Journal of Water Resources and Ocean Science
2022; 11(5): 76-85
http://www.sciencepublishinggroup.com/j/wros
doi: 10.11648/j.wros.20221105.11
ISSN: 2328-7969 (Print); ISSN: 2328-7993 (Online)

Seasonal Water Balance Estimation for Abbay River Basin Using Open Access Satellite Databases and Hydrological Model, East Africa

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To cite this article:

Agegnehu Kitanbo Yoshe. Seasonal Water Balance Estimation for Abbay River Basin Using Open Access Satellite Databases and Hydrological Model, East Africa. *Journal of Water Resources and Ocean Science*. Vol. 11, No. 5, 2022, pp. 76-85.
doi: 10.11648/j.wros.20221105.11

Received: November 18, 2022; **Accepted**: January 9, 2023; **Published**: January 30, 2023

Abstract: Water is a limited natural resource that no life can survive without. The problem of water resource utilization is the key problem throughout the world. Water balance assessment was pricing the water for water resource optimization and management. The main objective of this study was estimation of the seasonal water balance of Ethiopia. The QGIS tool was used for data analysis which was essential for estimation of water deficit for the dry season and water surplus for the wet season. Seasonal water balance for six years was calculated for dry and wet seasons. For each year, the results for wet were 17.8 BCM, 19.7 BCM, 42.9 BCM, 19.8 BCM, 46.1 BCM and 13.99 BCM for the year 2016-2017, 2017-2018, 2018-2019, 2019-2020, 2020-2021, 2021-2022 respectively. For the dry season, the seasonal water variation result shows that -14.6 BCM, -15.15 BCM, -19.8 BCM, -23.1 BCM, -71.83 BCM, -21.6 BCM for the year 2016-2017, 2017-2018, 2018-2019, 2019-2020, 2020-2021, 2021-2022 respectively. The result shows that there was a water surplus for the wet season and water deficit for the dry season. The result of this study was applicable for drought monitoring during the dry season, for urban drainage system management and flood monitoring, for agricultural systems, for industrial systems, for hydroelectric power generation systems, for urban and rural water supply systems, for understanding the effect of global climatic changes due to different processes in the study area.

Keywords: QGIS, GLDAS Data, Water Balance, Zonal Statistics, Seasonal Water Change, Dry Season, Wet Season

1. Introduction

Water is important for life and it is used for different purposes, such as domestic and industrial water supply, flood control, hydroelectric generation, irrigation, recreation, navigation, atmospheric cooling, leaching of saline water intrusion, dilution of polluted water, fishing and provisional to coastal ecosystems. Over environment of water in the water shade leads to a water environment and even harms the ecology of the environment. For optimization and effective management of this resource, understanding the availability of water during the wet season and dry season was an important issue.

Ethiopia has a high potential for water resources. But, it faces shortages of water and depends on rainfall for cropped agriculture due to improper utilization and lack of water resource management. The current utilized surface water is less than 5% while ground water is not utilized [15]. But, over the past 15 years, the economic development of Ethiopia has been among the fastest growing in the world at an average rate of 9.5% per year with growth in industry and services easing to single digits. has a 10-year development plan was launched by the government based on 2019 home growth reform Agenda which will run from 2020-2029/30 [16]. In order to meet this plan, reducing the shortage of water supply in urban and rural areas, increasing the production of agricultural products by irrigation, improving the coverage of hydroelectric power by constricting hydroelectric projects in the river basin and increasing the construction of multi-proposed reservoirs on the river, the was important for sustainable development of the economic system which needs assessment of water resources to utilize at required amount without affecting this resources.

Estimation of water balance was a key issue for water resource optimization and effective water shade management and it was assessing needs, current condition and trends of the water resource on the land surface which strengthened decision making for water resource optimization and management and said to be pricing [1]. The role of opening an inclusive strategy for optimization and management of water resources to manage demand was reducing the limit of water problem by identifying its balance [2]. Water balance estimation is important for making decisions to store the required amount of water during the dry season in the reservoir and essential for reduction of flood risk during the wet season. It was essential to know the daily demand for water for multi-functional usage based on the water balance in the season. Understanding balance is also important to meet the demand of downstream users and to give attention to upstream watershed protection. Assessing seasonal variation of surface water was important for characterization for temporal variation of water in the river [18]. Accurate detection and monitoring of water bodies and analyzing the change of water over time provide insight into water resources as well as their causes and consequences in natural and agricultural ecosystems [19].

Due to a high population growth rate in the world, the demand for water is increasing, and storage of sufficient water to meet water demand during the dry season and below-average rainfall years is becoming increasingly important. River basins require effective and compressive water management and planning for optimization of the basin' water resources [14]. The long term water balance assessment provides improved knowledge of regional and global climatic change and identifies the effect of human beings on water resources [9-13, 19]. Climatic change and anthropogenic modification was due to the change in river flow during the wet and dry seasons and is the witness of climate change [11]. Due to ongoing human activities and climatic changes, the water cycle on the earth's surface was influenced and more research was warranted to understand, simulate and predict the hydrological regimes of the water bodies [17]. Knowing water balance is an essential component of water management and water management is understanding the hydrologic cycle of the river basin [27].

Ethiopia has 12 river basins and this study was focused on the Abbay river basin. The Nile River starts from Africa and is the world's longest river [3]. The first world civilization in the art of irrigation and cultivation of crops was around the Nile River [4]. The river is a transboundary river which covers the drainage basin of 11 countries, such as the Democratic Republic of the Congo, Tanzania, Burundi, Rwanda, Kenya, Ethiopia, Eritrea, South Sudan and Egypt, flowing into the Mediterranean Sea [28]. The Blue Nile is located in the northern part of Ethiopia and the largest tributary of the Nile River and said to be the Abbay River [5] and its source was Lake Tana in the northern part of the basin, which is the largest fresh water lake in Ethiopia [5-8].

In the river basin, the flow of the river is seasonal, which depends on the rain season. Most of the communities which live in the basin depend on rain-fed agriculture. People in the river basin face different challenges such as poverty, limited development, extreme floods and drought. The loss of fertile soil upstream of the river leads to reduction of agricultural production. The availability of hydro climatic data and hydrological studies is known for the river basin. Soil erosion and hydrological change in the river basin has been largely influenced due to the constriction of Grand Ethiopian Renaissances dam project and human activities [4]. For optimization of the available water resource for multi-purposes in the river basin and effective management of the watershed to reduce water shortage in the downstream user estimation of resources water balance component was the primary issue in the river basin.

For water balance estimation, in-situ measurement of each element of water balance gives a completed understanding of the water in the basin ideally. But, in reality, direct measurement of all components of the water balance was not done at all. In-situ data is inadequate and incomplete to indicate the water balance of the water bodies. In recent decades, satellite remote sensing has played an important role in areas of water for water resource optimization and mentoring. Satellite images analyses the distribution of surface water in the river basin as static and as binary variable [22-26]. Due to a very Advanced High Resolution Radiometer, Moderate resolution Imaging Spectro-radiometer and Visible Infrared Imaging Radiometry Suite, Optimal sensors with coarse spatial resolution and daily orbit were detecting water changes at high temporal resolution. For MODIS data. Water surface change was estimated across lakes in China from 2000 to 2010 using 8-day MODIS data [21]. The monthly extent of inland water bodies from 1986 to 2012 in central Asia was estimated using MODIS and Advanced High Resolution Radiometer data was estimated [20]. To understand the seasonal variation of water over the Abbay River at basin level, this study was proposed to estimate the seasonal change of water balance components for the Abbay river basin by using GLDAS 2.1 model data and remote sensing data for 6 consecutive years from April 2016 up to February 2022 by using the QGIS python algorithm.

2. Material and Methods

2.1. Study Area

The Blue Nile is one of the tributaries of the Nile River, which starts from Tana Lake in Ethiopia in the eastern part of Africa and flows on to Sudan. In Ethiopia, it was said to be the Abbay River where the Grand Ethiopian Renaissances dam was being constructed on it for the purpose of electricity generation. The wet season in Ethiopia begins in April and ends in September. The dry season was from November up to February. But, due to the topographic variation of Ethiopia, there was little variation [35]. This climatic division was used for data analysis.

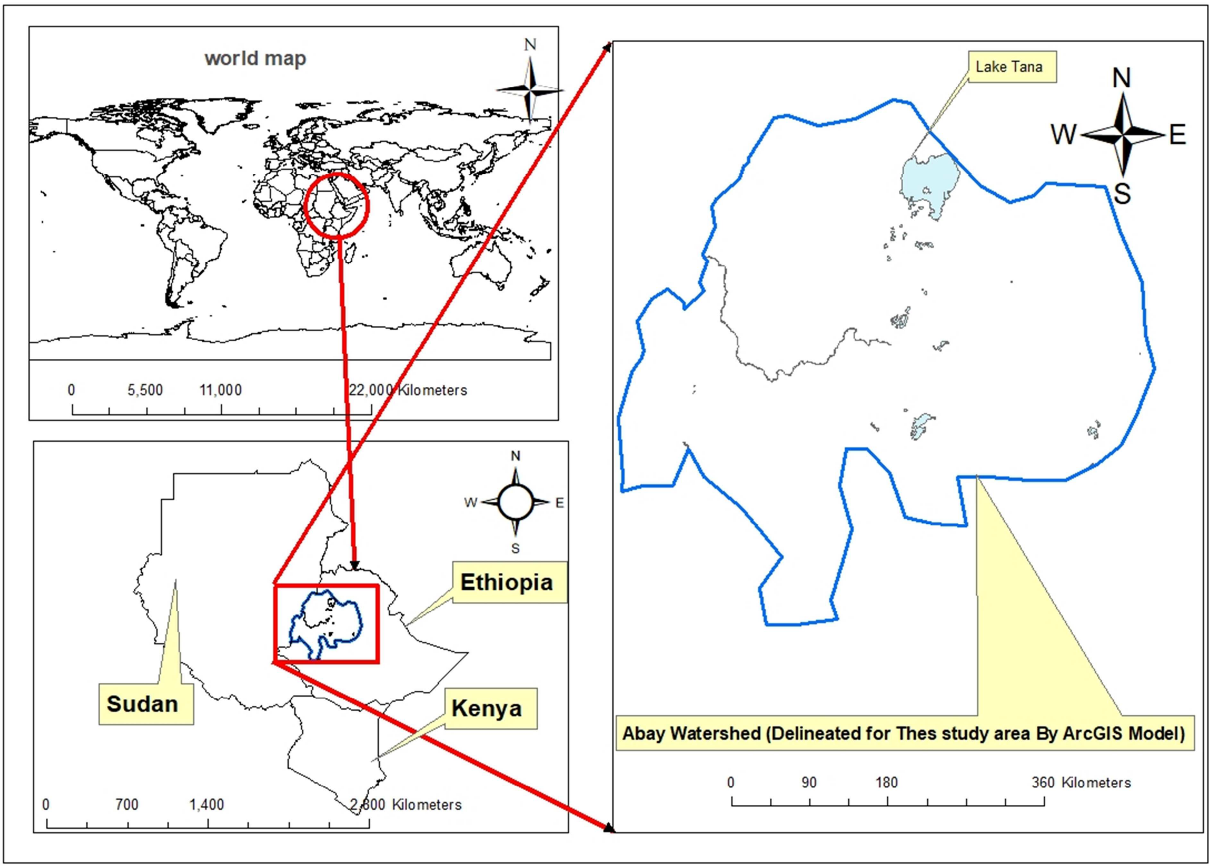

Figure 1. *Study area.*

2.2. Data Required for the Research

Global river data was collected from HydroRIVERS, which was Global network of all global rivers having a catchment area of 10 km^2 and above with an average flow greater than or equal to 0.1m^3/se [29]. For remote sensing data, merged satellite gauged precipitation estimates –Final run (IMERG Precipitation) was found in mm/month was present from 2000-06-01 up to 2021 09-30 at Giovanni satellite at 0.1^o resolution [30]. MODIS Evapotranspiration was extracted from an application for extraction and exploring analysis of ready samples (AppEEARS). The data availability was from 2001-01-01 to present at a 500, 8-day interval [31]. Terrestrial water storage data was collected from the Gravity Recovery and Climate Experiment (GRACE TELLUS) and for this data JPL, GFZ, CGR GRACE Level-3 monthly land water equivalent –thickness surface mass anomaly Release 6.0 version 04 and the data availability was 2002 April to 2017 October at 0.1^o resolution [32, 33]. Data for the water balance component for Global Land Data Assimilation System (GLDAS 2.1) were collected from GES DISC at 1^ox1^o resolution of GLDAS data from catchment land surface Model. Monthly data are available at 1^ox1^o from 2000-01-01 up to 20022-08-01 was present with models catchment-LSM variation 2.1 [34].

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2.3. Methodology Used for Data Analysis

For estimation of the seasonal water balance of the river basin, different required data are collected, checked for its availability for the entire season and prepared for estimation of seasonal water balance in the river basin. The watershed of the area was delineated by using the ArcGIS model and the final map for the data analysis of the watershed was generated. The zonal statistical analysis method of the QGIS model tool was used for estimation of the seasonal water balance of the study area. By the Water balance equation, seasonal water variation for wet and dry seasons of the watershed for 6 years was estimated. The general water balance equation used in this study was as follows.

$$P\text{-}SR\text{-}TWS\text{-}ET=\Delta S \quad (1)$$

Where

P is Precipitation, SR is Surface Runoff, TWS is Terrestrial Water Storage, ET is Evapotranspiration and ΔS is Change in storage for the wet season and dry season was used to understand the change in seasonal water change.

Data Preparation

The input data for QGIS for seasonal water balance estimation was Shape file, precipitation for wet and dry, Evapotranspiration for wet and dry, Terrestrial water storage for wet and dry season, surface run off for wet and dry season. For GRACE, data such as JPL, GFZ, CGR are collected and merged together for estimating remote sensing water balance estimation. A one-year seasonal water balance was estimated by this GRACE data but the data have certain gaps and, due to that, it was not used for further analysis of seasonal water change estimation for this study. Data is available at different resolutions, having different units and before data analysis, raster analysis was carried out.

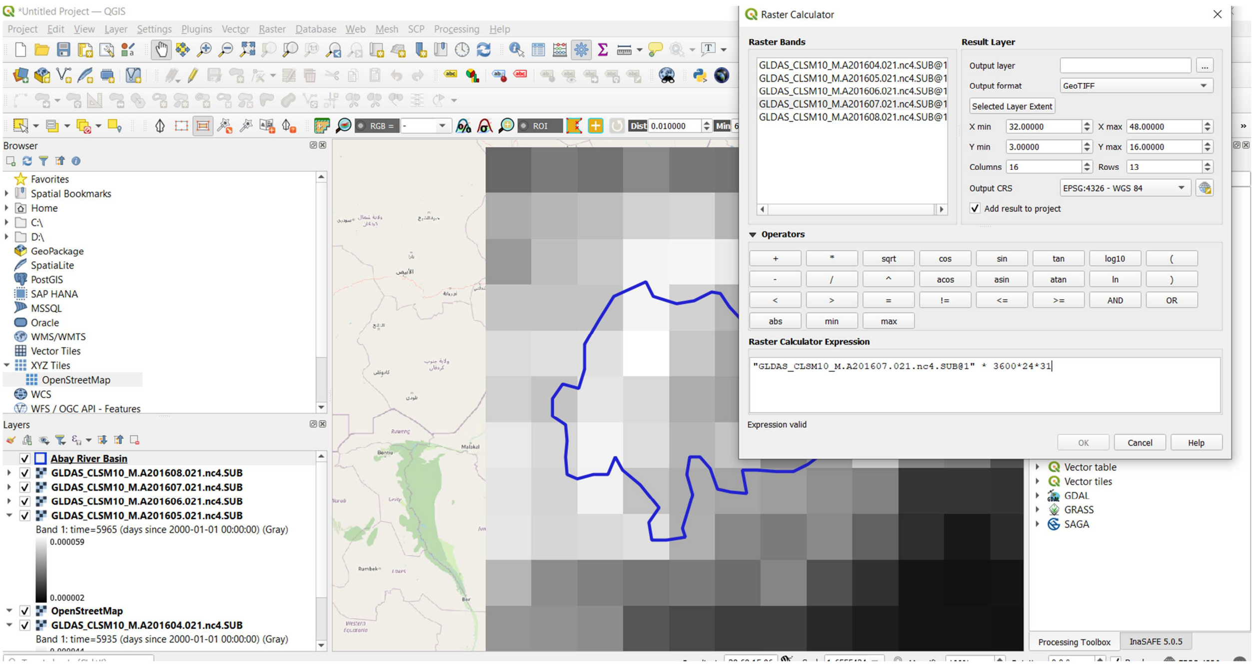

Figure 2. *Raster analysis for seasonal water balance estimation of the Abay River basin.*

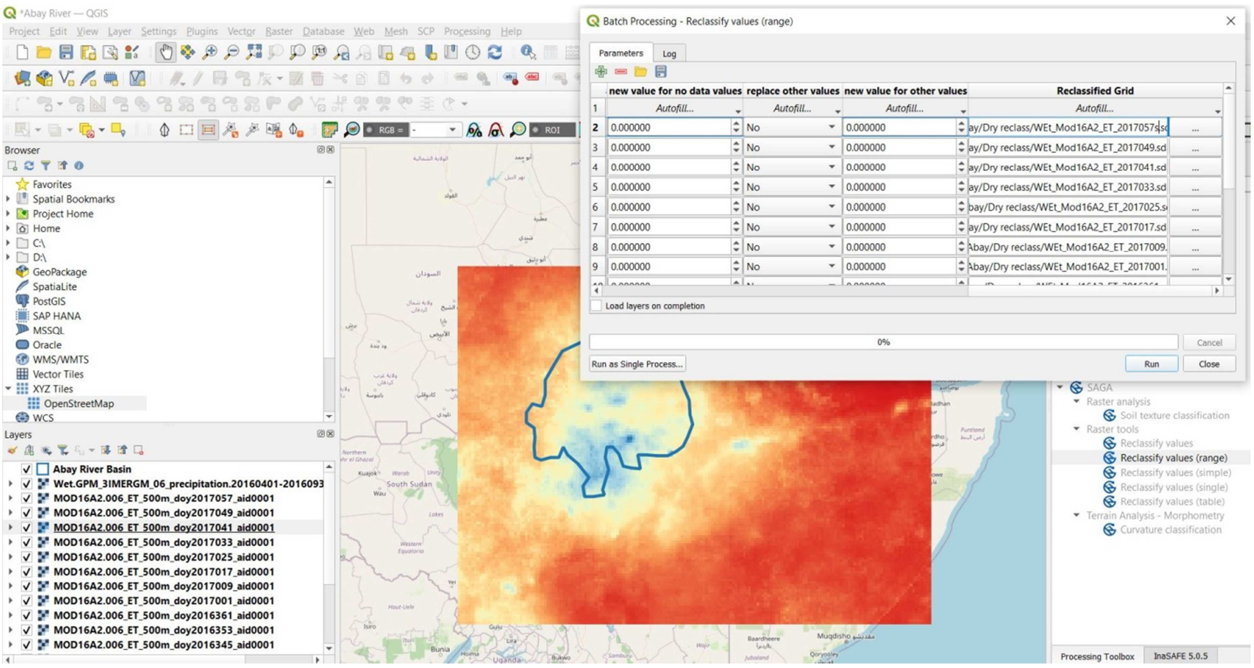

Figure 3. *Reclassification of data by range.*

Then raster analysis was carried out. Zonal statistics were used for estimation of the seasonal water analysis.

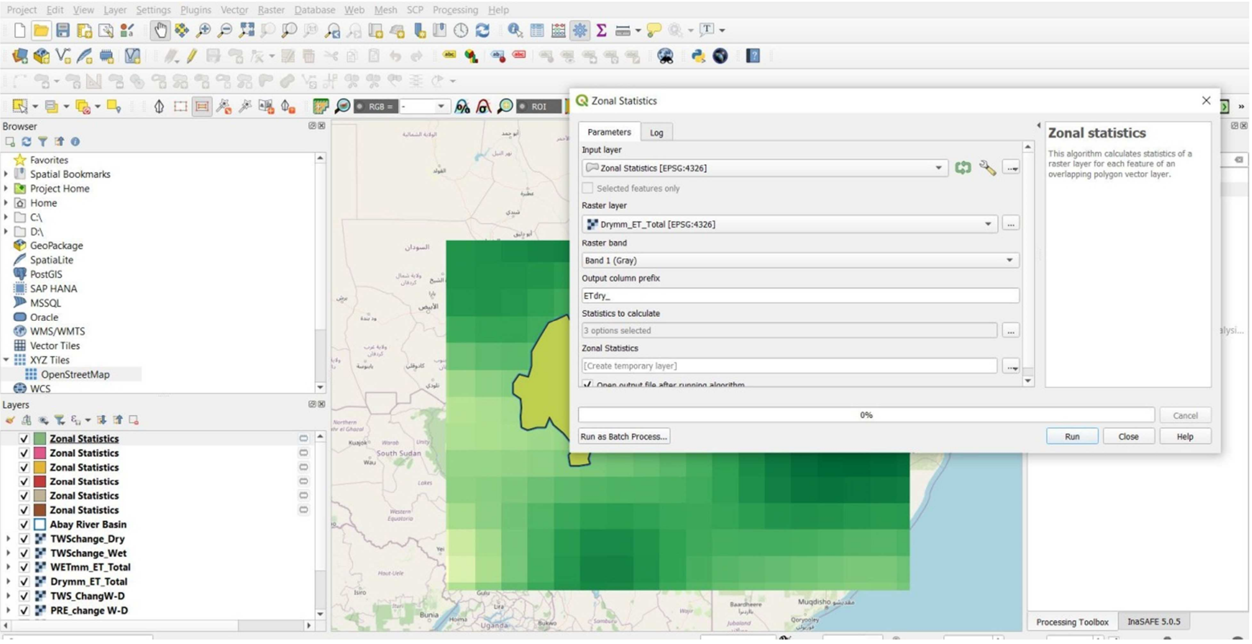

Figure 4. *Zonal statistical analysis.*

The final water balance equation was used to estimate the change in seasonal water change. The generalized water balance estimation methodology is shown below.

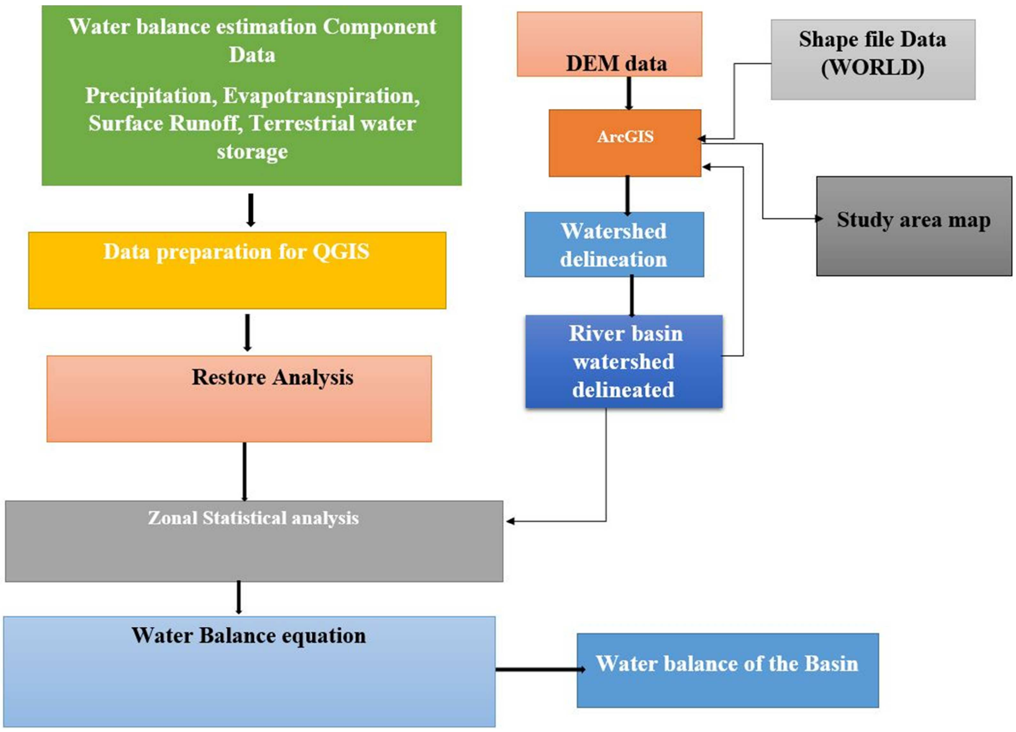

Figure 5. *Methodology of the used.*

3. Results and Discussion

Seasonal water balance for the Aby river basin was estimated for six years to understand the change in water balance in the season from April 2016 up to February 2022. The result was as shown in the table below. Seasonal water variation was estimated by the water balance equation. Volume was estimated by multiplying each water balance estimation component by area of the watershed. By using remote sensing, remote balance for seasons was estimated only for 2016 to 2017. Due to data limitation, the further analysis of seasonal water change estimation for this study was not used and GLDAS model data was used for this study.

The result was as follows.

Table 1. *Results for water balance estimation for the year April 2016 up to February 2017 using remote sensing data.*

Water balance components	Wet season			Dry season			Area in meter square
	Mean in mm	Min in mm	Max in mm	Mean in mm	Min in mm	Max in mm	
Precipitation	1246.42	594.0	2259.099	44.73	2.0	299.2409	1.76205e+11
Evapotranspiration	344.752	57.5	714.7	107.9	0.3	577	
Terrestrial Water Storage	8.95	8.75	9.2	-59.5	-81.41	-33.6426	
Run off	UN	UN	UN	UN	UN	UN	

The seasonal change in water for wet conditions was 157.34 BCM for wet season and -0.65BCM for dry season for remote sensing data. The mean precipitation for the wet season was estimated to be 219.63 BCM in the river basin and Evapotranspiration was 60.75 BCM. For the dry season, the mean precipitation over the basin was 7.9 BCM and Evapotranspiration was 19.01 BCM for remote sensing data analysis. The minimum and maximum value of each component were evaluated. The estimated minimum precipitation for this year was 594 mm and 2.0 mm for the wet and dry seasons respectively. The obtained maximum precipitation was 2259.1 mm and 299.24 mm for the wet and dry seasons respectively. For evapotranspiration, the evaluated maximum was 714.7 mm and 577 mm for wet and dry season respectively; the minimum evapotranspiration was 57.5 mm and 0.3 mm for wet and dry season respectively. Terrestrial water storage was estimated to be 8.95 mm for mean, 8.75 mm for minimum, 9.2 mm for maximum condition during the wet season and -59.5 mm for mean value, -81.41 mm for minimum and -33.643 mm for maximum condition. This result shows there was water deficit for the dry season and water surplus for the wet season. This result was very essential to understand the hydrological condition of the river basin for sustainable water resource management and optimization. For remote sensing data, the run off component was not estimated and there were also data gaps in some months. Due to that, for further assessment of seasonal water balance estimation, it was not used. The demand for water in the Blue Nile was increasing among upstream and downstream users and the obtained result was applicable for different water usage in the area.

Table 2. *Results for water balance estimation for the year April 2016 up to February 2017 using GLDAS model data.*

Water balance components	Wet season			Dry season			Area in meter square
	Mean in mm	Min in mm	Max in mm	Mean in mm	Min in mm	Max in mm	
Precipitation	949.04	692.2	1193.01	42.334	3.314	87.60	1.76205e+11
Evapotranspiration	530.014	367.6	665.253	187.52	68.5	415.31	
Terrestrial Water Storage	214.9	73.21	349.0	-109.3	-275.95	-37.93	
Run off	196.6	70.27	336.13	3.01	0.001	7.93	

For GLDAS data for the year April 2016 up to February 2017, important parameters that govern water balance were estimated for each parameter. The minimum and maximum values were calculated. The QGIS tool estimates water deficiency for the dry season and water surplus for the wet season. The estimated result shows that the seasonal water variation for the wet season was 1.33 BCM and -6.9 BCM for the dry season. The negative sign for the dry season shows that there was water scarcity during the dry season, which leads to drought in the river basin and needs drought monitoring during the dry season. The calculated mean precipitation for the wet season was 167.23 BCM and 7.50 BCM for the dry season. The mean evaporation for the wet season is 93.4 BCM and 33.05 BCM for the dry season. During the data analysis, the estimated maximum and minimum evapotranspiration for the wet and dry season was 665.253 mm maximum value for wet, 415.31 mm maximum value for dry, 367.6mm minimum value for wet, 68.5 mm minimum value for dry season. Terrestrial water storage was one of the components of water balance estimation and the obtained result shows that 214.9 mm for mean, 73.21 mm for minimum value, 665.253 mm for maximum value during the wet season. For the dry season, the estimated terrestrial water storage was -109.3 mm for mean value, -275.95 mm for minimum value and -37.93 mm for maximum during the dry season. For run off conditions, the obtained value was 196.6 mm for mean, 70.27 mm for minimum, 336.13 mm for maximum during wet season and 3.01 for mean, 0.001mm for minimum and 7.93 mm for maximum during dry season. For this year during the dry season, it shows that there was water deficit and required optimization of the water resources to reduce water shortages.

Table 3. *Result for water balance estimation for the year April 2017 up to February 2018 using GLDAS model data.*

Water balance components	Wet season			Dry season			Area in meter square
	Mean in mm	Min in mm	Max in mm	Mean in mm	Min in mm	Max in mm	
Precipitation	901.2	573.07	1245.3	35.8	7.6	71.6	1.76205e+11
Evapotranspiration	526.5	336.7	681.94	234.51	101.80	461.623	
Terrestrial Water Storage	194	97.2	381.82	-145.4	-324.63	-59.3	
Run off	137.1	42.56	276.8	0.74	0.004	3.05	

Seasonal water balance components were estimated for 2017 to 2018 using GLDA2.1 Data and the result shows that 158.8 BCM of mean seasonal precipitation for the wet season and 6.31 BCM for the dry season over the river basin. And the mean evaporation for the wet season was 92.8 BCM for the wet season and 41.32 BCM for the dry season. The seasonal change of water for the wet season was 7.68 BCM and -9.53 BCM for the dry season. As was shown in table 3 above, the minimum estimated precipitation were 573.01 mm and 7.6 mm for the wet and dry seasons respectively. For evapotranspiration, the obtained result shows that the minimum value was 336.7 mm and 101.8 mm for wet and dry seasons respectively. The maximum estimated evapotranspiration for the river basin was 681.94 mm and 461.623 mm for the dry season. This year the value of terrestrial water storage calculated was 194 mm for mean, 97.2 mm for minimum, 381.82 mm for maximum during wet season and -145.4 mm for mean, -324.63 mm for minimum and -59.3 mm for maximum during dry season. The terrestrial water storage is consumed by other components during the dry season. The calculated run off for this year was 137.11 mm for mean value, 42.56 mm for minimum value, 276.8 mm for maximum value during the wet season and 0.73 mm for mean, 0.004 for minimum and 3.05 mm for maximum value during the dry season. During the dry season there were water shortages in the river basin. The volume of water in BCM was obtained by multiplying the area of the water shade by the depth of water that was estimated during the analysis for each parameter.

Table 4. *Results for water balance estimation for the year April 2018 up to February 2019 using GLDAS model data.*

Water balance components	Wet season			Dry season			Area in meter square
	Mean in mm	Min in mm	Max in mm	Mean in mm	Min in mm	Max in mm	
Precipitation	926.43	631.5	1162.234	56.012	7.053	118.44	1.76205e+11
Evapotranspiration	533.034	347.1	674.02	238.733	119.68	441.70	
Terrestrial Water Storage	213.10	61.611	368.9	-144.10	-316.6	-58.85	
Run off	149.62	32.955	267.64	2.98	0.062	9.40	

The result for 2018 to 2019 indicates that the change in seasonal water for the wet season was 5.41 BCM and -7.34 BCM for the dry season. This indicates that there was a surplus of water during the wet season and a shortage of water for the dry season. The estimated precipitation during the wet season was 163.24 BCM and 9.87 BCM for the dry season and the mean evapotranspiration for the wet season was 93.923 BCM and 42.066 BCM for the dry season on a volume basis. The maximum and minimum values for each component were also estimated and those are shown in table 4 above. It indicates that the estimated precipitation is 631.5 mm for minimum, 1162.234 for maximum during wet conditions and 7.053mm for minimum, 118.44 mm for maximum during the dry season. For evapotranspiration, the estimated minimum value for the wet season was 347.1 mm and 674.02 mm for maximum during the wet season. The value for terrestrial water storage was estimated and it shows that 213.1mm for mean value, 61.611 mm for minimum value, 368.9 mm for maximum value for wet season and -144.1 mm for mean, -316.6 mm for minimum and -58.85 mm for maximum value of terrestrial water storage during dry season. In the case of run off, the estimated values were 149.62mm for mean, 32.955 mm for minimum, 267.64 mm for maximum during wet season and 2.98 mm for mean, 0.062 mm for minimum and 9.4 mm for maximum during dry season. The result shows the availability in the river basin. It indicates that there was water scarcity for the dry season and water surplus for the wet season. This result was very essential for water resource optimization and management during the dry and wet season depending on water usage.

Table 5. *The results for water balance estimation for the year April 2019 up to February 2020 using GLDAS model data.*

Water balance components	Wet season			Dry season			Area in meter square
	Mean in mm	Min in mm	Max in mm	Mean in mm	Min in mm	Max in mm	
Precipitation	849.1	480.52	1172.272	70.61	6.3	137.45	1.76205e+11
Evapotranspiration	491.278	335.20	622.7	259.784	109.70	473.212	
Terrestrial Water Storage	203.553	79.670	364.1914	-153.72	-290.56	-49.821	
Run off	115.70	38.30	236.8164	7.96	0.04	38.40	

Water balance estimation was pricing water and for the year 2019-2020 seasonal water variation was calculated. This result shows 6.8 BCM of seasonal water variation for wet season and -7.65 BCM water variation for dry season. As was explained above, water shortages occurred during the dry season and water surplus for the wet season. In volume, the mean precipitation over the basin for the wet season was 149.62 BCM and 12.44 BCM for the dry season. The mean evaporation for the wet season was 86.566 BCM and 45.78 BCM for the dry season. The maximum value for estimated precipitation was 1172.272 mm, 137.45 mm for wet and dry seasons respectively. The minimum estimated for the river basin was 480.52 mm, 137.45 mm for dry season precipitation. For evapotranspiration, the estimated maximum value was 622.7 mm, 473.212 mm for the wet and dry seasons respectively. It shows that the value for the wet season was higher than the dry season due to excess evaporation from stored water on the land surface during the wet season. The estimated terrestrial water storage was 203.553 mm for mean, 79.67 mm for minimum, 364.1914 mm for maximum during wet season and -153.72 mm for mean, -290.56 mm for minimum, -49.821 mm for maximum during dry season. In the case of run off, the estimated value was 115.7

mm for mean. 38.3 mm for minimum, 364.1914 mm for maximum during wet season and 7.96 mm for mean, 0.04 mm for minimum and 38.4 mm for maximum during dry season. This provides full information about water availability for the wet and dry season for sustainability of water resource management and optimization.

Table 6. *The results for water balance estimation for the year April 2020 up to February 2021 using GLDAS model data.*

Water balance components	Wet season			Dry season			Area in meter square
	Mean in mm	Min in mm	Max in mm	Mean in mm	Min in mm	Max in mm	
Precipitation	960.4	671.75	1246.10	26.720	2.02	57.20	1.76205e+11
Evapotranspiration	471.46	320.34	573.034	268.35	126.24	539.63	
Terrestrial Water Storage	218.241	88.180	431.53	-180.132	-401.61	-77.045	
Run off	178.60	28.15	328.542	0.80	0.0020	5.41	

In the year 2020-2021, the estimated seasonal change in water shows that 16.230 BCM seasonal water variation during the wet season and -10.973 BCM change in seasonal water variation for the dry season. On a volume basis, the mean precipitation over the basin for the wet season was 169.15 BCM and 4.71 BCM for the dry season. The Evapotranspiration for the wet season was 83.1 BCM and 47.3 BCM for the dry season. As was shown in table 6 above, the calculated value of each seasonal estimation component for both seasons. The minimum precipitation was 671.75 mm, 2.02 mm for the wet and dry seasons respectively. The maximum estimated precipitation was 1246.034 mm and 57.2 mm for wet and dry seasons respectively. In the case of evapotranspiration, the estimated value was 320.34 mm for minimum, 573.034 mm for maximum during wet season, 126.24 mm for minimum and 539.63 mm for maximum during dry season. For terrestrial water storage, the calculated value indicates that 218.241 mm for mean, 88.18 mm for minimum, 431.53 mm for maximum during wet season and -180.132 mm for mean, -401.61 mm for minimum and -77.045 mm for maximum during dry season. The result was important to manage drought during the dry season due to shortages of water in the river basin and for flood monitoring during the wet season. For run off, the result indicates that 178.6 mm of water for mean, 28.15 mm for minimum, 328.542 mm for maximum during wet season and 0.8 mm for mean, 0.002 mm for minimum and 5.41 mm for maximum during dry season.

Table 7. *The results for water balance estimation for the year April 2021 up to February 2022 using GLDAS model data.*

Water balance components	Wet season			Dry season			Area in meter square
	Mean in mm	Min in mm	Max in mm	Mean in mm	Min in mm	Max in mm	
Precipitation	746.15	473.98	1027.7	74.43	54.212	148.82	1.76205e+11
Evapotranspiration	452.1	311.10	569.80	180.05	114.67	248.6	
Terrestrial Water Storage	193.31	81.253	323.011	-131.1	-287.40	-55.10	
Run off	138.40	34.3	284.40	5.3	1.63	18.25	

The seasonal water balance estimated during the year 2021-2022 was presented in table 7 above. The change in water for the wet season was 9.68 BCM in the river basin and 3.56 BCM for the dry season in the river basin. On a volume basis, the mean precipitation over the basin for the wet season was 131.50 BCM and 13.11 BCM for the dry season. The evaporation for the wet season was 79.65 BCM and 31.73 BCM for the dry season. Mean, minimum and maximum components of water balance estimation were calculated for each component. The estimated precipitation was 473.98 mm for minimum, 1027.7 mm for maximum during wet season, 54.212 mm for minimum, 148.82 mm for maximum during dry season. For evapotranspiration, the calculated value was 311.1 mm for minimum, 569.8 mm for maximum during wet season and 114.67 mm for minimum, 248.6 mm for maximum during dry season. The estimated terrestrial water storage for this year was 193.31 mm for mean, 81.253 mm for minimum, 323.011 mm for maximum during dry season and -131.1 mm for mean, -287.4 mm for minimum during dry season. For run off, the obtained result was 138.4 mm for mean, 34.4 mm for minimum, 284.4 mm for maximum during wet season and 5.3 mm for mean, 1.63 mm for minimum, 18.25 mm for maximum during dry season. The result was essential for different water usages in the river basin.

Table 8. *Generalized Table for seasonal water balance from November 2016 to February 2022.*

Year	2016-2017		2017-2018		2018-2019		2019-2020		2020-2021		2021-2022	
Season	W. S	D. S	W.S	D.S	W.S	D.S	W.S	D. S	W.S	D.S	W.S	D.S
Seasonal water change in BCM	1.33	-6.9	7.68	-9.53	5.41	-7.34	6.8	-7.65	16.230	-10.97	9.68	3.56

Generally, the seasonal water balance for six years from November 2016 to February 2022 is estimated in the Abbay river basin. There was an increasing population in the river basin which needed high demand for different usages of water. Communities in the river basin depend on agricultural farmland. The seasonal water balance of the river basin was estimated based on water balance evaluation components. The result shows that 1.33 BCM, 7.68 BCM, 5.41 BCM, 6.8 BCM, 16.23 BCM and 9.68 BCM for the year 2016-2017, 2017-2018, 2018-2019, 2019-2020, 2020-2021, 2021-2022 for wet season.

For the dry season, the estimated value shows that -6.9 BCM, -9.53 BCM, -7.34 BCM, -7.65 BCM, -10.97 BCM and 3.56 BCM for the dry season for the year 2016-2017, 2017-2018, 2018-2019, 2019-2020, 2020-2021, 2021-2022 respectively. The QGIS tool was important for estimation of water balance in the river basin or study area the seasonally or annually. The result shows the surplus of water during the wet season and water deficiency in the dry season. To increase sustainable development in the river basin, understanding the availability of water is a key parameter for water resource optimization and monitoring. The result of this study was applicable for irrigation agriculture, for water supply, for flood mitigation during the wet season, for drought monitoring in conditions, for hydroelectric power generation in the river basin, for ecological conditions, for monitoring the demands of water in downstream and upstream users. The result was also important to hydrological and climatic change in the river basin and it is used as data sources for scholars and also important for decision making for water resource optimization and management in the river basin.

Study area delineation

The study area was delineated using ArcGIS, which has 435 Sub- watersheds and the area for each sub-watershed was calculated by which run-offs to their river. The total area calculated for the basin was 176200 meters square.

4. Conclusion

Estimation of seasonal water balance was the key point for understanding the availability of water seasonally, annually for optimization of water resources and management. It is one of the most important tools to estimate the surplus of water during the wet season and water deficit during the dry season. Seasonal water balance was estimated for the Abay River Basin for six years from November 2016 to February 2022 and water balance estimation components were evaluated.

A key parameter for water balance estimation was used to analysis the data for this study. Such key parameters were precipitation, evapotranspiration, terrestrial water storage and runoff. The result for this study was 1.33 BCM, 7.68 BCM, 5.41 BCM, 6.8 BCM, 16.23 BCM and 9.68 BCM for the year 2016-2017, 2017-2018, 2018-2019, 2019-2020, 2020-2021, 2021-2022 for wet season and -6.9 BCM, -9.53 BCM, -7.34 BCM, -7.65 BCM, -10.97 BCM and 3.56 BCM for dry season for year 2016-2017, 2017-2018, 2018-2019, 2019-2020, 2020-2021, 2021-2022 respectively. The result indicates that there was a surplus of water for the wet season and water deficit for the dry season. The result of this study was applicable to water usage in the river basin, such as drought monitoring, flood protection, irrigation agriculture, water supply, hydropower production, to understand hydrology and climatic variation, environmental conditions, downstream interests and other related uses. It is also important for decision makers and scholars as the source of data for water resource monitoring and optimization. The calculated study area was 176200 km^2.

Conflict of Interest

I declare that there is no conflict of interest in the publication of this paper.

Availability of Data and Materials

The data collected and or analyzed during the current study was available from the data collection and, for more analyzed data, including necessary information, was available from the corresponding author on request. The corresponding author had full access to all the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.

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