Analysis of spatiotemporal variability of water productivity in Ethiopian sugar estates: using open access remote sensing source

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**ABSTRACT**
This study focusses on mapping the seasonal and spatial variability of agricultural water productivity of sugarcane crop in three large irrigation schemes of Ethiopia (Wonji, Fincha’a and Metahara) using remote sensing derived datasets. The datasets used in this study were acquired from WaPOR, an open access portal, and included a 100m spatial resolution 10days interval (decadal data) of Net Primary Production (NPP) and Actual Evapotranspiration and Interception (AETI). Accordingly, the average seasonal AETI was compiled for the schemes during time period of January 1/2009 to June 30/2019 and corresponding average fresh weight yields per hectare for the schemes were gathered. Using AETI (as denominator) and yield (as numerator) the water productivity could be calculated into kg/m\(^2\). The calculated crop water productivity was 7.5kg/m\(^2\) at Wonji, 7kg/m\(^2\) at Fincha’a and 4.3kg/m\(^2\) at Metahara. When spatially and temporally comparing sub-irrigation schemes with each other and the derived multi-seasonal average varying water productivity performance is visualized. Within Wonji irrigation scheme, high WP values range 7.6 – 9 kg/m\(^2\) are found in Dodota, Sodare and Wake-Tyo during the time period of January 1/2018 to June 30/2019 and lower value of 5.7 – 7 kg/m\(^2\) was in Wonji main sub-irrigation scheme during time period of July 1/2013 to December 31/2014. For Fincha’a irrigation scheme, several plots located in the Northern part of East and West bank and the southern part of Neshie sub-schemes show a high water productivity range, from 7.3 to 11.2 kg/m\(^2\). Within Metahara irrigation scheme, plots located at southern part show high water productivity range 6.7 to 10.6 kg/m\(^3\).

1. Introduction

Water is a very vital natural resources to sustain life. But currently there are allot of challenge over water resource. Unlimited population growth, rapid growth of industrialization, urbanization, expansion of agricultural land, loss of agricultural water, and climate change are the major challenges fall on water resource. (Mali 2016). As (Osegrant, Mark, Cai, & A.Cline, 2002) put it, the worldwide scarcity of water is increasing. The agricultural sector is by far the largest user of water in the world. On a consumptive use basis, 80–90% of all the water is consumed in agriculture. Unfortunately, water use efficiency in this sector is very poor not exceeding 45% with more than 50% water losses; thereby, enormous water saving could be achieved in the agricultural sector comparable with other sectoral water uses (Hamdy, Ragab, and Scarascia-Mugnozza 2003). The population of Ethiopia is estimated to 109 million with annual growth rate of 2.4% in 2019 and it is projected to be 190 million in 2050 (UN 2019). This unlimited growth of population and improvement of the living standard of people will put a significant degree of stress on available water resources (Rijssberman 2006).

As (Khokhar, 2017) writes, by 2050, feeding a planet of 9 billion people will require an estimated 50 percent increase in agricultural production and a 15 percent increase in water withdrawals. To sustain the growing population of world, increasing the agricultural water productivity is important (Howell 2001). Water productivity is defined as the amount of agricultural output per unit of water depleted, and can be assessed for crops, trees, livestock and fish (Descheemaeker, et al., 2013). Scheierling et al. (2014) also defined water productivity as the ratio of the output(s) to the input(s) that a firm uses. FAO measure agricultural water productivity as, the economic or biophysical gain from the use of a unit of water consumed in crop production (FAO, 2017).
Many researchers have tried to estimate water productivity from satellite data. For example, (Zwart, Bastiaanssen, Fraiture, & Molden, 2010), use the WATPRO water productivity model for wheat, using remote sensing data products as input and came with result of water productivity for wheat varies from 0.2 to 1.8 kg/m² of harvestable wheat per cubic meter of water consumed. (Li, et al., 2008), also used satellite data to estimate water productivity of North China Plains and came with maximum and minimum water productivity of 1.67 kgm⁻³ and 0.5 kgm⁻³ respectively. The applications of the remote sensing techniques in sugarcane agriculture have been undertaken with particular emphasis on sugarcane classification and areal extent mapping, thermal age group identification, varietal discrimination, yield prediction and crop health and nutritional status monitoring (E. M. Abdel-Rahman, 2008). The sugarcane yield estimated in western Kenya from Moderate Resolution Imaging Spectrometer (MODIS) by using normalized difference vegetation index (NDVI) show a root mean square error (RMSE) of less than 5 ton/ha with the historical harvested yield (Mulianga, Bégué, Simoes, & Todoroff, 2013).

Sustainable methods to increase crop water productivity are gaining importance in arid and semiarid region (Debaeke 2004). For example in northern Ethiopia in May Zegzug catchment, crop performance was improved when using permanent raised beds with 30% standing crop residue retention and no-tillage on the top of the bed, followed by ploughing once at sowing and furrows made at 1.5 m interval. This comparing with the low performance when a minimum of three tillage operations and removal of crop residues takes place (Araya, et al., 2012).

To meet the future demands, water productivity in this cropping system needs considerable improvement as water is becoming scarcer and competition among agriculture and other sectors is increasing (Ahmad, Masih, and Turral 2004). Appropriate benchmarks for water productivity (WP) are needed to help identify and diagnose inefficiencies in crop production and water management in irrigated systems (Grassini et al. 2010). Water productivity in agriculture needs to be improved significantly in the coming decades to secure food supply to a growing world population. To assess on a global scale where water productivity can be improved and what the causes are for not reaching its potential, the current levels must be understood(Zwart, Bastiaanssen, and Charlotte de Fraiturec 2010). The value of water productivity will be varying both spatially and temporally. The spatial variability is mainly due to difference in water use, sowing dates, fertilizer use, soil quality and socio-economic conditions. Rainfall, amount and timing, emerged as the most important factor inducing temporal changes (Ahmad, Masih, and Turral 2004).

In most cases water productivity is modelled by means of agricultural models such as Aqua Crop or determined by using field data on yield and water application. However actual evapotranspiration may be unknown and measurements may not well represent spatial variation (Bastiaanssen, 2000). This calls for development of new technologies that can guide water productivity improvement to guarantee food security in the future. Among all the development, the FAO has recently developed a portal with datasets is one called WaPOR. WaPOR is the FAO portal to monitor Water Productivity through Open access of Remotely sensed derived data over Africa and the Near East countries (FAO) F. a., 2018).

The application of open access remote sensing method to estimate the spatial and temporal variability of sugarcane water productivity in Ethiopia has not been tried so far. WaPOR data base is a recent and freely available remote sensing source that anyone can access data from. The data provided by WaPOR has good temporal resolution (10 days interval) and spatial resolution of 100 m. Therefore, this specific study was focused on mapping the spatial and seasonal variation of water productivity of sugarcane crop at three large irrigation schemes of Ethiopia by using WaPOR data base.

2. Materials and methods

2.1. Study area

This specific study is mainly focused on three large irrigation schemes in Ethiopia being (Wonji, Fincha’a and Metahara). Wonji sugar estate is found in Oromia region estate near Adama City at 110 Kilo Metres from capital city of the contour Addis Ababa. It is the oldest sugar industry in Ethiopia’s. Wonji sugar estate have a total area of about 16,000 hectares with different expansion sites. Different irrigation type will be practiced at Wonji at different expansion sites. At Olenchiti site, surface irrigation with hydro flume is practiced. At Wonji main site furrow irrigation with surface canal is practiced. At Dodota area centre pivot sprinkler irrigation type is practiced. At Wake-Tiyo and Sodare site sprinkler irrigation type is practiced. Fincha’a Sugar estate is also located in Oromia regional states, Horoguduru Wollega administrative zone at about 350 km distance North-West of Addis Ababa. The average altitude of the area is 1460 m above sea level. Fincha’a irrigation scheme is the largest irrigation scheme in the country with total irrigation area of is about 19,965 hectares. The irrigation type practiced at Fincha’a
irrigation scheme is sprinkler irrigation. Meteharasugar estate is the other sugar estate located in Oromia regional state in EastShewa Zone. The area has an average elevation of 947 metres above sea level. Metahara Irrigation Scheme has a gross irrigated area of 11,500 hectares. The location map of the study area is presented on Figure 1.

### 2.2. Databases for water productivity

The data used for calculating water productivity is from the FAO-based WaPOR database (https://wapor.apps.fao.org). WaPOR stands for Water Productivity through Open access of remotely sensed derived data. This database provides data over water productivity, biomass, evapotranspiration, reference evapotranspiration, precipitation and more. The downloaded data for this analysis from WaPOR version 2.0 (100 m spatial resolution) is the 10 days interval (dekadal data) of Net Primary Production (NPP) and Actual Evapotranspiration and Interception (AETI). The shapefile-sused for this analysis is prepared from 30 m spatial resolution Landsat image (https://earthexplorer.usgs.gov/jby excluding all non-irrigation areas from each farm. All non-irrigation areas inside the schemes, like small towns, roads or reservoirs are removed from the shapefiles to create a good average only for the potential irrigation areas.

### 2.3. Actual evapotranspiration and interception (AETI)

The actual evapotranspiration and interception were acquired from WaPOR portal in dekadal (10 days) interval. To estimate the seasonal value of actual evapotranspiration and interception, the monthly value of actual evapotranspiration was estimated and summed up by the age of sugarcane.

\[
AETI(D) = AETI \times 0.1 \times n \tag{1}
\]

Where: AETI (D) is dekadal evapotranspiration and interception (mm/day), AETI is original evapotranspiration and interception acquired from WaPOR portal (mm/day). 0.1 is correction factor from WaPOR portal to convert raster value to numeric value and n is number of days in each decade. Then, the dekadal actual evapotranspiration and interception will be converted to monthly or seasonal by summing up the all decadal value together.

\[
AETI(M) = \sum_{D=1}^{3} AETI(D) \tag{2}
\]

\[
AETI(S) = \sum_{M=1}^{18} AETI(M) \tag{3}
\]

Where AETI(M) and AETI(S) are monthly and seasonal evapotranspiration and interception (mm/day) respectively. At all three irrigation schemes the average sugarcane age (growing season) is 18 months. And the number of dekadal per each month is 3.

### 2.4. Fresh yield of sugarcane

In order to calculate the fresh sugarcane yield from the area, the dekadal (10 dyas interval) value of net primary production (NPP) was acquired from WaPOR portal and converted to monthly data by multiplying average daily data by number of months. Then the seasonal value was calculated by summing up all monthly data per growing season.

\[
NPP(D) = NPP \times 0.001 \times n \tag{4}
\]

Where, NPP (D) is dekadal net primary production (g/m²), NPP is original net primary production acquired from WaPOR portal (g/m²), 0.001 is correction factor from WaPOR portal to convert raster value to numeric value and n is number of days in each decade.

\[
NPP(M) = \sum_{D=1}^{3} NPP(D) \tag{5}
\]

\[
NPP(S) = \sum_{M=1}^{18} NPP(M) \tag{6}
\]

Where, NPP(M) is monthly net primary production (g/m²), NPP(S) is seasonal net primary production (g/m²) and 18 is growing season (months) of sugarcane. And 3 is number of dekadal per month. Then the seasonal net primary production is converted to accumulated biomass production by the following equation.
\[ ABP(S) = \frac{|NPP(S)|}{0.45} * 1.8 \quad (7) \]

Where \( ABP(S) \) is seasonal biomass production in kg/ha, 0.45 is the correction factor to convert net primary production to total biomass production and 1.8 is the correction factor of converting net primary production from C3 crop to C4 crop (sugarcane is C4 crop).

\[ Fresh \ Sugarcane \ yield = \frac{[(ABP + HI)/(1 - MC)]}{100} \quad (8) \]

Where fresh sugarcane yield is ton/ha, HI is harvesting index and MC is moisture content of sugarcane.

### 2.5. Crop Water Productivity

The Crop Water Productivity (CWP) is calculated by:

\[ CWP = \frac{Y}{AEIT} \times 100 \quad (9) \]

Where \( Y \) Yield is in kg/ha, Actual Evapotranspiration and Interception (AEIT) is in m³ and the Crop Water Productivity is in kg/m³.

### 2.6. Cropping seasons

The harvesting yield of sugarcane crop was taken from all three-irrigation schemes and the average sugarcane growing period or age of sugarcane was estimated. The average harvesting period at all three irrigation schemes (Fincha’a, Wonji and Metahara) was 18 months. To analyse the water productivity at all three irrigation schemes, the 18 months actual evapotranspiration and interception (AEIT) and also netprimary production (NPP) data were calculated from 10 days interval (decadal) WaPOR data base. The first season started from January 1/2009 to June 30/2010 (18 months). Second season start from July 1/2010 to December 31/2011 and so on. In general, the data set from January 1/2009 to June 30/2019 were divided to seven growing seasons and analysed in this study. The cropping season of all three irrigation schemes was presented on Table 1.

### 2.7. Harvest index, moisture content

The average moisture content and harvesting index of sugarcane crop at Fincha’a irrigation scheme was 0.75 and 0.7 respectively (Gemechu et al. 2019). In other way (Yilma 2017), estimate the harvesting index and moisture content of sugarcane crop at Wonji irrigation scheme and came with value 0.65 and 0.59 respectively. For Metahara irrigation scheme, the harvesting index and moisture content estimated at Wonji farm is used (Metahara irrigation scheme is located to very near distance of Wonji irrigation scheme with in the same topographic location and the sugarcane variety grown at both areas were almost the same).

### 3. Results and discussion

#### 3.1. Actual evapotranspiration and interception (AEIT)

The value of actual evapotranspiration and interception calculated per seasonal time scale at all three-irrigation scheme is presented on Figure 2. From the comparison chart of actual evapotranspiration and interception (mm/season), we observed that the value of seasonal actual evapotranspiration and interception of sugarcane crop was 1693 mm/season at Wonji, 2316 mm/season at Metahara and 1977 mm/season at Fincha’a during the time period of January-1/2009 to June-30/2010. During the time period of July-1/2010 to December-31/2011, the seasonal actual evapotranspiration and interception of sugarcane crop was 1841 mm/season at Wonji, 2497 mm/season at Metahara and 2134 mm/season at Fincha’a irrigation schemes respectively. In the same way during the time period of January-1/2012 to June-30/2013, the value of actual evapotranspiration and interception was 1959 mm/season at Wonji, 2374 mm/season at Metahara and 2068 mm/season at Fincha’a respectively. And during the time period of July-1/2013 to December-31/2014 the seasonal value of actual evapotranspiration and interception was 1945 mm/season at Wonji, 2444 mm/season at Metahara and 2200 mm/season at Fincha’a respectively.

The value of actual evapotranspiration and interception during time period of January-1/2015 to June-30/2016 was 2057 mm/season at Wonji, 2389 mm/season at Metahara and 2304 mm/season at Fincha’a respectively. During July-1/2016 to December-31/2017 the value of actual evapotranspiration and interception was 2151 mm/season at Wonji, 2781 mm/season at Metahara and 2201 mm/season at Fincha’a respectively. Finally, for time period of January-1/2018 to June-30/2019 the value of actual evapotranspiration and interception was 2103 mm/season at Wonji, 2340 mm/season at Metahara and 2228 mm/season at Fincha’a respectively.

| Growing Seasons | Time Range       |
|-----------------|------------------|
| Season1         | Jan-1/2009 to Jun-30/2010 |
| Season2         | Jul-1/2010 to Dec-31/2011 |
| Season3         | Jan-1/2012 to Jun-30/2013 |
| Season4         | Jul-1/2013 to Dec-31/2014 |
| Season5         | Jan-1/2015 to Jun-30/2016 |
| Season6         | Jul-1/2016 to Dec-31/2017 |
| Season7         | Jan-1/2018 to Jun-30/2019 |
season at Wonji, 2666 mm/season at Metahara and 2146 mm/season at Fincha’a irrigation schemes respectively. The average value of actual evapotranspiration and interception from 2009 to 2019 was 1964 mm/season at Wonji, 2495 mm/season at Metahara and 2147 mm/season at Fincha’a irrigation schemes respectively. From the value of standard deviations, we observed there were high variation of average AETI among seasons at Metahara (157 mm/season) and low variation at Fincha’a (97 mm/season).

(Zhang, Andersona, and Wang 2015), use remote sensing model (METRIC) to estimate the water consumption (ETc) of Hawaiian sugarcane in USA and observed ETc of 2.5–4.5 mm/day (1350 to 2430 mm/season) at wind ward area and 2–4.5 mm/day (1080 to 2430 mm/season) at lee ward area. The average seasonal AETI of sugarcane (water consumption of sugarcane) we observed at three schemes; 1964 mm/season at Wonji, 2147 mm/season at Fincha’a and 2495 mm/season at Metahara were closer to the maximum seasonal ETc of sugarcane estimated by METRIC model at Hawaiian. (Luckson 2010), also use SEBAL model to estimate evapotranspiration (ET) of sugarcane at Zimbabwe and observed the ET value of 4–5 mm/day (2160 to 2700 mm/season) which is closer to the value we observed from WaPOR portal. (Ferreira et al. 2016), use Energy Balance System (SEBS) model to estimate sugarcane water requirement at Minas Gerais State, Brazil and observed ETc value of 2.89 mm/day to 4.0 mm/day (1560–2160 mm/season) which also very close to the value we observed from WaPOR portal.

3.2. Sugarcane fresh yield

The total biomass production calculated from net primary production (NPP) was converted to sugarcane fresh yield by using harvested index (HI) and moisture content (MC) of sugarcane. The result of sugarcane fresh yield at three irrigation schemes was presented on Figure 3. The value of sugarcane fresh yield at Wonji irrigation scheme was 121.1 ton/ha during time period of January-1/2009 to June-30/2010, 139.6 ton/ha during July-1/2010 to June-30/2011, 138.6 ton/ha during January-1/2012 to June-30/2013, 163.0 ton/ha during July-1/2013 to December-31/2014, 151.3 ton/ha during January-1/2015 to June-30/2016, 157.7 ton/ha during July-1/2016 to December-31/2017, 156.0 ton/ha during January-1/2018 to June-30/2019 with average value of 146.7 ton/ha. At Metahara irrigation scheme, the value of sugarcane fresh yield was 115.5 ton/ha during January-1/2009 to June-30/2010, 130.7 ton/ha during July-1/2010 to June-30/2011, 114.5 ton/ha during January-1/2012 to June-30/2013, 128.1 ton/ha during July-1/2013 to December-31/2014, 92.3 ton/ha during January-1/2015 to June-30/2016, 108.0 ton/ha during July-1/2016 to December-31/2017, 60.0 ton/ha during January-1/2018 to June-30/2019 with average value of 107.0 ton/ha. At Fincha’a irrigation scheme the value of sugarcane fresh yield was 127.0 ton/ha during January-1/2009 to June-30/2010, 161.3 ton/ha during time period of July-1/2010 to December-31/2010, 130.9 ton/ha during time period of January-1/2012 to June-30/2013,
172.3 ton/ha during July-1/2013 to December-31/2014, 152.7 ton/ha during January-1/2015 to June-30/2016, 171.1 ton/ha during July-1/2016 to December-31/2017, 144.2 ton/ha during January-1/2018 to June-30/2019 with average value of 151.4 ton/ha. From the result of seasonal variation, we observed the seasonal variation of yield is high at Metahara (22.5 ton/ha) and low at Wonji (13.4 ton/ha).

(Mulianga et al. 2013), use remote sensing data (Normalized Difference Vegetation Index) from MODIS satellites to estimate sugarcane yield at Kenya and come with annual sugarcane yield of 80 ton/ha at humid area. But, the seasonal yield of sugarcane we estimated at three irrigation schemes; 146 ton/ha at Wonji, 107 ton/ha at Metahara and 151 ton/ha at Fincha’a is relatively higher than the value observed at Kenya. Since the growing season of sugarcane at selected three scheme is more than a year (18 months) the higher value observed is expected. (Morel et al. 2014), estimated the value of the sugarcane yield of Reunion Island based on remote sensing data and came with result of 80 ton/ha to 160 ton/ha which is closer to the value we estimated at three irrigation schemes.

3.3. Crop water productivity (CWP)

The crop water productivity of sugarcane crop in kilogram per cubic metre per growing season for all three-irrigation schemes was estimated and presented in chart Figure 4. The value of sugarcane water productivity was 7.2 kg/m³ at Wonji, 5.0 kg/m³ at Metahara and 6.4 kg/m³ at Fincha’a during the time period of January-1/2009 to June-30/2010. During July-1/2010 to December-31/2011, the sugarcane water productivity of 7.6 kg/m³ at Wonji, 5.2 kg/m³ at Metahara and 7.6 kg/m³ at Fincha’a was observed. In the same way during time period of January-1/2012 to June-30/2013 the sugarcane crop water productivity of 7.1 kg/m³ at Wonji, 4.8 kg/m³ at Metahara and 6.3 kg/m³ at Fincha’a was observed. The sugarcane water productivity of 8.4 kg/m³ at Wonji, 5.2 kg/m³ at Metahara and 7.8 kg/m³ at Fincha’a was observed during the time period of July-1/2013 to December-31/2014. During January-1/2015 to June-30/2016 the sugarcane water productivity of 7.4 kg/m³ at Wonji, 3.9 kg/m³ at Metahara and 6.6 kg/m³ at Fincha’a was observed. Similarly, during July-1/2016 to December-31/2017 the sugarcane water productivity of 7.3 kg/m³ at Wonji, 3.9 kg/m³ at Metahara and 7.8 kg/m³ at Fincha’a was observed. During time range of January-1/2018 to June-30/2019 the sugarcane water productivity of 7.4 kg/m³ at Wonji, 2.3 kg/m³ at Metahara and 6.7 kg/m³ at Fincha’a was observed. In general, the average water productivity of 7.5 kg/m³ at Wonji, 4.3 kg/m³ at Metahara and 7.0 kg/m³ at Fincha’a was observed during the study years of 2009 to 2019. High season water productivity variation of 1 kg/m³ at Metahara and low seasonal water productivity variation of 0.4 kg/m³ at Wonji were observed.

(Yilma, 2017), estimated the sugarcane water productivity at Wonji Ethiopia by applying an automated version of SEBAL (pSEBAL) model and the result range between 2.57 to 11.95 kg/m³ with a mean value of 5.12 kg/m³. Therefore, the average sugarcane water productivity we observed at Wonji from WaPOR portal (7.5 kg/m³) was closer to the value observed by SEBAL model. (Sharma et al. 2018), estimate crop water productivity of sugarcane crop in India and observed the
average value of 5.2 kg/m³ which is also closer to the average value we observed from WaPOR portal.

3.4. Spatial variation of water productivity

3.4.1. Wonji scheme

The spatial and temporal (seasonal) variability of water productivity is analysed for Wonji irrigation scheme from January 1/2009 to June 30 2019 and presented on map of Figure 5. The value of water productivity of Wonji irrigation scheme through different sites was show some variation during time period of January-1/2009 to June-30/2010. High water productivity was seen at Wake-Tiyo site and some part of Wonji main during this time. At Olenchiti site moderate (medium) water productivity was observed. Low water productivity was observed at Dodota and Sodare site during this season (January-1/2009 to June-30/2010). The same value of water productivity was observed during time period of July-1/2010 to December-31/2011, but there was some reduction of water productivity at Olenchiti site were observed. During time period of January-1/2012 to June-30/2013, the incremental value of water productivity at Dodota site and also the declination of water productivity at Wonji main and Olenchiti site were observed. During time period of July-1/2013 to December-31/2014, still low water productivity was observed at most plot of Wonji main and incremental of water productivity was observed at Sodare and eastern part Dodota sites. During January-1/2015 to June-30/2016, again low water productivity was observed at most plots of Wonji main site, relatively high-water productivity was observed at eastern part of Dodota site, northern part of Wake-Tiyo and northern part of Olenchiti sites. The same value was observed in next season (July-1/2016 to December-31/2017). But during time period of January-1/2018 to June-30/2019, high water productivity was observed at most part of Dodota, at most plot of Sodare, at most plot of Wake-Tiyo and also at northern part of Olenchiti sites. There was also an incremental of water productivity at Wonji main during this time period.

3.4.2. Fincha’a Scheme

The value of spatial and seasonal variability of water productivity at Fincha’a irrigation scheme during the time period of January-1/2009 to June-30/2019 was also analysed and presented below in map of Figure 6. The value of water productivity shows spatial variation at Fincha’a irrigation scheme during time period of January-1/2009 to June-30/2010. Accordingly, low water productivity was observed at northern part of Neshie site and eastern part of East bank site. Relatively high-water productivity was observed at Fincha’a irrigation scheme during time January-1/2009 to December-31/2010 at northern part of West Bank site, northern part of East Bank site and southern part of Neshie site. The same value of water productivity was observed during time period of July-1/2010 to December-31/2011. During the time period of July-1/2013 to December-31/2014, still low water productivity was observed at Northern part of Neshie site and southern part of East Bank site of the scheme. But, during this time period some plots located at northern part of East Bank site,
northern part of West Bank site and southern part of Neshie site show high water productivity. In general, the patios-temporal variation of water productivity map show, high water productivity value at northern part of East Bank site (east side of river), northern part of West bank (west side of Fincha’a river) and southern part of

Figure 5. Spatio-temporal variation of water productivity at Wonji irrigation scheme from January 1/2009 to June 30/2019.
3.4.3. Metahara Scheme

The spatial and seasonal variation of water productivity at Metahara irrigation scheme during time period of 2009–2019 was analysed and presented in maps of Figure 7. The spatial variability map of water productivity at Metahara irrigation scheme show low water productivity value at norther east part, some plot around Basaka lake, and also some plots located at southern part of the scheme during time period of January-1/2009 to June-30/2010, July-1/2010 to December-31/2011 and January-1/2012 to June-30/2013. During time period of July-1/2013 to December-31/2014, January-1/2015 to June-30/2016, July-1/2016 to December-31/2017, January-1/2018 to June-30/2019, the similar pattern of water productivity; low water productivity at some plots around southern part of the state were observed.

4. Conclusion

The seasonal and spatial crop water productivity of sugarcane crop was analysed from 2009 to 2019 in three irrigation schemes of Ethiopia (Wonji, Fincha’a, and Metahara). Accordingly, the average seasonal actual evapotranspiration and interception were 1964 mm/season at Wonji, 2495 mm/season at Metahara and 2147 mm/season at Fincha’a irrigation schemes were observed. The average seasonal fresh sugarcane yield observed were 147 ton/ha at Wonji, 107 ton/ha at Metahara and 151 ton/ha at Fincha’a irrigation schemes. Providing for an average seasonal water productivity of 7.5 kg/m³ at Wonji, 4.3 kg/m³ at Metahara and 7.0 kg/m³ at Fincha’a irrigation schemes.

Based on observed result, the high value of actual evapotranspiration and interception was observed at Metahara irrigation scheme with average seasonal value of 2495.4 mm/season. The second-high value was observed at Fincha’a irrigation scheme and relatively small value of seasonal actual evapotranspiration and interception was observed at Wonji scheme. The high average seasonal fresh sugarcane yield was observed at Fincha’a irrigation scheme with average seasonal value of 151.4 ton/ha. And the smallest sugarcane fresh yield was observed at Metahara scheme with average value of 107 ton/ha. When comparing the value of crop water productivity, high crop water productivity was found at Wonji scheme with average value of 7.5 kg/m³ and a lower value of 4.3 kg/m³ was observed at Metahara scheme.

Within Wonji irrigation scheme spatiotemporal differences could be distinguished. The value of water productivity increased starting from July-1/2013 to December-31/2014 in Dodota sub- irrigation scheme, but declined in

Figure 6. Spatio-temporal variation of water productivity at Fincha’a irrigation scheme from January-1/2009 to June-30/2019.

Neshie (site located at northern part). Low water productivity was observed at northern part of Neshie site and southern part East Bank site.
Wonji main site starting from January-1/2012 to June-30/2013. High water productivity was also observed at plots located in Wake-Tiyo site, Sodare site, Dodota site and some plots of Wonji main during time period of January-1/2018 to June-30/2019. Spatial differences of water productivity were also observed at Fincha’a scheme. High
water productivity values were observed in the northern part of West Bank site (site located at west side of Fincha’a River), the northern part of East Bank site (site located at east side of Fincha’a River) and the southern part of Neshie site (site located at northern west part of the state and irrigated from Neshie River). Low water productivity was observed at most plots located in the southern part of East Bank site, and some plots located in the southern part of West Bank site and a plot located in the northern part of Neshie site. Within Metahara scheme, high water productivity was observed at some plots located in the southern and east part of the scheme. And low water productivity was observed in plots located at northern and north eastern part of scheme including plots located near to Lake Basaka.

**Disclosure statement**

No potential conflict of interest was reported by the authors.

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