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Implications of Uncontrolled Water Withdrawal and Climate Change on Water Supply and Demand Gap in Tana Lake Sub-basin

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ABSTRACT

Climatic variability, uncontrolled irrigation water abstraction, and other non-climatic factors create a great pressure on freshwater resources. This study focuses on the impact of three drivers (land use change, irrigation expansion, and climate change (CC)) on water resources of the Gumara Watershed of Lake Tana Sub-basin, Ethiopia. Land use land cover (LULC) and actual irrigated-area were mapped using the Random Forest (RF) machine learning classifier in the Google Earth Engine (GEE) platform. Climate data was obtained from the Climate Hazards Group InfraRed Precipitation (CHIRP), Ethiopian Meteorological Institute (EMI) and global climate models. Streamflow and crop water demand were estimated using the HBV model and Crop Wat software, respectively. The supply-demand gap was estimated for the current and future climate. The results revealed the increasing trend of cropland in the expanse of forest, grassland, waterbody, and shrubland. A widespread irrigation was observed near the lake shore and upstream parts of the catchmentwhich experienced an increasing trend of potential evapotranspiration because of the increase in temperature. The rising of potential evapotranspiration created high water demand for irrigation. The supply-demand relationship showed uneven distribution in the current and future periods. The increase in temperature and uncontrolled expansion of irrigated land area will increase the unmet water demand for irrigation in the future. This can cause conflict of interest between the users, and potentially affect available water for environmental demands. Therefore, there is strong need to promote sustainable water resource management practices and adaptive management of irrigation in the Gumara Catchment.

Keywords: Random Forest, Google Earth Engine, supply-demand, unmet demand, adaptive management

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1. INTRODUCTION

The water resources of Lake Tana Sub-basin, which is the source of the Blue Nile River, is under pressure owing to multiple climatic and non-climatic factors. Climate variability is causing erratic rainfall distribution that produces large streamflow and lake level variations (Gebremicael et al., 2013, Tesemma et al., 2010). The sub-basin receives low rainfall amount in the northern part and highest rainfall amount in the southern part of the sub-basin (Birara et al. 2018; Haile et al. 2009). Most studies agree with the projected increasing rate of rainfall and temperature in the future. The annual rainfall is projected to increase by 202 mm and 255 mm by 2050s and 2080s, respectively (Setegn et al. 2009; Getachew & Manjunatha 2021; Enyew et al. 2014; and Desalegn et al. 2016).

Historically, the sub-basin had minimum and maximum temperature increase by 0.037°C and 0.15 °C per decade, respectively (Mengistu et al. 2014; Mohamed & Mahdy 2021; Fetene et al. 2018). Similarly, studies predicted the rise of maximum temperature from 1.38 °C to 3.59 °C under RCP 4.5 scenarios by 2080s, while minimum temperature increase by 5.92 °C under RCP 8.5 by the end of the 21st century in Tana Lake Sub-basin (Getachew & Manjunatha 2021). The increasing trends of temperature will lead to increased evapotranspiration by 4.7% to 12.2% (Chakilu et al. 2020; Teklay et al. 2020). Such increase in temperature and evaporation rates may result in less freshwater sources while increasing water demand for various purposes.

Literature shows significant land cover change in the sub-basin because of increasing rate of cultivated land that ranges from 29.95% to 48.02% over the last 40 years (Tewabe and Fentahun 2020; Woldesenbet et al., 2017; Tefaw et al. 2023). Some studies reported forestland, wetland, bush/shrublands, and grassland have continuously decreased over the recent decades (Asitatikie 2019; Elhamid et al. 2019). The changes in land use are primarily driven by population growth, agricultural expansion, urbanization, increasing energy and food demands, and changes in lifestyle and socio-economic conditions (Malede et al. 2023; Alemayehu 2006; Tewabe and Fentahun 2020).

Non-climatic aspects such as population and economic growth including urbanization have their own impact on water resources of the Lake Tana- Sub-basin. The sub-basin has undergone developmental changes since the start of 2000s with the growth of irrigation and hydropower projects (Alemayehu et al., 2010; Mequanent and Mingist, 2019; Yenehun et al., 2021). One of the major developmental changes occurred in 2010 with inter-basin water transfer from Lake Tana to Beles Basin for hydropower production (Yenehun et al., 2021). It is expected that a total of 60,077 ha of the sub-basin will be categorized under medium size irrigation schemes when all the planned irrigation schemes are completed (e.g., Koga, Ribb, Megech, Gumara, and Gilgel Abay). The construction of Koga Irrigation was completed in 2010 (Asres 2016) with planned irrigation command area of about 7,000 ha and with a reservoir storage capacity of 78.5 Mm3. In the Koga Watershed, there was a plan to improve rainfed agriculture, forestry, livestock, soil conservation, water and sanitation on 22,000 ha (Birhanu et al. 2015). The second multi-purpose reservoir in the basin was constructed in Ribb River. The reservoir had a capacity of 234 Mm3. The irrigation project was expected to be constructed on 20,000 ha of land and benefit 40,000 farmers.

Taye et al. (2021) reported that irrigation water abstraction by smallholder farmers during the dry season in Lake Tana Sub- basin is causing water scarcity, conflicts, and environmental damage. The researchers evaluated the implication of uncontrolled rate of water abstraction and irrigated land expansion on the water availability in the sub-basin. However, this paper did not consider the impacts of climate change on water irrigation . It did not combine different data sources (e.g., remote sensing data) and neither used hydrological models to characterize the sub-basin's water availability for different periods. In short, limited studies showed the implication of combined drivers (land use change, climate change, and irrigated land expansion) in the hydrology of Lake Tana Sub-basin at sub-basin scale (Dile et al.2013; Asitatikie 2019; Taye 2021; Shaka 2008).

Therefore, this study addresses some of the mentioned research gaps. It evaluates the implication of the three drivers (land use change, irrigation expansion, and climate change) on the current and future water availability across the sub-basin. Hydropower water use, domestic water use, and industrial water use in the sub-basin were already reported by Taye et al. (2022). These water uses would not be repeated here. Environmental flow was not considered since the current water use in Gumara did not allocate water for the environment. This study used both observed and remote sensing data to map the actual irrigated area and evaluate the land cover change within the sub-basin. Taye et al. (2021) studied land and water constraints in the eastern side of the Tana Sub-basin especially water shortages in the dry season flow. This study showed the gap between water demand and supply in Gumara catchment the current and future period of , as an experimental site including climate change impacts. The information generated on current quantified volume of abstracted water, and the projected available water in the river is important to minimize the negative impacts of climate change.

2. Study area

The Lake Tana Sub-basin extends from UTM coordinates of 260000 to 400000 m (36.8° to 38.2°) east and from 1210000 to 1420000m (11° to 12.8°) north. It is located at the headwater of the Blue Nile (Abbay) River Basin, in the North-western Ethiopia highlands (Figure 1). Elevation variation across the sub-basin ranges between 1779 and 4110 m. Most of the low land part of the sub-basin surrounds Lake Tana. The mean elevation of the basin is 2945 m. The sub-basin area under the highest elevation range (>4000 m) is in a small portion of northern, eastern and southern parts of the sub-basin.

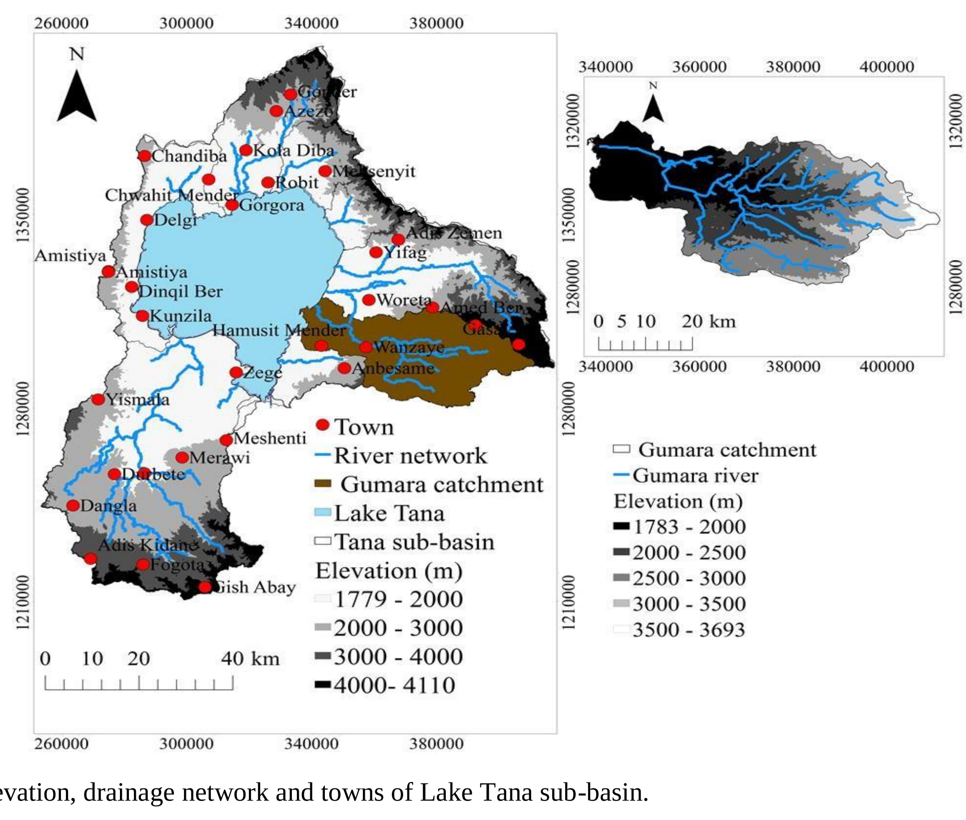

Figure 1: Elevation, drainage network and towns of Lake Tana sub-basin.

The length of the sub-basin from North-South and East-West is 203 km and 179 km., respectively. Based on various studies, the sub-basin covers a drainage area between 15,000 and 16,000 km2. (Rientjes et al.2011; Chebud and Melesse, 2009, Dessie et al., 2014) and the lake covers about 3,000 km2 which is 20% of the drainage area. The mean annual rainfall of the sub-basin is 1,280 mm (Setegn et al. 2008) but it varies from 815 to 2344 mm/year, and it shows large variation across the sub-basin. It has one main rainy season that extends from June to September, which accounts for more than 80% of the annual rainfall. The rest of the year is dry except for some rains from March to May. Rainfall variation in Lake Tana Sub-basin is large spatially and temporally. Rainfall magnitude shows an overall decreasing trend from south to north.

Unlike the rainfall, the temperature of the sub-basin is on average 20°C with small seasonal changes. The mean annual temperature of the area varies from 7.26-23.4 °C (Goshu and Aynalem 2017) with the highest temperature from March to May whereas, the lowest temperature from July to September (ADSWE: LUPESP, 2015). Average annual evaporation over the lake surface is approximately 1,675 mm (SMEC 2008).

There are four major rivers that feed Lake Tana; they account for 93% of the inflow (Kebede et al., 2006). These are Gilgel Abay, Gumara, Megech, and Ribb. Gilgel Abay is in the south, Gumara and Ribb are in the east, and Megech in the north. Studies reported that the mean annual rainfall of Ribb and Gumara falls in the range between 1278and1279 mm. As shown in Table 1, the Gilgel Abay receives the highest annual rainfall compared to others. The highest mean potential evapotranspiration (1633 mm/year) is reported in Megech, the north part of the sub-basin while the lowest (1193 mm/year) in Gilgel Abay. ,. The east part of the sub-basin has potential evapotranspiration ranging from 1223to 1247 mm/year in Gumara and Ribb. The Lake Tana gets the highest inflow from Gilgel Abay (Atanaw et al. 2018) and the minimum from Megech in the northern catchment.

Table 1. Characteristics of the main catchments of Lake Tana sub-basin

Sub-catchment	Area (% of sub-basin area)	Mean annual rainfall (mm)	Mean annual Evapotranspiration (PET) (mm)	% Contribution to Lake Tana's inflow
Gilgel Abay	11.62	1407	1193	28
Ribb	9.32	1278	1247	27
Gumara	8.42	1279	1223	27
Megech	3.4	1248	1633	11

Extensive wetlands surrounding the lake provide broad ecosystem services. In the sub-basin, an increasing rate of irrigation water use resulted in hydropower, domestic water supply, environmental flow, industrial water use, navigation, and tourism developments (de Fraiture et al., 2001). The challenges of water resources management in the Lake Tana Sub-basin are many and it is important to consider the trade-off between hydropower, irrigation, navigation, and fishing considering the changing climate.

3. Data Collection and Methodology

3.1 Dataset

Data for this study were obtained from various sources including global and national data sources, and field surveys. A Digital Elevation Model (DEM) of 30 m resolution was obtained from Shuttle Radar Topography Mission (https://doi.org/10.5066/F7K072R7). The DEM was used to delineate the catchment, its sub-catchments, and the drainage network.

To map the land use land cover (LULC) in the Tana Sub-basin, Landsat Surface Reflectance Tier 1 imagery of Landsat OLI/TIRS and TM sensors available in Google Earth Engine were used. At a decade interval, LULC was mapped for the years 1990, 2000, 2010, and 2021 during the dry season (January to March). Images acquired during the dry season were used to minimize the effects of seasonal land cover dynamics and the cloud cover. Ground Control Points (GCPs) were collected between February 12 and 17, 2022 and served as reference data for training and validating the LULC classification algorithm. A Global Positioning System (GPS) device with positional error of ±3 meter was used to record the geographic coordinates of the 523 GCPs. SPOT images of 2006 and 2016 and Google earth map were used to generate GCPs for classifying LULC historical periods.

For remote sensing based irrigated area mapping, Sentinel-2 (S2) satellite images were used for the entire sub-basin. The mapping was using S2 images which were acquired in the main irrigation season that stretched from October-2021 to April-2022.

Meteorological data were obtained from Ethiopian Meteorology Institute (EMI). Only one station at Deber Tabor was a first-class station and hence provided data on maximum and minimum temperature (oC), relative humidity (%), wind speed (km/day) and sunshine hours to calculate evapotranspiration (ETo) for the period 1996–2019. Satellite daily rainfall data (CHRIP) was downloaded from climate SERV 2 web page (https://climateserv.servirglobal.net/) for the period 1981 – 2021. CHRIP data had 0.05 ◦ x 0.05 ◦ horizontal resolution.

Historical trends of rainfall and temperature were evaluated using Climate Hazards Group InfraRed Precipitation with Station data, CHIRPSv2 (C. Funk et al., 2015; C. C. Funk et al., 2014) and Climate Hazards Group InfraRed temperatures and stations (CHIRTS, Funk et al., 2019), respectively. The historical and projected daily precipitation and temperature (min and max) with a spatial resolution of 0.25 by 0.25 degrees were downloaded from NASA Global Daily Downscaled Projections (NASA NEX GDDP), (available at https://doi.org/10.7917/OFSG3345).

The period 1985–2014 indicated the historical climate while 2035-2064 showed the projected future scenarios for SSP45 and SSP85. . Data was obtained from 9 General Circulation Models (GCMs) to study the climate change impact. The data were statistically downscaled (using delta approach). The models' name and resolutions are summarized in Table 2.

Table 2:-Summary of the models used for climate change analysis

Model name	Modelling Center	Horizontal resolution (Atmosphere) (km)	Horizontal resolution (ocean) (km)	Vertical resolution (levels)
HadGEM3-GC31-MM		100	25	75
HadGEM3-GC31-HM		50	25	75
HadGEM3-GC31-HH		50	8	75
CNRM-CM6-1	CERFACS	100	100	91
CNRM-CM6-1-HR		50	25	91
EC-Earth3P	SMHI, KNMI, BSC, CNR, and 23other institutes	100	100	91
EC-Earth3P-HR		50	25	91
MPI-ESM1-2-XR	Max Planck institute for Meteorology	100	50	95
MPI-ESM1-2-HR		50	50	95

3.2 Methods

3.2.1 LULC Classification and Change detection

The major LULC classes in the sub-basin were identified through unsupervised classification and validated during field survey. There are nine major LULC classes in the Lake Tana sub- basin (bare land, built-up, cropland, grassland, natural forest, plantation, shrubland, water body, and wetland). Sampling points for GCPs were identified from unsupervised classification. Google earth images were selected for identifying locations of GCPs from each LULC class. Stratified and random sampling were used to identify the sampling points.

Although a minimum of 60 GCPs should be collected from each class through survey (Cochran, 1953 and Shetty, 2019), 523 field observation data were collected by random sampling criteria and 700 additional GCPs from high resolution SPOT and Google earth images. This study used SPOT and Google earth images to minimize the complexity of the environment. As a result, a total of 1223 GCPs were recently generated.

To work out historical period images, visual inspection of the Landsat image and prior knowledge about the region during the field survey were used as data sources. As a result, 700, 850, 950, and 1223 GCPs were collected for the years 1990, 2000, 2010, and 2021. Of the collected GCPs, about 75% of the data was used for training, whereas 25% was used for accuracy assessment of the LULC maps.

The LULC was classified using the random forest (RF) machine learning classifier available at the Google Earth Engine (GEE) platform. The classified LULC maps were analyzed to identify the gains and losses in each of the LULC classes. Changes in each LULC class were estimated for the periods 1990-2000, 2000-2010 and 2010-2021.

3.2.2 Mapping of actual irrigated area

Actual irrigated area was mapped using GEE following four steps: (1) generation of time series of Normalized Difference Vegetation Index (NDVI) from Sentinel-2 images over a crop growing season (12 images were acquired between October 2021 and April 2022).

The NDVI values range from +1.0 to -1.0; (2) training of a remote sensing algorithm for multi-crop irrigated area mapping using Sentinel-2 images; (3) validation of the irrigated area map using GCP data, and (4) post processing of the actual irrigated area map to exclude areas which were less likely to be irrigated. To map the irrigated area, we used a multi-temporal supervised random forest (RF) classification algorithm (Biggs et al. 2006; Velpuri et al. 2009). When compared to other traditional machine learning algorithms, the RF classifier produced high-quality classification mapping while requiring minimal computing time (Rodriguez-Galiano et al. 2012; Inglada et al. 2017). The number of trees increased gradually and set at 1000 until the classification accuracy converge reached the best classified range (Li et al. 2021). The RF classification algorithm was used to classify image pixels into two classes: non-irrigated and irrigated. To discriminate between irrigated and non-irrigated areas, multi-temporal data analysis was used. Supervised classification was applied in this study; GCPs were used to train the algorithm.

3.2.3 Classification accuracy assessment

The accuracy of the LULC and actual irrigated area maps was evaluated through visual inspection, a confusion matrix with appropriate accuracy indices (user accuracy, producer accuracy and overall accuracy) and nonparametric Kappa coefficient. The overall accuracy was calculated by summing the number of pixels correctly classified and dividing them by the total number of pixels. This was expressed in percentages, 100% accuracy being a perfect classification whereas accuracy of more than 85% was considered an acceptable level of accuracy (Gashaw et al. 2017). Kappa values between 0.70 and 0.85 were regarded as excellent predictors of the classified image's ability to represent ground truths (Monserud 1990).

3.2.4 Evaluation of historical climate change

Both datasets provided gridded data. Using CHIRPS and CHIRTS data over the Lake Tana Basin, linear trends were estimated at each grid cell with statistical significance of 95% and 90% for precipitation and temperature, respectively.. The p-value for testing statistically significance whose null hypothesis, the slope is zero, was tested using Wald Test.

The t- distribution of the test statistic was used to map the trends. During analysis, the durations 1981-2020 and 1981-2016 indicated precipitation and temperature, respectively.

3.2.5 Irrigation crop requirement

The crop water requirements for all existing crops in Gumara Watershed were computed using CROPWAT 8.0 software developed by FAO (Food and Agriculture Organization). The input data included climate data, crop evapotranspiration (ETo), monthly rainfall data, crop data, and soil physical properties. CROPWAT 8.0 uses Penman- Monteith method for ETo computation. The Gumara Catchment, upstream of its river gauging site, was discretized to 29 sub-catchments and the downstream of the gauging station was considered as a single watershed for the crop water requirement analysis. As a result, a total of 30 watersheds were considered during crop water requirement analysis for the entire Gumara Catchment.

Crop types and percentage of area coverage by the major three crop types were selected based on Taye et al. (2021). The crop calendar (planting and harvesting date of the crop) was obtained from agronomists in the respective districts of the sub-catchments. The soil texture information was obtained from FAO-UNESCO soil map of the world.

To calculate gross irrigation water requirement (GIR), the estimated net irrigation requirement (NIR) was divided by 45% of efficiency value to consider application and other losses. GIR was estimated for the current period (1994-2021) and future period (2035-2064).

3.6 Rainfall-runoff modeling

Surface water supply to irrigation sites in each of the 30 sub-catchment was estimated using the Hydrologiska Byråns Vattenbalansavdelning (HBV) rainfall-runoff model. The model was used to simulate the current and projected future water supply in Gumara River and in its tributaries. First, model calibration was conducted for six years (i.e.1994 -2000 G.C.), and validation was done for three years (i.e.2001-2003 G.C.). Rainfall input of HBV was obtained from CHRIP rainfall data corrected using the Power Bias Correction method. The LULC map generated was one of the data inputs for modeling the catchment using HBV model.

The classes of land cover were aggregated into two major classes (field and forest) for HBV purpose. In the forest category only one class, forest, was considered and the remaining eight classes (bareland, built-up, cropland, grassland, plantation, shrubland, water body, and wetland) were considered together as single land cover class in the field category. Then, streamflow of the 30 sub-catchments was simulated assuming that the model parameters remain the same across the Gumara Catchment. The simulation was run for all sub-catchments for the current (1994-2021) and future (2035-2064) periods. Delta change bias correction method was used to correct temperature data from the GCMs for the future period. The future rainfall data bias was corrected using the power bias correction method.

A subtraction method was applied for analyzing the supply-demand relationship. The analysis started from upstream part of the catchment. At each irrigation demand site, the estimated irrigation water requirement was subtracted from the estimated annual streamflow of the watersheds. . The surplus streamflow from upstream watershed was added to the next tributary river flow and was considered for the supply-demand analysis of the downstream irrigation site. This continued until the outlet of the catchment was estimated either as supply-demand gap or surplus.

4. Results and Discussion

4.1 LULC classification and change

The accuracy evaluation of the generated LULC maps indicated a good classification performance with at least 85% overall accuracy and Kappa values greater than 0.80. Also, the producer and user accuracies showed good agreement (>70%). However, for the year 2000, built up, plantation, and wetland areas were poorly classified with 68%, 66% and 68% user accuracies and 67%, 68%, and 67% producer accuracy, respectively. Similarly, in 1990, built up, plantation, and wetland were poorly classified with 69%, 65%, and 68% user accuracies and 68%, 64%, and 65% producer accuracy, respectively. The lower accuracies for the built up might have contributed to their spectral similarity with barelands and croplands. Similarly, the lower accuracy in plantation was due to plantations being confused with shrublands and natural forest whose spectral profiles were similar.

The relatively low user accuracy of wetlands could be related to the spectral similarity of wetland with grassland and water body. Classification of past LULC maps was constrained by lack of archived GCPs collected through field surveys.

Fig 2 depicts the LULC classification maps of Lake Tana Sub-basin. The LULC spatial distribution reveals that cropland is the dominant land cover in the basin. The next dominant land cover types are grassland and shrubland mostly concentrated in the North- Eastern and South-West of the sub-basin. Over the past few decades, the southern part of the sub-basin has experienced a decline in both grassland and shrubland. Moreover, bare lands and natural forest are scattered in few pocket areas of the sub-basin but dominantly exist in the East and South-West of the sub-basin. Plantations have been increasing in the southern and northern parts of the basin since 2010. Furthermore, wetland and cropland areas have increased in most parts of the sub basin, more particularly in the northern and eastern parts. Conversely, grassland has disappeared in the eastern part of the sub-basin.

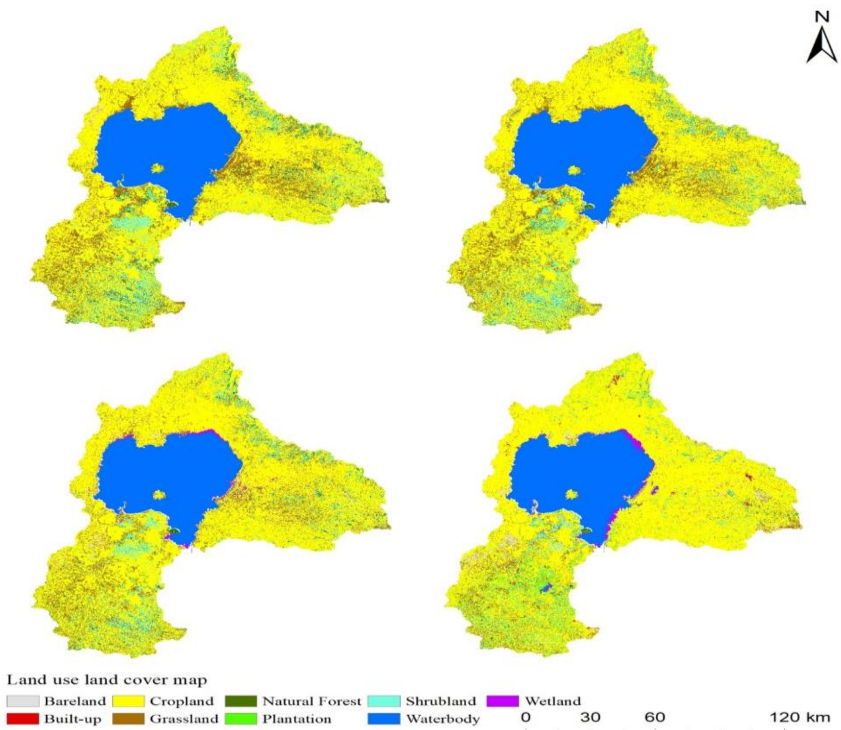

Figure 2: LULC maps of Lake Tana sub-basin in 1990 (top left), 2000 (top right), 2010 (bottom left) and 2021 (bottom right).

Fig 3 shows the coverage of the major LULC classes and the corresponding changes during 1990-2000, 1990-2010 and 1990-2021. In the base year (i.e., 1990), the dominant LULC types included cropland (covered about 53.49% of the total land area), waterbody (20.09%), grassland (11.83%), shrubland (9.29%), and forestland (4.44%). The remaining areas were covered by plantation, bare land, settlement, and wetlands.

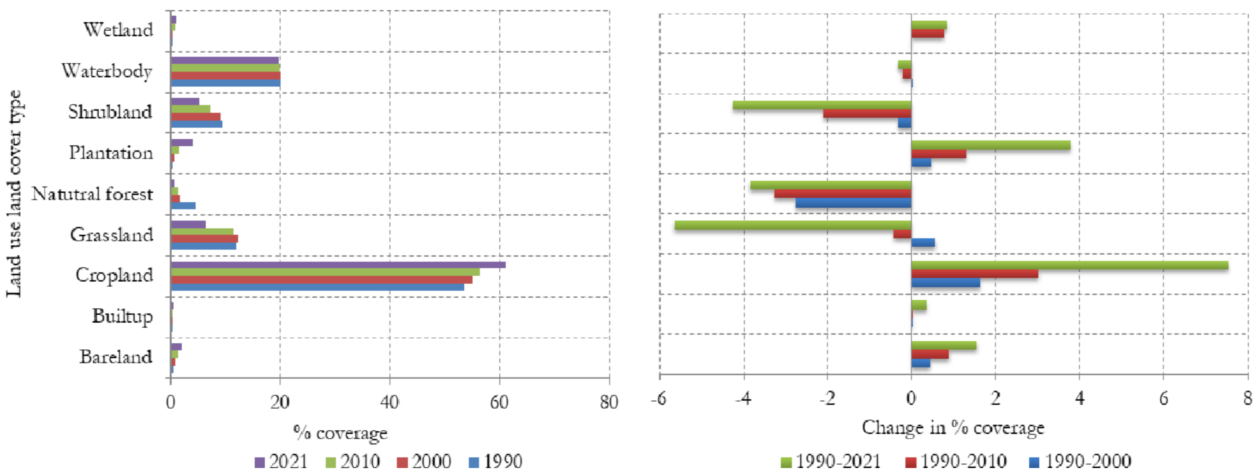

Figure 3: Coverage of LULC classes and changes in percent for three periods.

The results reveal that LULC of Tana Basin has changed significantly since 1990. Cropland, bare land, built-up, plantation, and wetland displayed positive changes over 30years while forest, grassland, waterbody, and shrubland showed negative changes. As a benchmark result, in 2021, 61% of the sub-basin was covered by cropland while nearly 20% was covered by grassland. The coverage of built-up area and shrubland was very small. As a result, cropland exhibited a larger net gain (8.65%) followed by bare land (2.71%) and plantation (1.5%). The expansion of cropland lands over the last 30 years was mainly due to the expense of forest land, grasslands, and shrubland. During this period, about 5.85% of grassland and 9.31% of shrubland have been converted to cropland. Tewabe (2020) showed the significant increasing rate of agricultural land and residential area for the last 32 years (1986-2018) by 13% and 9% respectively in the sub-basin. For the last 30 years (1989-2019), the farmland and built-up areas increased by 17.6% and 0.2%, respectively (Getachew and Manjunatha, 2022). The sub-basin experienced the largest changes in LULC in the most recent decade.

The increasing rate of crop land in the expenses of natural forest, shrub land, and grassland might have caused high soil erosion, runoff/flood, and lower rate of groundwater recharge or base flow. High percentage of rainfall amount was converted into runoff because of reduced time to infiltrate and enter into the ground.

4.2 Actual irrigated area

The actual irrigated area of the Lake Tana Sub-basin was mapped with high overall accuracy (i.e., 93%) and with Kappa coefficient value of 0.86. The classification algorithm result indicated that 94% of the irrigated area on the map was irrigated.,. It captured 95% of the irrigated lands, which indicated very good classification accuracy. In this study, the irrigated area of the Lake Tana Sub-basin covered 777.21 km2 (5.14%) of the total sub-basin. (Fig 4). The map shows that the irrigated land is clustered near to the lake, which agrees with our field observation. Farmers are also diverting river water to irrigate upstream areas. Irrigated areas cover 37.36, 23.10, 15.43 and 24.11 % of the eastern, southern, western and northern parts of the sub-basin.

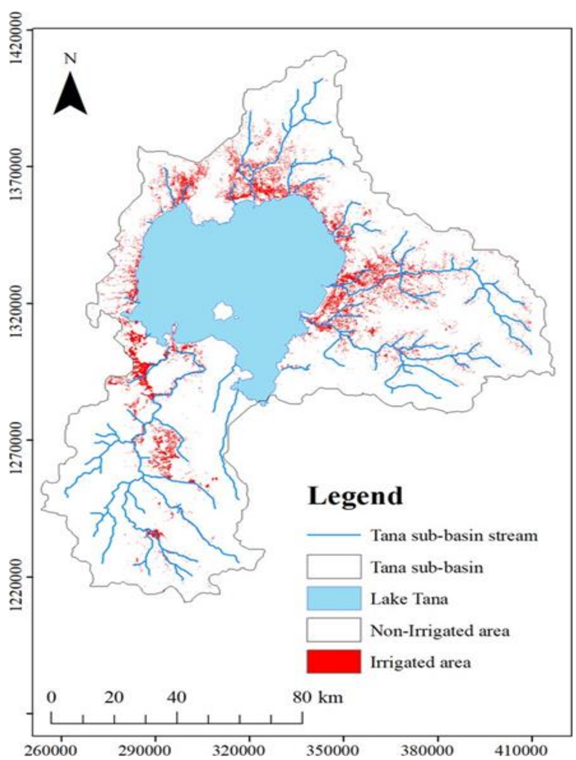

Figure 4- Spatial distribution of the actual irrigated area of Tana sub-basin based on the classification of multi-temporal Sentinel- 2 images

4.3 Historical climate analysis

According to the SSP scenarios, the temperature in Lake Tana Sub-basin showed a significant increase from 1983 to 2016 over the last three seasons (January–May, June–September, and October– December) (Fig 5). The largest increase in temperature occurred in the period from January to May (up to ~0.6 oC increment per decade). This might have contributed to increased potential evapotranspiration during the irrigation season. While maximum temperature was basin wide, minimum temperature was localized (not shown).

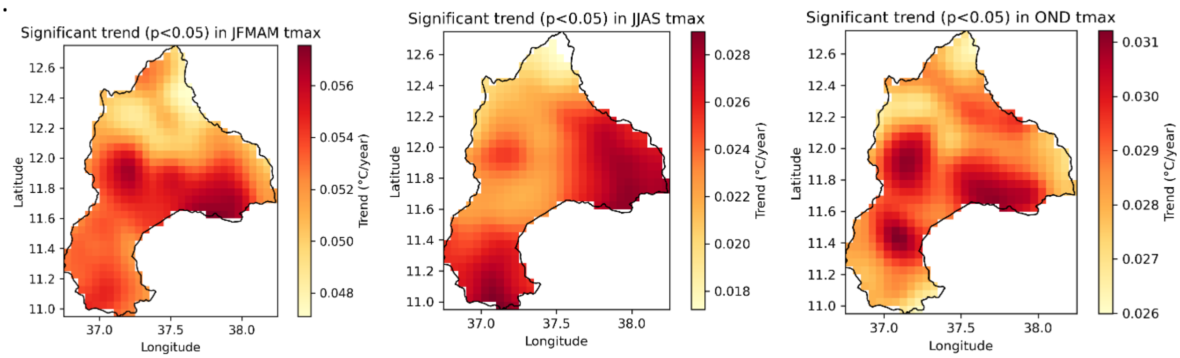

Figure 5: Trends of maximum temperature in the Lake Tana sub-basin from 1983 to 2016

The annual and dry season rainfall of Lake Tana Sub-basin had not changed significantly over the period 1981-2020. However, the rainfall amount showed a statistically significant increase (by up to ~5 mm/year) in JJAS (wet) season except for the southern part of the sub-basin (Fig 6). Moreover, the inter-quartile range (IQR) showed that most parts of the sub-basin experienced significant inter-annual change in rainfall variability during the wet season.

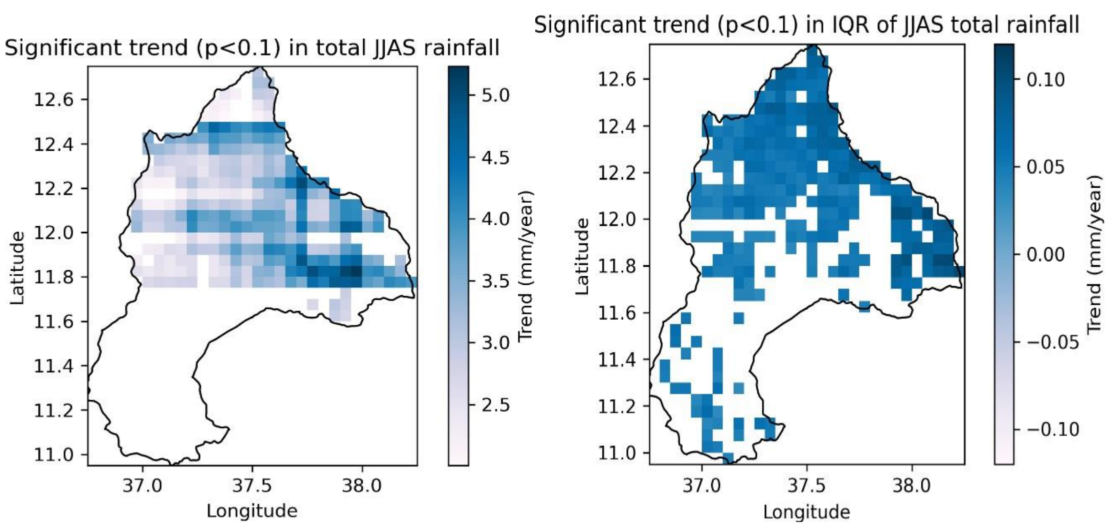

Figure 6: Historical trends in seasonal rainfall amount of the Lake Tana Sub-basin from 1981-2020

4.4 Supply-demand gap

Table 3 shows the calibrated values of HBV model parameters of Gumara Watershed. Default values indicated the parameters that were not used during model calibration.

Table 3: Summary for calibrated default and calculated parameters and values

Parameter	Value	Calibrated value	Default value	Calculated value
Alfa	0.2	*		
Beta	1.6	*		
Cflux	0.72	*		
Fc	330	*		
K4	0.02	*		
Khq	0.16	*		
Lp	0.87	*		
Perc	1.1	*		
Maxbaz	0.5	*		
Athorn	0		*	
Cevpfo	1.15		*	
Ecalt	0		*	
Ecorr	1		*	
Pcalt	0		*	
Pcorr	1		*	
Rfcf	1		*	
Hq	7.2			*

As shown in Fig 7, the simulated streamflow captures the overall patterns of observed streamflow in a good way except in 1996. The rising and falling limbs of the hydrograph were similar to simulated and observed ones. However, the simulated streamflow suggested some overestimation and underestimation of the peak flows. Baseflow was well captured except for minor overestimation in the first falling limb of 1995 and 1996.

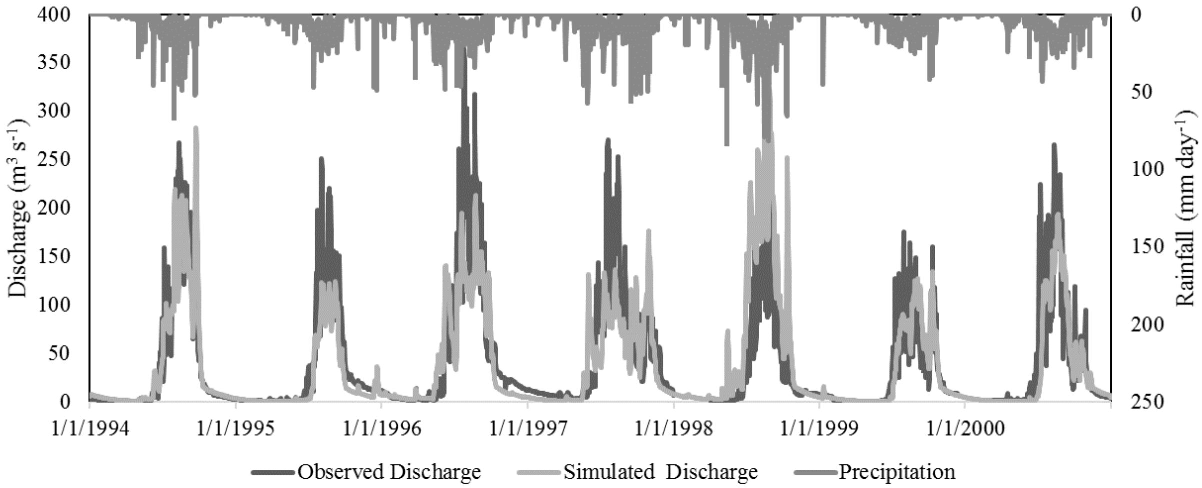

Figure 7: HBV Model Calibration result of Gumara Catchment from 1994-2000 G.C

The NS for calibration and validation indicated a relatively good performance of 0.61 and 0.62, respectively. NS values between 0.6 and 0.8 indicated fair to good performance (Nash and Sutcliffe, 1970). Based on the relative volumetric error analysis, the model performance was categorized under the well performance (+5% and −5%) during the calibration period with the estimated value of 0.11%. The relative volume error was -1.78 %.

The HBV model showed that the simulated streamflow of the Gumara Watershed was 178.64 Mm3 from 1994-2001. The streamflow at the gauged and ungauged part of Gumara was 160.57 Mm3 and 18.07 Mm3, respectively. For the future period (2035-2064), the streamflow may increase to 221.35 Mm3; specifically, the gauged and ungauged part of Gumara may have a streamflow of 196.5 Mm3 and 24.85 Mm3 , respectively. Similarly, Chakilu et al. (2020) reported the increasing rate of the annual average streamflow of Gumara Catchment because of climate change under RCP 2.6, RCP4.5, and RCP8.5 at a rate of 4.06%, 3.26%, and 3.67% increase, respectively for the period 2020-2080. Wubneh et al. (2022) showed impacts of climate change under RCP4.5 for the 2040s and 2070s in Gumara Catchment, with percentage increment of streamflow between 0.5% and 36.2% and 7.7% and 58.2 %, respectively. Fig 8 shows the gross irrigation requirement (GIR) of Gumara Catchment. GIR peaked twice during the irrigation season, the first was in December and January and the second in April, suggesting that farmers grew crops twice during the irrigation season. For the current period, the GIR was estimated to be 29.7 Mm3 per irrigation season, comprising GIR values of 14.6 and 15.1 Mm3 for the gauged and ungauged parts of the Gumara Watershed. In the future, the GIR will be estimated to be 36.4 Mm3 per irrigation season, comprising GIR values of 15.61 and 20.77 Mm3 for the gauged and ungauged parts of the watershed.

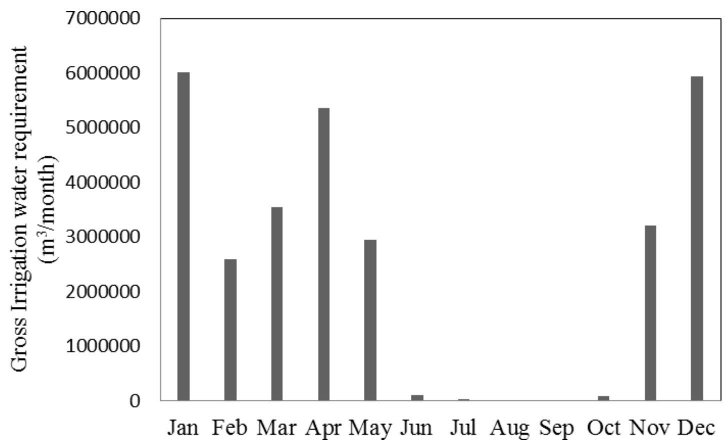

Figure 8. Monthly variation of the total Gross irrigation water requirement of Gumara Catchment

In current and future scenarios, there will be uneven distribution of water in the Gumara Watershed. This may lead to conflict betwe farmers having more water and those experiencing water shortage.. According to the supply-demand relationship analysis, most farmers demanded nodes in the middle of the watershed might have a positive relationship. This indicated the availability of sufficient irrigation water supply to meet the required water demand. However, unmet irrigation water demand existed at some demand nodes that diverted water from tributaries. Despite the surplus water in the middle of the watershed, farmers in this part of the watershed will still face water shortages in the future due to climate change. Similarly, climate change will worsen the water shortage problem for farmers who are receiving less water than they demand. In Gumara, many irrigation schemes were concentrated in small tributaries because farmers could more easily divert small streams than large ones. This could also relate to land suitability for irrigation. Furthermore, most negative supply-demand relationships (irrigation water scarcity) were observed downstream of the watershed. Fig 9 shows that the future period scenario will have more water stress compared to the current one because of the increase of temperature that causes the rising of evapotranspiration in the catchment. Again, the rise in evapotranspiration can cause increase in irrigation crop water demand. If evapotranspiration increases in dry season, the water demand in various sectors also will increase. The other cause of water stress in Gumara Catchment was uncontrolled water withdrawal for irrigation. Farmers withdrew excess amount of water without any controlling and monitoring infrastructures. Owing to lack of awareness and organized rule and regulation, farmers in this area diverted unlimited amount of water day and night without considering the current and future water sectors' demand (environmental, domestic etc.). As a result, the supply-demand relationship of the catchment showed irrigation water abstraction was unbalanced with the supply for the entire watershed in both periods. When uncontrolled water withdrawal and climate change impact come together, the water stress will significantly increase for all water sectors and the unmet demand of irrigation land will expand widely in the catchment in the future.

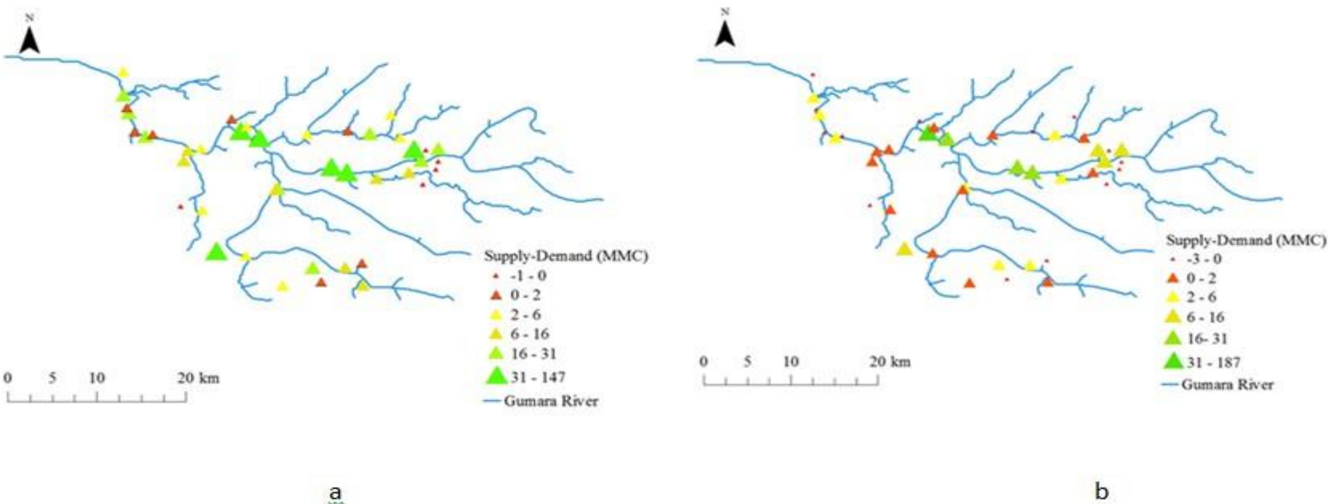

Figure 9 :- The current Supply-demand relationship (a) and future supply-demand relationship (b) of Gumara Catchment (MMC:- million meter cube)

5. Conclusion

In this study, we evaluated how climate change, irrigation, and LULC in the Lake Tana Subbasin are impacting the gap between water supply and demand. Our findings indicated that the Gumara Catchment experienced significant conversion of forest, bushland, and grassland into agricultural and residential areas.

There was a widespread irrigation near the lake shore and it was rapidly expanding to the upstream parts of the watersheds. Change in climate was manifested in the sub-basin through historical increasing temperatures with evidence of possible warming in the future. These changes had a potential impact on water availability and demand in the sub-basin.

In the study area, the increasing rate of evapotranspiration owing to rising of temperature was causing water shortages in the dry season, and it will likely exacerbate in the future. Besides, the significant increasing rate of rainfall in the wet season might cause floods in the sub-basin. Therefore, there was a strong need to investigate the role of various water storage mechanisms (small ponds, weir/dam. etc.) to store the excess rainfall in the wet season and supply to smallholder farmers in the dry season. Research should address the role of land management practices (soil and water conservation), and adaptive management of irrigation (monitoring, learning and continuously revising the irrigation management accordingly) to prevent the occurrence of conflict over water. Hence, we need to raise awareness from farm to basin administration office level.

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