ANALYSIS OF WATER PRODUCTIVITY USING WAPOR DATABASE

(CASE STUDY AL-GEZIRA SCHEME- SUDAN)

A DISSERTATION

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF MASTER OF TECHNOLOGY

IN

Hydraulics and Water Resources engineering

SUBMITTED BY

MUSTAFA MHMOUD ALHAMEEM YOUSIF

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Under the supervision of

Prof. Rakesh Kumar

CIVIL ENGINEERING DEPARTMENT

DELHI TECHNOLOGICAL UNIVERSITY

(Formerly Delhi College of Engineering) Bawana Road Delhi-110042

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Place: Delhi

Date:

Mustafa Mhmoud

ABSTRACT

The aims of this study are calculating and analyze the seasonal and spatial variability of agricultural water productivity of wheat crop in AL-Gezira irrigation scheme in Sudan by using remote sensing derived datasets. The data used in this project were collected from WaPOR, an open access portal, and content a 30m spatial resolution 10 days interval (decadal data) of Actual evapotranspiration and interception (AETI) and Net primary production (NPP). Accordingly, the average seasonal AETI and NPP was compiled for the scheme during the period from (1/11/2017) to (1/4/2018) for the first season, (1/11/2018) to (1/4/2019) for the second season, (1/11/2019) to (1/4/2020) for the third season, (1/11/2020) to (1/4/2021) for the fourth season and (1/11/2021) to (1/4/2022) for the fifth season. The results of the AETI from the first to the fifth were as follows (553.69mm, 561.964mm, 570.88mm, 279.4mm and 278.32mm) respectively. And results of crop water productivity as follows (0.34 kg/m^3, 0.13 kg/m^3, 0.15 kg/m^3, 0.1 kg/m^3, and 0.1 kg/m^3) respectively. The highest water productivity was in the first season, while the lowest water productivity was in the fourth and fifth seasons. By comparing AETI and CWP, we can see that the third season is when water is wasted and water distribution isn't adequately handled. Through AETI spatial analysis, it was found that the northeastern part of the scheme suffers from a real problem in water distribution.

CERTIFICATE

I hereby certify that the project Dissertation titled " ANALYSIS OF WATER PRODUCTIVITY USING WAPOR DATABASE" submitted by Roll number 2K20/HFE/10 of M. Tech (HRE), Delhi Technological University, Delhi in fulfilment of the requirements for the award of the degree of Master of Technology, is a record of the project carried out by students under my supervision. To the best of my knowledge, this work has never been presented for a degree or diploma at this university or anywhere else.

Place: Delhi

Date

Prof. Rakesh Kumar
(SUPERVISOR)

Table of Contents

LISTS OF TABLES

LIST OF FIGURES

ACRONYMS

RS	REMOTE SENSING
FAO	FOOD AND AGRICULTURE ORGNIZATION
WAPOR	WATER PRODUCTIVITY OPEN-ACCESS PORTAL
AETI	ACTUAL EVAPOTRANSPIRATION AND INTERCEPTION
NPP	NET PRIMARY PRODUCTION
CWP	CROP WATER PRODUCTIVITY
ET	EVAPOTRANSPIRATION
ET_0	REFERENCE EVAPOTRANSPIRATION
GWBP	GROSS WATER BIOMASS PRODUCTIVITY
RMSE	ROOT MEAN SQUARE ERROR
FWP	FAO” s WAPOR PRODUCT
PM	PEMAN-MONTEITH METHOD
KF	KOHLI AND FRENKEN METHOD
SOS	START OF SEASON
EOS	END OF SEASON
N	NUMBER OF DAYS
NPP(M)	MONTHLY NET PRIMARY PRODUCTION
NPP(S)	SEASONAL NET PRIMARY PRODUCTION
ABP	ACCUMULATED BIOMASS PRODUCTION
ABP(S)	SEASONAL BIOMASS PRODUCTION
HI	HARVEST INDEX
MC	MOISTURE CONTENT

CHAPTER 1

Introduction

1.1 Background

Water, energy, and food are all essential to human life, poverty elimination, and lengthy development (Andrews-Speed and Zhang 2019). Food security in the future while maintaining a sustainable use of water resources will be a big problem for current and future generations (Remote et al. 2018) (Blatchford et al. 2019). Population increase and migration, economic progress, and international trade are all under pressure., urbanization, Diversifying diets, cultural and technological advancements, and climate change are all expected to boost demand for freshwater, energy, and food in the coming decades, according to worldwide predictions. Water is used for agricultural production, forestry, and fisheries, as well as to produce and transport energy in various forms, throughout the entire agri-food supply chain. Agricultural production is the world's largest water user, accounting for 70% of all freshwater withdrawals. By 2050, total global water demands for irrigation are expected to increase by 10% (Andrews-Speed and Zhang 2019) (Nile and Basin 2019). Water shortage has become a major issue in many parts of the world, as water use has increased at twice the rate of population expansion in the twentieth century **(**Tantawy et al. 2018). Growing bioenergy crops in an irrigated agriculture system may assist enhance energy supply and create jobs, but it may also raise competition for land and water resources, posing a threat to local food security (Andrews-Speed and Zhang 2019).

Agriculture is a major water user, thus it's important to take care of water productivity in agriculture and work to improve it (Remote et al. 2018). The proper management of a region's water resources must have an effect on the economic, agricultural, and social development (Analysis and Assessment 2019). Systematic water productivity monitoring using Remote Sensing techniques can aid in the identification of water productivity gaps and the evaluation of viable ways to combat these gaps (Remote et al. 2018). Unfortunately, water usage efficiency in this sector is very low, with water losses surpassing 50% (Gemechu et al. 2020); as a result, huge water savings in the agricultural sector may be obtained, if we use technology to monitor water productivity.

Water productivity is defined as the ratio of net benefits from agriculture, forestry, fisheries, livestock, and mixed agricultural systems to the amount of water required to supply those benefits. It represents the goals of providing additional food, money, livelihoods and the environment advantages at a lower Per unit of water, there is a social and environmental cost consumed, where there is water consumption refers to water given to a user or water drained via means of user. Simply said, it means that you can grow more food or get more advantages with less water. Economic productivity is defined as the value derived per unit of water utilized, whereas physical water productivity is defined as the ratio of the mass of agricultural production to the amount of water used (Molden et al. 2013). Improving water productivity is frequently the most essential way for agriculture to deal with increased water demand. Systematic water productivity monitoring using Remote Sensing techniques can aid in the identification of water productivity gaps and the evaluation of viable strategies to address these gaps (Remote et al. 2018).

1.2 Study Area

Sudan is a huge African country with large rich areas, covering 597 million feddans. Only 27.8 million feddans were under agriculture, leaving around 85.5 million feddans arable. The agriculture industry is organized into two sub-sectors: modern irrigated, rain-fed mechanized, and traditional. Wheat, sorghum, and millet, for example, are classed as food crops, whereas cash crops such as cotton, groundnuts, Gum Arabic, sesame, and sugar are classified as cash crops. Cotton, wheat, peanuts, sorghum, sugar cane, and horticulture vegetable crops are all produced in the contemporary irrigated sector. The Gezira Rahad, New Halfa, White Nile schemes, as well as the Northern State, Tokar, and Gash Deltas, span around 4.5 million feddans (Bushara and Dongos 2010).

The Gezira irrigation scheme is Sudan's biggest, oldest, and most important irrigated agriculture scheme (Bushara and Dongos 2010). it is located in central Sudan, between the Blue and White Nile states, with 400 meters above Sea level (EL-Hwary and Yagoub 2011), on a muddy plain that stretches from Sennar in the south to Khartoum in the north (Anon 2021). In 1925, the Gezira Irrigation Scheme was created. and expanded in the early 1960s to its current Irrigable land capacity of 2.1 million feddans (882.000 ha). between the Blue and White Niles, roughly an hour north of Sudan's capital, Khartoum. The scheme continues to provide about 3% of the country's GDP. It employs roughly 7000 qualified administrators, technicians, scientists, clerks, and craftspeople and offers a basic livelihood to 114.000 tenant households, as well as various job prospects for 0.5–1.0 million temporary employees (Eldaw,Deutsches Institut für Entwicklungspolitik., and J*ami*at al-Jaz*irah. 2004).

The Gezira absorbs about 35 percent of the Nile resources provided to Sudan under the Nile Water Agreement with Egypt, and it covers about 42 percent of Sudan's developed irrigated area. During the last few decades, The Gezira Scheme has made a significant contribution to the country's agricultural production. Thus, the Gezira Scheme accounts for around 2/3 of Sudan's cotton exports, as well as 70%, 30%, and 12% of the country's total wheat, peanut, and sorghum production, respectively. (Eldaw et al. 2004). The climate in the Gezira Scheme is arid to semi-arid. The maximum temperature varies between 34 and 36 degrees. Celsius in January to 42 degrees Celsius in April and May, with minimum temperatures ranging from 14 degrees Celsius in January to 25 degrees Celsius in June. The typical yearly rainfall is 200-300 mm (30-year average), with the most of it falling between July and October (A.S.AL-Zubedi 2011).

The Roseires (1.9 km3) and Sennar (0.4 km3) reservoirs on the Blue Nile River are the major source of irrigation water for the Gezira Scheme. The irrigation system, which is represented by the main canals of Gezira and Managil, receives water from the reservoirs (Fig. 2). The twin major canals are 260 kilometres long (from Sennar's headwork to a shared pool at the 57-kilometer cross-regulator), with capacities of 168 and 186 m3sec-1 for Gezira and Managil, respectively, and a daily total discharge of 30.5 million m3. Each canal's water contribution system consists of a series of branch, secondary, and tertiary canals, as well as a water course known as "Abu Ashreen" (Abu 20) and a field channel known as "Abu Sitta" (Abu 6) that delivers irrigation water to the field (A.S.AL-Zubedi 2011). The Al-Gezira system is divided into 18 sections (10 in Aljazeera and 8 in Almanagil), each with 5 to 10 inspections (Taftish) covering an area of 60 to 190,000 feddan. The Aljazeera scheme's irrigation network is one of the world's largest, most interconnected, and efficient irrigation networks, with a total length of (150,680) km and consisting of two main Canals with 260 km, 11 Sub-channels (Megir) with 650 km, 107 main Canals (Canar) with 1,650 km, 1,570 km small Canals (Canals) with 8,120 km, 29,000 Abu-Ashrin Canals with 40,000 km, and Due to natural flow irrigation, it has a high efficiency in terms of performance and a low cost (Anon 2021).

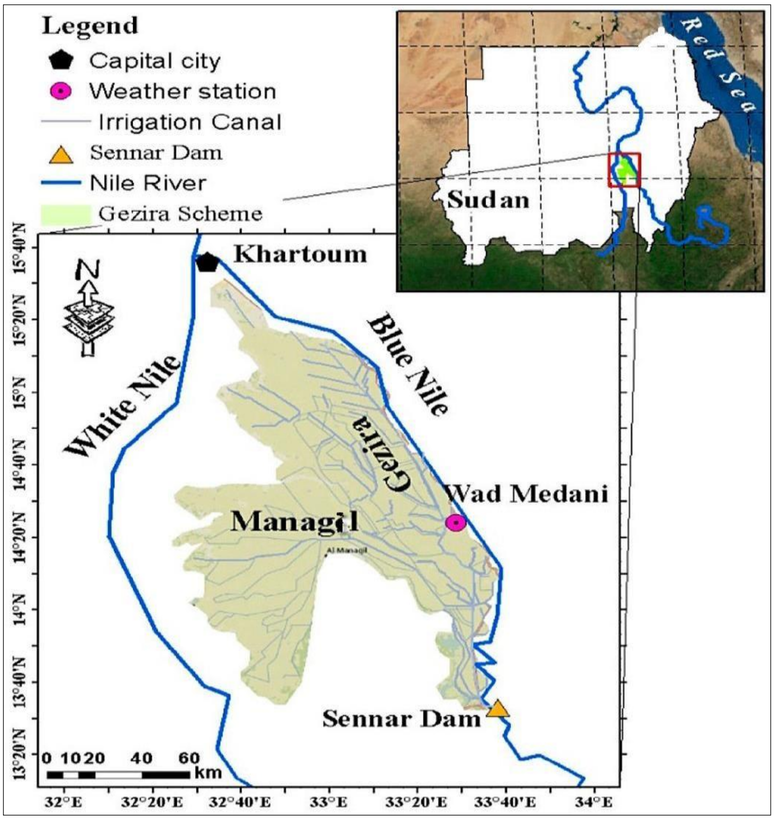


Fig.1. location map of AL-Gezira scheme in Sudan (A.S.AL-Zubedi 2011)

1.3 Wheat in the Gezira Scheme

Wheat was not in high demand in the past because the majority of the Sudanese population's diet consisted primarily on sorghum. Wheat consumption has risen recently, and the government is aiming to become self-sufficient in wheat. To achieve that goal, the cultivated area must be increased, and the greatest production from each unit volume of water (m3) utilised must be obtained. As a result, for efficient water use, labour, and capital, knowledge of the best moment to use available water is required. Wheat farming in Sudan's semi-arid environment is now a success. With the use of advanced technologies, grain yields of above 5 tons/hectare were achieved. However, a lack of yield consistency between seasons and locations has remained a problem the crop is farmed fully under irrigation, either from river flows, as in the Gezira, New Halfa, and White Nile Agricultural Schemes, or from the River Nile and wells, as in the Northern State and River Nile State. (EL-Hwary and Yagoub 2011).

Gezira had the highest area under wheat production in 1993–1994, with over 0.5 million feddans out of a total of 0.9 million feddans in Sudan, followed by the Northern State, which accounted for about 150 thousand feddans. The other producing areas, on the other hand, had a minor part of the market. The Gezira project began with large-scale wheat growing as a result of the import substitution policy. In the 1970/71 season, roughly 150 thousand feddans were planted, yielding an average of 0.085 tonnes per feddan.

Nonetheless, the Gezira Scheme's local irrigation authority, like the majority of the agricultural projects in the region, despite rivalry among many water users, declining and inadequate water resources, sedimentation, and restricted water storage capacity, the Gezira Scheme faces a number of formidable obstacles. Nonetheless, knowledge of the water balance and proposals for integrated water management are scarce in the research region. The cornerstone for making the optimum use of land and water resources is good management, and performance evaluation is an important part of that. (A.S.AL-Zubedi 2011).

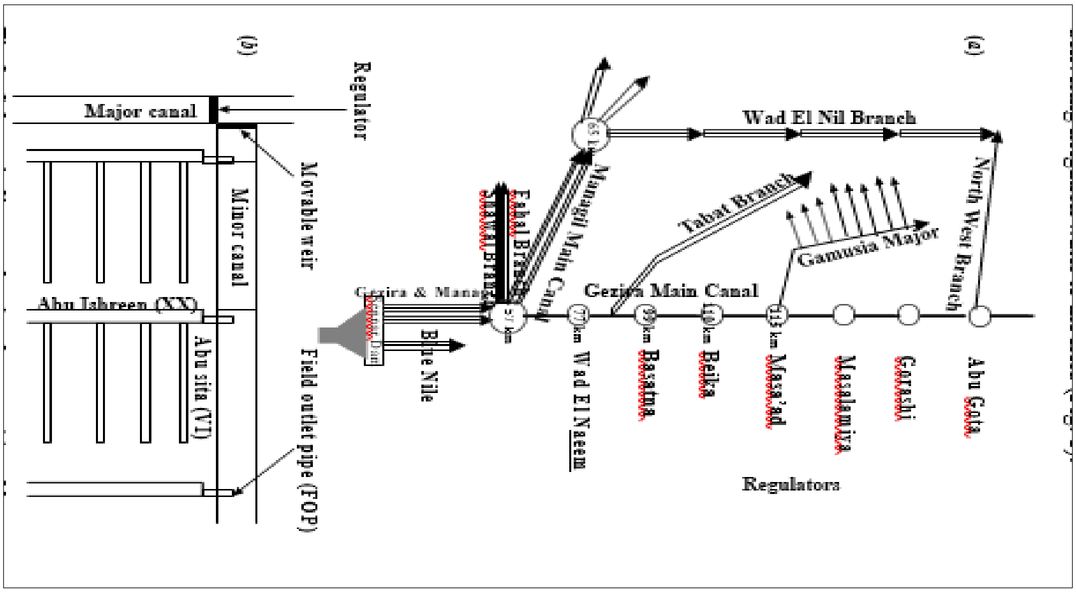


Fig.2. Schematic diagram showing the upper (*a*) and lower (*b*) systems irrigation network of the Gezira Scheme (A.S.AL-Zubedi 2011).

1.4 Remote Sensing

In remote sensing, electromagnetic radiation reflected and emitted from the Earth's surface is sampled. It interprets photos from satellites and aeroplanes to comprehend features on the Earth's surface (Ajour n.d.). Enhancing crop water productivity is a frequently recommended strategy for addressing food insecurity and water scarcity issues at the same time (WP). As a result, WP improvements have been a major policy aim for a number of international organisations, and significant public and corporate investments have been made in this area. WP analysis for agricultural monitoring is now possible thanks to advances in remote sensing. However, it appears that converting the data into actionable information will be difficult, given it just offers spatial and temporal variability in WP and no information on the reasons of the variability (Blatchford et al. 2019).

Agricultural performance may now be measured utilising remote sensing at high spatial and temporal resolutions. Remote sensing is increasingly being used to estimate agricultural performance indicators because it provides a cost-effective, repeatable way of assessment that may cover wider physical regions than in-situ methods like field water balances or ground measurements (Blatchford et al. 2019).

Water productivity can be monitored using Remote Sensing techniques to assist discover water productivity gaps and evaluate viable ways to close them (Remote et al. 2018).

Remote sensing is a powerful technique that allows for thorough analysis while requiring minimal ground data. In the best-case situation, it allows for Estimation of WP with reasonable precision, with errors ranging from 7% to 22%. Remote sensing is less expensive than ground measurements and allows for a quick scan of the WP over a vast area (Blatchford et al. 2019).

1.5 Model WaPOR

WaPOR is a website for water productivity that allows open access to data collected from remotely sensed sensors. This portal came as an output of a project titled: '(Using Remote Sensing Support of solutions to reduce agricultural water productivity gaps') (Ajour n.d.). The FAO's Water Productivity through Open Access of Remotely Sensing Derived Data (WaPOR) webpage gives users access to ten years of continuous observations over Africa and the Middle East. The portal enables for direct data inquiries, time series analysis, area statistics, and data download of key variables in irrigated and rain fed agriculture. WaPOR's beta version was released on April 20, 2017. In June 2018, a new version of WaPOR 1.0 was released, focused First, at a coarser resolution level (Level 1), encompassing all of Africa and the Near East at 250 m ground resolution, and then at a finer resolution level (Level 2), at 100 m resolution, covering all of Africa and the Near East, based on the methodological review process. This article covers the methods used to create the database at Level 3 (30 m), which was made available in August 2018 through the WaPOR Version 1.0 release (https://wapor.apps.fao.org). (Remote et al. 2018) (Blatchford et al. 2019).

The WaPOR database includes various data layers with extra information on water -0productivity, biomass production, evapotranspiration, and land cover, as well as several supplemental data layers(Remote et al. 2018).

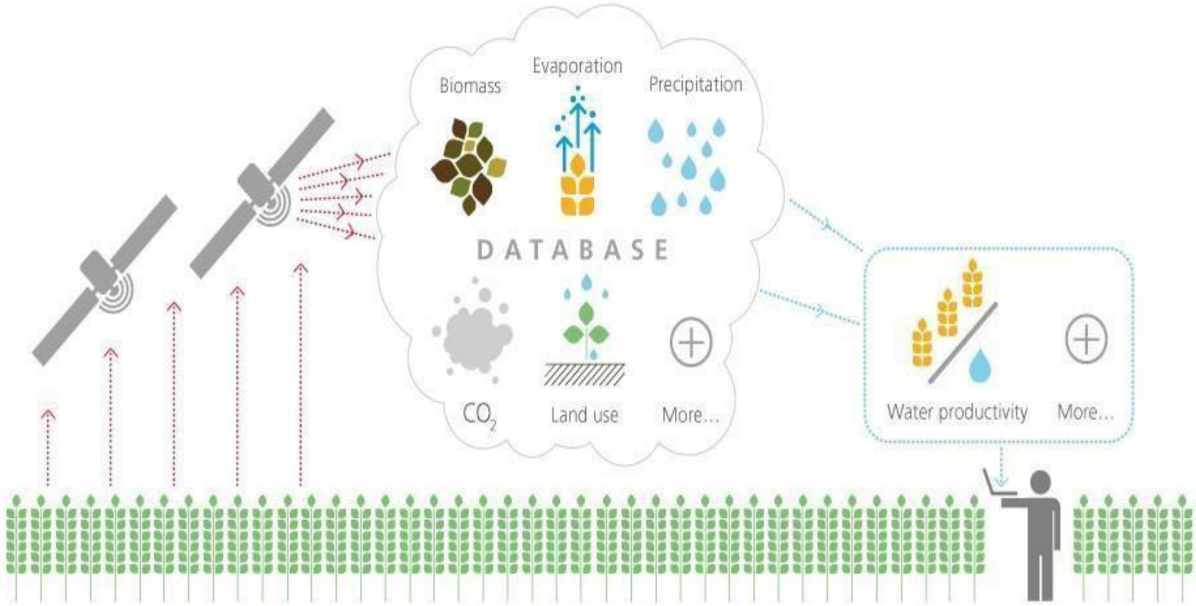


Fig .3. Impression of FAO WaPOR (Nile and Basin 2019).

WaPOR provides data with a spatial resolution of 250m for the African continent and the Near East (which represents the first level data). The database was then enhanced by the addition of second-level data with a spatial resolution of 100 metres, which included the countries and river basins listed in the table (1). Later, third-level data for five distinct irrigation systems with a spatial precision of 30m were added (shown in the table).

The accuracy as well as the total area covered by the three levels are shown in Table (1).

Dataset	**Resolution**	**Region of Interest**
Level I	~250m	Africa and the Near East (bounding box 30W, 40N, 65E, 40S)
Level II	~100m	*Countries:* Morocco, Tunisia, Egypt, Ghana, Kenya, South Sudan, Mali, Benin, Ethiopia, Rwanda, Burundi, Mozambique, Uganda, West Bank and Gaza Strip,Yemen, Jordan, Syria, and Lebanon *River Basins:* Niger, Nile, Awash, Jordan, and Litani
Level III	~30m	Irrigation schemes and rainfed areas in Egypt, Ethiopia, Mali, Sudan, and Lebanon

Table .1. Spatial resolution and designated regions of interest of the different datasets (levels).

Table 2 lists the data elements that are currently available on WaPOR. The data resolutions vary resolutions on a daily, dekad, seasonal, and yearly basis. A dekad, sometimes known as a dekadal, is a 10-day period. It divides The month is divided into three parts, the first and second dekads lasting 10 days each, and the third dekad lasting ten days lasting between eight and eleven days. A time scale that encompasses a growing season is referred to as seasonal. The length and number of growing seasons may vary, with a maximum of two each year (Nile and Basin 2019).

Data components	**Level I (~250m)**	**Level II (~100m)**	**Remarks**
Actual Evaporation (AET)	Annual/Dekadal	Annual/Dekadal	Methodology updated since June 2018 (Interception considered)
Net Primary Production (NPP)	Dekad	Dekadal	
Above Ground Biomass Production (AGBP)	Annual	Seasonal	
Phenology		Seasonal	
Reference Evaporation (RET)	Daily		Different resolution: ~5000m
Precipitation (PCP)	Daily		Different resolution: ~20000m
Transpiration (T)	Annual/Dekadal	Annual/Dekadal	
Soil Evaporation (E)*	Annual/Dekadal	Annual/Dekadal	Available since June 2018
Interception (I)*	Annual/Dekadal	Annual/Dekadal	Available since June 2018
Transpiration Fraction	Dekadal	Dekadal	
NDVI Quality Layer		Dekadal	

Gross/Net Water Productivity	Annual		Direct product from AGBP/AET (gross) and AGBP/T (net)
Land Cover Classification (LCC)*	Annual	Annual	Available since June 2018
Land Surface Temperature Quality Layer*	Dekadal	Dekadal	Available since June 2018

Table .2. Overview of the WaPOR data components per level, with temporal and spatial resolutions specified

1.6 OBJECTIVES

The main objectives of this study are First: providing an overview of AL-Gezira Irrigation scheme's water productivity. Second: calculate of water productivity indicators for wheat crop in the last five seasons. Third: analysing the spatiotemporal variability land and water productivity as well as Indicators of irrigation performance.

CHAPTER 2

LITERETURE REVIEW

(Blatchford et al. 2019) evaluated the accuracy of the remote-sensing CWP using WaPOR data against the accuracy of the estimated on-site CWP.

(Rahim et al. 2022) Present a standard approach using open source remote sensing data to diagnose the underlying causes of water yield differences, and to compare high-performance fields with low-performance fields.

(Anon 2021) He conducted a research to assess wheat farmers' agricultural methods in the Al-Jazeera scheme and their impact on area production.

(Khabba et al. n.d.) A simple model based on the light-use efficiency model is constructed in this paper. To calculate the growth and yield of irrigated winter wheat grown in semi-arid conditions.

(Ajour n.d.) The goal of study was to validate WaPOR's yield product in Lebanon's Beqaa Valley. The research was divided into two categories. In one field, the yield of potatoes and wheat planted in 2017-2018 was certified. In addition, yields of barley, vetch, barley/vetch mixed fields, and vetch/oat mixed fields planted between 2012 and 2019 were validated in the other field by comparing yields provided by farmers. This validation was carried out using statistical indicators such as % relative error (RE), Root Mean Square Error (RMSE), R2, correlation (r), and bias.

(Gemechu et al. 2020) By using remote sensing derived datasets, this work focused on mapping the seasonal and spatial variability of agricultural water productivity of sugarcane crop in three big irrigation schemes in Ethiopia (Wonji, Fincha'a, and Metahara). WaPOR, an open access portal, provided the datasets for this investigation, which contained a 100m spatial resolution 10days interval (decadal data) of Net Primary Production (NPP) and Actual Evapotranspiration and Interception (AETI).

(Geshnigani, Mirabbasi, and Golabi 2021) in this study the reference evapotranspiration (RET) data from the FAO's WaPOR product (FWP) is compared to the corresponding values estimated using the Modified Hargreaves-Samani (MHS) and Penman-Monteith (PM) methods.

(Golabi, Niksokhan, and Radmanesh 2020) This study used the Kohli and Frenken (KF) method and the KF modified (MKF) method (for the modification of this method, level

I (250 m) reference evapotranspiration (RET) data were obtained from the FAO's WaPOR Product (FWP), which is a ready product based on remote sensing (RS)) were used to estimate reservoir evaporation (RE) in seventeen stations in Iran over a nine-year period.

(Blatchford et al. 2018) This study provides a CWP framework that takes advantage of remote sensing's spatiotemporal availability to identify CWP goals and sub-indicators specific to the domain's demands.

(Soares, Folhes, and Renno 2009) This study assesses the utility of a method for determining the amount of water used in an irrigated area in Ceara'. During two months of the agricultural season, the experiment, which mimics evapotranspiration (ET), was conducted within the Jaguaribe-Apodi irrigation project (DIJA). Internalized Calibration and the model Mapping Evapotranspiration at High Resolution were used to calculate the ET (METRIC). The model estimates ET for each pixel in the image using the residual of the energy balance equation.

(Jalilvand et al. 2019) a novel approach is provided in this work that uses satellite soil moisture data to estimate irrigation water use at the watershed size.

(Blatchford et al. 2020) This study analyzed the impact of the geographic evaluation scale on irrigation performance indicators in small and medium-sized agriculture is examined Three performance indicators are evaluated in five irrigation schemes for three spatial resolutions: 250 m, 100 m, and 30 m: adequacy (i.e., sufficiency of water use to meet the crop water requirement), equity (i.e., fairness of irrigation distribution), and productivity (i.e., unit of physical crop production/yield per unit water consumption).

(Rost et al. 2009) This modelling study investigates the potential for increasing global crop production through on-farm water management strategies such as (a) reducing soil evaporation ('vapour shift') and (b) collecting runoff on cropland and using it during dry spells ('runoff harvesting')—spatially explicitly, for current and projected future climate, and for different management intensity levels.

(Nile and Basin 2019) The project focuses on quantifying monthly water withdrawals for irrigation and measuring physical water productivity of the principal irrigated crops within Sudan, Egypt, and Ethiopia's so-called AgroEcological Zones.

(Elshaikh et al. 2018) The goal of this research is to provide a complete evaluation of the effects of policies and institutional structures on irrigation management performance. The Gezira Scheme is the case study.

(Javadian et al. 2019) Compare two ET products appropriate for regional investigation at high spatial resolution in this study: The FAO's recent WaPOR product and the METRIC methodology. WaPOR is based on ETLook, a two-source model that uses microwave pictures as input.

(Guzinski et al. 2021) During the evolution of the WaPOR portal, the goal of this project is to assess the suitability of using Copernicus data (Sentinel-2 and Sentinel-3 observations, as well as the ERA5 meteorological model) to build high-resolution, national-scale ET maps. In comparison to MODIS-based WaPOR maps, Copernicus-based maps reveal broadly similar ET patterns to WaPOR maps across climatic and land-use gradients while giving more accurate and detailed field-level estimates.

(Dissertation 2021) The goal of this study was to use a water productivity tool to assess the risks and possibilities in rice production in Cameroon, as well as to examine farmers' perceptions of those risks and opportunities. The potential of the Highlands zone and the Sudano-Sahel zones were assessed through a review of literature and field trips. Crop water requirements and gross water biomass productivity (GWBP) were also studied using the CROPWAT model and the WaPOR portal, respectively.

(Gebremedhin et al. 2022) Direct field estimates of potential evapotranspiration (PET) are difficult to come by due to their high cost and lack of geographical representativeness. PET can also be calculated remotely as a product of reference evapotranspiration (ETo) and the land use-land cover (LULC) factor (Kc). The objectives of this work were to: I validate satellite-derived Daily Reference Evapotranspiration (DMETREF-ETos); ii) correct the advection-bias of DMETREF-ETos in comparison to in-situ FAO Penman-Monteith ETo (FAO-ETog); and iii) convert the bias-corrected DMETREF-ETos into PET. The DMETREF-ETos was validated using 1-year daily data from four ATMOS 41 weather stations. PET was validated using data from the FAO Water Productivity Open-access Portal (WaPOR) during the wet season.

CHAPTER 3

METHODOLOGY

3.1 Collecting water productivity data

The FAO Open Access Portal for Water Productivity (https://wapor.apps.fao.org).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 in near real-time for the sub-Saharan African, Middle East, and North African regions between 2009 and today(Chuckalla et al. 2020). WaPOR version 2.1 (30 m spatial resolution) was used to download 10-day intervals of Net Primary Production (NPP), Actual Evapotranspiration, and Interception for this study (AETI).

3.2 Calculating Actual evapotranspiration and interception (AETI)

Evapotranspiration is the sum of the soil evaporation, canopy transpiration and interception (Chuckalla et al. 2020) (Remote et al. 2018). The actual evapotranspiration values are obtained from the WaPOR portal in the dekdal period (10 days). The seasonal actual evapotranspiration values are obtained by the equation:

$$\mathrm{AETI(s)} = \sum_{\mathrm{SOS}}^{\mathrm{EOS}} \mathrm{AETI(d)} \qquad \text{equation (1)}$$

Where:

AETI(s) is the seasonal actual evapotranspiration (mm/season).

AETI(d) is the actual evapotranspiration and interception obtained from WaPOR portal (mm).

SOS is start of season.

EOS is end of season.

3.3 calculating Net primary production (NPP)

Net Primary Production (NPP) is a key feature of an ecosystem that expresses the photosynthesis-driven conversion of carbon dioxide into biomass (Remote et al. 2018). To To determine the amount of fresh wheat crop from the study area. The dekadal value (10 days) for The WaPOR portal was used to acquire net primary production, which was then transformed into monthly statistics by multiplying the average daily data by the number of months. Then, using monthly data, calculate the seasonal value.

Net Primary Production (NPP) is a key feature of an ecosystem that expresses the photosynthesis-driven conversion of carbon dioxide into biomass (Remote et al. 2018).

$$\mathrm{NPP(D)} = \mathrm{NPP} * \mathrm{n} \qquad \text{equation (2)}$$

Where:

NPP(D) is the dekadal net primary production (g/m^2).

NPP is the net primary production which is obtained from WaPOR portal (g/m^2).

n is the number of days in each calendar month.

$$\mathrm{NPP(M)} = \sum \mathrm{NPP(D)} \qquad \text{equation (3)}$$

$$\mathrm{NPP(S)} = \sum \mathrm{NPP(M)} \qquad \text{equation (4)}$$

Where:

NPP(M) is monthly net primary production (g/m^2).

NPP(S) is seasonal net primary production (g/m^2).

3.4 calculating yield of wheat

To calculate yield of wheat it is important to calculate accumulated biomass production by following equation:

$$ABP(S) = \frac{NPP(S)}{0.45} \qquad \text{equation}(5)$$

Where:

ABP(S) is seasonal biomass production (kg/ha).

0.45 is an adjustment factor used to convert net primary production to total biomass production.

After that calculate fresh yield of wheat by applying the following equation:

$$Y = \frac{\frac{ABP(S) * HI}{1 - MC}}{100} \qquad \text{equation (6)}$$

Where:

Y is fresh wheat yield (ton/ha).

HI is harvest index.

MC is moisture content.

3.5 Crop water productivity calculation

Calculate crop water productivity is obtained by applying the following equation:

$$CWP = \frac{Y}{AETI(s)} * 100 \qquad \text{equation (7)}$$

Where:

Y is yield of wheat is in kg/ha.

AETI(s) is actual evapotranspiration and interception (m^3).

CWP is crop water productivity is in kg/m^3.

3.6 Cropping seasons

The yield of harvesting wheat crop was taken from the Al-Jezira agricultural scheme, and the growth period or the age of the crop was estimated from the first of November to the first of April, and then the harvest phase begins where the plant does not need water. The 5 months actual evapotranspiration and interception (AETI) and also net primary production (NPP) data were derived using the 10 days interval (decadal) WaPOR data set to analyze the water productivity at irrigation scheme. The following table shows the dates of start seasons and end of seasons

Season	Start of season	End of season
1	1/11/2017	1/4/2018
2	1/11/2018	1/4/2019
3	1/11/2019	1/4/2020
4	1/11/2020	1/4/2021
5	1/11/2021	1/4/2022

Table .3. shows start of season and end of season

3.7 Harvest index and Moisture content

The harvest index (HI) is a measure of reproductive efficiency based on the ratio of grain to total shoot dry matter (Porker, Straight, and Hunt 2020). The harvest index is used to distinguish between harvestable and non-harvestable biomass output Crop yield and crop water productivity can be calculated using the harvest index in general, the harvest index is used to evaluate a plant variety's productivity by quantifying how much biomass production contributes to the harvestable fraction of a crop (yield) (Remote et al. 2018).

Parameter	Description	Value	Source
HI	Harvest index	0.48	(Remote et al. 2018)
MC	Moisture content	15%	(Elaleem et al. 2018) (Remote et al. 2018)

Table .4. parameters used in analysis.

CHAPTER 4

RESULTS AND DISCUTION

4.1 RESULTS

4.1.1 actual evapotranspiration and interception (AETI)

The values of **AETI** are shown in the fig (4). Where the value of **AETI** in first season is 553.69mm, second season is 561.964mm, third season is 570.8873mm, fourth season is 279.422mm and the fifth season is 278.32mm.

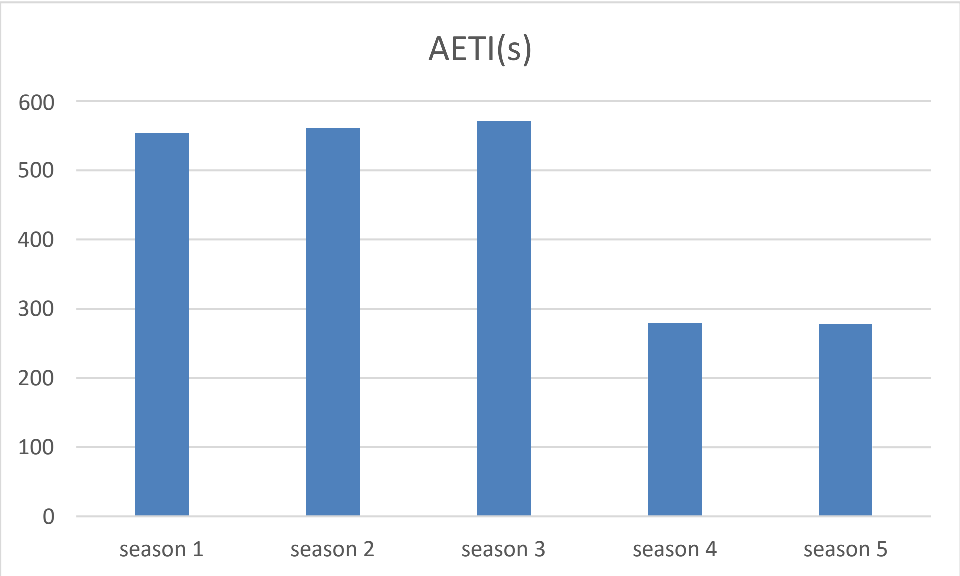


Fig .4. values of actual evapotranspiration and interception.

Season	Season 1	Season 2	Season 3	Season 4	Season 5
AETI (mm)	553.69	561.964	570.887	279.422	278.32

Table .5. values of actual evapotranspiration and interception(mm).

4.1.2 Net primary production (NPP)

The values of **NPP** are shown in the fig (5). Where the value of **NPP** in first season is 156.07g/m^2, second season is 129.04 g/m^2, third season is 157.58 g/m^2, fourth season is 51.95 g/m^2 and the fifth season is 49.9 g/m^2 mm.

Season	Season 1	Season 2	Season 3	Season 4	Season 5
NPP(g/m^2)	156.07	129.04	157.58	51.95	49.9

Table.6. values of net primary production(g/m^2).

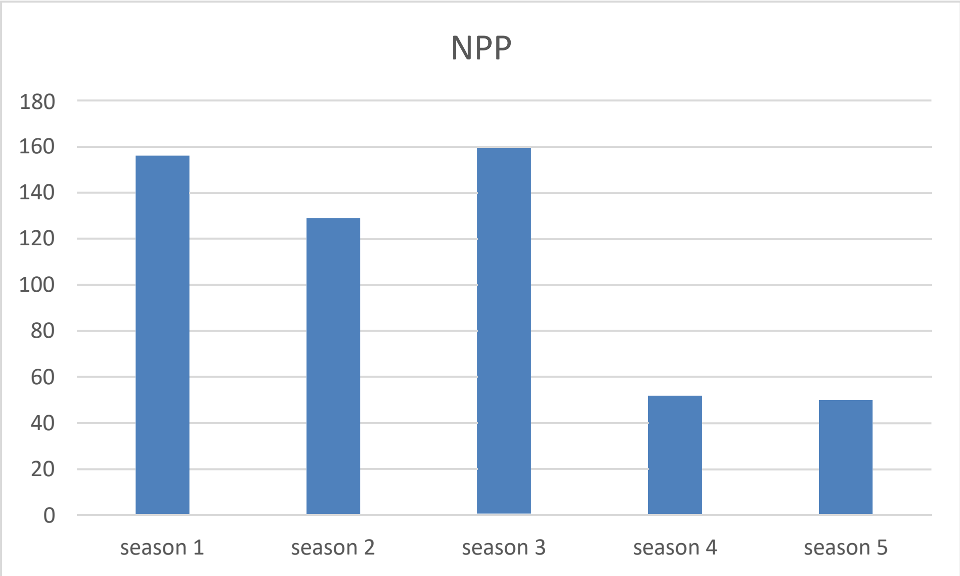


Fig .5. values of net primary production.

4.1.3 Accumulated biomass production (ABP)

The values of **ABP** are shown in the fig (6). Where the value of **ABP** in first season is 346.82kg/ha, second season is 286.75kg/ha, third season is 350.18kg/ha, fourth season is 115.44kg/ha and the fifth season is 110.88kg/ha.

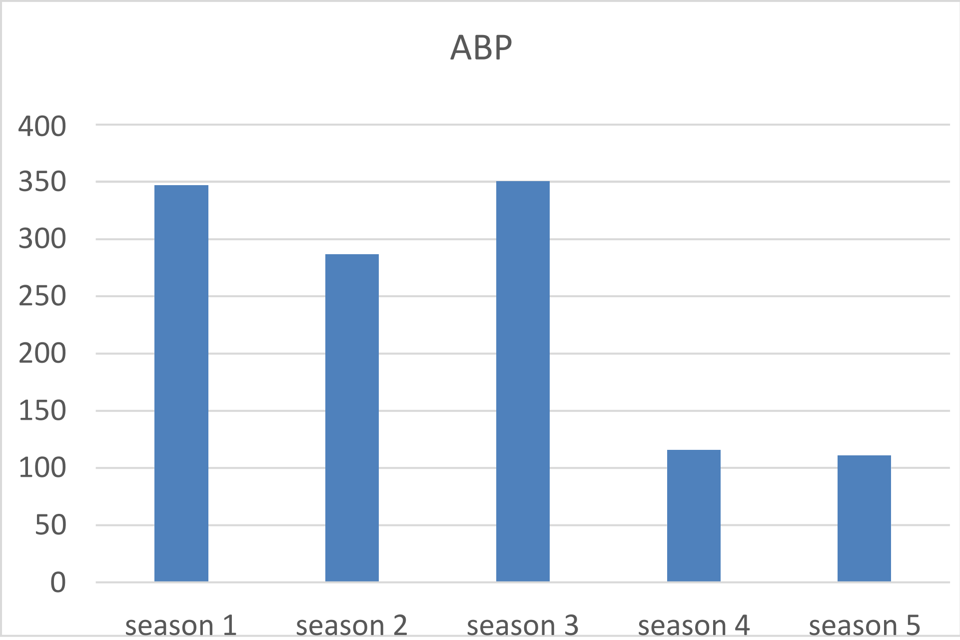


Fig.6. values of accumulated biomass production(kg/ha).

Season	Season 1	Season 2	Season 3	Season 4	Season 5
ABP (kg/ha**)**	346.82	286.75	350.18	115.44	110.88

Table.7. accumulated biomass production(kg/ha).

4.1.4 Fresh yield of wheat

The values of **Y** are shown in the fig (7). Where the value of **Y** in first season is 1.9 ton/ha, second season is 0.728ton/ha, third season is 0.89 ton/ha, fourth season is 0.29 ton/ha and the fifth season is 0.28 ton/ha.

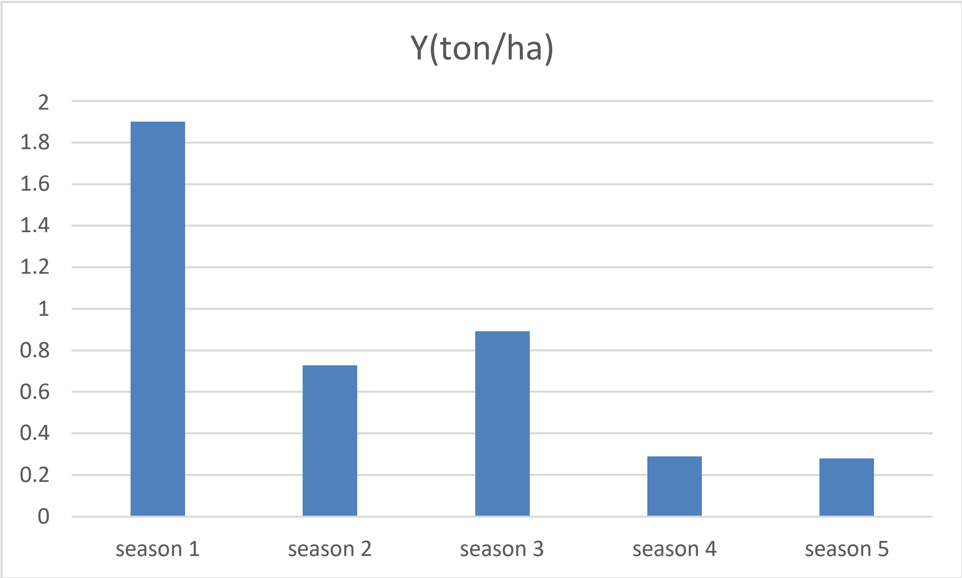


Fig.7. values of fresh yield production of wheat(ton/ha).

Season	Season 1	Season 2	Season 3	Season 4	Season 5
Y(ton/ha)	1.9	0.728	0.89	0.29	0.28

Table.8. fresh yield of wheat(ton/ha).

4.1.5 Crop water productivity (CWP)

The values of **CWP** are shown in the fig (8). Where the value of **CWP** in first season is 0.34 kg/m^3, second season is 0.13kg/ m^3, third season is 0.15kg/ m^3, fourth season is 0.1 kg/m^3 and the fifth season is 0.1 kg/m^3.

Season	Season 1	Season 2	Season 3	Season 4	Season 5
Cwp(kg/m^3**)**	0.34	0.13	0.15	0.1	0.1

Table.9. crop water productivity (kg/m^3)

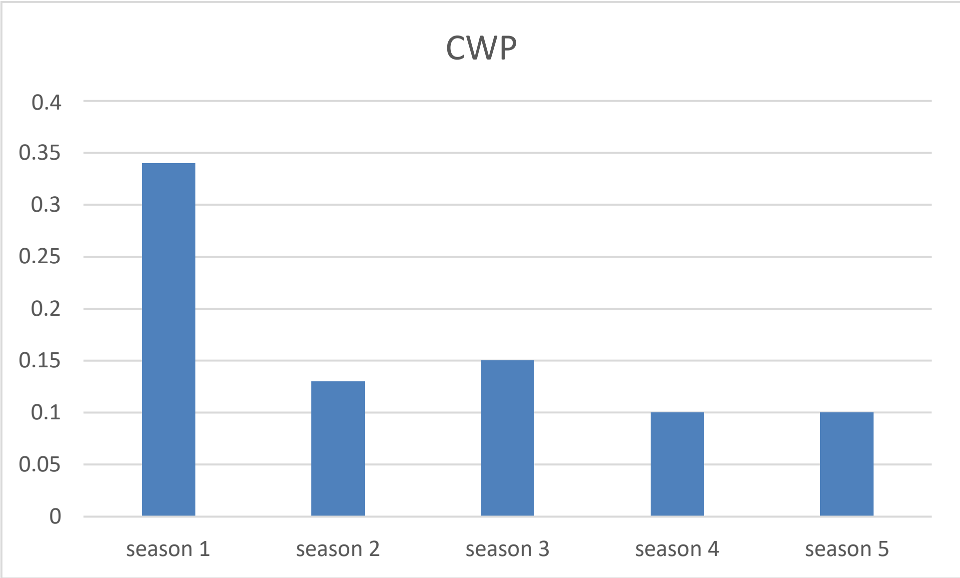


Fig.8. values of crop water productivity.

4.2 DISCUSSION

The spatial and temporal (seasonal) variability of actual evapotranspiration is analyzed for AL-Gezira scheme from 1/11/2017 to 1/4/2018 (season 1), 1/11/2018 to 1/4/2019 (season 2), 1/11/2019 to 1/4/2020 (season 3), 1/11/2020 to 1/4/2021 (season 4) and 1/11/2021 to 14/2022 (season 5). and it is a period during which the wheat crop is planted. and presented the values of AETI in AL-Gezira scheme through different sites was show some variation during season 1 high AETI this indicates that the water productivity in this season was high compared to the rest seasons. in season 4 and 5 the water productivity was less compared to others seasons. The third season shows that AETI had the highest value compared to the preceding seasons, but the water productivity was poor, indicating that there was a lot of water waste.

It was also noted that the value of AETI is nearly non-existent or zero in some sections of the scheme, for example, in the eastern and northeastern sides, the value of AETI is very low in the first and second seasons, but equal to zero in the third, fourth, and fifth seasons. The decline or lack of AETI implies that water productivity is non-existent in these locations, implying that there is a serious problem with water distribution.

Fig.9. actual evapotranspiration and interception (season1)

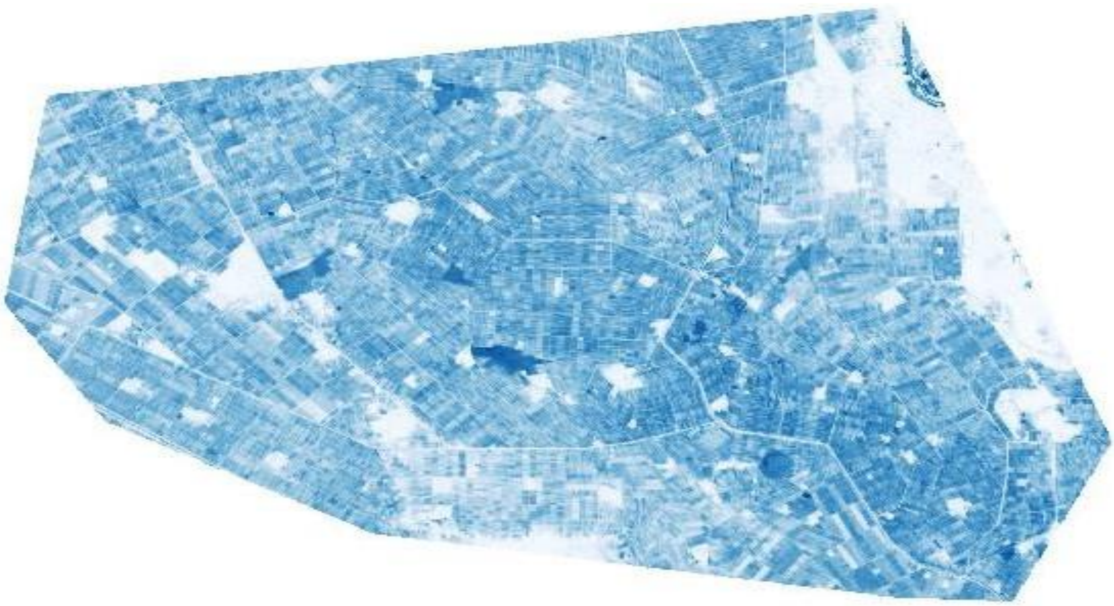


Fig.10. actual evapotranspiration and interception (season2)

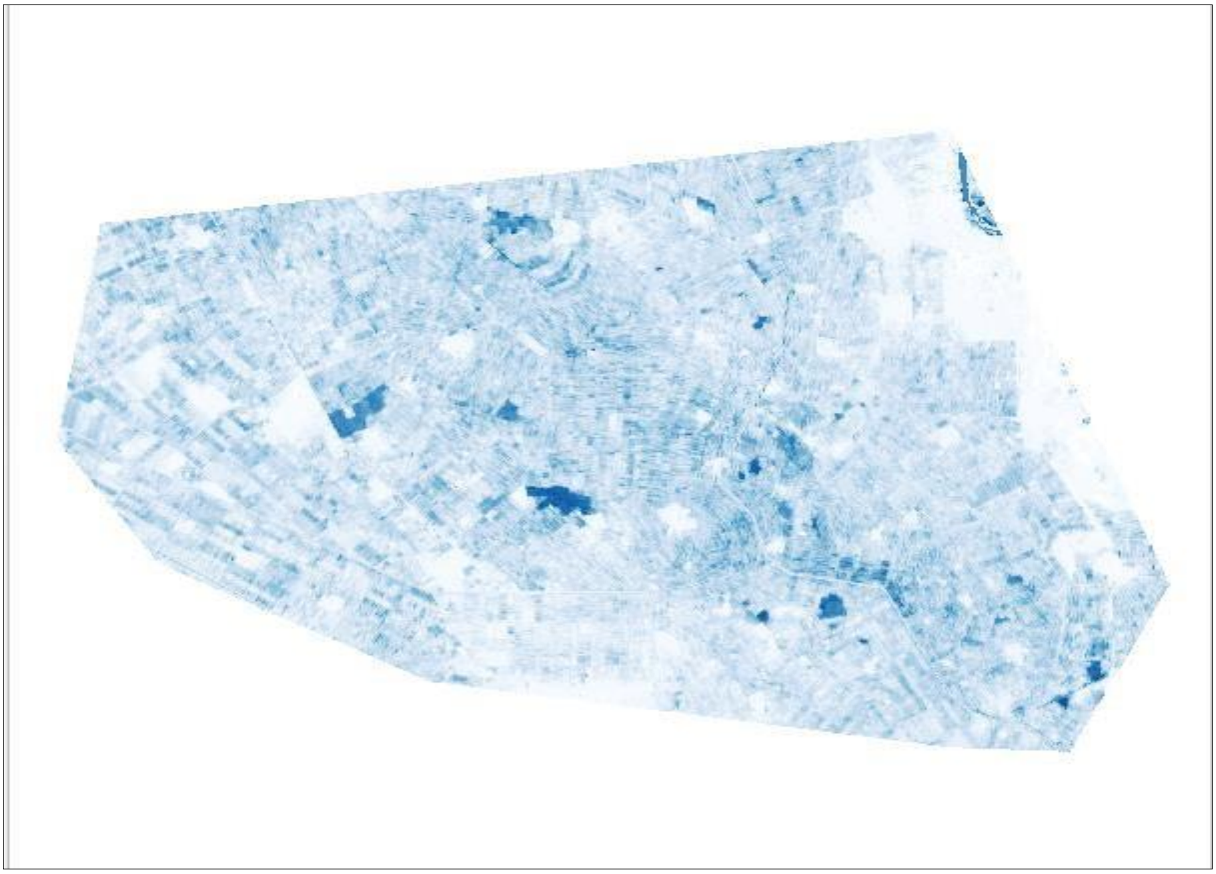


Fig.11. actual evapotranspiration and interception (season3)

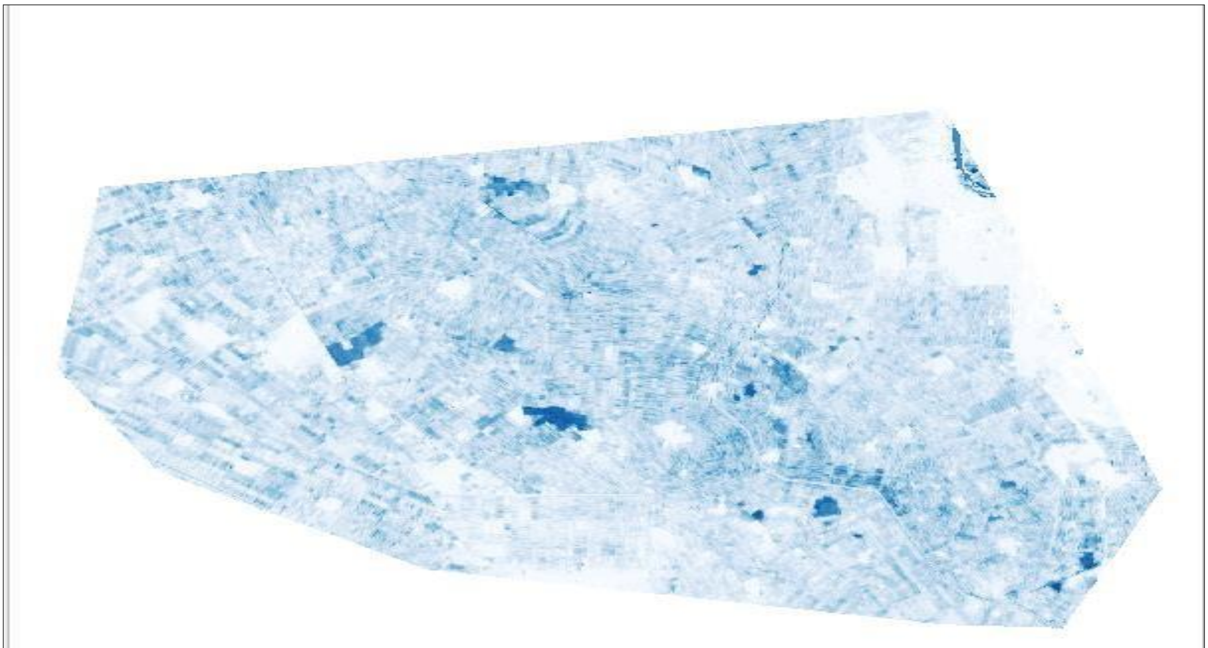


Fig.12. actual evapotranspiration and interception (season4)

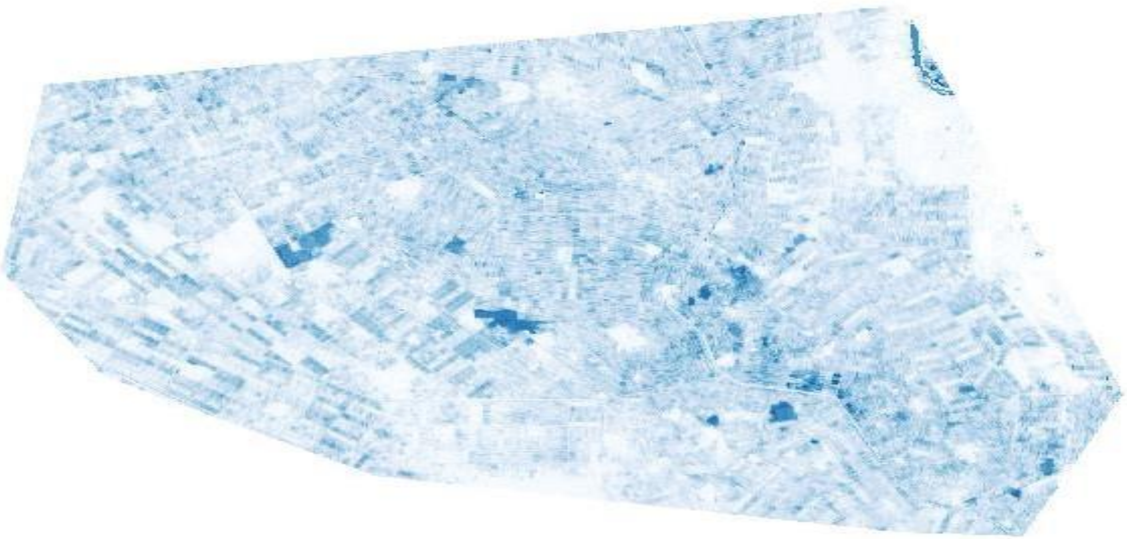
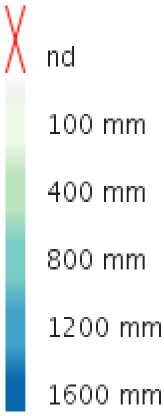


Fig.13. actual evapotranspiration and interception (season5)



CHAPTER 5

Conclusion

The main objectives of this study are calculate and evaluate water productivity indicators for wheat crop in last five seasons in AL-Gezira scheme in Sudan.

Remote sensing allows for the estimation of CWP on considerably greater scales and in places where observations are typically unavailable.

The two main components of CWP datasets are AETI and Y, because CWP are not given as a remote sensing product. Therefore, CWP was calculated from equations derived after compiling AETI and NPP data from the WaPOR portal developed by FAO.

The highest water productivity was in the first season, while the lowest water productivity was in the fourth and fifth seasons. By comparing AETI and CWP, we can see that the third season is when water is wasted and water distribution isn't adequately handled. Through AETI spatial analysis, it was found that the northeastern part of the scheme suffers from a real problem in water distribution.

The locations of the defects in the water distribution in the scheme, which do not receive water on a regular basis or are almost non-existent, have been discovered.

Recommendations:

Water, food, and energy are all necessary components of human life, and maintaining them necessitates work, research, and implementation of that research in order to prevent wasting these resources. Food security is a crucial resource for supporting life, and we must pay attention to water resources and how to sustain them in order to preserve it. Water shortage has become a major problem in the world, and for the optimal use of water resources, technology must be introduced in this field.

Agriculture uses a lot of water, and using remote sensing to monitor water productivity in agriculture can assist discover water productivity gaps and evaluate possible solutions to eliminate the gaps.

The system of irrigation water management in the Gezira agricultural scheme has not changed and has not been developed since the project's inception. As a result, one of the project's management tools must be remote sensing technology, which is employed in water distribution, evaluating plant water needs, and monitoring water productivity to identify productivity gaps. And assist in the development of relevant solutions to close these gaps.

Water loss must be handled first in the project, which is accomplished by effective water distribution and the treatment of flaws in areas where water does not reach, such as the project's northeastern section.

Field trips to the northeastern section of the project must be recorded to address the problem of lack of water availability to those areas, and the low water production in the last two seasons must be handled quickly to avoid exacerbating the situation.

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