ANALYSIS OF SPATIO TEMPORAL VARIABILITY OF WATER PRODUCTIVITY USING; OPEN-SOURCE REMOTE SENSING DATA AND GIS; A CASE STUDY OF UPPER AWASH AGRO INDUSTRY

Yonatan Efrem Mersie

A Thesis Submitted to the department of Geomatics Engineering, School of Civil Engineering and Architecture

Presented in Partial Fulfilment of the Requirement for the Degree of Master's in Geoinformatics

Office of Graduate Studies

Adama Science and Technology University

August, 2022

Adama, Ethiopia

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ADVISOR: TILAHUN ERDUNO (PHD)

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APPROVAL SHEET

I am the thesis advisor for "Analysis of spatio-temporal variability of water productivity using remote sensing and gis: a case study of upper Awash agro-industry." developed by Yonatan Efrem Mersie. I hereby certify that the recommendations and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

Tilahun Erduno (PhD)	__________________	__________________
Advisor	Signature	Date

We, the undersigned, members of the Board of Examiners of the thesis by Yonatan Efrem Mersie have read and evaluated the thesis entitled "Analysis of spatio temporal variability of water productivity using; remote sensing and gis; a case study of upper awash agro industry". and examined the candidate during open defense. This is, therefore, to certify that the thesis is accepted for partial fulfilment of the requirement of the degree of Master of Science in Geo- Informatics Engineering.

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Internal Examiner	Signature	Date
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Finally, approval and acceptance of the thesis is contingent upon submission of its final copy to the Office of Postgraduate Studies (OPGS) through the Department Graduate Council (DGC) and School Graduate Committee (SGC).

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Head of Department	Signature	Date
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DECLARATION

I declare that this thesis proposal entitled “Analysis of spatio temporal variability of water productivity using; remote sensing and gis; a case study of upper awash agro industry” is my own work and has not been submitted to any university for similar purpose. The references used in this proposal are duly recognized by proper citations.

Yonatan efrem	____________________	________________
Name of student	Signature	Date

RECOMMENDATION

We, the advisor(s) of this thesis, hereby certify that we have read the revised version of the thesis entitled “Analysis of spatio temporal variability of water productivity using; remote sensing and gis; a case study of upper awash agro industry”. prepared under my guidance by Yonatan Efrem Mersie. submitted in partial fulfilment of the requirements for the degree of Mater’s of Science in Geo-informatics. Therefore, we recommend the submission of revised version of the thesis to the department following the applicable procedures.

Tilahun Erduno (Phd),	________________	________________
Major Advisor/Supervisor	Signature	Date
________________	________________	________________
Co-advisor	Signature	Date

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ABBREVIATIONS

E	Evaporation
EB	Energy balance
e.g.	For example
ET	Evapotranspiration
ETa	Actual evapotranspiration
ETa-METRIC	Actual evapotranspiration estimated with METRIC
ETc	Crop evapotranspiration
ETr	Reference evapotranspiration
ETr-P-M	Reference evapotranspiration from Penman-Monteith equation
ETrF	Reference evapotranspiration fraction
ET24	Evapotranspiration for 24-hour period
FC	Field capacity
G	Soil heat flux
Kc	Crop coefficient
LAI	Leaf area index
METRIC	Mapping Evapotranspiration at high Resolution using Internal Calibration
NDVI	Normalized Difference Vegetation Index
NIR	Near-infrared band
PWP	Permanent wilting point
Rs	Solar
SAVI	Soil adjusted vegetation index
SEBAL	Surface Energy Balance Algorithm for Land
SEBS	Surface Energy Balance Systems
SSEB	Simplified Surface Energy balance
Std. Dev.	Standard deviation
T	Transpiration
Ta	Air temperature
TIRS	Thermal Infrared Sensor
Ts	Surface temperature
UAAIE	Upper awash agro- industry

Abstract

This study focuses on assessing and mapping the seasonal and spatial variability of water productivity of citrus crops at different farms of the upper awash (UAAIE irrigation) scheme using remote sensing-derived datasets, GIS-based spatial analysis, and programming. The physical crop water productivity (kg/m3) is the ratio of crop yield (ton/ha) to the amount of water used (m3/ha). Using AETI (as denominator) and yield (as numerator), the water productivity is calculated in kg/m3. In 2009, the calculated crop water productivity was 3.1 kg/m3, 2.9 kg/m3, 3.2 kg/m3, and 2.7 kg/m3 for the crop seasons of 2013, 2020, and 2021, respectively. When spatially and temporally comparing the two sub-schemes (Merti-Jeju and Nurahera) with each other and at the enterprise level, the seasonal varying crop water consumption, land yield, and water productivity performance are visualized. Initially (2009–2017), the Nurahera units and the 10th and 9th areas in the UAAIE irrigation system showed high WP values ranging from 3.1 to 3.75 kg/m3, but the majority of this productivity shifted south to the Abadiska farm, the scheme's only pump-supplied area. High WP values between 3.6 and 2.9 kg/m3 were observed for the crop season 2020–21. Nurahera Farm, south of 6th Camp, showed lower values (0-2.6 kg/m3) between July 8, 2020, and June 8, 2021, which could be attributed to extensive new planting and land preparation operations that left the plots fallow. While this study is done for citrus in one irrigation scheme, The techniques used can be applied to examine other crops grown in various fields and irrigation systems throughout Africa and the Middle East regions covered by FaO WaPOR. Better crop management, frequent canal (conveyance) maintenance, reduction in seepage losses, and canal water reallocation with small-scale farmers, updating and implementing the existing schedule with existing conditions, and shifting the irrigation system to advanced systems such as pivot and drip are recommended to improve the schemes' WP.

Keywords Open source; GIS; remote sensing; land yield; seasonal variation; spatial variation; water productivity.

CHAPTER I. INTRODUCTION

1.1. Background

Water is one of the most critical resources for human life and survival. However, the stress on water use is only increasing with the global population expected to reach around 10 billion by 2050. Securing food and livelihoods for the world's rapidly growing population will place a high demand on water. Further, the populations in the emerging markets are becoming increasingly consumer-oriented, requiring more food and products, which all require water to produce. On the other hand, climate change impacts are creating uncertainties in water availability due to changes in seasonal climate patterns, reduced glacier sizes, and heavy overexploitation of groundwater. according to Osegrant, Mark, Cai, and A. Ciine (2002) Increasing water scarcity and competition for water and land from agricultural and non-agricultural sectors drive the need to improve crop water productivity to guarantee adequate food for future generations with the same or less water and land than that is currently available for agriculture (FAO, 2018; Grassini et al., 2011; Nazarifar et al., 2012).

The Awash River Basin is the most utilized river basin in Ethiopia with a number of small, medium, and large scale irrigation schemes (e.g., Ada'aBecho, Wonji-Shoa, Fental-Tibila, Metahara, Upper Awash Agro Industry, Kesem, Amibara, Gewane, and Tendaho), totaling 200,000 ha of farmland (AWBA, 2017). Other water users include agricultural industries located along the river and urban and rural water supply schemes. (AWBA, 2017) According to current estimates, the irrigated land in the basin reaches about 200,000 ha (ARBA, 2017). Due to the intensive irrigation development in the basin, particularly along the Awash River, there is high water stress during the peak of the irrigation season (April to June). On the other hand, flooding is frequently observed in the basin during the rainy season (July to September). (AWBA, 2017).

The concept of water productivity (WP) is offered by Molden et al. (2010) as a robust measure of the ability of agricultural systems to convert water into food. While it has been used principally to evaluate the function of irrigation systems as the amount of "crop per drop," Assessing the current situation and introducing improved techniques to manage water Resources used efficiently are vital for improving irrigation efficiencies, sustainability, and productivity of irrigated agriculture (McCornick et al., 2003). Crop water productivity is a vital parameter to assess the performance of irrigated and rain-fed agriculture (Molden et al., 2010), and it can be represented in physical or economic units.(Ali & Talukder, 2008) The physical crop water productivity (kg/m3) is the ratio of crop yield (ton/ha) to the amount of water used (m3/ha). The economic water productivity ($/m3) represents the financial benefits per unit of water used. FAO recently developed a publicly accessible database of biomass, actual evapotranspiration, water productivity, and other datasets mainly derived from remote sensing covering Africa and the Middle East at spatial resolutions of 250 m (level I), 100 m (level II), and 30 m (level III) starting from the year 2009. The aim is to help monitor water productivity, identify water productivity gaps, propose solutions to reduce these gaps, and contribute to the sustainable improvement of agricultural production (FAO, 2017).

1.2. Statement of the problem

Water productivity studies at different scales are the direction of investigation for many researchers in the world, but existing studies are predominantly dependent on non-remote sensing approaches based on capturing point data and/or official statistics. In most cases, water productivity is determined using field data on yield and water application. However, actual evapotranspiration (consumptive use) may be unknown, and measurements may not well represent spatial variation.

The common traditional methods used for quantifying agricultural consumptive use (cu), namely, the water delivery-based method, the reference/potential Penman-Monteith method, and estimation from point-based soil moisture sensors, A water delivery-based method is based upon the water delivery data collected by gauges installed at the head gates (offtakes) of agricultural farm blocks. (Zwart & Bastiaanssen, 2004).

The spatially dispersed farm blocks of UAAIE, which span a distance of 25 kilometers, as well as a lack of staff, availability, and access to energy, make it difficult to use electronic and manual measuring structures.

Several biophysical and water use inefficiencies resulting from irrigation, disease, harvesting inefficiencies, poor farming practices, and un-uniform fertilizer applications, among other things, affect the company's yield productivity and water productivity. For example, within spatially distributed farm blocks in the UAAIE, the reported harvested productivity difference in 2012 ranged from 8.1 qt/ha to 943.7 qt/ha for oranges and citrus, 350 qt/ha to 700 qt/ha for tomato varieties (Albatross and Gelila), and 100 qt/ha to 250 qt/ha for green beans. The above productivity figures are harvested yields, which do not include goods stolen or abandoned on the farm due to disease, harvesting inefficiencies, or other related agronomic practice issues. In addition to water productivity variances, the company's huge swaths of land ownership (5000 ha with a 27-km reach), a lack of measuring tools, resources needed for intensive data collection, continuity, limited knowledge of the past, and its scattered farm blocks all contribute to a general information gap and the difficulty of precisely identifying areas with inefficiencies and productivity difficulties.

Given the foregoing context, the primary purpose of this research is to create a picture of past and current consumptive water usage patterns and estimate water productivity utilizing Wapor database level-3 (30 m resolution) data components combined with field data. The study focuses on the Upper Awash Agro Industry's plantation in Ethiopia's Upper Awash subbasin, the country's most intensively exploited and water-scarce basin.

1.3. Objectives

The main objective of this study is to investigate the spatial and seasonal water productivity variation of citrus crops along the Upper Awash Valley in the Upper Awash agro-industry using remote sensing and programming techniques. In the process, conduct a diagnostic study to obtain a picture of current water consumption patterns and possibilities of water use efficiency improvements. Specific objectives of the study include

1. to estimate actual crop evapotranspiration (ETc) using a satellite remote sensing-based vegetation index (Water use maps actual evapotranspiration, mm).
2. estimate the harvestable yield compared with field (insitu)data
3. execute irrigation performance analysis using efficiency, adequacy, uniformity and equity(performance indicators).

1.4. Research question

The main research question of this study is:
What is the extent of productivity variation among spatially varied farm blocks in the upper Awash scheme and upper Awash agro-industry enterprises?

1.5. Limitations of the study

It is necessary to mention some RS and WaPOR data limitations that are well recognized. They might result from: WaPOR's Land Surface Temperature (LST), which is derived from MODIS and has a resolution of 1 km, is used to determine moisture stress and subsequently calculate actual evapotranspiration and net primary production; this could account for the decreased fluctuation in WaPOR biomass data and may affect the spatial variation of evapotranspiration as well.

Within a pixel, there is land cover noise from non-citrus land uses such as agricultural roads, irrigation systems, and drainage systems.

It is difficult to reconcile the predicted values because there are only limited seasonal data (3 years) available on land production and none on water productivity and water use (evapotranspiration).

The number of cloud-free RS photos that served as the foundation for the analysis and numerical interpolation (the higher the number of cloud-affected images, the worse the quality of the data, and the higher the level of uncertainty in the indicators).

Crop-specific parameters such as the harvest index, the moisture content of the fresh yield, and the ratio between the above-ground and total biomass ratio values are determined using literature. However, it is known that these crop parameters can vary significantly based on climatic or field management conditions. Other variations may result from varied susceptibility to pests and diseases, as well as waterlogging and soil salinity-related soil and root conditions that are not taken into account.

All of these elements have the potential to cause small numerical discrepancies in WaPOR output, which could result in over and under estimations of crop yield and WP.

Taking this into consideration, the research sought to support the WaPOR biomass statistics using observed harvested data from the entire citrus farms over the course of three seasons. WaPOR yield data at field level comparison differed within a ± 6% range. The comparison between the enterprise-measured yield and WaPOR estimated biomass showed acceptable statistics.

The research further defined citrus farm blocks by omitting other crop blocks, roads, and villages in order to minimize the effects of land cover noises from non-citrus elements.

CHAPTER II. LITERATURE REVIEW

2.1. Agricultural water productivity (WP)

The concept of water productivity (WP) is offered by Kijne et al. (2003) as a robust measure of the ability of agricultural systems to convert water into food.

Varied disciplines have different definitions of 'efficiency' and 'productivity,' and they also tend to focus on different water measurements. Irrigation efficiency, for example, is a concept that originated in irrigation engineering and refers to the ratio of water consumed to water applied or extracted from a source.

Plant physiologists and agronomists often use the term "water-use efficiency" and apply different definitions, such as the ratio of plant biomass or yield to transpiration or the ratio of yield to water consumed. A further confounding factor is the range of scales (both spatial and temporal) at which the terms can be defined and applied, e.g., from field-scale, seasonal measures of grain biomass per unit of water transpired to basin-scale, annual estimates of the economic value obtained per unit of water applied in agriculture or other sectors (Kijne et al. 2003a; Bouman 2007; Molden et al. 2007b).

Non-economic benefits from water by agriculture can be significant factors to include in assessment of total WP. They can, however, be difficult to evaluate – each type demanding complex methodologies to assess complex benefits. Environmental benefits can include direct product (including protection of fish resources), indirect benefits (e.g. impact on carbon stocks) or environmental flows – namely, flows deemed necessary for proper function of basin processes (Smakthin et al., 2004). The potentials for payment for ecosystem services (PES) appear to be increasing as more effort is put into practical evaluation and implementation (Farber et al., 2002; Kozanayi, 2002).

A key distinction when computing WP is to differentiate between water input to an agricultural system and water depleted by it. WP is estimated from the amount of water directly consumed by the agricultural system (that is, evaporation and transpiration), not simply the amount of water supplied. This distinction is increasingly important as we move upscale from field to farm to basin, because water that is taken into a system, but not consumed, is available downstream and hence is excluded from calculation (see Molden, Table 2. Productivity indicators.

Note: Commonly used denominators for calculating water productivity-based indicators are amount of water diverted/supplied, water applied, gross inflow of water (rainfall plus irrigation), and crop evapotranspiration (Et). Indicators Average product per unit of water Average gross value of product per unit of water Average gross margins per unit of water Average gross net value of product per unit of water Water productivity-based indicators Value of marginal productivity of water. 6 Cook, Gichuki and Turral 1997). In measuring depleted water, we account for flows not used by the crop and returned to the hydrologic system.

Water productivity refers to the ratio of physical production (in terms of biomass or crop yield) or, in some instances, the "economic value" of production (in terms of the gross or net value of the product) relative to water use (in terms of water withdrawn, applied, or consumed). It is, therefore, expressed in kilograms per cubic meter (kg/m3) or US dollars per cubic meter (USD/m3). The selection of the numerator and denominator depends on the scale and focus of the analysis. It measures how the system converts water into goods and services.

The generic equation is:

$$\text{WP (kg/m3 or \$/m3)} = \frac{\text{Output derived from water use (ks/m}^2\text{ or \$ /m2}}{\text{Water input (m}^3\text{/m}^2\text{)}} \qquad (1\text{-}1)$$

Output derived from water use includes physical measures, e.g., crop yield, biomass, fish, and livestock production, which are all expressed in units of kilogram; it can also be expressed in economic values (e.g., dollars) like the market value of grain yield and/or biomass.

Water input can be gross inflow, net inflow, available water, irrigation, and actual evapotranspiration. Field tests, (agro-) hydrological modeling, spreadsheet calculations, and remote sensing are all methods that can be used to determine the numerator and, in particular, the denominator. Field monitoring, household surveys, government statistics, weather stations, remote sensing photography, and literature reviews are among the possible sources of data.

The concept of water productivity in agricultural production systems is based on “more crop per drop," a key term in the evaluation of agricultural water use and, in its broader sense, defined as the value or benefit obtained from the use of water (Molden et al., 2010; Oweis et al., 2010).

Water productivity is estimated for an agricultural system or sub-system, defined within a given area and time period. The simplest purpose of WP is to enable rapid comparisons between water use systems in space and time; a WP of 1.5 kg/m3 might be considered ‘good’ whereas one of 0.5 kg/m3 might be thought ‘bad’.

For this purpose, it is preferable to restrict the concept to component parts of a system, rather than try to estimate overall productivity for the entire system. Systems are defined by plot, field, sub-basin and basin. Estimates of WP for single activities are called partial WPs. WP of larger areas containing complexes of multiple land use requires integration of partial WPs for each activity contained within them.

The simplest option is to consider the water productivity of a principal crop, in kg or t, for an area of known extent for which there exist data on agricultural water use. Primary yield data may be generated from direct measurement or by crop survey.

More commonly, crop production data will come from secondary statistics – as total tonnage for a given administrative area (convertible to t/ha if the area dedicated to each crop is known). In some cases, global or national level statistics can be manipulated to provide useful insight (e.g. Falkenmark and Rockström, 2004). This will enable partial water productivity of principal crops to be estimated for large areas. Raw production in kg may be converted to nutritional value (see Rockström et al., 2003).

WP indicators enable performance assessment and comparison for better water management, which is driven by water scarcity and increasing food demand (Sharma et al., 2015; FAO, 2018). It is a useful tool when comparing the productivity of water in different parts of the basin and also when comparing the productivity of water in agriculture with other competing sectors (Zwart & Bastiaanssen, 2004).

Water productivity is a performance metric that can be used to track changes in an agricultural area (at the plot, farm, or irrigation system level). If initiatives are implemented, water productivity can be used to determine if the intervention had a positive or negative influence on water use, or if it had no effect. Furthermore, spatial data on water productivity might reveal high-performing areas (early adopters) and whether strategies are being adopted by other farmers and large-scale growers.

In the context of this study, it is defined as kilograms of yield (or dry biomass) produced per unit of m3 water lost by evapotranspiration (equation2-1).

$$WP = Y/AET \ (kg/m^3) \qquad (1\text{-}2)$$

where Y is the actual crop yield (kg/ha) and AET is the sum of water lost by soil evaporation and crop transpiration during the crop cycle (m3/ha).

It is possible to believe that agricultural water output is solely based on transpiration (i.e., only transpired water is used in a productive way). Because it's difficult to separate evapotranspiration into crop transpiration and soil evaporation (which doesn't contribute directly to crop production), describing crop WP in terms of evapotranspiration makes more sense. (Zwart & Bastiaanssen, 2004).

WP can be affected by several factors, such as crop cultivar type, water availability, climate, soil characteristics, and management practices (Ali & Talukder, 2008). Indicative WP values of various crops around the world were first compiled by Doorenbos and Kassam (1979) and published on FAO drainage paper 33.

More recently Steduto et al. (2012) have published WP values of various crops on FAO drainage paper 66 based on their review of the result of field experimental measurements reported in international literature. It has been reported that the recent WP values of most crops are higher than those of 1970's, this was attributed to the development of improved crop varieties that are able to produce higher yields, drought and pest/disease resistant crops, improved soil fertility and land water management practices.

Remote sensing provides a third option to estimate production over large areas. Wide area estimation of grain yield from the normalized difference vegetation index (NDVI) has been used successfully for basin or national scale estimation of biomass and crop yield for several years. Its accuracy varies widely, depending on the ability for an episodic estimation of reflectance to estimate biomass and final yield. Under good conditions, remotely sensed imagery correlates about 70% with final grain yield.

Local calibration seems essential since in some area's correlation between NDVI-based estimates and actual yield can be extremely low. Remote sensing has also been used to assess total feed value of pastures. In all cases, the accuracy of remote sensing techniques is highly dependent on the availability of timely imagery. Remote sensing tends to be most successful in arid and semi-arid regions in which cloud-free imagery is available for the whole growing season. (Ahmad et al. (2005).

2.2. Remote sensing and water productivity

Ahmad et al. (2005) propose a combined remote sensing approach to estimate water productivity at a regional scale, using a variety of scales of imagery (Landsat at 28.5 m pixel to Moderate Resolution Imaging Spectroradiometer (MODIS) at 1km (thermal) and 500m (visible, near- and medium- infrared wavebands)). Ground truth, crop histories, classification, biomass development and yield will be required to understand the relationship between net primary productivity and yield and better assess harvest index as a function of crop condition. Representative areas for survey can be selected from a preliminary analysis of satellite images, and local knowledge.

The potential use of satellite data is of great importance for obtaining reliable and accurate real-time information on physical land surface processes, especially over vast agricultural lands (Bastiaanssen et al., 2000).

On the one hand, the derivation of remotely sensed WP requires the conversion of remotely sensed spectral radiances into energy fluxes and the estimation of crop parameters (biomass and yield). And once those two parameters are derived, WP can then be easily estimated by using equation (2-1).

Energy balance algorithms such as SEBAL (Bastiaanssen et al., 2000), SEBS (Su, 2002), METRIC (Allen et al., 2007), and ETLook (Bastiaanssen et al., 2012) can be used to derive AET from satellite images. ETLOOK is an algorithm used by Wapor for the calculation of AET.

The idea of estimating crop production from RS was derived from Monteith (1972), who related that the plant biomass production is directly proportional to the photochemically active radiation (PAR) over the course of the crop's growing cycle. PAR (0.4–0.7 m), which is a part of shortwave solar radiation (0.3–3.0 m), is the primary source responsible for the production of crop biomass. PAR is absorbed by chlorophyll for plant photosynthesis, and it regulates the net primary production (Bastiaanssen & Ali, 2003). The algorithm used for the derivation of biomass production from satellite imagery is given in detail in Veroustraete et al. (2002), and it has been implemented by WAPOR.

By applying the harvest index, i.e., the harvestable portion of above-ground biomass, the yield from biomass production can be estimated.

Increasing crop WP is one important way toward more efficient water use in agricultural production as it helps in achieving real water saving and thereby meeting food demands (Seckler, 1996).

Two critical phases must be completed in order to establish an action plan for enhancing WP. First, a reliable and precise mapping of current WP levels at the farm level is required, which necessitates knowledge of current farm circumstances. Second, figuring out why there are such large variances in WP throughout the region Bastiaanssen et al. (2000), Cai et al. (2009), Ahmad et al. (2009), Blatchford (2016), Van Dam et al. (2006), and several other studies have used satellite data (high and low resolution) for mapping spatial variations of WP.

It was highlighted throughout all of this research that RS has the capacity to offer an overview of geographic variance in WP at both farm and regional scales, enabling water managers in identifying areas where water resources are misused and areas where WP can be raised. The FAO recently created FRAME, an operational and open-access remotely sensed database covering Africa and the Middle East, in order to assess and monitor WP in real-time. This was motivated by recent RS successes.

CHAPTER III. MATERIALS AND METHODS

3.1. Study area

3.2. Description of the Awash basin

Strategic geographic location made Awash Basin to be a center for urbanization and its suitability enable it to become focus for agricultural and industrial development. In this section physical, socio economic, agricultural and water resources settings are described.

The Awash River Basin is the fourth largest catchment in Ethiopia in terms of area, following WabiShebele, Abbay and Genale-Dawa River Basins. Awash Basin is located between 7^{0} 53’42’’ to 12^{0}07’20’’ North and 37^{0} 56’56'' to 43^{0} 17’04’’ East. (AWBA, 2017)

The basin is bordered by Danakil, Abbay, OmoGibe, Rift-Valley lakes and Wabi-Shebele basins and Republic of Djibouti. The river originates near Ginchi in the central highlands of Ethiopia, and flows north east through the northern section of the Rift Valley to eventually discharging into Lake Abbe near Djibouti boarder, traveling a distance of about 1200km. The total catchment area of the basin is about 116,000 square kilometers.(AWBA, 2017)

Awash Baisn is the main population centers of the country in which Addis Ababa, Dire Dawa, Adama,Bishoftu, Dessie and Kombolacha lies in the Basin. The population of the Basin is currently estimated to be 18.3million. This population is triggering pressure on the natural resources resulting in its degradation and pollution. Majority of this population is engaged in agriculture and animal husbandry.(AWBA, 2017)

The number of industrial firms in Ethiopia has tripled in the past four decades. More than sixty five percent of these industrial firms are located in the Awash Basin mainly along the Addis Ababa - Adama, Addis Ababa - Holeta and Adiss Ababa- Sebata industrial development corridor (Tecsult and PPESA, 2010). In addition, Dire Dawa and Kombolcha are among the main industrial zones of the country which are also found in the basin.

According to Water Audit Report (2011), 77.4% of the irrigable land in the basin has been cultivated. This made Awash Basin to be the most developed basin in Ethiopia based on irrigation wise. Large scale mechanized state and private farms such as Ada‟aBecho, Wonji-Shoa,Fental- Tibila, Metahara, Upper Awash Agro Industry, Kesem, Amibara, Gewane and Tendaho are found in this basin. A wide varieties of crops are cultivated ranging from cereals, vegetables, flowers, cotton to perennial fruit orchards and sugarcane. (AWBA, 2017).

3.3. Upper Awash Agro Industry

The study focuses on one of Ethiopia's largest irrigations schemes the upper awash scheme, which is part of the awash basin. Upper Awash Agricultural industry (UAAIE) was founded along the awash river's banks where commercial farming is best suited in the upper awash valley.

In Ethiopia, the upper awash agricultural industry is the leading producer of oranges, mandarins, and other tropical fruits such as mango and papaya. In addition, the company is the country's leading manufacturer and supplier of tomato paste, tomato juice and orange marmalade.

Location

The enterprise is located 174 km away from Addis Ababa along the Awash River. Merti Processing Factory and two of its farms, namely the Merti-jeju and Nura-hera, are found in the Arsi zone, in Merti and Jeju woredas and in Boset woreda of the East Shoa zone, respectively, all of which are located in the Oromia region.

Historical Background

Upper Awash Agro-Industry Enterprise was established when the Government of Ethiopia nationalized all private commercial farms in the country in 1974. In the early and mid-1990s, four private farms were merged to form the then-Nura Era Agricultural Development Enterprise. With the downfall of the Derg regime in 1986, the enterprise was reorganized and its name changed to Upper Awash Agro-Industry Enterprise (UAAIE 2007).

Merti jeju farm

There are two units on the farm, namely Merti and Jeju. These are found in Merti and Jeju woredas, respectively. The total area of the farm is 1638 hectares. An Italian named Seignior Tiliota Santo started Merti Farm. Seignior Tiliota and his children brought irrigation water from the Awash River to the farm in 1961/1962. A group of officials were also operating private farms at Merti, managed by Ato Bekele Lemma. At present, the latter is a residential area.

Jeju Farm was started by a group of higher officials that included Ato Abebe Reta, Ato Addis Alemayehu, Ato Eshete Gizaw, and Ato Kassa Diro and was named ABADESHKA. After the nationalization of land, both farms were merged and became

Merti Jeju. They continued producing cotton. It was in 1975 that horticultural crops were introduced to the farm. The farm became part of HDC. Merti and Jeju are unit farms in the present Merti Jeju Farm under UAAIE.

Nura era

Seignior Montrare established the farm in early 1950. Initially, cotton was the major crop on the farm. A few mango trees were established from seedlings. The trees were too tall for proper harvest and were removed. The National Resource Development Office transferred it to the Horticulture Development Corporation (HDC) as Nura Era Enterprise after nationalization (1967).Nura Era Enterprise is made up of farms that are currently part of the Upper Awash Agro-Industry Enterprise (UAAIE).After nationalization, the farms gradually changed to sole horticultural crop production. The total area under the current Nura Era Farm is 3277 ha. About 33 percent of this (1087 ha) is under fruit. The major fruits produced on the farm are oranges, mandarins, mangoes, grapes, and tomatoes. In the early years, the demand for fruits was low. Quite a lot of fruits were dumped. Through market development and advertisement, the demand for fruits has increased, and there is no problem with marketing fruits at the present time. During the early years of the enterprise, most of the area was covered with cotton and tobacco, but with time, the area was identified as a potential site for horticulture production, and it shifted to the production of high-value horticultural crops. Now the enterprise is the number one producer and processor of horticultural crops in the country. (UAAIE 2007)

Merti processing plant

In the 1974–75 crop season, experimental productions were made. The factory became operational in 1975. Fruit crops used in the factory were citrus (orange, lime, lemon, and grapefruit), guava, and strawberry. Despite the use of varieties that mature at different times, fruit production is seasonal. The purpose of processing is to increase shelf life. Fruits are processed when they are cheap (picking season), and the products are sold when fruits are out of season. Employment Contribution The total number of permanent employees in the enterprise is 1,050. An additional 7,000 temporary and contract employees are hired every year to carry out farming and factory processing. When the employees' families are counted, the total number of employees in the company is 31,000.

Physical Feature

The enterprise is found at an elevation of 1100–1,210 m.a.s.l. The average annual rainfall is 500 mm, with an annual average minimum temperature of 15.30 °C and a maximum temperature of 32.60 °C. The two most important soil types are heavy clay soil and sandy soil. loam, whose pH value ranges from 8.1 to 9.1.

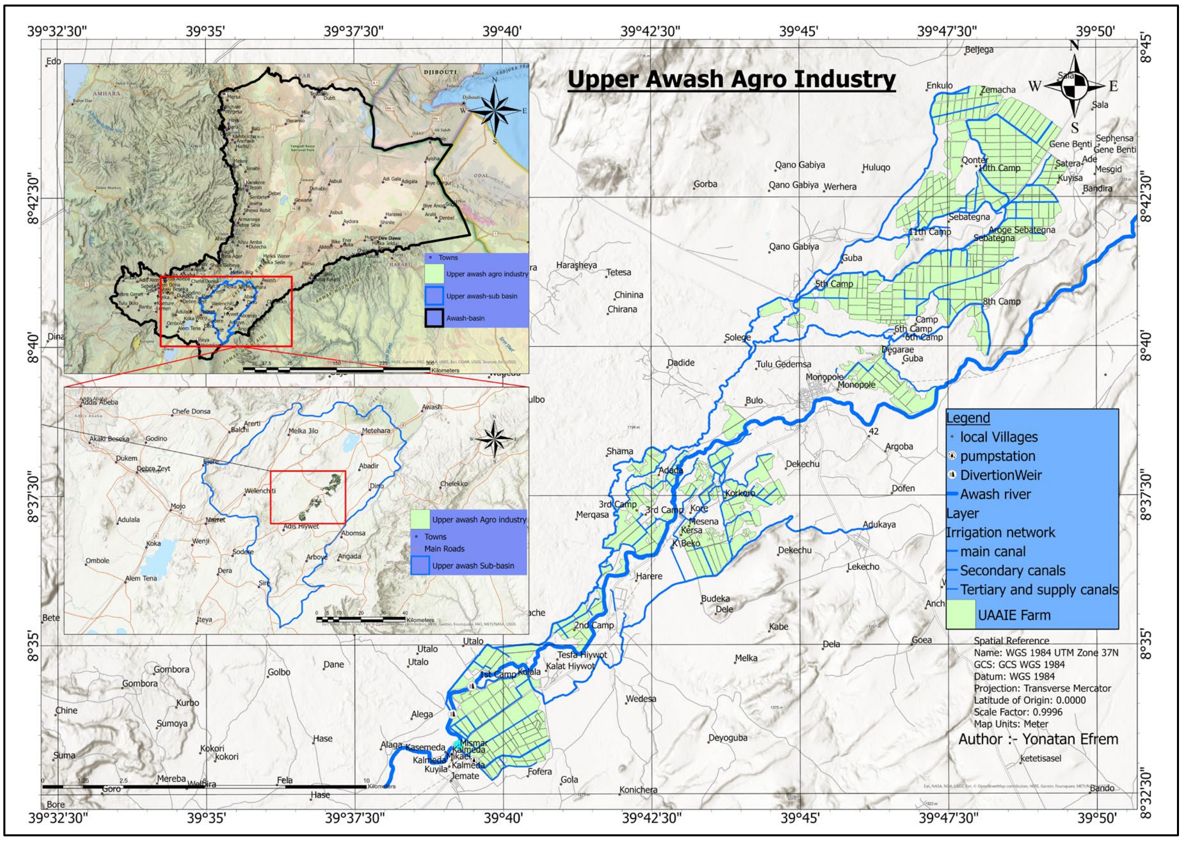


Figure 1 The study area

The farm's entire landholding is about 5,000 hectares, with roughly 4,200 hectares of arable land. Perennial crops occupy around 1481 hectares of the total (1,232 hectares of citrus, 237 hectares of mango, 104 hectares of banana, and the remaining papaya, lemon, lime, and grape vine). The remaining 2,000 hectares of land are used to grow a variety of annual crops, with tomatoes being the most important, followed by beans and cotton. The Merti Horticultural Crops Processing Factory and two farms, Nura Era (3,277 ha) and Merti Jeju (1,633 ha), make up the enterprise.

3.3.1. *Topography and Land Use Land Cover*

Although there are some ups and downs, the vast plains of the research area are nearly level. Small, arid valleys that occasionally cut through the plateau area are to blame for these ups and downs. These characteristics describe the district's overall relief, which consists primarily of little ups and downs. Contrary to other areas, the research region and subbasin's physical characteristics include diverse heights with relatively low slopes in the northwest (946 m) and southeast (2768 m a.s.l.). The subbasin's highest point lies in the south-western corner of the district, at a height of 2768 meters above sea level. Only 946 m to 1300 m a.m.s.l is the range of the enterprise's slope class, which is nearly flat. Topographically speaking, the region is flat. It doesn't have any sharp dips, hills, or long ridges.

Table 1 Slope classification of the farm

Designation	Slope	Area (ha)	Percent (%)
Flat or almost flat	0-3%	2638.56	85.75
Gently sloping	3-8%	329.49	10.71
Sloping	8-15%	107.35	3.49
Moderately steep	15-30%	1.73	0.06
steep	30-50%	0.00	0.00
very steeply	>50%	0.00	0.00
Total		3077.12	100.00

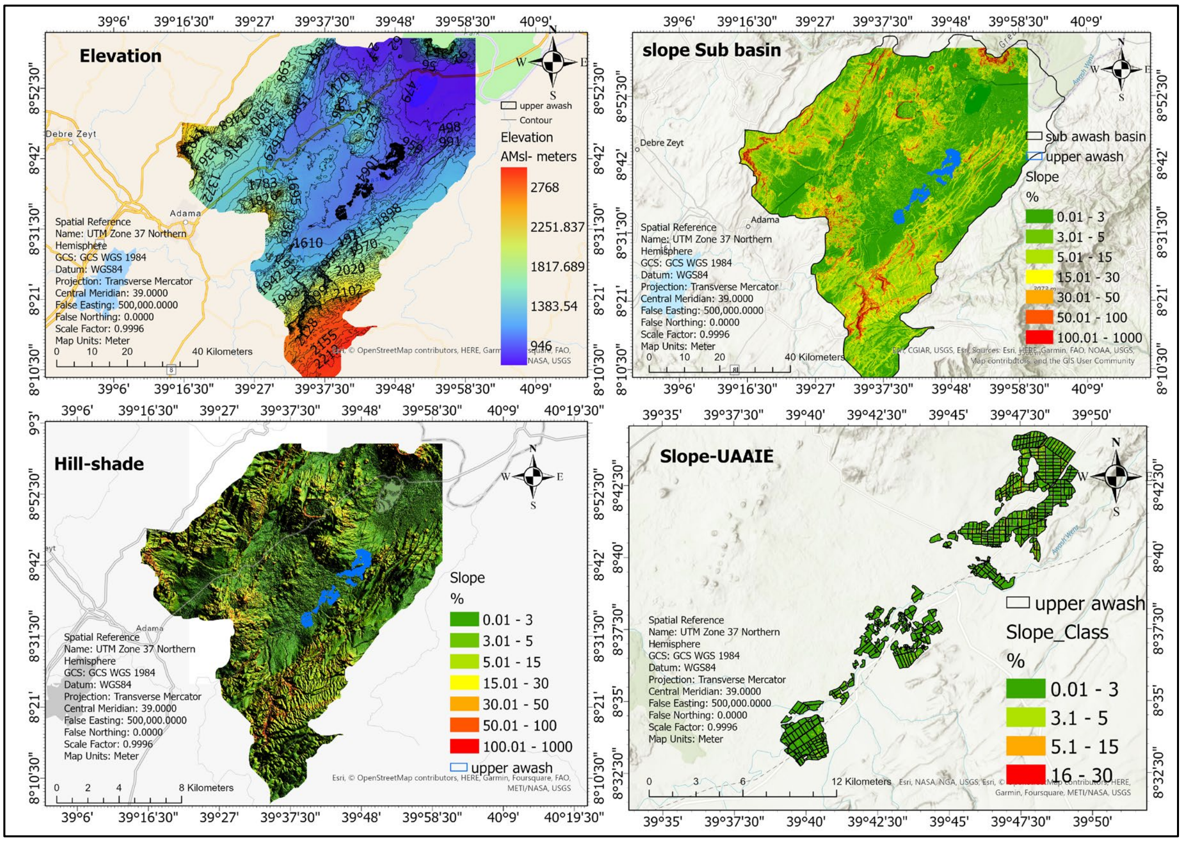


Figure 2 Terrain classification of the sub basin and the farm area

Concerning the land use of the sub-basin, large swaths are covered dominantly with cropland, woodland, and savannah at its western part, followed by grassland, cropland, and grassland at its eastern part. The UAAIE's land holdings are primarily made up of perennially grown mature and young orchard fruit trees, annual crops like cotton, tomato, and beans, fallow lands, and barren lands.

Sentinel 2 satellite data with a resolution of 20 m was used to perform supervised classification to divide the farm land holding into four primary classes, each with a specific share of the land. The findings are shown in the following table.

Table 2 Land use classification of the farm

No	Land Class name	Total area(hectares)	percent
1	Planted/cultivated-Matured	2790.14	47.70%
2	Planted/cultivated -young	524.47	8.97%
3	Fallow-land	790.75	13.52%
4	barren land	1743.96	29.81%
	Sum	5849.33	100.00%

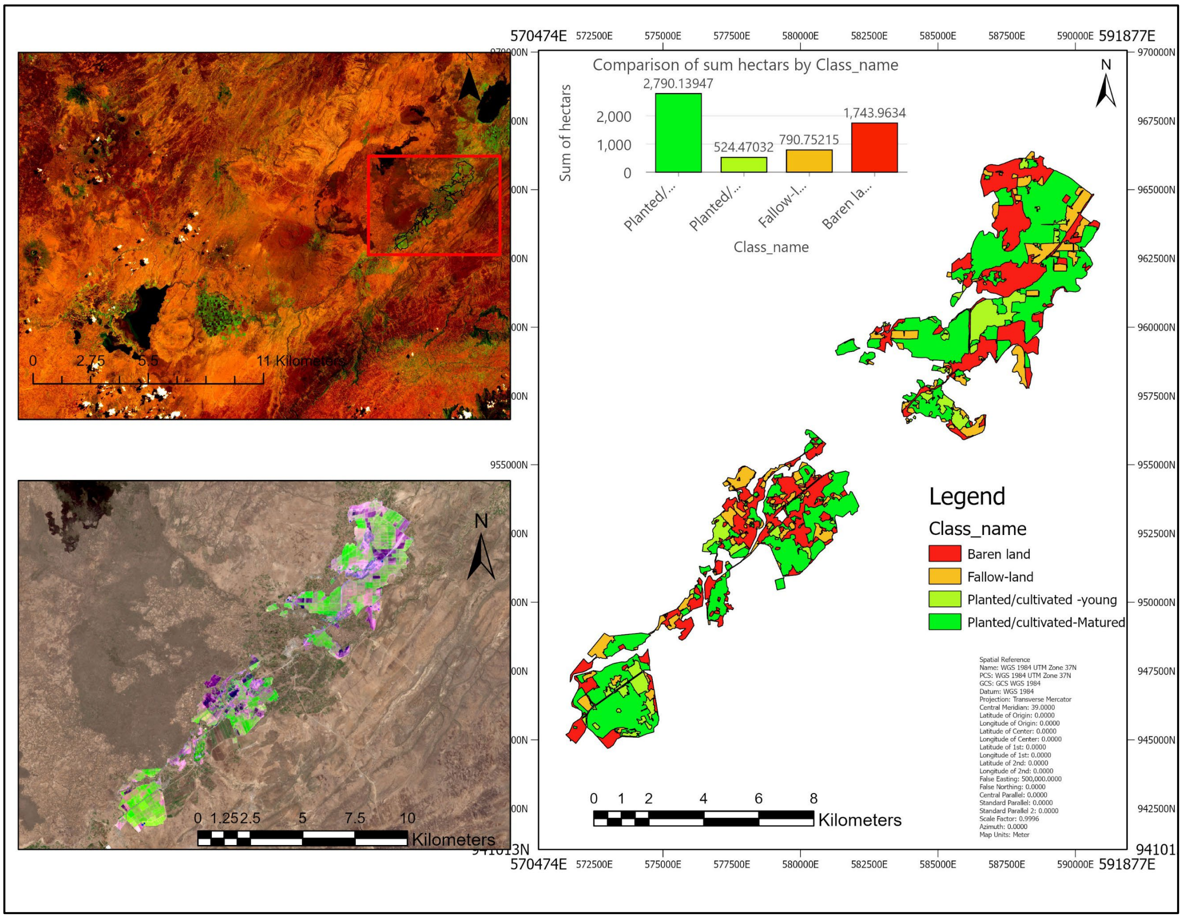


Figure 3 Land use land cover classification of the farm

3.3.2. *Climate, Rainfall & Catchments*

Cool temperate (dega), temperate (woyna) dega, warm zone (dry kola), warm humid (humid kola), arid, semi-arid, and sub-desert (bereha) are the seven agro-climatic zones found in Ethiopia. The study area is characterized by a semi-arid desert (bereha zone). A semi-arid desert agro-ecological zone is characterized by low annual precipitation and high temperatures.

Table 3 Monthly averaged climate data for the Nura Era area and Merti Jeju farms: T, for temperature; P, for precipitation; and PET, for potential evapotranspiration.

Months	T Max	T Min	T Mean	P	PET
	[°C]	[°C]	[°C]	[mm]	[mm]
January	31	12	22	15	127.1
February	32	15	23	45	119
March	34	17	25	44	144.6
April	34	17	26	63	139.6
May	35	17	27	34	142.3
June	36	19	28	21	159.5
July	33	19	26	120	154.9
August	32	18	25	122	141.6
September	34	18	26	46	133
October	34	14	24	9	133.8
November	32	11	22	3	120
December	31	12	21	2	115.9
Mean	33	16	25	43.67	135.94
Total				524	1631.3

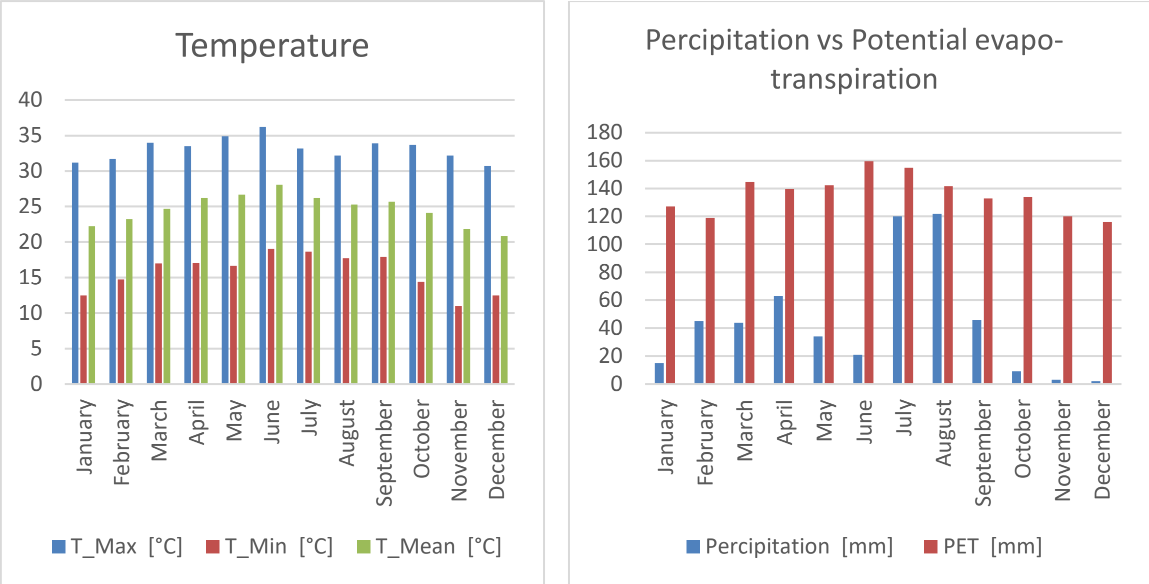


Figure 4 Temperature (left) Precipitation vs potential evapotranspiration (right)

The area is dominated by a bimodal rainfall pattern. The main rainy season lasts from June to September (meher), with two distinct dry periods in between the two wet seasons. The abadiska (Jeju) unit farm of the enterprise is relatively cool, with a temperature that increases towards the eastward fentalle woreda at a similar altitude. Rainfall is also decreasing towards the east.

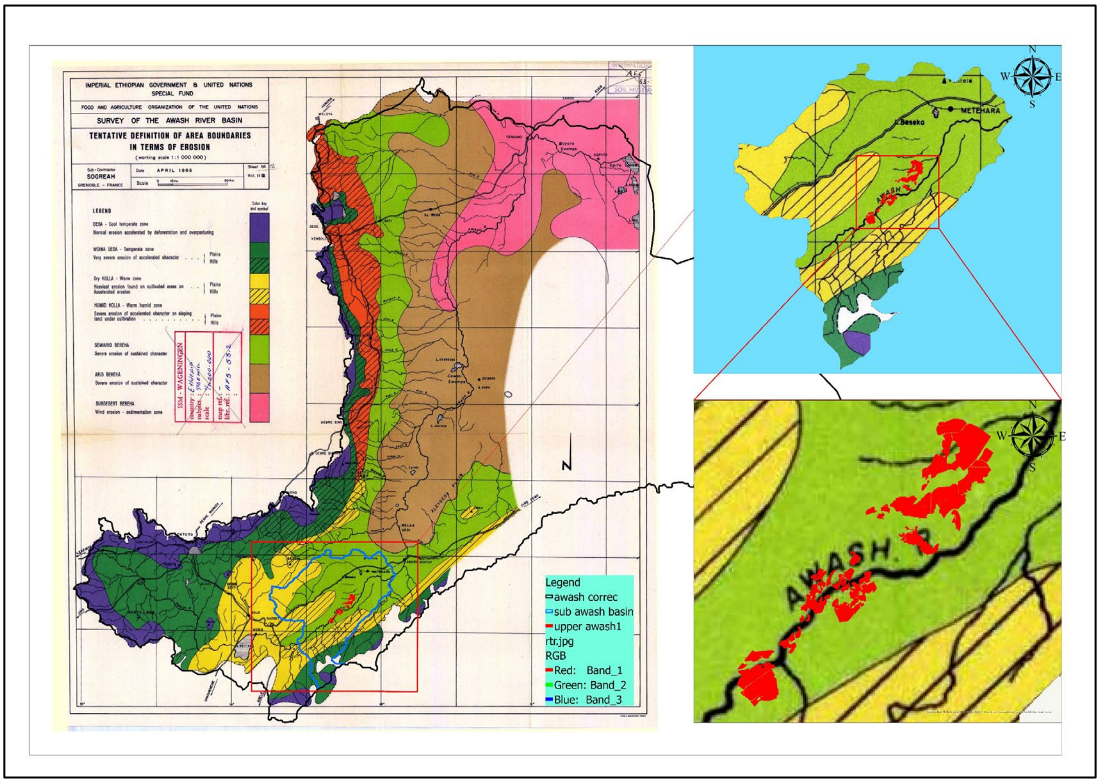


Figure 5 Agro-climatic map(geo-referenced) (source of map: FAO; "Survey of the Awash River Basin")

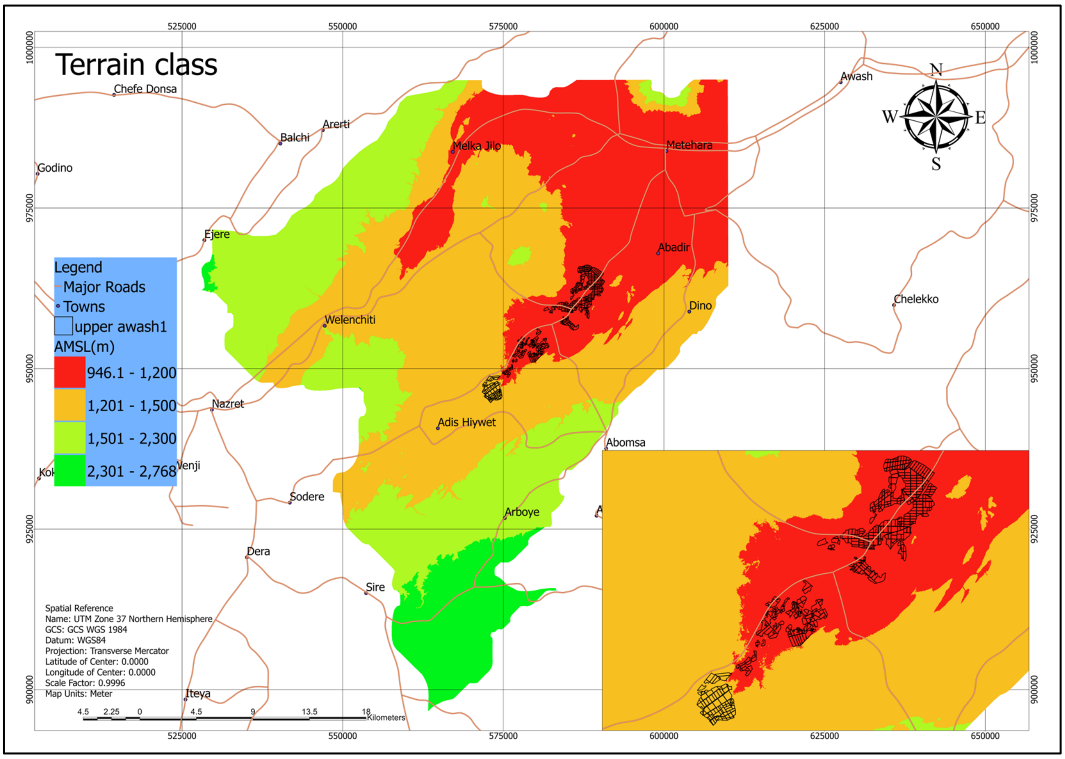


Figure 6 Terrain classification of the sub basin

Left bank basins and right bank basins are the two categories used to describe the main catchments that surround the farm area. The Lege Ferda, Buge, Nurahera 1, Monopol, and Zemecha 1 and 2 basins are some of the major catchments that flow through the area. Each watershed has its own topographic variation. For instance, all different types of slopes are present in Nurahera 1, the largest of the catchments. The dominant slope class is flat or almost flat (0–3%), which covers 42.2 percent of the total area, followed by sloping (8–15%), which is 25.2 percent. Gently sloping (3–8%), moderately steep (15–30%), steep (30–50%), and very steep (>50%) account for 14.32%, 10.69%, 5.31%, and 2.21%, respectively. Table 3 and Table 4 show the slope classes and the proportions of the left and right-side watersheds.

Table 4 Slope classes (Left side catchments)

Nurahera 1 catchment			
Designation	Slope	Area (ha)	Percent (%)
Flat or almost flat	0-3%	5633.60	42.22
Gently sloping	3-8%	1910.91	14.32
Sloping	8-15%	3368.82	25.25
Moderately steep	15-30%	1426.10	10.69
steep	30-50%	708.41	5.31
very steeply	>50%	294.53	2.21
Total		13342.38	100.00

Monopol catchment			
Designation	Slope	Area (ha)	Percent (%)
Flat or almost flat	0-3%	3063.93	61.88
Gently sloping	3-8%	978.88	19.77
Sloping	8-15%	841.21	16.99
Moderately steep	15-30%	51.19	1.03
steep	30-50%	12.17	0.25
very steeply	>50%	3.81	0.08
Total		4951.19	100.00
Zemecha catchment			
Designation			
Flat or almost flat	Slope	Area (ha)	Percent (%)
Gently sloping	0-3%	4003.54	48.26
Sloping	3-8%	1502.42	18.11
Moderately steep	8-15%	1813.47	21.86
steep	15-30%	572.43	6.90
very steeply	30-50%	304.40	3.67
Total	>50%	100.14	1.21
		8296.41	100.00

Table 5 Slope class (right side catchments)

Lege buge catchment			
Designation	Slope	Area (ha)	Percent (%)
Flat or almost flat	0-3%	1937.23	14.58
Gently sloping	3-8%	2003.35	15.08
Sloping	8-15%	6423.09	48.34
Moderately steep	15-30%	1693.97	12.75
steep	30-50%	709.16	5.34
very steeply	>50%	520.09	3.91
Total		13286.89	100.00
Lege ferda catchment			
Designation	Slope	Area (ha)	Percent (%)
Flat or almost flat	0-3%	1646.65	13.02
Gently sloping	3-8%	4210.15	33.30
Sloping	8-15%	3563.99	28.19
Moderately steep	15-30%	2116.76	16.74
steep	30-50%	797.92	6.31
very steeply	>50%	307.69	2.43
Total		12643.16	100.00

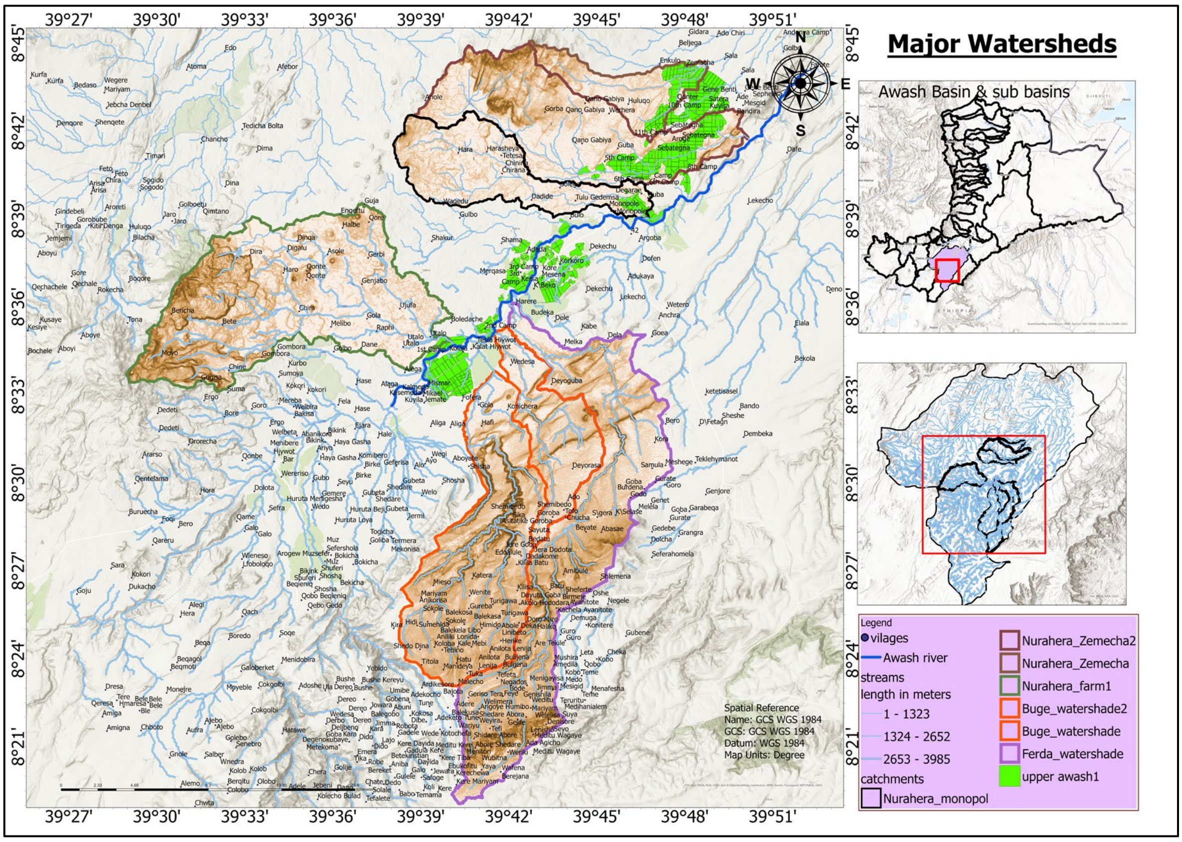


Figure 7 Catchments surrounding the study area

3.3.3. *Irrigation Water Source and Management*

The enterprise consists mainly of a gravity scheme that spans the two sides of the Awash River and is fueled by two diverting weirs, a pumping station on the river, and other lifting stations along the canals. A primary pumping station, a secondary lifting station, and gravity abstraction are all used to supply the upper part, or Merti Jeju. Three horizontal-axis pumps with a combined capacity of 480 l/s, 250 l/s, and 250 l/s make up the primary pumping stations, which have an overall delivery of about 1 m3/sec with a head of about 8 m, while the suction, which varies with the awash water level, does not exceed 4 m.

The Merti-Jeju main canal, which serves the unit one and colonel camp areas, diverts awash waters directly by gravity, with no special intake structure. The canal has a discharge capacity of 3 m3/s.

Water used for irrigation is diverted at Nura Era using a gravity sill structure made of loose stones of small sizes on the Awash River. The 32-kilometer-long main canal and its numerous smaller branches serve the Nura Era Farm.

There is a regulating structure with four vertical lift gates that are one meter wide at a distance of around 100 meters from the intake. Next to the regulating structure, a concrete canal with a rectangular cross section follows up to the discharge measurement structure.

The canal enables a diversion of more than 7 m3/sec to be made directly from the awash. Furrow and basin irrigation are widely practiced. Basin irrigation is employed to irrigate citrus crops, whereas furrow irrigation is used to irrigate row crops such as cotton, tomatoes, and beans. Siphons are employed to supply furrows with irrigation water.

Furrow lengths of 10-30 m are typically used for small vegetables such as onion and tomato, as well as pulses such as green beans, maize, and cotton, with a furrow spacing of 0.9 irrigation interval in the farm depending on soil and crop type. For perennial crops, it varies between 9 and 14 days with a total of 24 irrigation applications until maturity; for small vegetables, it is in the range of 5 to 8 days with a total of 15 to 17 irrigation applications; and for cotton, it is between 10 and 23 days with a total of 12 to 14 irrigation applications. Plant spacing commonly used in the farm include 6 m x 4 m for oranges, 6 m x 4 m for mandarins, 8 m x 8 m for guavas, 8 m x 8 m for grapefruit and 7 m x 7 m for lemons.

Agricultural Production

The main crops cultivated are fruits (oranges, mandarins, tomatoes, grape vine, and mangoes), vegetables (tomatoes), cotton, and beans. The average yield of tomatoes is 350 quintals per hectare (qt/ha); for oranges, 340 qt/ha; for green beans, 100 qt/ha; and, recently, the yield of cotton declined to 15 qt/ha due to disease. DAP, urea, and potassium nitrate are the common fertilizers used in the enterprise.

The level of fertilizer used in the enterprise was relatively high in the early 1970s but declined tremendously in the following decades. For example, for oranges, it was about 1.69 qt/ha DAP and 12.89 qt/ha Urea, but, recently, this figure declined to 0.11 qt/ha and 0.42 qt/ha for DAP and Urea, respectively. Pesticides like Suprathion 60% EC, Diaznon, Ridomil Gold, Fetrilion Combi, and Karate 5% EC are widely employed in the enterprise.

Socioeconomic

The enterprise produces fresh as well as factory-processed fruits and vegetables for export and local consumption.

The major export crops are beans, linted cotton and haricot bean seed. It also produces cotton and grapefruits, which are utilized as input in other factories within the country, as well as seeds and seedlings of fruits and vegetables, which are used by farmers and private investors. Also, the enterprise hasn't noticed any significant environmental effects. A closer inspection is necessary to determine whether specific salinity or sodicity issues have arisen.as well as seeds and seedlings of fruits and vegetables, which are used by farmers and private investors. Also, the enterprise hasn't noticed any significant environmental effects. A closer inspection is necessary to determine whether specific salinity or sodicity issues have arisen.

3.4. Methodology

This section starts with an explanation of the performance assessment framework, including the consumption, yield, water productivity, and other irrigation performance indicators used in this study. The final section describes and reviews the data and information used in the analyses.

Productivity and irrigation performance indicators provide a way to measure the effectiveness of resource use and to evaluate irrigation services.

Figure 8 shows the yield and productivity determination and performance assessment framework used in this study to calculate indicators of water, land productivity, and irrigation performance in the Upper Awash agro-industry enterprise. The procedure can be summarized in three main steps.

First, actual water consumption, actual transpiration, reference evapotranspiration, and net primary production datasets are collected from the FAO Water Productivity through open access remotely sensed derived data (WaPOR), followed by the pre-processing steps of masking out the study area and resampling the data to match the spatial resolution and remove non-crop areas.

Second, the seasonal water consumption (transpiration, actual evapotranspiration, and reference evapotranspiration) and the seasonal net primary production and biomass are calculated. Third, the WaPOR data is compared to in-situ data.

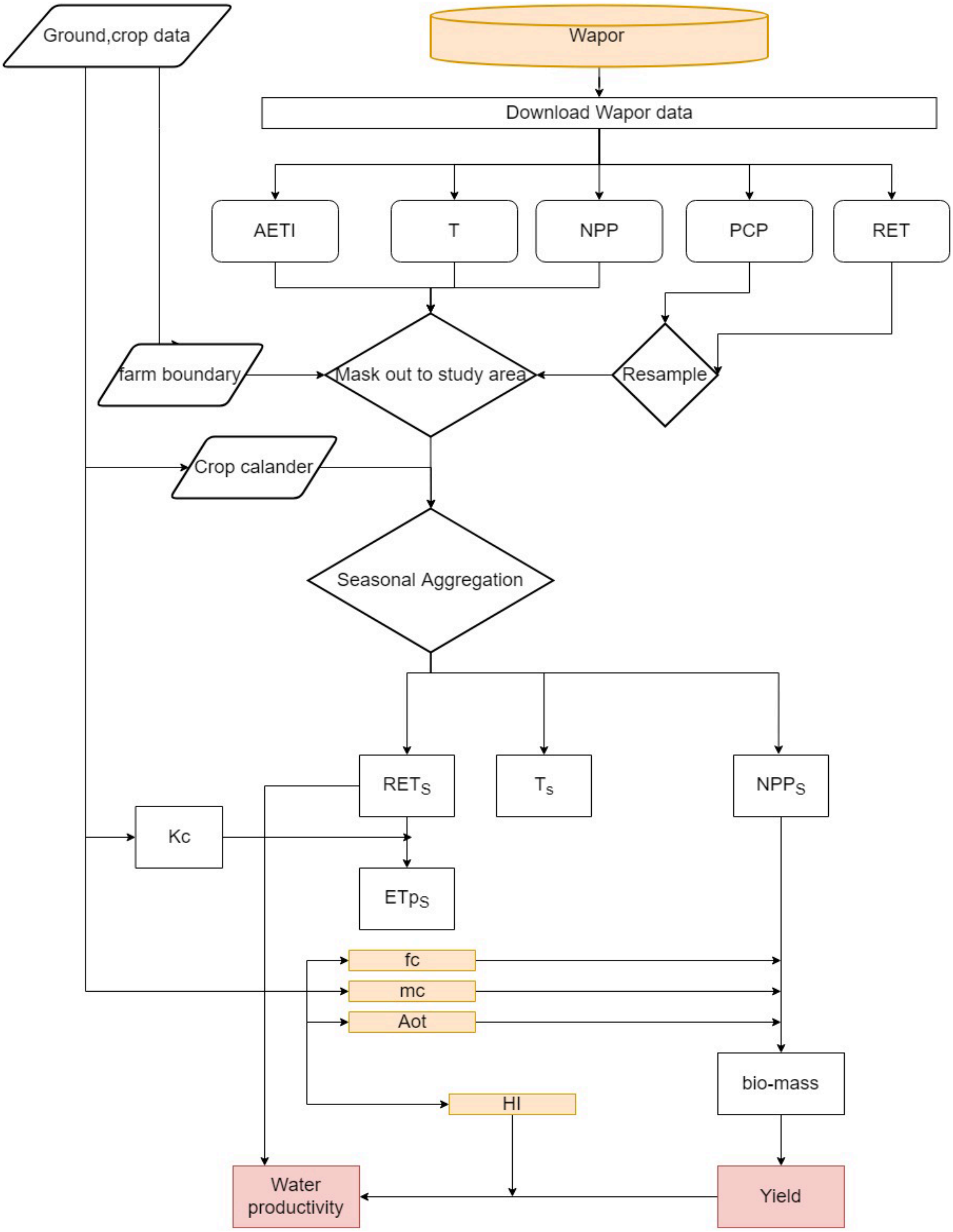


Figure 8 Flow chart used in the study

AETa stands for actual evapotranspiration, T for actual transpiration, s-for seasonal, ETref for reference Evapotranspiration, ETp_s- seasonal potential transpiration PCP for precipitation, NPP for net primary production, NPP_s for seasonal net primary production, MC for moisture content in fresh biomass, Kc for crop coefficient and AOT for the above ground over total biomass coefficient.

3.4.1. *Data sources*

Databases for water productivity

The data used for calculating water productivity is from the FAO-based WaPOR database (https://wapor.apps.fao.orR). WaPOR stands for "water productivity through open access to remotely sensed and derived data."

WaPOR is the first comprehensive dataset that combines water use (actual evaporation, transpiration, and interception), production (net primary production), land use (land cover classification), phenology, climate (precipitation and reference evapotranspiration), and water productivity layers covering sub-Saharan Africa and the Near East and North African regions.

The data is available at decadal time steps and in near real-time for the period between 2009 to present day. WaPOR datasets are available at the continental scale (Level 1 at 250 m), country and river basin (Level 2 at 100 m) and project level (Level 3 at 30 m).

This database provides data over water productivity, biomass, evapotranspiration, reference evapotranspiration, precipitation and more.

The downloaded data for this study area is from WaPOR version 3.0 (30 m spatial resolution); these are the 10-day intervals (dekdal data) of net primary production (NPP), actual evapotranspiration, and interceptions (AETI).In addition, decadal precipitation at 5 km resolution and decadal reference evapotranspiration at 25 km resolution The precipitation and reference evapotranspiration datasets were downscaled to 100 m resolution.

Table 6 Wapor layers used in the analysis

No	Wapor raster data	Spatial resolution	Temporal coverage	Coordinate system
1	Actual evapotranspiration & interception (AETI)	30m	Dekad(2009-2021)	WGS-84
2	Transpiration(T)	30m	Dekad(2009-2021)	WGS-84
3	Net primary production (NPP)	30m	Dekad(2009-2021)	WGS-84
4	Precipitation(P)	5km	Dekad(2009-2021)	WGS-84
5	Reference Evapotranspiration (REF)	25km	Dekad(2009-2021)	WGS-84

3.4.2. *Ground-based local data collection*

The shape files used for this analysis were extracted from the enterprise cadaster database by applying geo-referencing to Google Earth and excluding all non-irrigation areas from each farm.

Annual crop and perineal crop farm blocks except citrus plots and non-irrigation areas inside the scheme, like small towns, camps, roads, or reservoirs, are removed from the shape files to create a good average only for the potential irrigation areas.

During field visits, additional data relevant to the analysis was collected. These include crop, irrigation, and field management data. All of the enterprise's citrus plant plots are selected for analysis.

In addition to point and polygon extraction, the location of each selected plot with their respective names was recorded using handheld GPS. Consequently, the shape files of newly developed plots that are not included in the enterprise cadaster are created using hand GPS and Google Earth.

Cropping seasons used for this analysis were extracted from the enterprise archive; the harvesting yield of annual and perennial crops was taken from the enterprise’s database; and the average crop growing and harvesting period, or age of crops, was recorded for the citrus crop.

The above collected Ground data’s such as the boundary of the farm (to download WaPOR data and filter non cropped area), moisture content of fresh biomass (to convert dry matter to biomass), above ground over total biomass ratio (to estimate the above ground biomass), start and end of seasons (to aggregate water and climate data per crop season), harvest index (to derive crop yield from above ground biomass) and crop coefficient (to estimate potential evapotranspiration from reference evapotranspiration) are all used for calculating and estimating the water use (actual evapotranspiration) transpiration biomass and in determining the Yield and crop water productivity of the enterprise.

Table 7 Field in-situ data and parameters used for the study

No	Data and Parameters	Value	Source
1	Boundary of UAAIE(shape file)	Polygon	UAAIE cadaster, digitized
2	Crop calendar	July 08 - June 08	Company Database
3	Ratio of light use efficiency (fc)	1.6	(Fan et al., n.d.)
4	The ratio of above ground over total biomass(AOT)	0.7	(Morgan et al., 2006)
5	Crop coefficient kc stages at initial, mid and late season.	0.7,0.65 and 0.7	(Dirk RAES, Pasquale STEDUTO, Theodore C. HSIAO, 2009)
6	Crop Growing stages at initial, development, mid-season and late season.	60,90,120,95	(Dirk RAES, Pasquale STEDUTO, Theodore C. HSIAO, 2009)
7	Harvesting index (HI)	0.65	(Fan et al., n.d.)
8	Land productivity (QT/hec)	2015 – 2021	Company Database
9	Moisture content (MC)	0.6	(Morgan et al., 2006)

3.5. Analysis and evaluation

3.5.1. *Step 1 Data preparation and pre processing*

Level -3 primary data components net primary production (NPP), actual evapotranspiration (AET), transpiration of the Awash basin (T), precipitation (P), and reference evapotranspiration (REF) have all been bulk downloaded with temporal extent of 2009-2021 from wapor by employing pre-developed scripts to bulk download and process the WaPOR data on Jupyter Notebook. Temporal resolution of data components are in dekadal resolutions.

In one month, there are 3 dekads with the first two dekads containing 10 days while the last dekad ranges between 8 to 11 days. A total of 432 dekadal raster data were downloaded for each dataset.

Upon obtaining the raster data, the precipitation and reference evapotranspiration layers were resampled to meet research area resolution. The boundaries of the research area were created using the shape file to produce a mask, which was later used to filter out non-crop areas. To further filter out non-citrus farm blocks, masking was carried out once more.

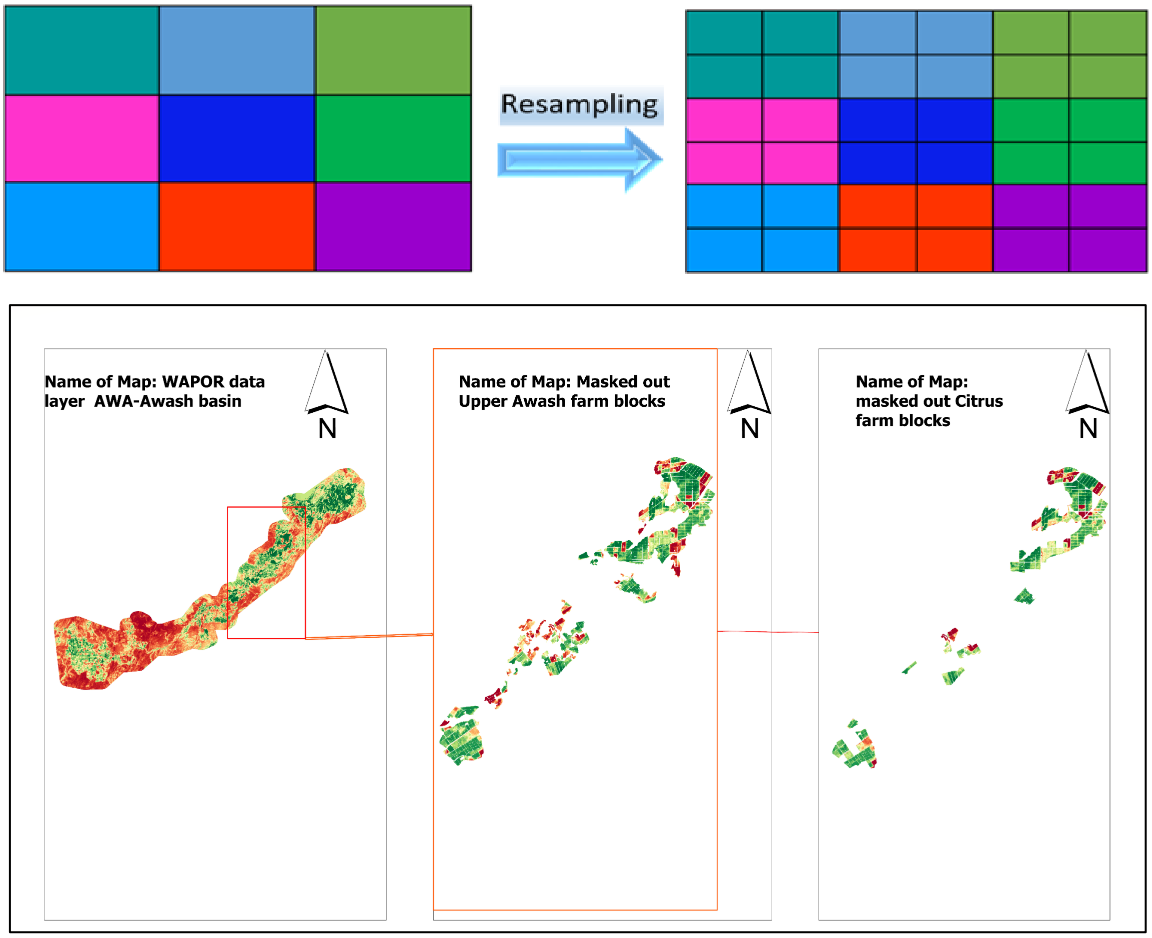


Figure 9 Schematic pre-process (resampling & mask filtering)

3.5.2. *Step 2 Calculating Seasonal Water Consumption (Actual evapotranspiration and interception, AETI*

Actual evapotranspiration is defined as a combined process of both evaporation from soil and plant surfaces and transpiration through plant canopies. Interception, on the other hand, is defined as rainfall that is intercepted by the plant's canopy and evaporates directly from the leaves.

In WaPOR, the evaporation and transpiration are calculated based on the ETLook model described in Bastiaanssen et al. (2012). In the ETLook model, the Penman-Monteith (P-M) equation is solved by adapting to remote sensing input data for evaporation and transpiration separately. The difference in the P-M equation applied to derive evaporation and transpiration is in the inputs used to estimate the net available radiation and the aerodynamic and surface resistance: the P-M for evaporation uses soil heat flux as well as the aerodynamic and surface resistance at the soil surface as influenced by soil moisture availability, and the P-M for transpiration uses the aerodynamic and surface resistance at the canopy as influenced by soil moisture availability.

The actual evapotranspiration and interceptions covering the study area were acquired from the WaPOR portal in a dekadal (10-day) 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 the specific crop.

$$\text{AETI (D)} = \text{AETI} \times 0.1 \times n \qquad (1)$$

Where: AETI (D) is dekadal evapotranspiration and interception (mm/day), and AETI is original evapotranspiration and interception acquired from the WaPOR portal (mm/day). 0.1 is the correction factor from the WaPOR portal to convert a raster value to a numeric value, and n is the number of days in each decade. The dekadal actual evapotranspiration and interception were then converted to seasonal by adding the all-decadal values together using Python scripts to process multiple raster files.

$$\text{AET}_s = \sum_{Eos}^{Sos} AETI(D) \qquad (2)$$

Where AETI (D) is the actual evapotranspiration that includes evapotranspiration and interception, AETs is the seasonal actual evapotranspiration in mm/season, and SOS and EOS are the starting and ending of the crop season, seasonal actual evapotranspiration and interception were aggregated for 11 seasons with a temporal range of 2009-01-01 to 2021-04-30, with each season having 365 days.

3.5.3. *Step 3 Calculating Seasonal, Reference, potential Transpirations (T_s,RET, ETp) And Net primary production (NPP)*

The transpiration (T) data component (dekadal, in mm/day) is the actual transpiration of the vegetation canopy. In the primary dekadal data obtained from the wapor, the value of each pixel represents the average daily actual transpiration for that specific dekad. Using the crop calendar, the decadal layers were added to produce monthly reference evapotranspiration, which was then followed by season-specific RET layers for all 11 seasons.

$$\text{T}_s = \sum_{Eos}^{Sos} T(D) \qquad (3)$$

Reference Evapotranspiration (RET) is defined as the evapotranspiration from a hypothetical reference crop, and it simulates the behaviour of a well-watered grass surface. Similar to the above process using the crop calendar as a temporal bound, the decadal layers were summed up to give monthly reference evapotranspiration followed by seasonal RET layers for the entire 11 seasons.

$$RET_s = \sum_{Eos}^{Sos} RET(D) \quad (4)$$

All The above-listed processes were conducted by computing using a Jupyter notebook. The dekadal, seasonal, reference, and potential transpirations were first converted to monthly, then to seasonal by adding the decadal values together using Python scripts. For every data component, 34 raster files were aggregated to generate a single seasonal dataset.

Potential evapotranspiration (PET)

is defined as the amount of evaporation that would occur if a sufficient water source were available. To calculate seasonal potential evapotranspiration, the seasonal reference evapotranspiration RET is multiplied by the crop coefficient kc of the study crop.

$$PET_s = RET_s \times kc \quad (5)$$

The plant employed in this study is citrus, and the crop coefficient Kc values used are 0.7 for the initial, 0.65 for the mid-season, and 0.7 for the late season. (Anderson & French, 2019) Net Primary Production (NPP) and Above-ground Biomass Production (AGBP) The conversion of carbon dioxide into biomass, fueled by photosynthesis, is expressed as net primary production (NPP), which is a fundamental component of an ecosystem. It is used to calculate above-ground biomass production (AGBP). Dry matter production (DMP), which represents the dry biomass increase of vegetation, is directly related to NPP.

To calculate the accumulation of biomass production during a growing season, the beginning and end of the growing season must first be determined. AGBP is then calculated as the sum of NPP, converted into DMP units (kgDM/ha), between the start of the season (SOS) and the end of the season (EOS).

In addition, a factor (F) is included to account for the division between the above- and below-ground components, here referred to as the AGBP over Total (AOT) biomass production correction factor. According to literature, the above-ground fraction F for citrus is approximately 0.7 (see, for instance, K. T. Morgan et al., 2006).

$$AGBPs = \sum_{Eos}^{Sos}(NPPd) \times 22.222 \text{ kgDM/ha/day (DMP)} \times AOT \quad (6)$$

Where: DMP is the dry matter production at deckad, expressed in kgDM/ha/day, and AOT accounts for the fractioning between the above- and below-ground biomass (i.e., the AGBP over total (AOT) biomass production correction factor, NPPs net primary production (dekad)).

3.5.4. *Step 4 Calculating Biomass Production and land production (yield)*

The biomass production is calculated from the seasonal above-ground biomass production (AGBP). There are two steps involved in converting AGBP to biomass. Its seasonal AGBP needs to be corrected. This is done by applying a light-use efficiency correction factor (fc), which is used to drive the NPP layer and set at 1.6 (Fan et al., n.d.). Second, the total biomass (land productivity) is calculated by correcting the dry biomass production for moisture content in the crop (MC). Finally, the biomass (B) is estimated.(Equation 7).

$$B = fc \times \frac{\text{AGBPs}}{(1-mc)} \qquad (7)$$

Land productivity is defined as the biomass production or yield in ton/ha/season. Crop yield can be estimated by multiplying the biomass land productivity by the harvest index.

The harvest index is used to separate biomass production into a harvestable and a non-harvestable fraction. The harvest index makes it possible to calculate crop yield and crop water productivity. In general, the harvest index is used to assess the productivity of a specific plant variety, indicating how much of the biomass production contributes to the harvestable fraction of a crop (yield). It is expressed as the ratio of the weight of dry grains over the total dry matter. Seasonal crop yield is estimated using HI (Equation 8).

$$Y = B \times HI \qquad (8)$$

In absence of field data, literature was referred to estimate these crop parameters. Table 7 shows the values and the source of the parameters.

Table 8 Parameters used in the analysis

Parameter	Description	Value	source
AOT	The ratio of above ground over total biomass	0.7	(Morgan et al., 2006)
Fc	Light use efficiency correction factor	1.6	(Fan et al., n.d.).
HI	Harvest index	0.65	Fan et al., n.d.)
MC	Moisture content	0.6	(Morgan et al., 2006)

3.5.5. *Step 4 Calculating Crop Water Productivity*

The crop water productivity expresses the quantity of the major crop yields in relation to the volume of water beneficially consumed (by canopy transpiration) in the season, and thus net of soil evaporation. Contrary to gross crop water productivity, net crop water productivity is particularly useful in monitoring how effectively crops use water to develop yield. This study focuses on biophysical production per unit of land or water resources, also known as land and water productivity. The calculated yield was converted from tons per hectare per season to kilograms per square meter per season, and the AETI was converted from millimeters per season to meters per season.

$$CWP = Y/AETI \qquad (9)$$

4.1. Water use maps (actual evapotranspiration, transpiration)

The average water consumption at Upper Awash Agro Industry Farm is 1497.692 mm/year, ranging from 1723 to 1305 mm/year. For the citrus orchards, the Enterprise's farm is irrigated by applying a surface irrigation technique called ring basins. As a result, a spatial comparison is made between the Enterprise's two farms, the Nurahera farm and the Merti-Jeju farm. Spatially, significant et variations along the cropping pattern are revealed on the generated maps for the 12 seasons (years) from 2009 to 2021. For example, a clear alternation of high ET in the northern part, which is Nurahera, can be observed in the sequence of image dates (from July 2009 up to June 2018). From 2019 on, the high Et shifted from the northern command (Nurahera) to the southern (Merti-Jeju) commands. Due to aging, the majority of Nurahera Farm citrus orchards are experiencing population decline, which is one of the major causes of these fluctuations.

The company is also engaged in removing the old citrus trees from the orchards for new plantations. while Merti-Jeju Command's citrus plants are significantly younger and more productive. Significant variances have also been seen within individual farm plots; for instance, in the year 2020, farm block C-61 had the lowest ET while farm block B-17 had the highest ET, with readings of 625mm and 2300mm, respectively. Fig. 15–22 presents the observed spatial variances. A significant decrease in consumption was observed in 2014 (the 2013–14 crop season), and 1322.3 mm accounted for the Elnino drought period. Fig. 10 shows the temporal variation and pattern of water consumption for the past 11 or 12 seasons.

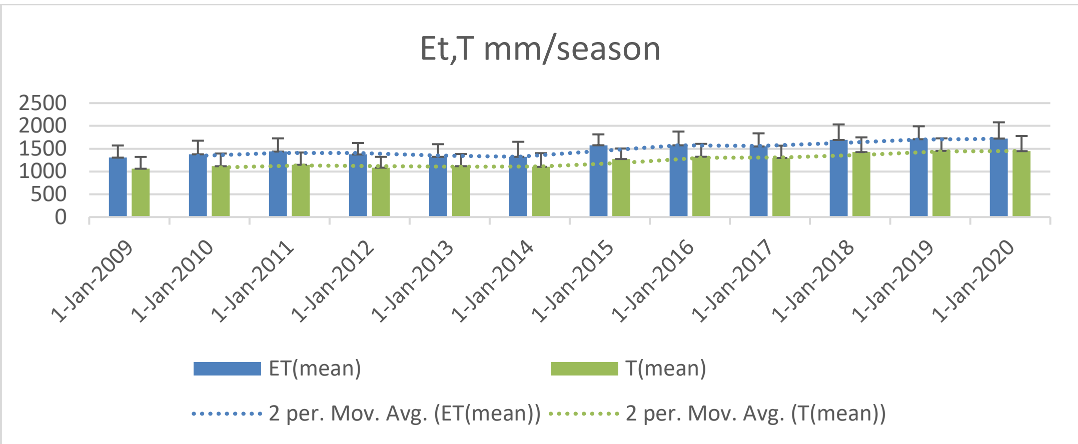


Figure 10 Annual average water consumption (actual evapotranspiration (ETa)), annual average Transpiration and the standard deviation (error bars) across the pixels

4.2. Reference Evapotranspiration (ETref, ET_o)

Reference crop evapotranspiration or reference evapotranspiration, denoted as ETo or ETref, is the estimation of the evapotranspiration from the reference surface. The reference surface is a hypothetical grass reference crop with an assumed crop height of 0.12 m. The reference surface closely resembles an extensive surface of green, well-watered grass of uniform height, actively growing and completely shading the ground.

Comparatively, the reference evapotranspiration rate observed is much higher in Nurahera, with the elevation and temperature differences between the Nurahera and Merti-jeju farms most likely accounting for the observed significant variance in ETo between the two farms.

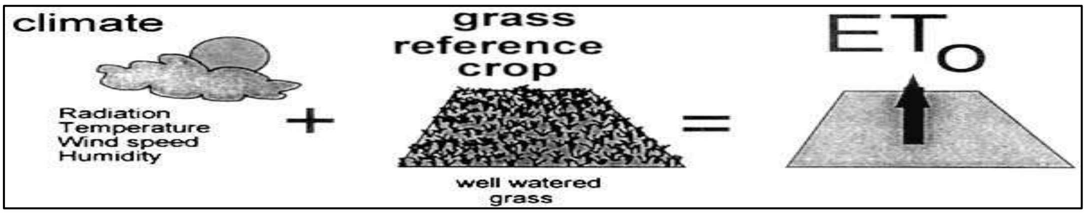


Figure 11 Reference (ETo), crop evapotranspiration under standard (ETc) (source- FAO Irrigation and Drainage Paper No. 56)

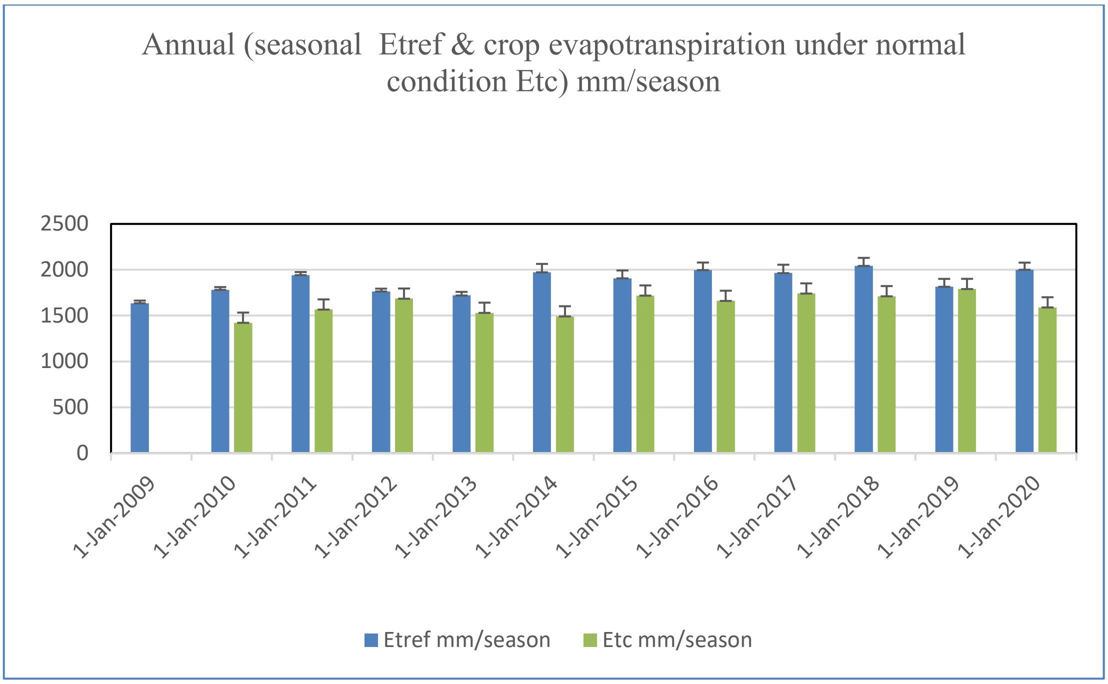


Figure 12 Monthly reference crop evapotranspiration (Eto-Etref) & (ETc) (2009, 2014,2020)

4.3. Crop evapotranspiration under standard conditions (ET_c)

The crop evapotranspiration under standard conditions, denoted as ET_c, is the evapotranspiration from disease-free, well-fertilized crops, grown in large fields, under optimum soil water conditions, and achieving full production under the given climatic conditions. In terms of location, reference evapotranspiration values tend to rise in the direction of Nurahera (the northern command), while the merti jeju command exhibits lower Etc. The amount of water required to compensate the evapotranspiration loss from the cropped field is defined as crop water requirement.

Although the values for Crop evapotranspiration under standard conditions (ETc) and crop water requirement are identical, crop water requirement refers to the amount of water that needs to be supplied, while crop evapotranspiration refers to the amount of water that is lost through Evapotranspiration. By converting these Etc values to flow per liters irrigation water requirement can easily be computed in lit/month/hectare. Fig 11 shows the monthly crop evapotranspiration under standard condition for selected three years.

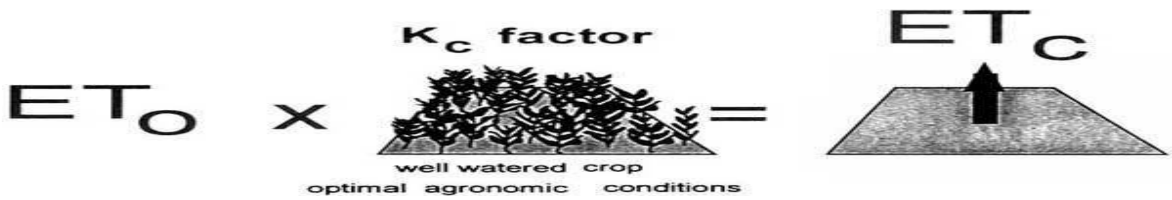
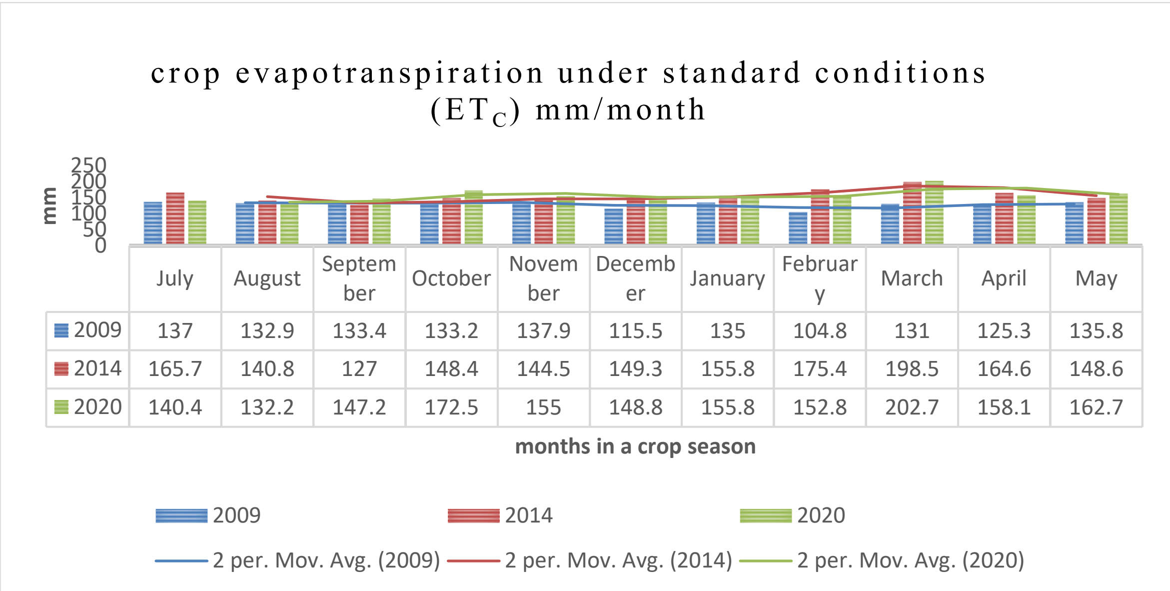


Figure 13 Crop evapotranspiration under standard conditions (source-FAO Irrigation and Drainage Paper No. 56)



	July	August	September	October	November	December	January	February	March	April	May
2009	137	132.9	133.4	133.2	137.9	115.5	135	104.8	131	125.3	135.8
2014	165.7	140.8	127	148.4	144.5	149.3	155.8	175.4	198.5	164.6	148.6
2020	140.4	132.2	147.2	172.5	155	148.8	155.8	152.8	202.7	158.1	162.7

Figure 14 Monthly Eto & ETc -2009,2014,2020

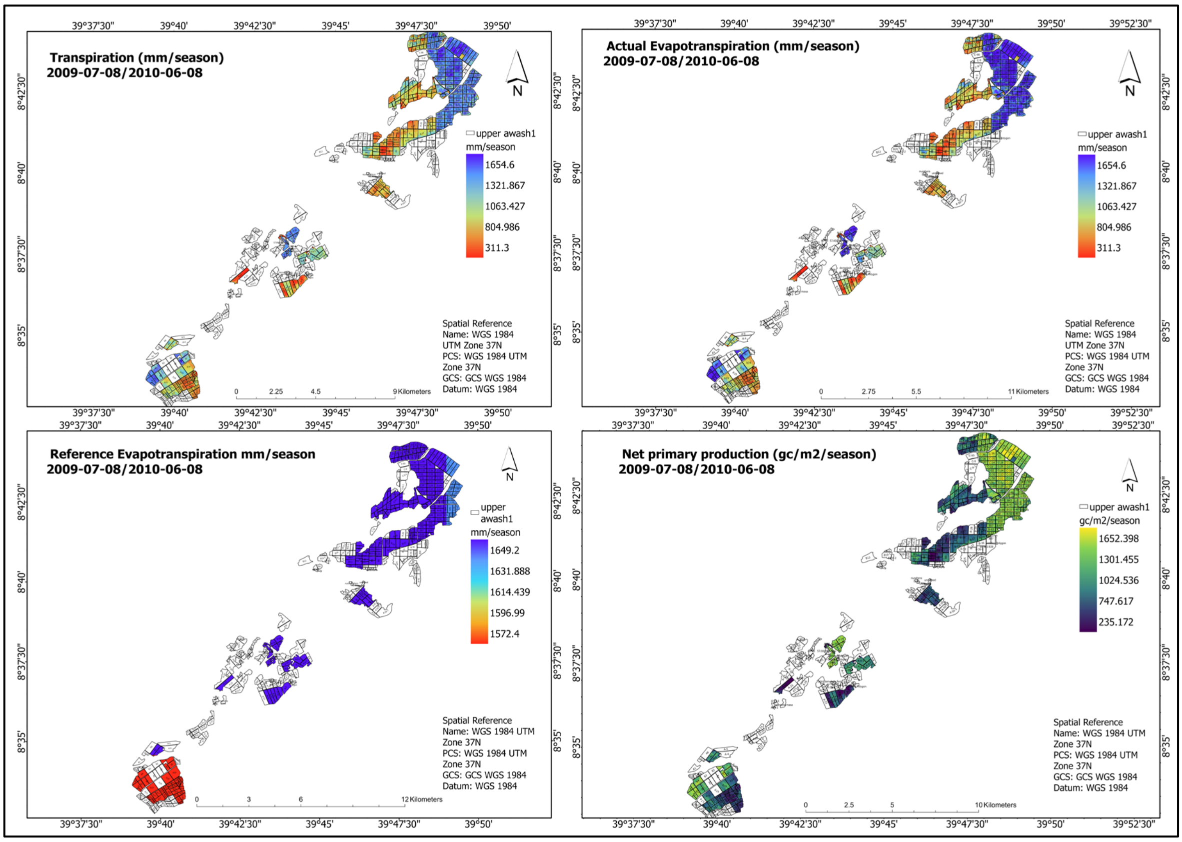


Figure 15 Water use maps T(top-left), AET (top- right), Ref (bottom-left), NPP (bottom-right)-2009-2010

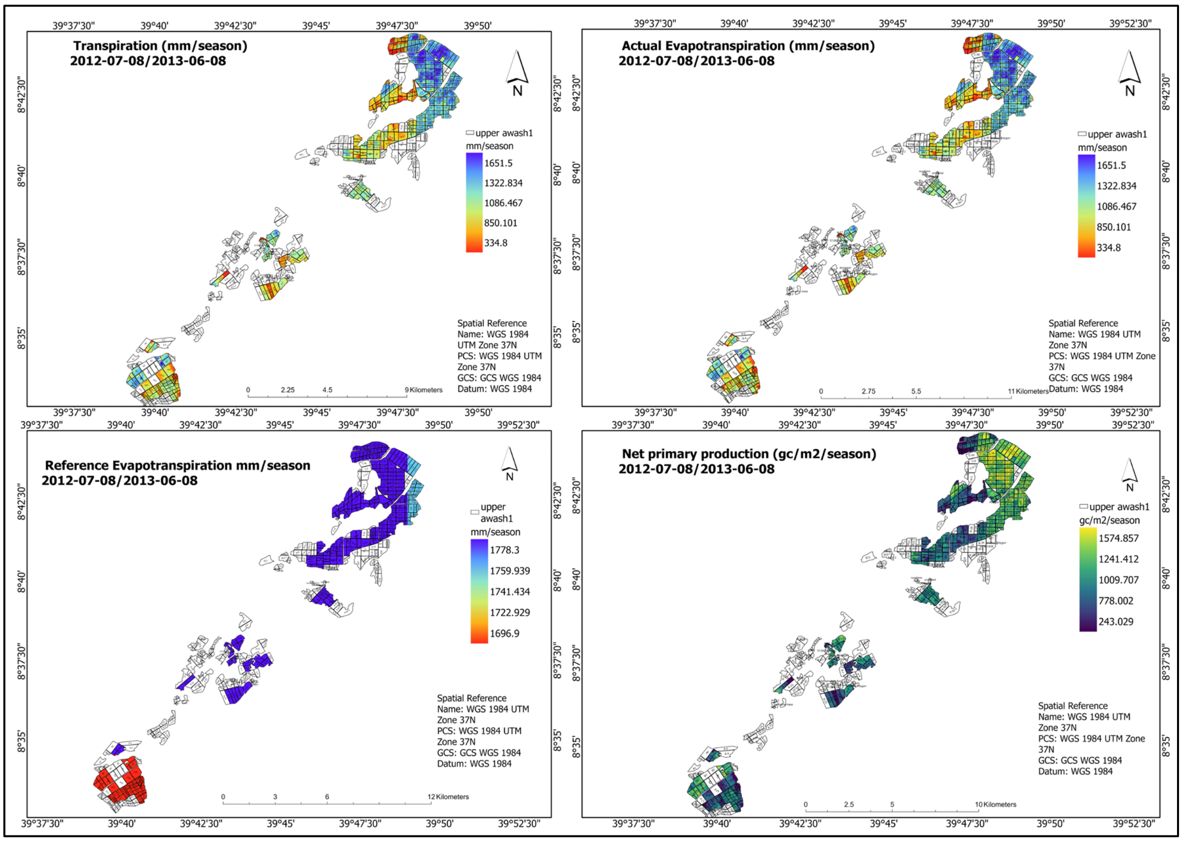


Figure 16 Water use maps T(top-left), AET (top- right), Ref (bottom-left), NPP (bottom-right 2012-2013

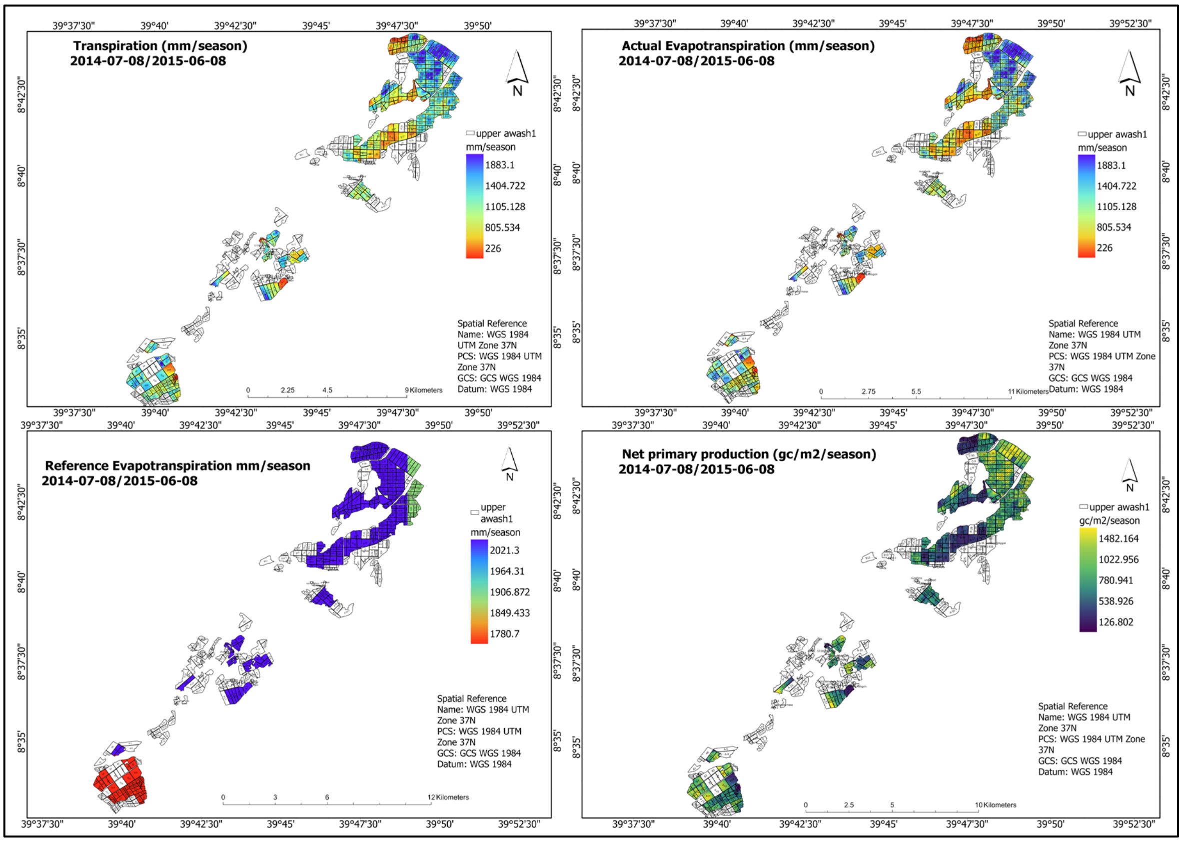


Figure 17 Water use maps T(top-left), AET (top- right), Ref (bottom-left), NPP bottom-right)- 2014-2015

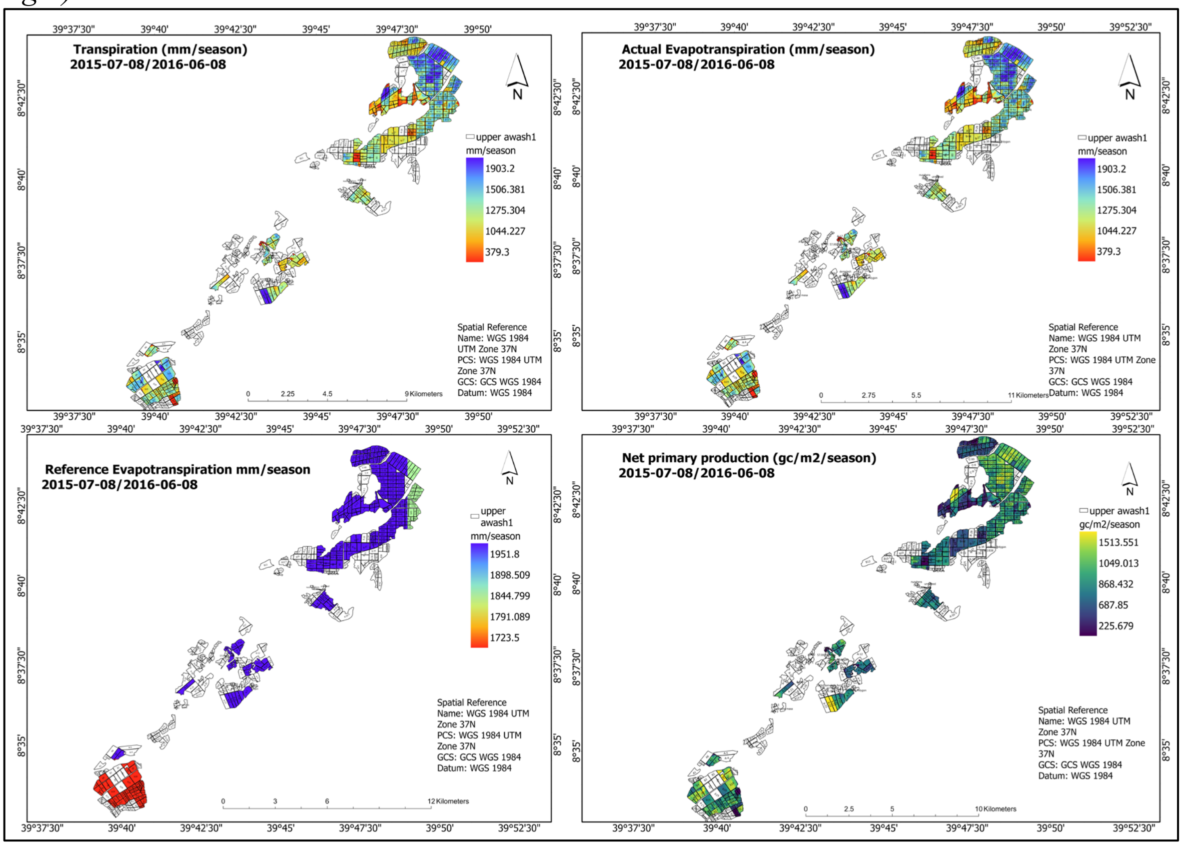


Figure 18 Water use maps T(top-left), AET (top- right), Ref (bottom-left), NPP bottom-right)- 2015-2016

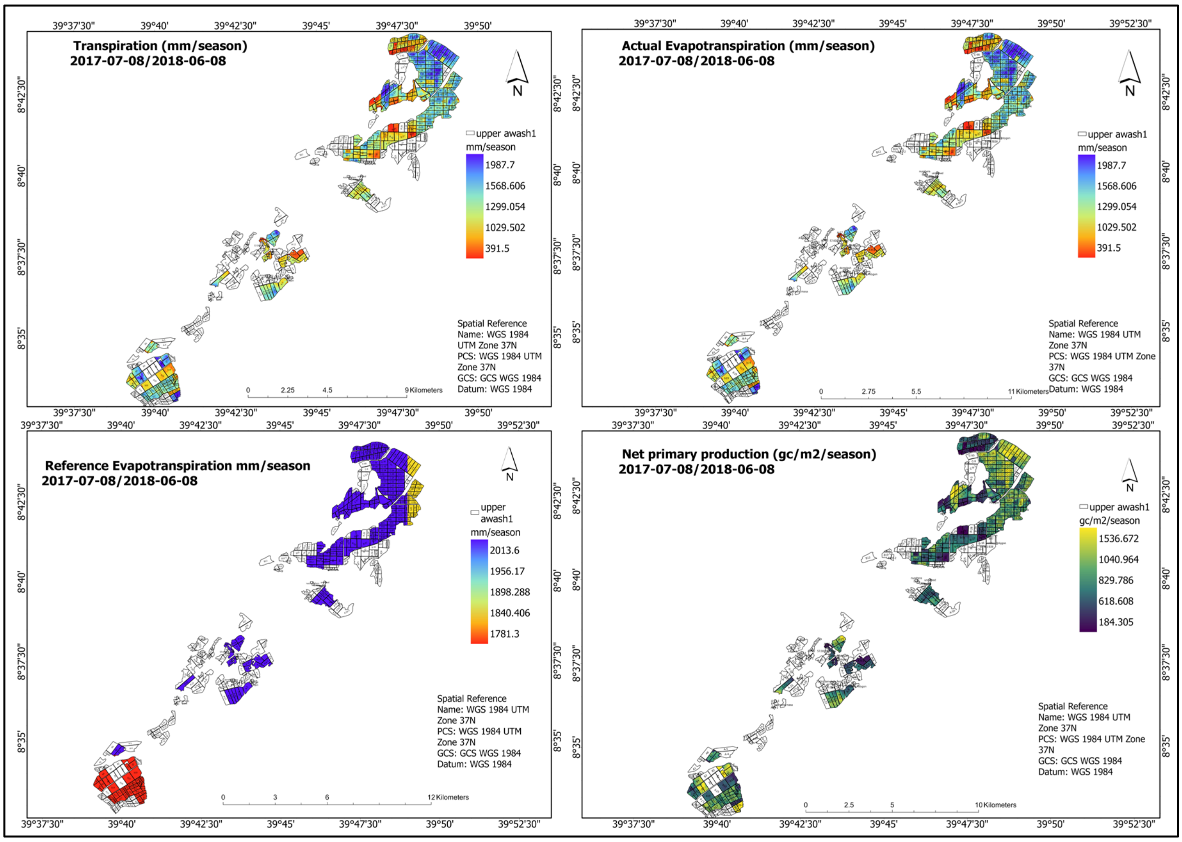


Figure 19 Water use maps T(top-left), AET (top- right), Ref (bottom-left), NPP bottom-right)- 2017-2018

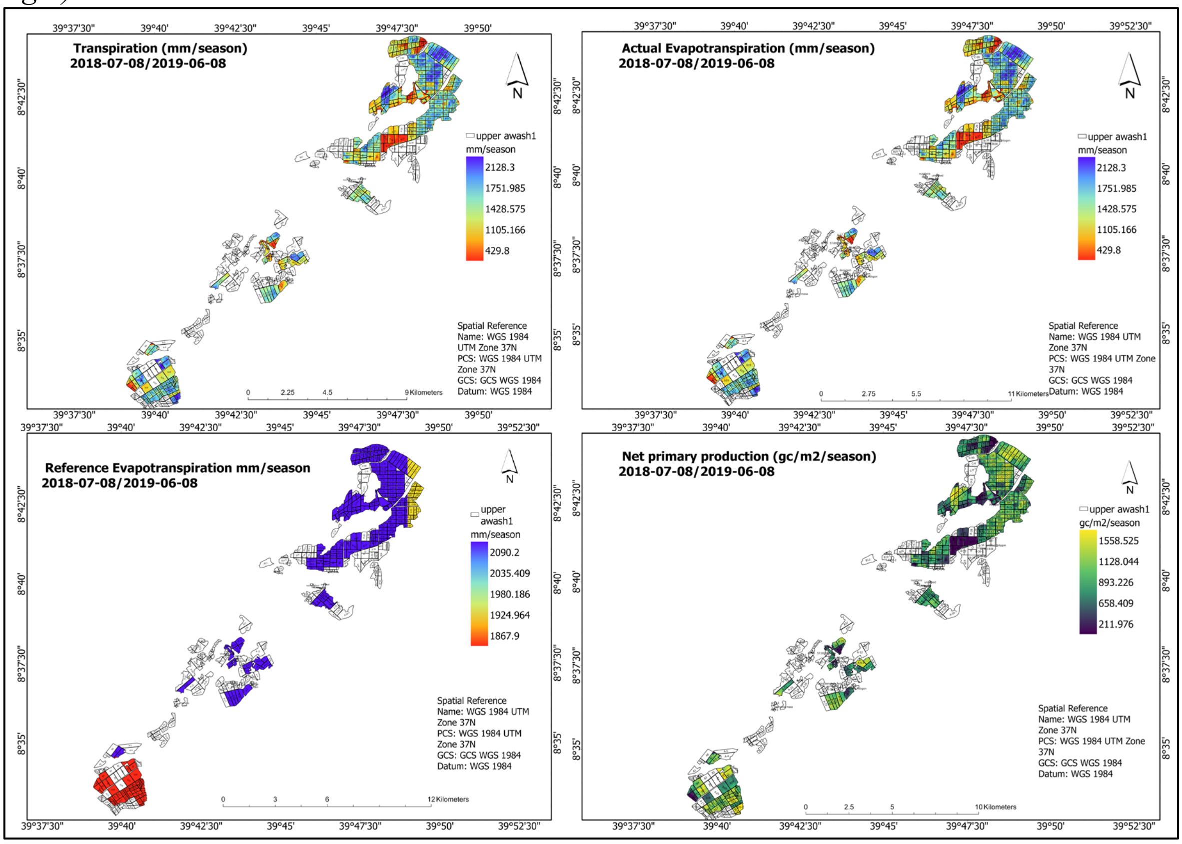


Figure 20 Water use maps T(top-left), AET (top- right), Ref (bottom-left), NPP bottom-right)- 2018-2019

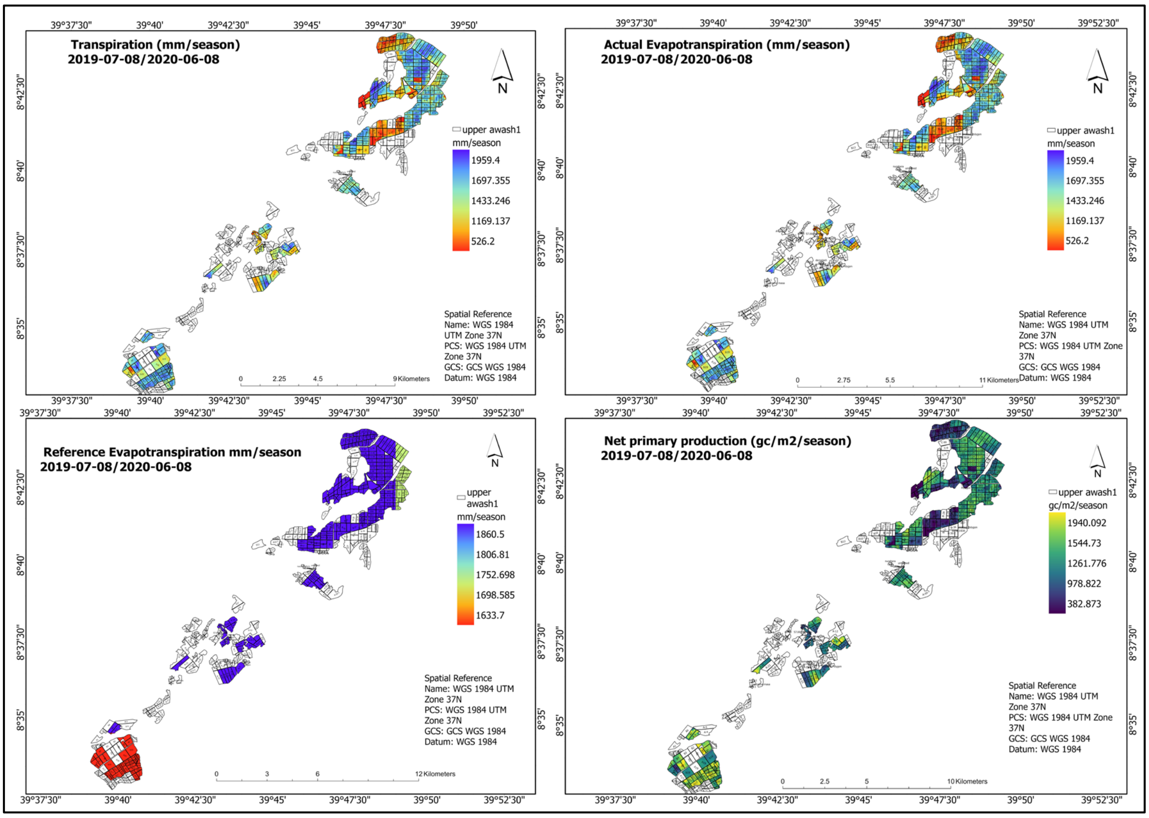


Figure 21 Water use maps T(top-left), AET (top- right), Ref (bottom-left), NPP bottom-right)- 2019-2020

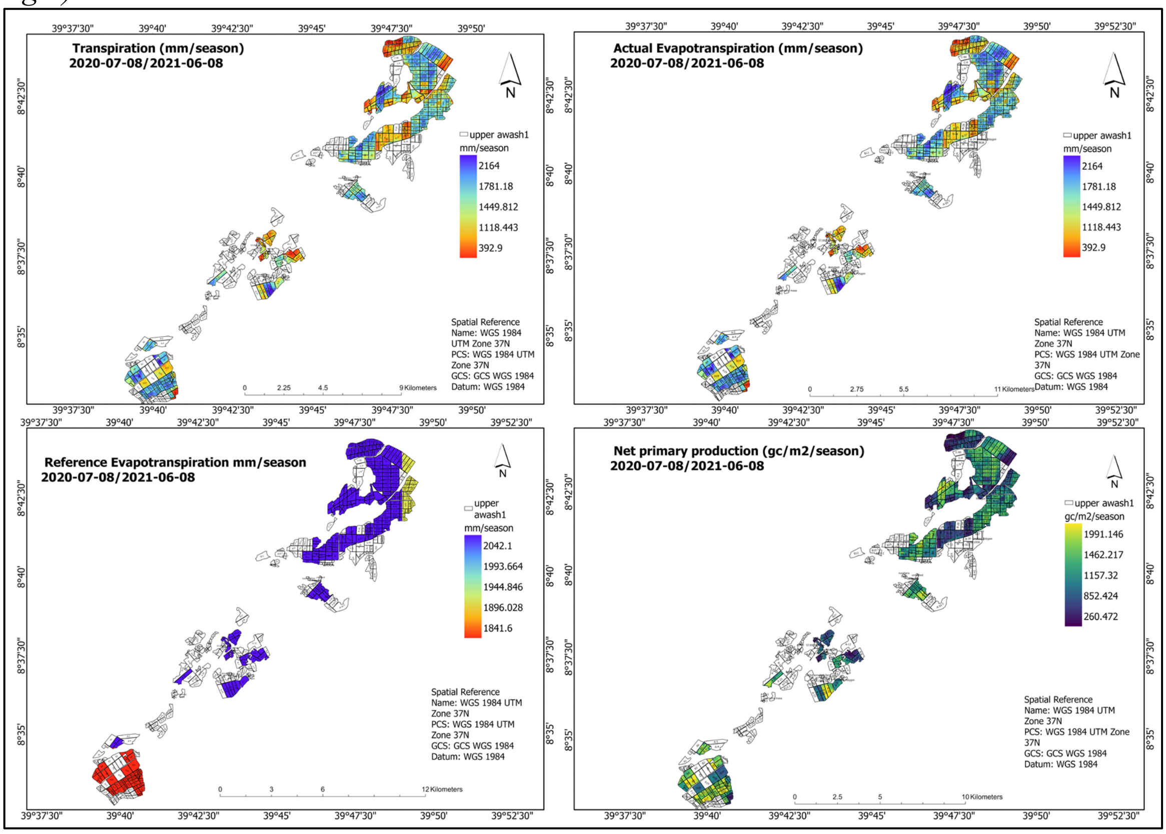


Figure 22 Water use maps T(top-left), AET (top- right), Ref (bottom-left), NPP bottom-right)- 2020-2021

4.4. Land Productivity (yield)

The estimation of citrus yield production at enterprise level is quite close to the available 3 seasons' observed yield (2015–2017). Higher productivity variance is observed in the farm over time; a decrease in productivity from 2009 to 2012 was followed by gradual increases until 2013, but a sudden drop was observed in 2014 due to the El Nio drought period. The crop seasons of 2015 to 2021 are characterized by increased production. The highest yield was observed in 2019 (50.9 tons per hectare/crop). Figure 23 depicts the temporal variation of yield over an 11-year period.

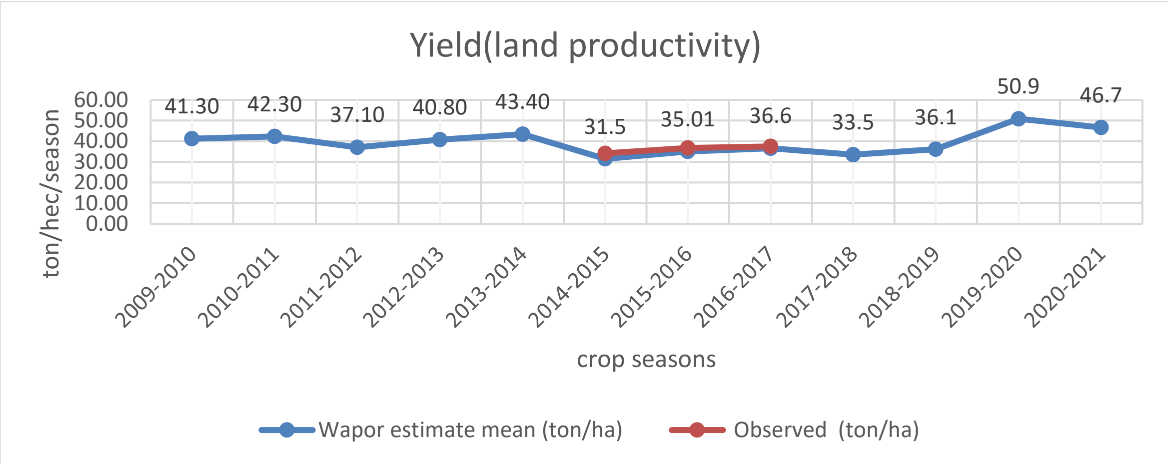


Figure 23 Land productivity (yield) 2009-2012

The annual average yield at upper awash was 39.6±6 ton/ha/year. table 8 & 9 presents the observed yield derived from WaPOR data based on the crop season over the study area.

Although the irrigation method is common (ring basin) for citrus orchards in both farms of the enterprise the water abstraction method and main canal characteristics differs; mainly pump and gabion rock fill diversion abstraction service the merti-jeju farms whereas the nurahera farm is irrigated by 32km long main canal which is heavily shared by surrounding community farms.

Water scarcity, followed by uncontrolled competition in addition to poor water and canal management, adds fuel to the problem. for the farms in the Upper Awash agricultural industry. Contrary to previous years (2009–2015), plots under the southern (Merci-Jeju) command tend to have higher agricultural yields than those under the norther. due to the very identical agronomic methods used throughout the entire farm. Other Merti Jeju's higher yields can be attributed to a variety of factors, including the young citrus orchards, their proximity to a water source, the effectiveness of the main canals for transporting water, and the quality of the land. 34–36 show the spatial distribution of yield through the enterprise.

The observed result suggests that a detailed study is required to assess the root causes of variations in yield, starting from irrigation conveyance efficiency.

Table 9 Land productivity(yield) 2009-2012

season	Enterprise level		In-situ vs Frame	Merti-Jeju		Nura-Hera	
	Estimate (ton/ha)	Observed (ton/ha)	RMSE (ton/ha)	Estimate (ton/ha)	Observed (ton/ha)	Estimate (ton/ha)	Observed (ton/ha)
2015-2016	35.01	34.172	2.36	37.15	28.945	34.119	39.4
2016-2017	36.6	36.77	2.36	37.51	31.109	36.28	42.44
2017-2018	33.5	37.5	2.36	33.397	34.072	33.4	41.037
2018-2019	36.1	-	-	38.64	-	34.99	35.594

Table 10 Twelve season Wapor estimated yield at enterprise level

	Enterprise level	
Crop season	Wapor estimate	Observed
	mean (ton/ha)	(ton/ha)
2009-2010	41.30	-
2010-2011	42.30	-
2011-2012	37.10	-
2012-2013	40.80	-
2013-2014	43.40	-
2014-2015	31.5	34.172
2015-2016	35.01	36.77
2016-2017	36.6	37.5
2017-2018	33.5	-
2018-2019	36.1	-
2019-2020	50.9	-
2020-2021	46.7	-
Mean	39.60	

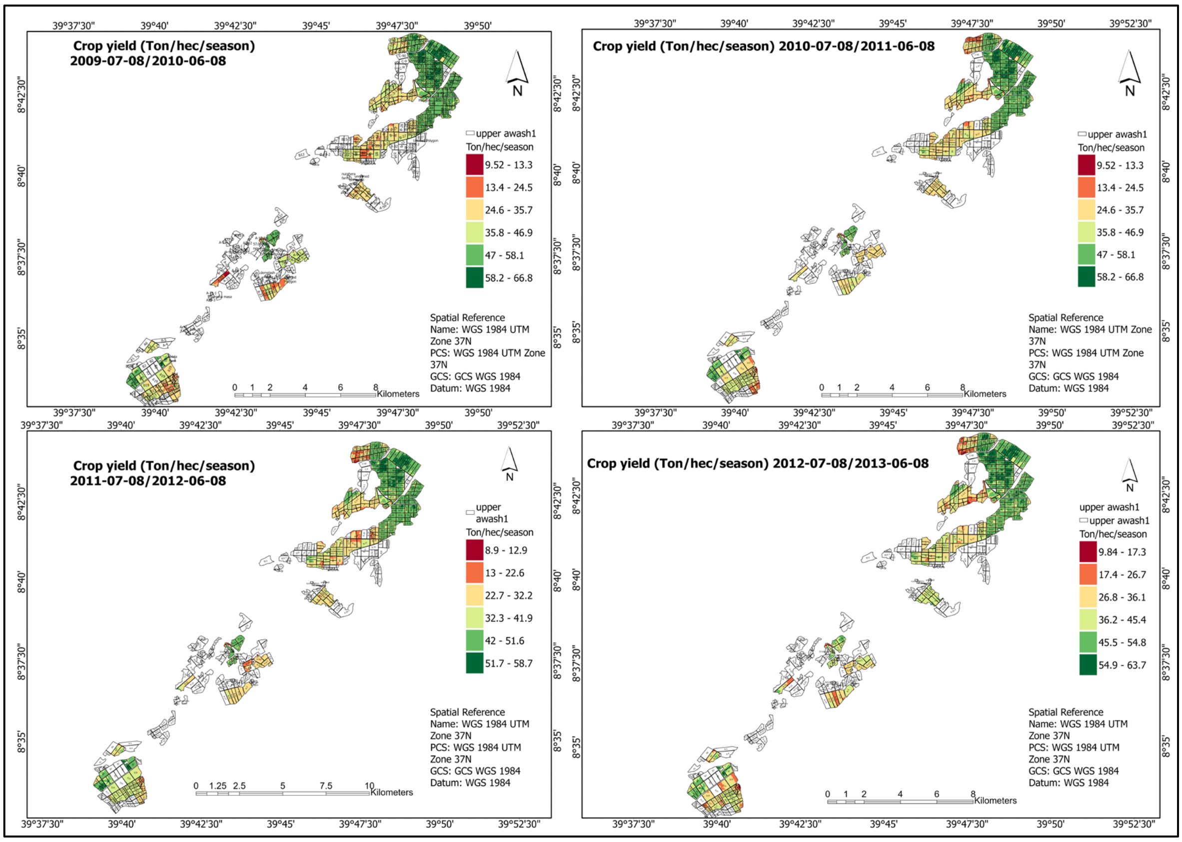


Figure 24 Land productivity (yield) 2009-2013

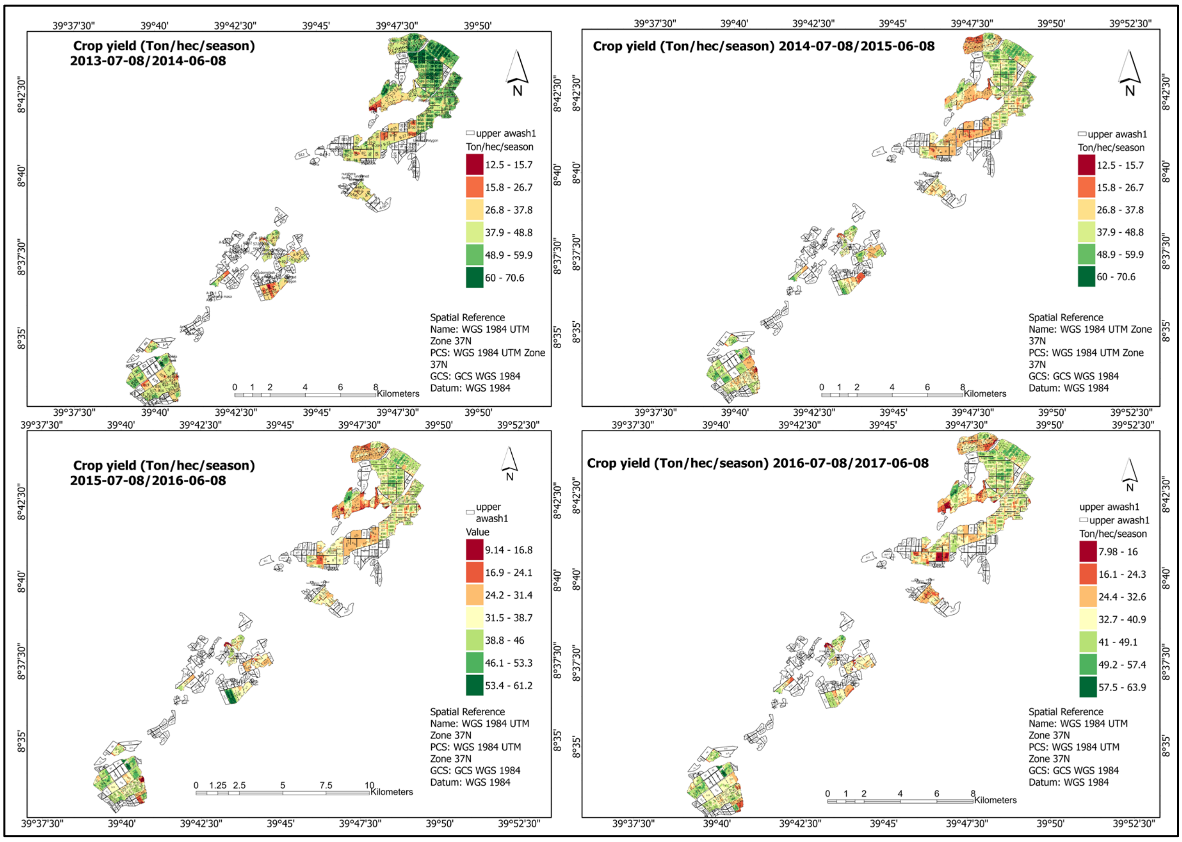


Figure 25 Land productivity (yield) 2013-2017

-

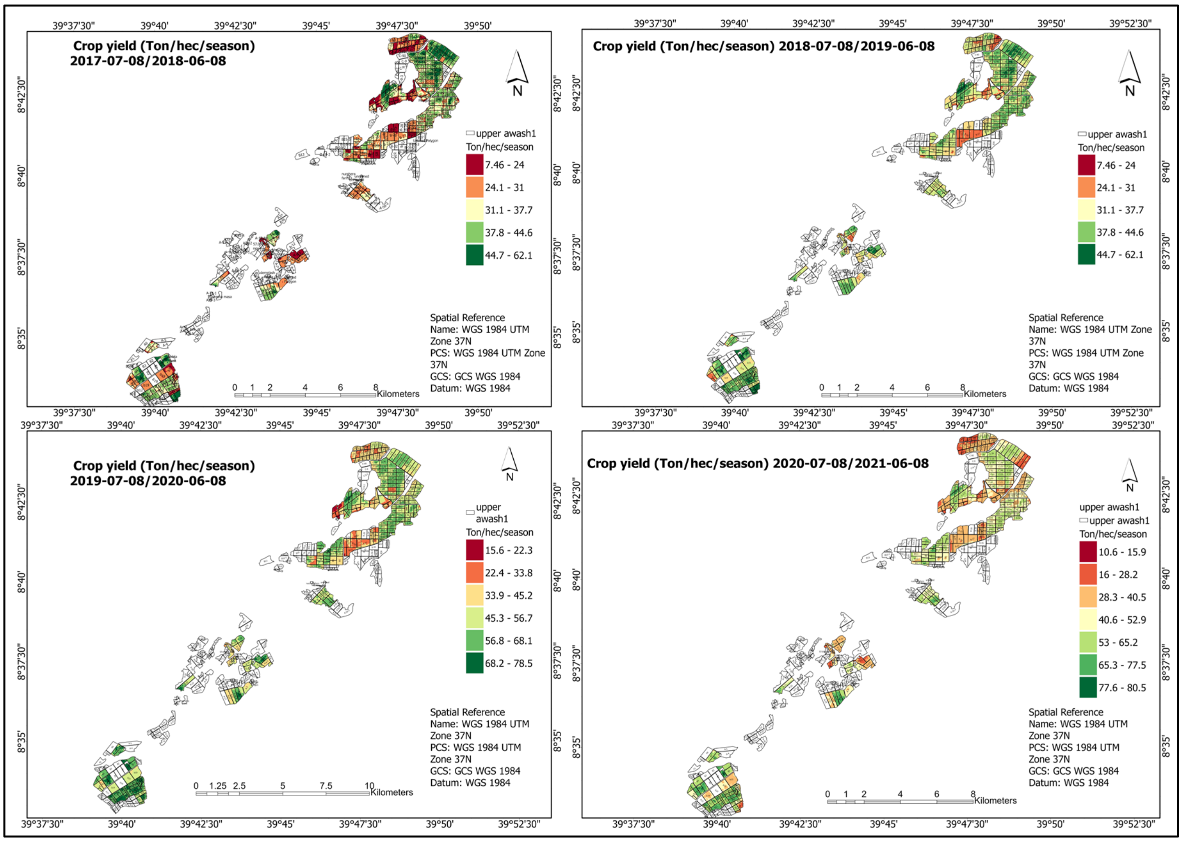


Figure 26 Land productivity (yield) 2017-2021

4.5. Crop Water Productivity (CWP)

Among many, Crop Water Productivity (CWP) is defined in this study as the amount or the value of product over volume or value of water depleted or diverted. CWP is computed as the ratio of grain yield to actual crop water use:

$$CWP = \frac{\text{Y(Crop Yield)}}{\text{Eta}} \qquad 10$$

Where, CWP is expressed in kg/m3 on a unit water volume basis, Y is grain yield (Kg/ha) and ETa (m3/ha) is actual crop evapotranspiration. Figure 28-30 illustrates UAAIE citrus plantations' water productivity throughout the course of 11 seasons. (2009/2010 to 2020/2021).

The upper awash agricultural industry's average CWP is 2.62 ± 0.25 kg/m3, with ranges of 3.2 to 2.1 kg/m3. The results showed how CWP varies with time and location, for instance, farm blocks B14, B15, B16, B17, and B18 all scored more than 3 kg/m3 in the crop season 2020–2021, in a season most of Abadiska unit farm blocks obtained higher water production. Good CWP, exceeding 3kg/m3, was shown by plots A20 & A21 of merti jeju unit 2 blocks and A2, A3 of nurahera unit 1. Most of the northern command, which is nurahera, failed to attain good water productivity, with the exception of A2 and A3 plots. Even Plots C6, C7, and C22, which has some of the highest land productivities but the lowest water productivity, perhaps as a result of the significantly higher water use. Table 10 presents the observed values from 2009-2021.

Table 11 Crop water productivity & Yield 2009-2021

	Enterprise level	
Season	Land productivity	Water productivity
	(ton/ha)	kg/m3
2009-2010	41.30	3.10
2010-2011	42.30	3.00
2011-2012	37.10	2.50
2012-2013	40.80	2.90
2013-2014	43.40	3.20
2014-2015	31.5	2.30
2015-2016	35.01	2.2
2016-2017	36.6	2.3
2017-2018	33.5	2.1
2018-2019	36.1	2.1
2019-2020	50.9	3
2020-2021	46.7	2.7
Mean	39.60	2.62

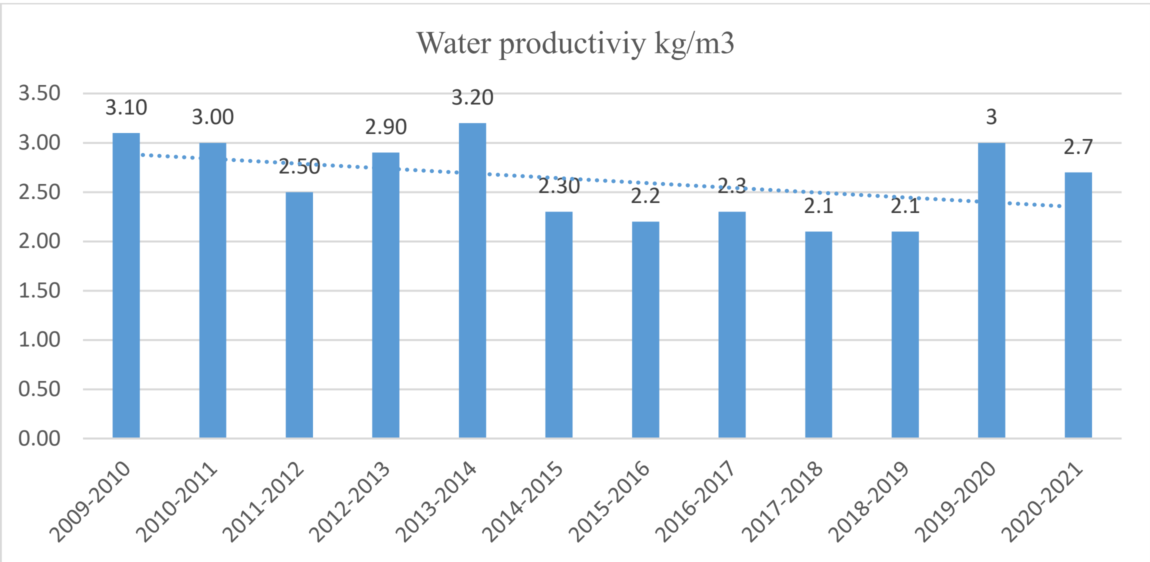


Figure 27 CWP trends 2009-2021

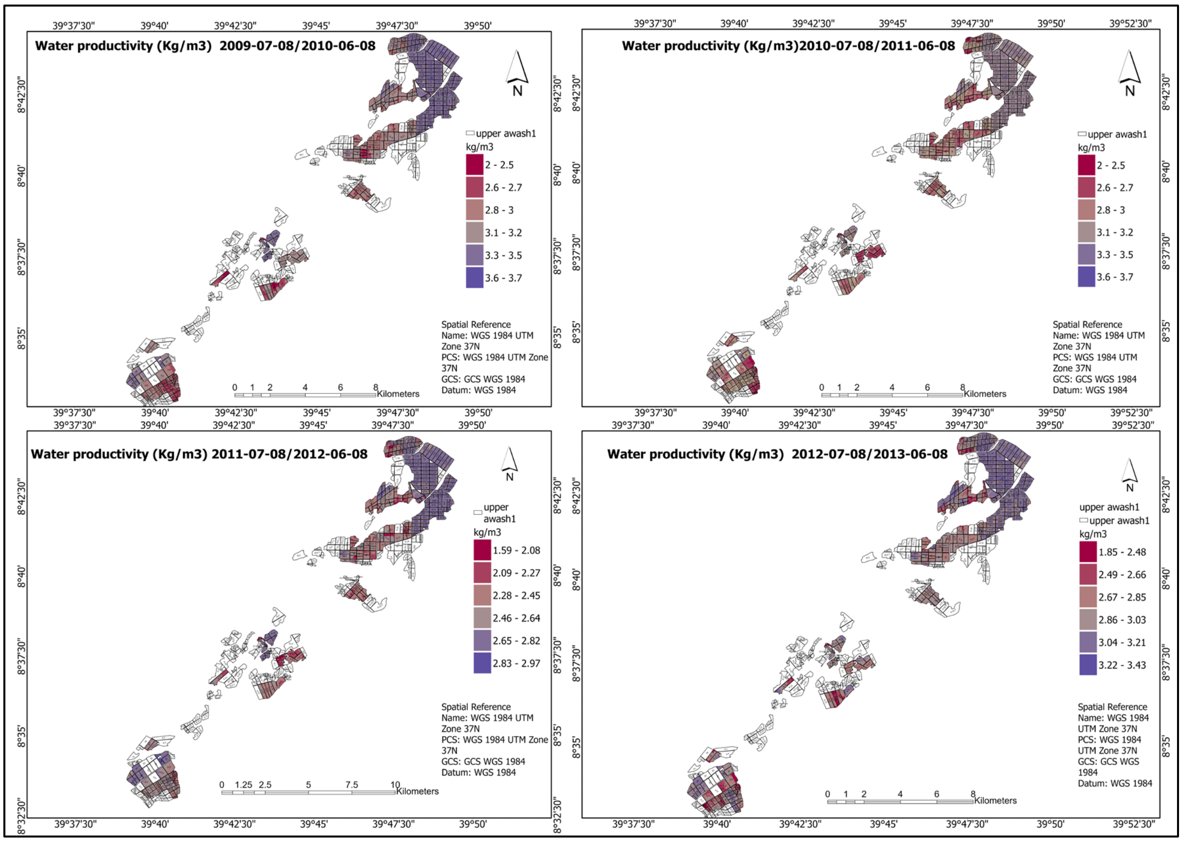


Figure 28 Crop water productivity 2009-2013

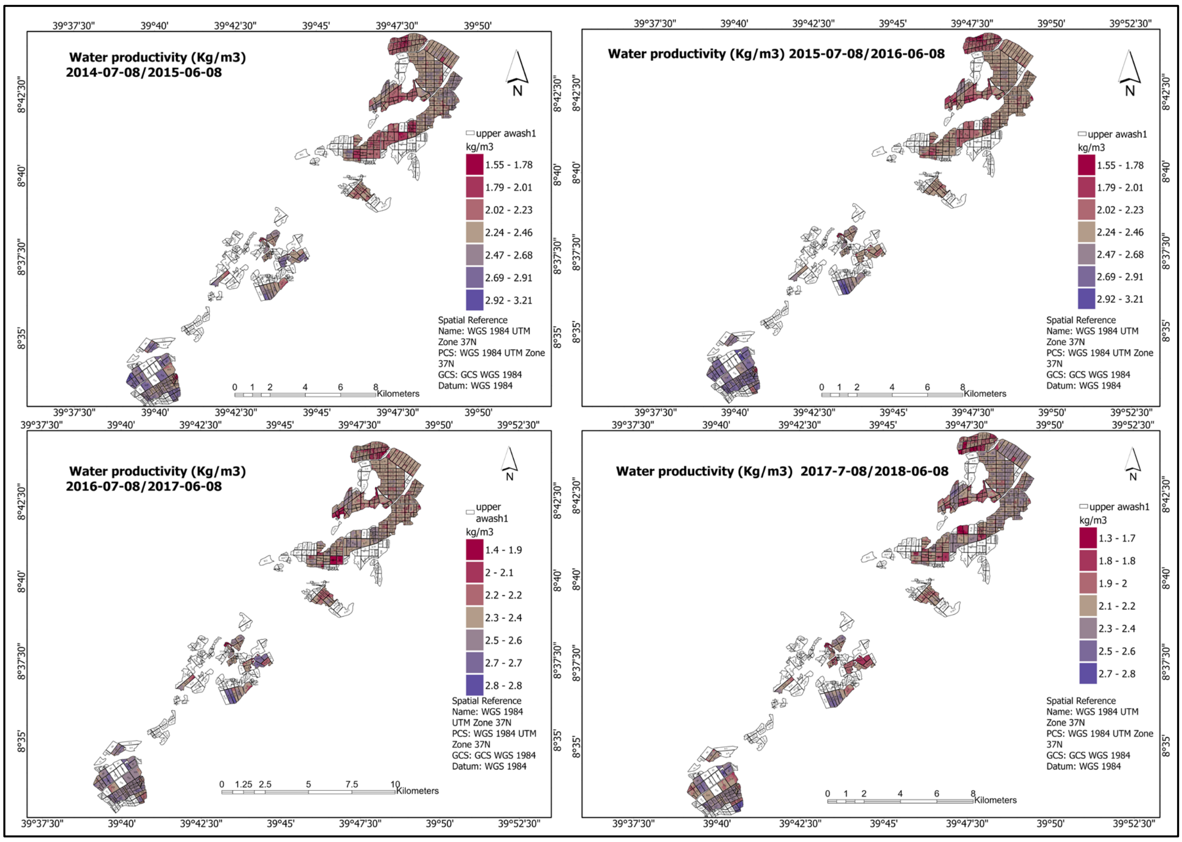


Figure 29 Crop water productivity 2013-2017

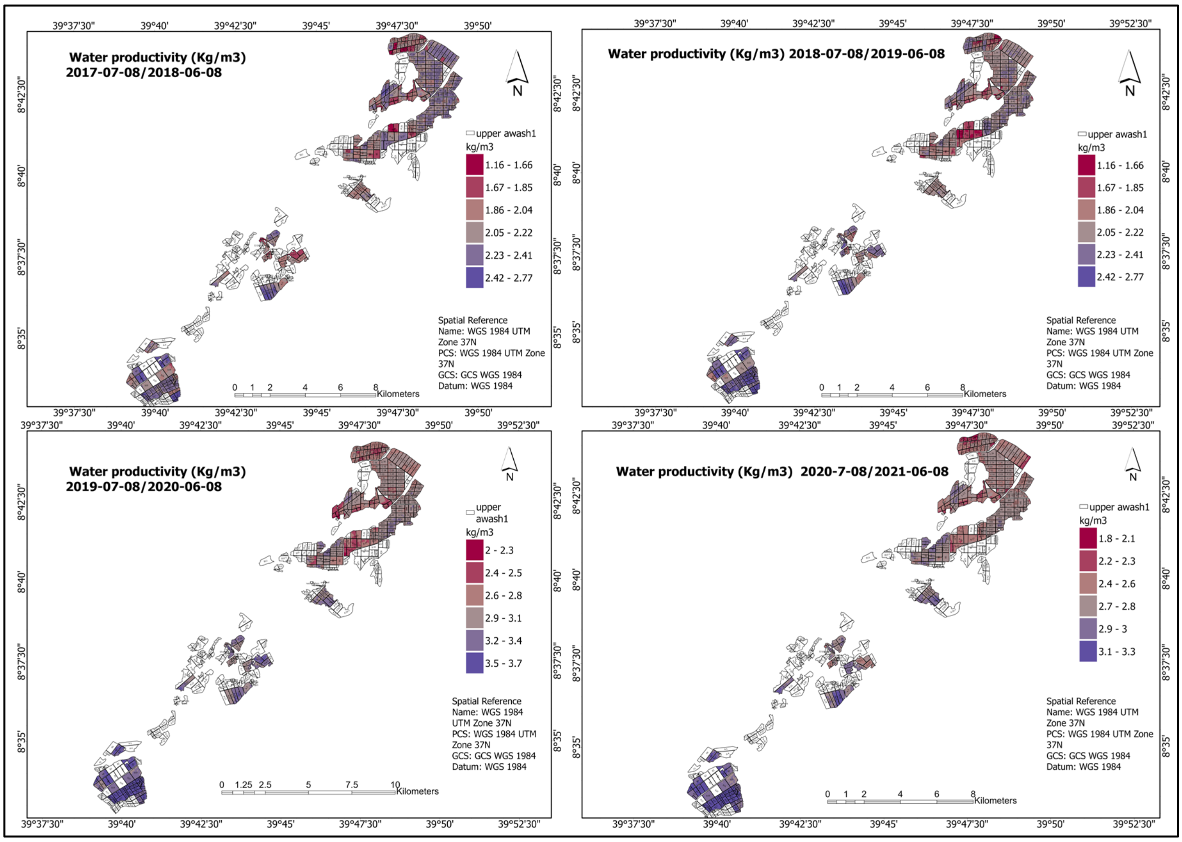


Figure 30 Crop water productivity 2017-2021

4.6. Uniformity of water consumption (Equity) and Efficiency

Equity is defined as the coefficients of variation (CV) of seasonal ETa in the study area. It evaluates how evenly a water supply is distributed in an irrigation system.(Chukalla et al., 2022)

$$CV = \frac{AETIsd}{AETI\ mean} \times 100 \qquad 11$$

CV of 0 to 10% is good, 10 to 25% is fair and CV > 25% is considered poor uniformity (Bastiaanssen et al., 1996)

Table 12 Equity of water distribution (scheme level)

Season	CV value	Designation
2014-2015	24.8	Fair Uniformity
2015-2016	15.1	Fair Uniformity
2016-2017	19	Fair Uniformity
2017-2018	18.5	Fair Uniformity
2018-2019	20.1	Fair Uniformity
2019-2020	16.5	Fair Uniformity
2020-2021	20.6	Fair Uniformity

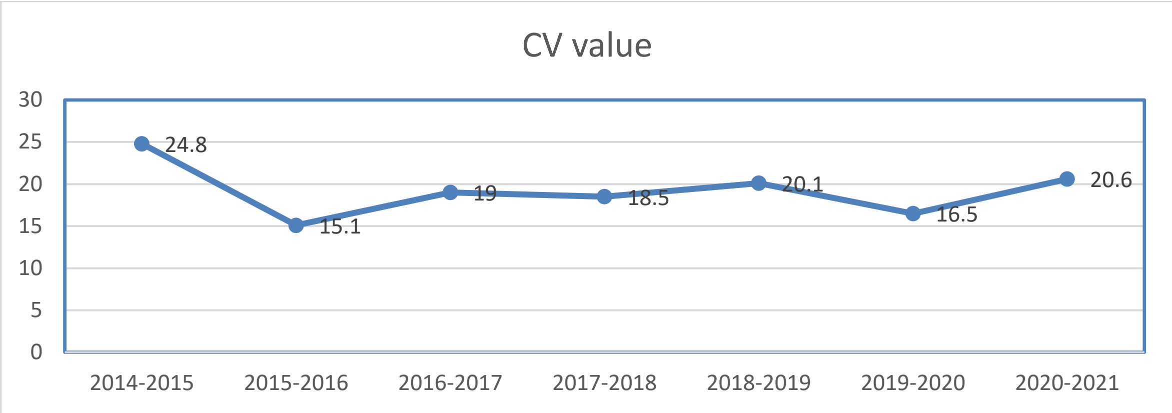


Figure 31 Temporal variation of distribution uniformity (2014-2021)

Beneficial fraction (BF) is an indication of the efficiency of on-farm irrigation and agronomic practices in converting water use to crop growth. It is the percentage of the water that is consumed as transpiration compared to overall field water consumption (ETa). (Chukalla et al., 2022)

$$Beneficialfraction = \frac{Ta}{Eta} \qquad 12$$

Overall efficiency of the farm is good at above 0.85 abadiska and southern nurahera farm units observed the highest 0.86-0.89 irrigation efficiency in the five-year average (2016-2021).

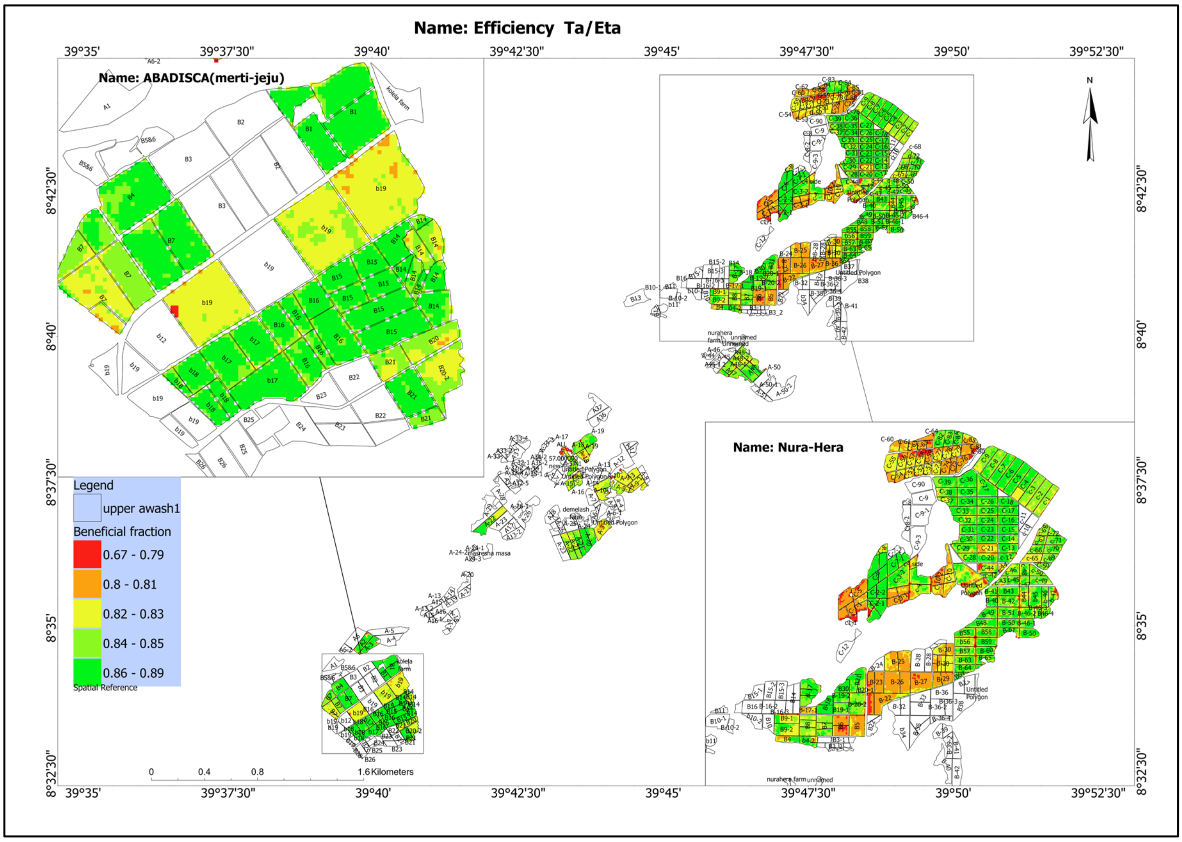


Figure 32 Efficiency (Beneficial fraction) of recent years (2016-2021)

4.7. Adequacy

Adequacy is defined as the ratio of actual evapotranspiration to the crop water requirement (ETa / ETrequired) for the purpose of the study the equation is modified to ETa / ETref. The averaged adequacy range for the last four years revealed that most farm blocks in the Abadisca unit had high adequacy values, while much of the farm blocks in southern Nurahera and Merti Jeju fell below the acceptable range. blocks such as C-1, C-5, and C-10 of the southern Nurahera unit have been found to be performing poorly. The overall adequacy performance of field water distribution under the enterprise is categorized as good (0.8-1) with a slight decrease for the drought period known as Elnino (0.7) in 2014-15.

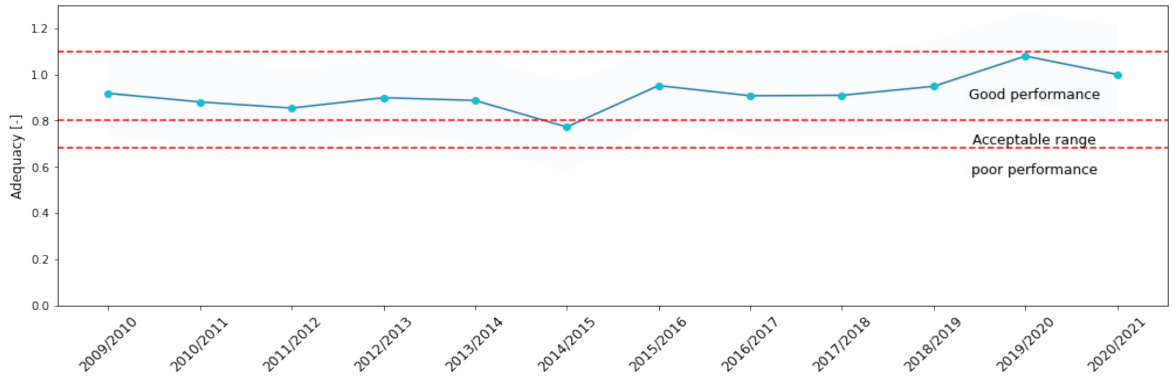


Figure 33 Temporal adequacy of the UAAIE

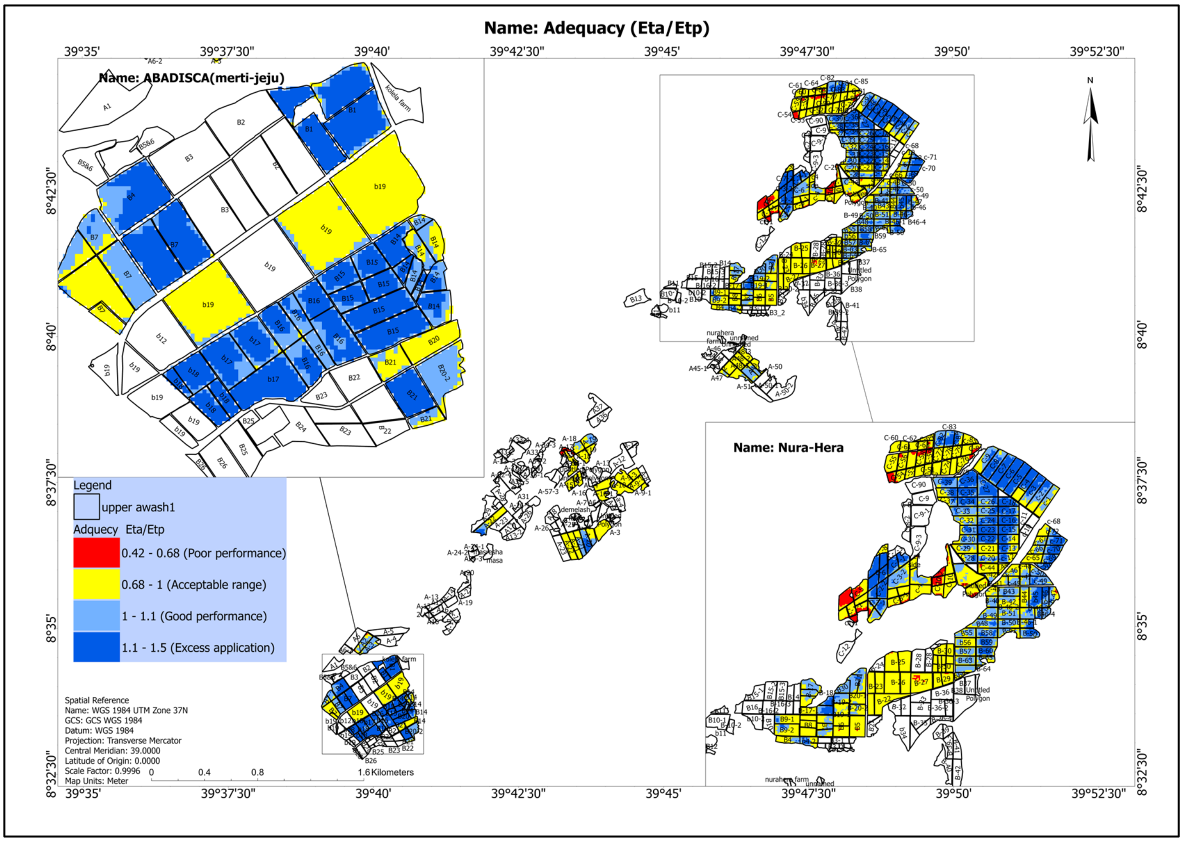


Figure 34 Spatial distribution of Adequacy at UAAIE

CONCLUSIONS AND RECOMMENDATIONS

Conclusion

The current study's objective was to use remote sensing and in-situ data to examine the degree of change in crop water productivity and citrus production with time and place in the Upper Awash agro-industry. Five data components: net primary production (NPP), actual evapotranspiration (AET), transpiration (T), precipitation (PCP), and reference evapotranspiration (Ref) of the Wapor Framework for the years 2009–2021 were extracted in ten-day intervals for each plot and used for the analysis. The study also applied a comprehensive number of performance indicators that include water consumption, uniformity, and adequacy in addition to land and water productivity. Given the remarkably good result in the correlation of estimated yield and recorded in-situ data, it is possible to say that the study effectively assessed the spatial and temporal variability of water and land productivity in citrus orchards over the course of eleven crop seasons. additional observations made;

- Inter-farm and inter-unit water consumption highly varies; the far end of the northern command known as Zemecha is the highest consumer, while comparatively lower consumption is observed in the Mertijeju and Abadiska areas, respectively. In addition to the old citrus orchards, the climate that dominates in the area (lower height and higher temperature) could probably cause the high evapotranspiration recorded at Nurahera Farm.
- Citrus productivity highly varies with temporal bound (50.9 tons/hec/season in 2020 compared to 30.5 in 2015); this could be attributed to a change in climate, agronomic practices such as fertilizer and chemical application sowing, and planting methods applied.
- Nearness to a water source has been found to be a key factor in production variances. Farms and plots near the source have shown a higher yield rate compared to those far away from water abstraction points, indicating conveyance inefficiencies.
- Farm plots such as A22 of Merti Jeju with high slope gradient differences showed varied productivity at the plot level. citrus productivity varies greatly in a single parcel in some relatively flat plots, such as A22 of Nurahera's Unit 1, ranging from 67 to 50 tons per hectare per season, indicating other biophysical factors other than slope that require additional research.

Recommendations

The study shows how plots with the highest and lowest levels of water and land productivity can be identified using RS-derived data. but unable to pinpoint the underlying causes of the variability from remote sensing because farm management, inputs, and pressures brought on by components like salt and waterlogging can affect it. More research is needed to determine the underlying reasons for the variation in land and water productivity, whether maintaining conveyance systems managing salinity and drainage effectively could close the productivity disparities.

The study assessed water consumption using remote sensing data, but in order to perform a comparative analysis, ground in situ data such as measured Etref, AETI, and irrigation water flow canal profile readings are required, which are not available, and keeping track of those critical factors is not practiced in the enterprise. This can be achieved by undertaking the in-situ pan evaporation method and AET measurements using things like flux towers.

Crop characteristics such as canopy development above ground biomass over total biomass kc should be recorded for further assessment.

The study also shows the potential use of WaPOR-derived products to assess key performance indicators such as uniformity, efficiency and adequacy that are relevant for operation and improvement of irrigation schemes.

Before planting, the irrigation network's layout (including supply canals, ring basins, and the farm's slope) should be carefully planned to prevent water logging and salinity.

Increasing the productivity per unit of ET at the plant-, field-, and farm-scale, as indicated above, by minimizing non-productive depletion of water flows by reducing water flows to sinks and minimizing salinization and pollution of return flows improving management of existing irrigation facilities and reusing return flows by controlling, diverting, and storing drainage flows

Future research may also take into account socio-economic performance indicators, such as social water productivity (e.g., employment per water use or land use) and economic water productivity (economic return per water use or land use), to conduct thorough performance evaluations of irrigation schemes.

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