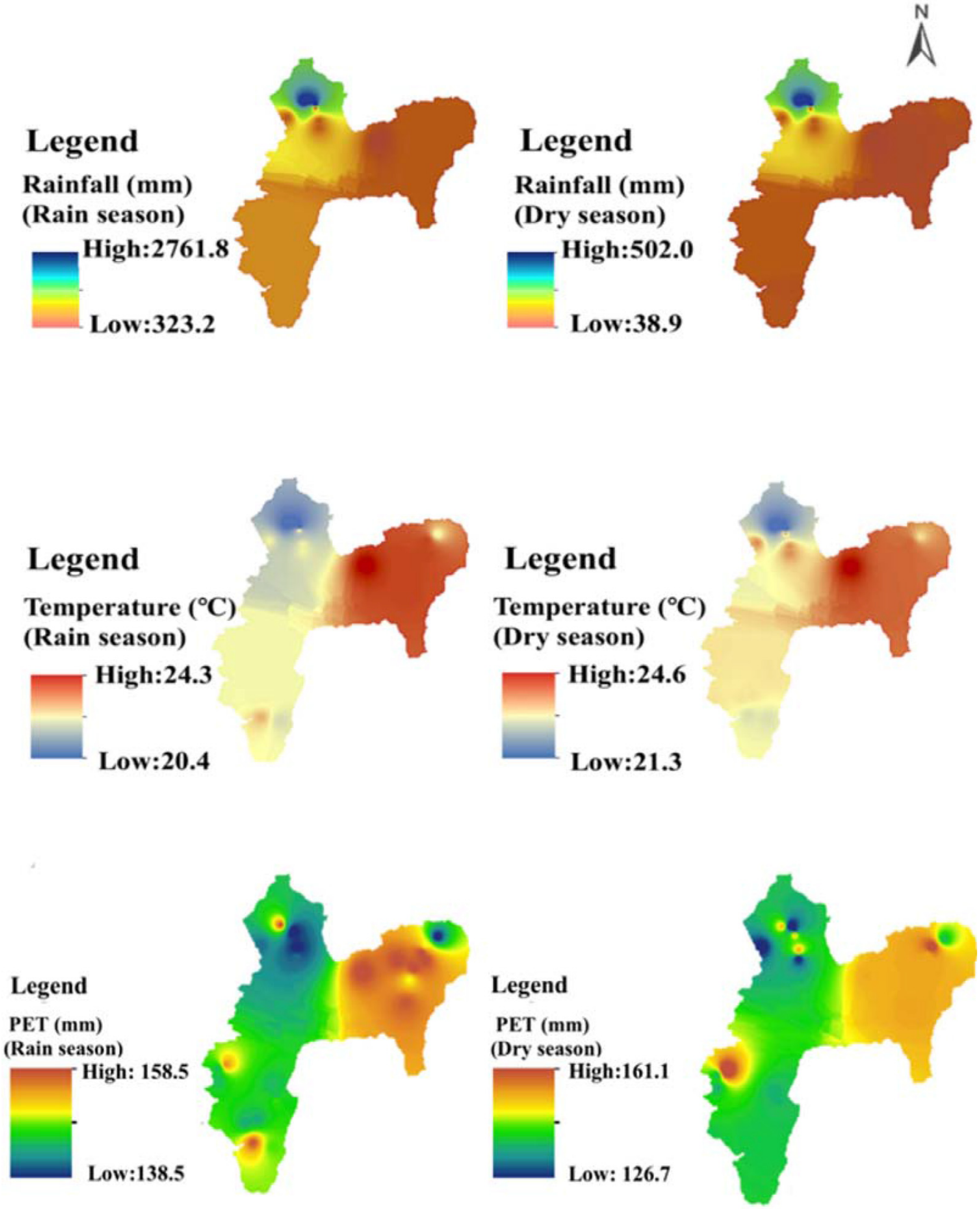
Appendix 1. Spatial distribution of rainfall, mean temperature and potential evapotranspiration for the rainy and dry season from 1989 - 2015



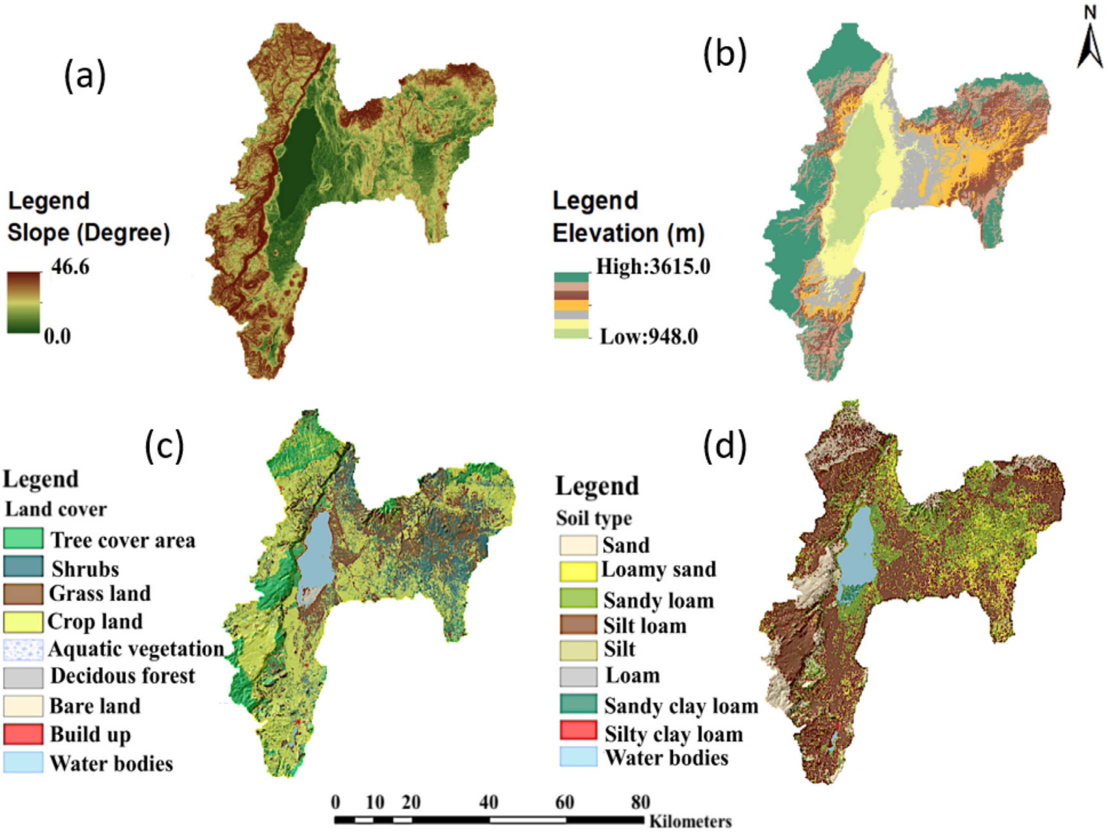
Appendix 2. Spatial distribution of PET, and groundwater levels for the rainy and dry season for the period 1989–2018 and 2010–2015, respectively



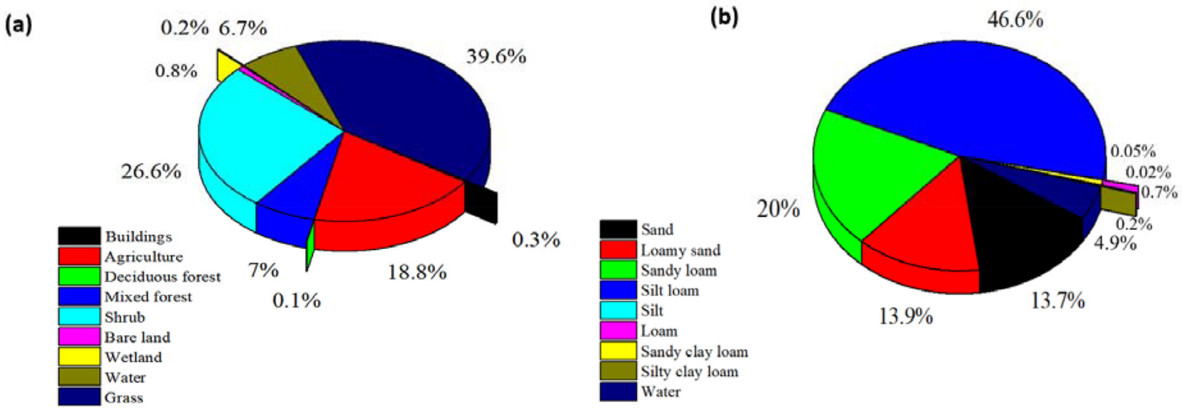
Appendix 3. Spatial distribution of rainfall, mean temperature and potential evapotranspiration for the rainy and dry season under RCP 8.5 scenario for the period 2021–2050



Appendix 4. Spatial distribution of (a) Slope, (b) elevation, (c) LULC cover types, and (d) soil types in Lake Manyara catchment



Appendix 5. (a) percentage distribution of 2016 land use/land cover types, and (b) Soil type classification and area coverage in the Lake Manyara catchment



Appendix 6. Main global parameters and corresponding threshold values used for the model calibration (Liu and De Smedt, 2004)

Parameter	Description	Unit
Ki	Interflow scaling Parameter	–
Kg	Groundwater recession coefficient	–
K_ss	Relative soil moisture	_
K_ep	Correction coefficient for PET	_
GO	Initial groundwater storage	Mm
G_Max	Groundwater storage	Mm
K_run	Surface runoff coefficient	–

Appendix 7. Global parameters and calibration result for the Lake Manyara catchment

Parameter	Value range	Calibrated value
Ki	0–12	3.2
Kg	0–0.06	0.04
K_ss	0–2	1.02
Kep	0–2	0.3
GO	0–100	18
G_Max	0–3000	19
K_run	0–5	2.6

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