International Journal of Multidisciplinary Research and Growth Evaluation.

Application of remote sensing for irrigation performance assessment: preliminary evaluation at di perimeters in Sourou valley, Burkina Faso

Abdoul Aziz Millogo
School of Agriculture, Class of master's degrees in Agricultural Sciences and Technologies, Burkina Faso

* Corresponding Author: **Abdoul Aziz Millogo**

Article Info

ISSN (online): 2582-7138
Volume: 03
Issue: 05
September-October 2022
Received: 03-08-2022
Accepted: 06-09-2022
Page No: 317-325

Abstract
Irrigation performance assessment is important information to water resources managers, farmers and governments especially in arid and semi-arid areas. Unavoidable time delays in this process cause delays in the decision-making process. Satellite remote sensing provide near-real time data in an objective and unbiased manner. Advance in remote sensing technology and related applications have considerably reduced over reliance on ground data. This research aimed to give a preliminary assessment of irrigation system in the commercial irrigation perimeters of Di in Sourou Valley (Burkina Faso) for the dry growing season. It involved the use of both ground data and data derived from remote sensing. It actually computed the irrigation water requirement by perimeter by using three methods (evapotranspiration maps derived from remote sensing, Hargreaves equation and ETo from pan evaporimeter). The Mapping Evapotranspiration at high Resolution with Internalized Calibration (METRIC) was used together with Landsat images, meteorological data and statistical software (R) to obtain monthly and seasonal evapotranspiration map. Monthly irrigation consumption was directly computed from these maps due to the absence of rain at the given period. The seasonal irrigation efficiency was calculated by comparing the irrigation requirements to the season water withdrawal data. Totally eight perimeters were considered. In conclusion, the METRIC model is good for mapping the evapotranspiration by providing to the high spatial resolution maps useful for water resources management at perimeters scale. Using the evapotranspiration from the model and the ETo from the pan evaporimeter, computed efficiencies are closer than the efficiency calculated using Hargreaves equation.

Keywords: Remote sensing, irrigation performance assessment, Di Perimeters

Introduction

Agriculture, and especially irrigated agriculture, is the main global water consumer and, consequently, a more productive use in this sector will have a large impact. Moreover, it is estimated that by 2025 cereal production will have to increase by 38% to meet world food demands [1, 5], thus, putting even more stress on an already scarce resource that is water.

Current projections indicate that world population will increase from 7.9 billion people today to 9.1 billion in 2050 (5) As a result, global food demand will rise, while food production will rise by 70% globally and 100% in emerging nations [13]. The challenge is that irrigated agriculture is expected to produce much more in the future while using less water than it uses today. Over the next years, the additional food supplies required to feed the world will depend on irrigation.

The irrigation demands on water resources will keep increasing while the resource itself is becoming scarcer in a global climate change context. Therefore, monitoring the irrigation performance is meaningful. The term of ‘‘irrigation performance’’ for different irrigation level (field, irrigation system and basin) can be quantified by factors such as water inflows and outflows, crop demand (net irrigation water requirement), water use, system losses, crop production and the extent cultivated [1]. Indeed, most irrigation systems across the world perform below their capacity and are not adapted to the needs of today’s agriculture.

The ultimate purpose of performance assessment is to achieve an efficient and effective use of resources by providing relevant feedback to the scheme management at all levels [6]. To achieve this, a systematic and timely flow of actual (measured or collected) data on key aspects of a scheme is an essential condition.

Evapotranspiration (ET) is an important factor in water productivity and monitoring irrigation performance. However, direct measurement of actual evapotranspiration is difficult and, when it is done, mostly provides non accurate and/or point values. In many countries, and particularly in Burkina Faso, accurate evaluation of irrigation system performance and sustainability is difficult to carry out due to the lack of adequate, reliable and timely irrigation data.

The complexity associated with the estimation of ET has, therefore, led to the development of various methods for estimating this parameter over time [2]. At present, in most cases, satellite remote sensing data have been used for estimating potential and actual evapotranspiration at regional scale. Many researchers have worked on developing models that accept remote sensing data as input to estimate potential evapotranspiration and actual evapotranspiration [1].

The main advantage of this approach is that large areas are covered, and that data is easily obtainable without extensive monitoring networks in the field. To regularly obtain local, regional and even global ET, some attempts have been made to improve ET algorithms or models to reduce the use of ground data. For this study, energy-balance methods using the mapping evapotranspiration at high resolution with internalized calibration (METRIC) developed by [2], will be combined to the remote sensing to estimate the actual and potential evapotranspiration. METRIC is a satellite-based image-processing model for calculating evapotranspiration ET as a residual of the surface energy balance. It uses as its foundation the pioneering SEBAL energy balance process developed in The Netherlands by [1].

The national goals described in the National Policy for a Sustainable Development of Irrigated Agriculture (MAHRH, 2004), specify to increase the productivity of any crop through improved management of the available resources. In the goal achieving process, performance of the irrigated agriculture process determines whether the targets are attained. Performance assessment from the operational level of the scheme up to the national level is of prime importance. Hence, it is necessary to evaluate whether the current performance assessment program can assess the performance of the schemes as well as the irrigated agriculture sector.

In most of the irrigation schemes, seasonal performance is quantified only at the end of the season [4] The indicators used measure the productivity of water in terms of irrigated land area, seasonal grain yield, and the district level crop production contributes to fulfil the national demand, respectively. Since we are facing unusual weather conditions (a long unexpected drought or excessive rainfall), these indicators are too much susceptible to not be easily attained. Performance information on related activities such as water delivery, drainage control, water shortage is required by the operational managers on time to make relevant decisions [4, 7]. To assess performance, objective data on actual field performance is needed, but unavoidable time delays in this process cause delays in the decision-making process. In order to make decisions at the right time, the delays of acquiring and processing of field data should be minimized. Satellite remote sensing can provide near-real time data in an objective and unbiased manner [4].

The use of remote sensing has several distinct advantages over traditional field data collection. Remote sensing can be used to gather information over an entire area, while field data collection relies on sample areas for instance, sample survey for crop cutting data, crop evaporation using evaporation pan. Hence, the amount of field data can be reduced by the use of satellite remote sensing.

Irrigation policy makers and managers need information on the irrigation efficiency at various scales to devise appropriate water management strategies. Significant savings on irrigation water can be made by improved water management, especially in water scarce regions. One of the key elements of irrigation system management is assessment and monitoring of irrigation.

The main purpose of this paper is to make a rapid scan of the performance of an irrigation system at high resolution, in term of detecting areas with good and poor performance combined to field data (soils characteristics, irrigation systems, crops and management) and to provide strategic information for the improvement of overall system performance. We decided to make the assessment of Di perimeters, in the Sourou Valley, Burkina Faso, taking into account the dry period that is the period during which irrigation systems are mostly used. In this case, the chosen period is October 2014 to May 2015 from which we can consider the entire setting done and which corresponds to the first irrigated period with new management and new equipment. Due to the lack of data for the periods before and after the chosen period, the study will not be able to give a multi-periodical analysis of the system and would like to be a reference point for further studies. The specific objective of this study is to determine the actual evapotranspiration in irrigated farms from processed satellite images, in order to establish a reference state by mapping the evapotranspiration for the given period (October 2014- May 2015).

Material and method

Study area

The Mouhoun, a tributary of Volta River, is an international waterway whose catchment covers parts of Burkina Faso, Benin, Ivory Coast, Ghana, Mali and Togo, with 145,750km^2 (*Figure 1*). In Burkina Faso, the Mouhoun Basin covers 96,096 km^2 and takes a large part of the North and Southwest of the country. With approximatively 1,000km in Burkina Faso, the Mouhoun river is characterized by its loop shape. The basin consists of twenty-six (26) sub-hydrographic basins.

This potential provides the opportunity to make this area a growth pole for the economy of the country. Thus, the Sourou Valley has been identified as a priority development area of irrigated agriculture.

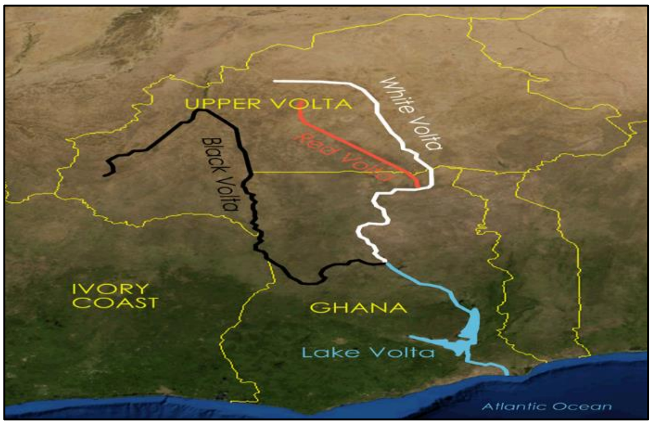


Fig 1: Main Rivers crossing Burkina Faso

The Sourou Valley is administratively located in the province of Sourou, at 328 km from the capital Ouagadougou. It lays at the longitudes 2° 26' 24"W and 3° 28' 48"W, and at latitudes 12° 46' 48"N and 13° 43' 12"N, bounded to the north by the Republic of Mali, to the south by the province of Nayala and west by the province of Kossi and covers an area of 3,906 km². Our study will focus on the perimeter of Di.

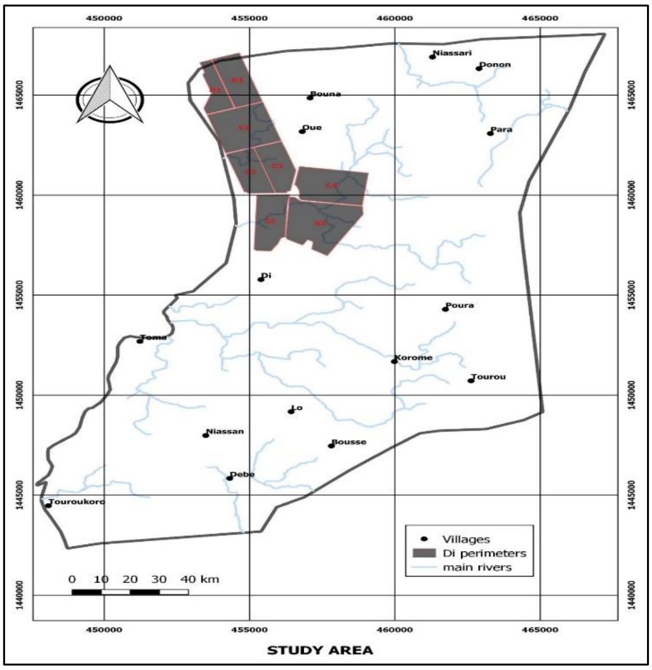


Fig 2: Presentation of the Study Area

1.8 Climate

The average annual rainfall is 500 to 700mm. and the mean temperatures are approximatively 15 °C (December-January) for the minimum and 35 °C (March-April) for the maximum [9, 8, 7].

To date, the Sourou valley has 3,818 hectares of developed irrigated areas whose water supply is done by pumping and irrigation according to the gravity irrigation systems (3,035 ha). The entire field of Di (2,240 ha) is irrigated by gravity using channels that uptake and supply water from the Sourou river to different plots. Each pumping station consists of screw pumps or Archimedean screw. For the management, associations of water users are set for each perimeter, the so-called sector. Each association is independent and is in charge of the monitoring and evaluation of all activities related to the exploitation of equipment and infrastructures.

Data

A fieldwork was conducted to collect data related to the concerned perimeters, from May 18 to July 9 2016 aiming to collect both primary and secondary data. The collection was done by meeting responsible, research departments, and farmers. Among the activities conducted: data collection on the irrigation farms in the locality of Di which aimed to obtain information about the irrigated areas, the management practices, the irrigation systems, the crops grown during the dry seasons, cultural calendars.

Meteorological data collection (period 2006/2015): data obtained with the "Société Burkinabè des *Fibres Textiles"*, SOFITEX and "*Institut de l'Environement et de Recherche Agricole"*, INERA, two national institutions of research. The data contain mainly precipitation, temperatures, wind speed and solar radiation, data on water withdrawal from the river, the transportation and distribution method obtained with the office in charge of the perimeters, 'AMVS'. An overview of data obtained with farmers, associations of farmers and "AMVS" is shown in the (Table 1).

Table 1: Irrigation calendar

Crops	Period of irrigation		
	Nursery	Planting	End of irrigation
Onion	Oct 15th, 2014	Nov. 30th 2014	March 15th, 2015
Tomato	Oct 1st, 2014	Dec. 5th 2014	March 15th, 2015
Maize	-	Nov 15th, 2014	March 15th, 2015

For this chosen dry period, only onion and maize were intensively grown (around 1043 ha of land cultivated for onion and 360 ha for maize).

The chosen period (growing period) of study is the peak irrigation season from October 2014 to April 2015. A set of satellite images from Landsat 8-OLI/TIRS (*Table 2*) and a Shuttle Radar Topography Mission Digital Elevation Model (SRTM DEM) covering the study area have been downloaded for the concerned period. These Landsat images are identified and downloaded also on the basis of cloud cover to avoid shadow and to avoid some extra processing (Akbari *et al.*, 2007) [1].

Table 2: Satellite images from Landsat 8-OLI/TIRS

Satellite	Sensor	Path/Row	Day Of Year (DOY)	Cloud cover (%)	Day Of Year (DOY)	Cloud cover (%)
Landsat8	OLI-TIRS	196/051	278	0	041	0
		196/051	294	0	057	0
		196/051	310	0	073	0
		196/051	326	0	089	0
		196/051	342	0	105	0
		196/051	358	0	121	20.59
		196/051	009	25.03	137	11.53
		196/051	025	0		

Method

For this study, the program used is "R".

Each ET24h was renamed using numbers. The length of the irrigation period is 151 days and the acquired satellite images cover 181 days. An existing script (originally designed for NDVI interpolation) was modified to interpolate the evapotranspiration images over the irrigation period using a spline algorithm.

The validation of the evapotranspiration obtained using the METRIC model and the evapotranspiration calculated using the ETo from the Pan evapotranspiration was done by comparing them to the evapotranspiration using modified Hargreaves equation and the climatic data provided by "AMVS". The volume of required water was obtained using three methods (modified Hargreaves equation, ETo from pan evaporimeter and the ET maps from the METRIC model) in to have a better qualitative and quantitative appreciation of the efficiency. Using the ET maps, the required water was obtained by the product of the pixel area (30m x 30m) and the monthly irrigation depth (m), and summing all the volume of the irrigated pixel during the irrigation month. Using Hargreaves equation and the ETo from the pan evaporimeter, the crop evapotranspiration was obtained by the following formula: $\boldsymbol{ETc = ETo\ x\ Kc}$

With ETo, the reference evapotranspiration (mm); Kc the crop coefficient. The irrigation requirement was calculated as following: $\boldsymbol{ETirr = ETc - P}$. With ETirr. The effective rainfall P equal 0 in this study considering the chosen study period (November 2014- May 2015). The irrigation efficiency was computed on the seasonal basis since there was not reliable monthly irrigation water abstraction data. Therefore, the efficiency was calculated comparing successively the requirements obtained from the Hargreaves equation, the evaporimeter and the METRIC model. The following equation was applied:

$$\boldsymbol{IE = \frac{IR}{IS} x100}$$

Equation 7 Irrigation efficiency

IE the irrigation efficiency in %, IR the irrigation requirement (m3) and IS the irrigation water supplied (m3).

Results and Discussion

Metric monthly ET maps

Using downloaded weather data and the high-resolution satellite images, the monthly high resolution ET maps were obtained by running the algorithm METRIC on ArcGIS. The results are shown in the Figure 3. The maps reflect the variability of areas where ET is higher during the wetter month (when the irrigation application is high) and lesser during drier or lesser irrigation application. The variability is also seen according to the crop type and the farm. The variability is also observable according to the occupation of the farms. Indeed, not all the hectares were cropped. So we can notice a non-regular distribution of ET (Figure 3).

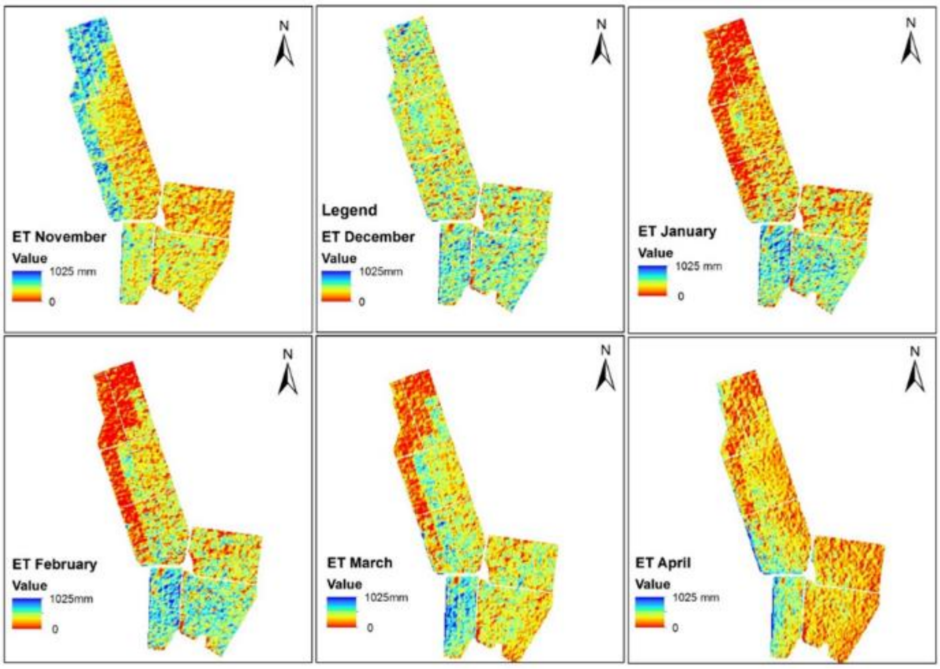
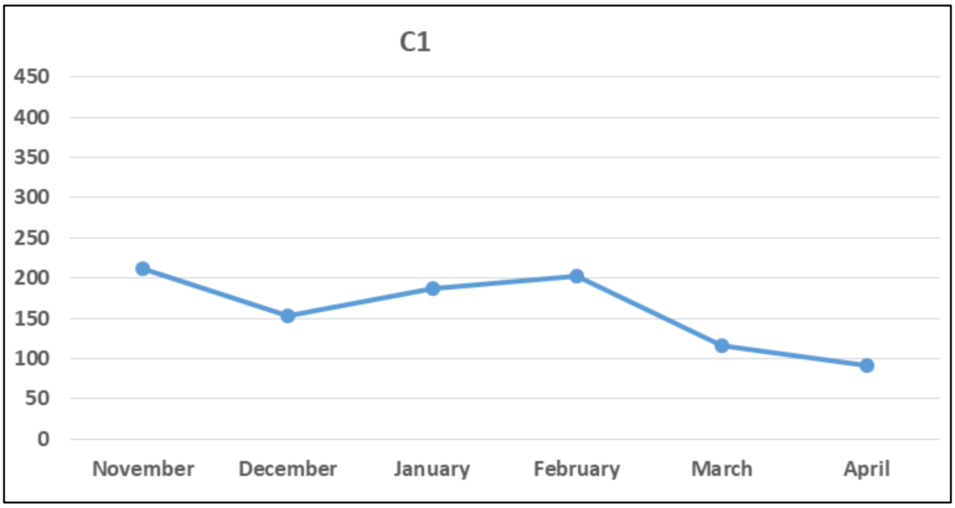
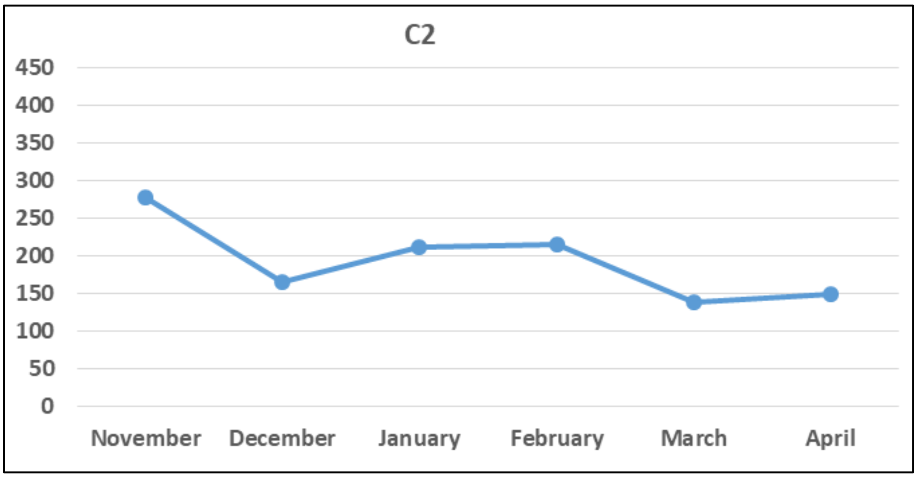
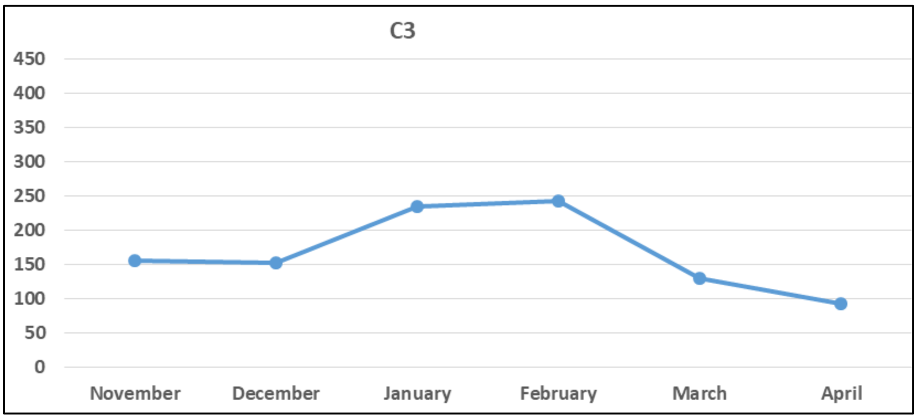
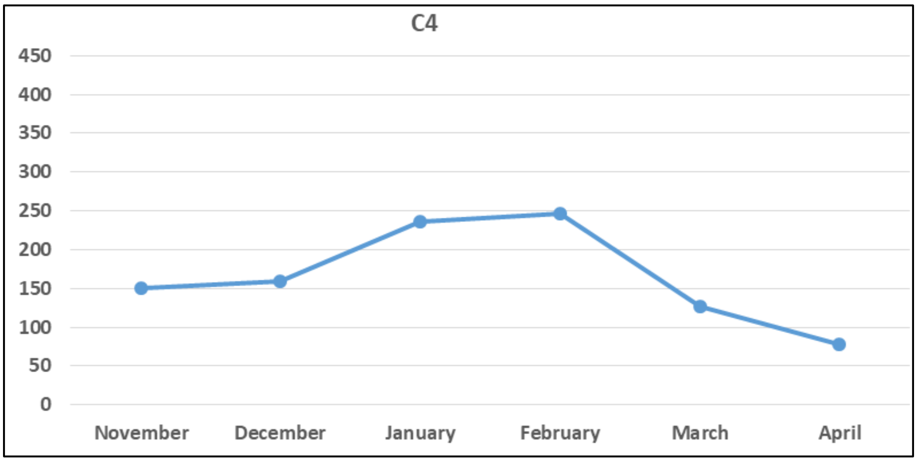


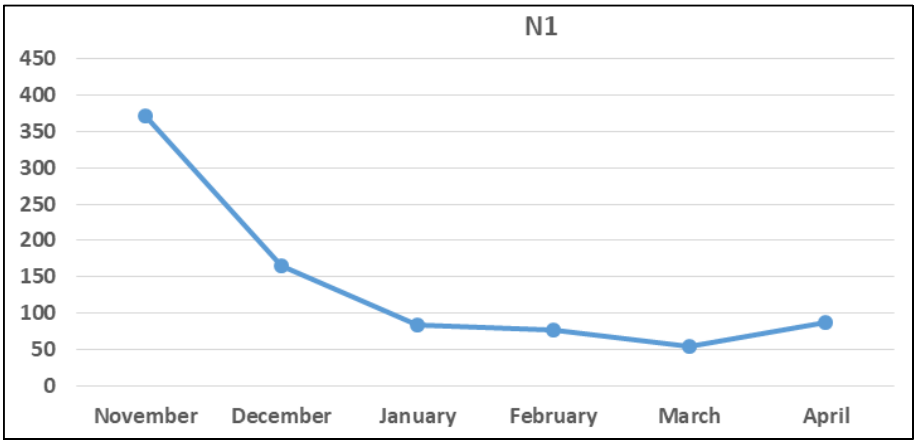
Fig 3: Non-regular distribution of ET




C2
450
400
350
300
250
200
150
100
50
0
November
December
January
February
March
April


C3
450
400
350
300
250
200
150
100
50
0
November
December
January
February
March
April


C4
450
400
350
300
250
200
150
100
50
0
November
December
January
February
March
April


N1
450
400
350
300
250
200
150
100
50
0
November
December
January
February
March
April

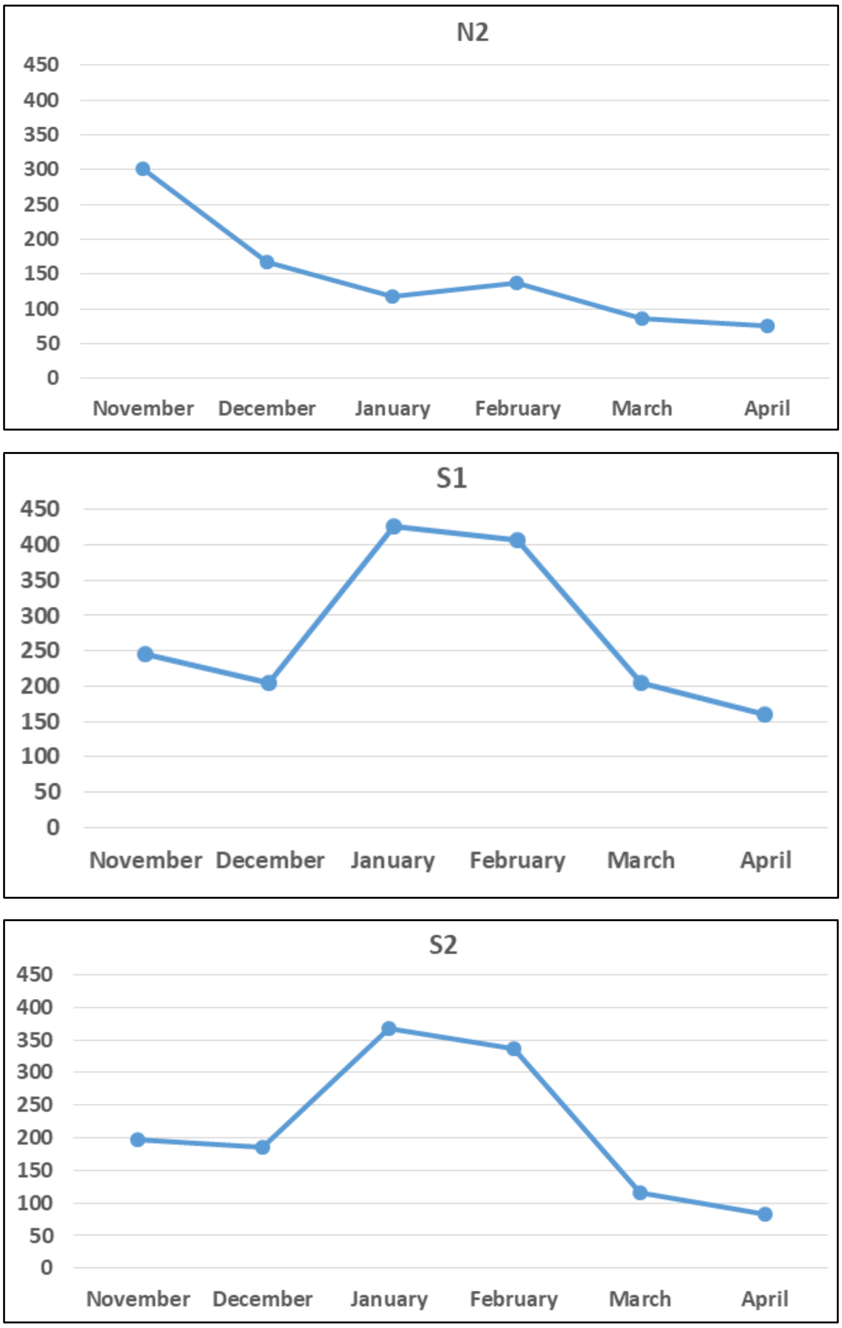


Fig 4: Monthly ET maps

The Figure 6 shows the variation of ET during the growing season. ET is quite low during the initial stage of crops (small LAI), except for the farms N1, N2, C1 and C2 which were highly wet in the month of November due to their position close to wet zones. We can also notice that from January to March ET is high due to the high-water delivery and also the growth stage of crops. This period corresponds to the development stage where the LAI is high.

Metric seasonal ET map

Due to the gap (16 days between each Landsat 8 Images), summing the monthly ET maps was not advised. So, the statistic software “R” was used to interpolated the monthly ET and to obtain the Seasonal ET map. The results are shown in the Figure 5.

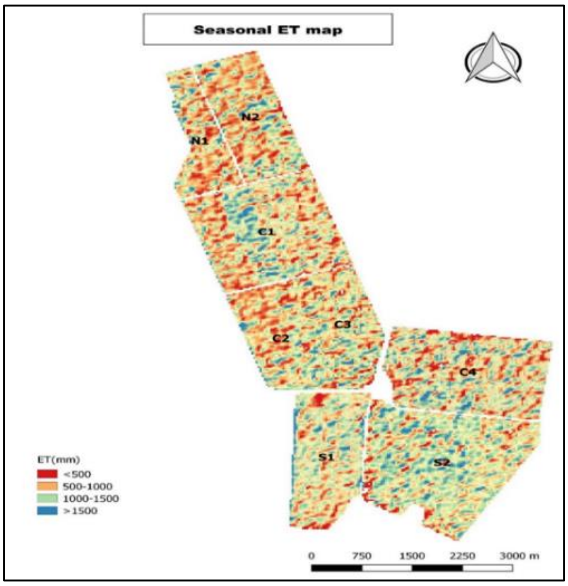


Fig 5: Seasonal ET map

Due to the lack or unreliable data about the crop patterns for each farm, it has been difficult to clearly identify the crop with the highest or lowest ET. These results give a general idea on the water distribution and utilization on each farm. These results clearly show a great difference between farms. This variability is due to the difference between total and cropped areas. In fact, the farm S2 presents the highest ET (>2000 mm). It had been cropped at more than 85% and is the biggest farm of the site. The farms N1 and N2 present the lowest ET (<1000 mm).

Irrigation requirement

The Table 3, 4 and 5 present the monthly irrigation requirements by farm according to method used. These results show high values of the evapotranspiration which can be explained by the crop response. The highest annual requirement was reported for the farm S2, while the farm C2 has the lowest requirement. The Figure 6 shows a comparison between the cropped areas and the irrigation requirement.

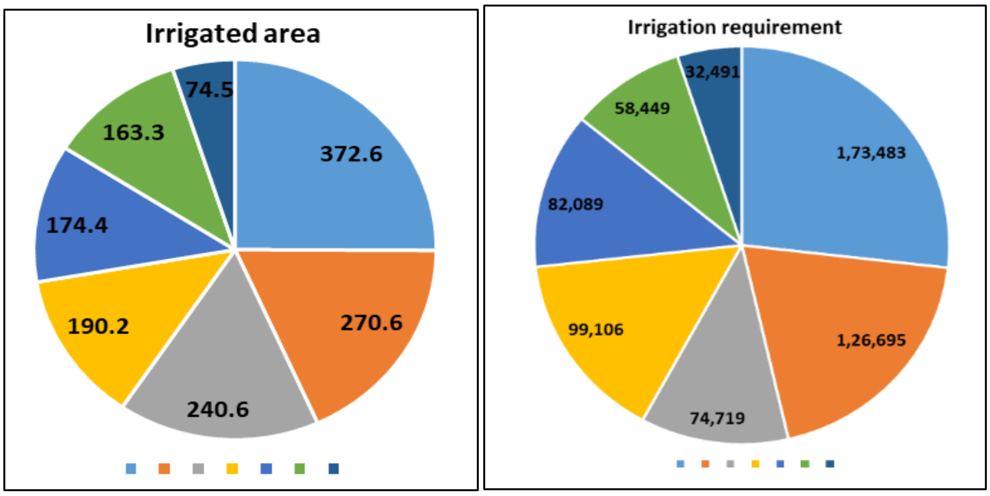


Fig 6: Comparison between irrigated areas and irrigation consumption

Table 3: Irrigation requirement using ETo from Pan evaporimeter

Irrigation requirement from ETo Pan evaporimeter							Volume (m3)	
	Perimeters	**Nov**	**Dec**	**Jan**	**Feb**	**March**	**Required**	**Supplied**
Volume	C1	11,452	146,518	171,655	165,944	152,609	648,178	1,477,633
	C2	3,453	72,671	79,941	80,753	92,022	328,839	1,173,164
	C3	13,703	236,495	263,919	264,099	284,697	1,062,913	1,870,384
	C4	19,451	268,197	309,918	302,541	291,700	1,191,808	1,753,326
	N1	3,759	61,297	68,862	68,591	72,314	719,850	2,327,193
	N2	7,671	100,436	116,991	113,573	106,354		
	S1	3,650	181,646	192,451	199,261	259,452	836,459	1,264,558
	S2	14,708	35,826	407,661	400,449	439,098	1,297,743	1,899,000

Table 4: Irrigation requirement using ETo from Hargreaves equation

Irrigation requirement from ETo using Hargreaves equation							Volume (m3)	
	Perimeters	**Nov**	**Dec**	**Jan**	**Feb**	**March**	**Required**	**Supplied**
Volume	C1	17,411	210,863	242,391	227,309	109,422	807,396	1,477,633
	C2	5,250	104,239	112,883	110,615	65,980	398,967	1,173,164
	C3	20,833	340,153	372,675	361,763	204,130	1,299,554	1,870,384
	C4	29,572	385,951	437,630	414,420	209,151	1,476,724	1,753,326
	N1	5,715	88,204	97,239	93,955	51,850	890,242	2,327,193
	N2	11,663	144,586	165,201	155,573	76,257		
	S1	5,549	258,615	271,757	272,947	186,029	994,897	1,264,558
	S2	22,362	508,361	57,565	548,534	314,836	1,451,657	1,899,000

Table 5: Irrigation requirement using ETo from ET maps (METRIC)

Irrigation requirement from ETo using METRIC model							Volume (m3)	
	Perimeters	**Nov**	**Dec**	**Jan**	**Feb**	**March**	**Required**	**Supplied**
Volume	C1	81,898	163,797	247,599	163,797	163,797	820,888	1,477,633
	C2	29,413	58,826	88,924	88,924	58,826	324,914	1,173,164
	C3	74,546	149,092	225,372	149,092	149,092	747,194	1,870,384
	C4	126,401	252,802	382,142	252,802	252,802	1,266,948	1,753,326
	N1	58,313	116,626	176,295	116,626	116,626	584,486	2,327,193
	N2							
	S1	89,717	179,434	271,238	271,238	179,434	991,061	1,264,558
	S2	173,080	346,160	523,265	346,160	346,160	173,483	1,899,000

Irrigation efficiency

Due to the lack of reliability of monthly water supply data, only the seasonal irrigation efficiency was computed. For the farms N1 and N2, the water supply data (*Table 7*) was combined. So, the irrigation efficiency was computed for the combined farm N. The results of the computation are presented in *Table 6*. The efficiency was computed using the three methods for irrigation requirement calculation. Farms N1, N2 and C2 present little water requirements but received a great amount of water during the irrigation period (over 2,327,193 m3 for N1 and N2 and 1,173,164 m3 for C2), which is showing a great water loss. This considerably reduces the irrigation efficiency of the whole system. Most irrigation systems across the world operate below capabilities and are not suited to today's agricultural needs [14].

Table 6: Seasonal irrigation efficiency (%)

	Efficiency (%) from		
Sectors	**Evaporimeter**	**Hargreaves equation**	**Metric Model**
C1	44%	55%	56%
C2	28%	34%	28%
C3	57%	69%	40%
C4	68%	84%	72%
N1	31%	38%	25%
N2			
S1	66%	79%	78%
S2	85%	104%	91%
Whole System	54%	67%	55%

Three farms (C4, S1 and S2) present high irrigation efficiency (70% and above). The whole has a weak efficiency and this can be explained principally by the misuse of water for the farms N1, N2 and C2 (Table 7). Therefore, it is observed that the pumping and the irrigation schedule don't really take into consideration the crop water requirement. The ultimate goal of performance evaluation is to ensure that resources are used efficiently and effectively by giving meaningful feedback to scheme management at all levels [6].

Table 7: Irrigation water supplied

Perimeters	Volumes supplied (m3)
C1	1,477,633
C2	1,173,164
C3	1,870,384
C4	1,753,326
N(N1+N2)	2,327,193
S1	1,264,558
S2	1,899,000
Total	11,765,258

Conclusion

In conclusion, the METRIC model is good for mapping the evapotranspiration by providing to the high spatial resolution maps useful for water resources management at perimeters scale. Difference in irrigation water requirement between farms mainly depends on the percentage of cropped area and also on the agriculture practices. Therefore, it was recommended that soil moisture should be taken into account by the model to improve ET estimation; and the models should be adapted to arid area by calibration and validation.

References

1. Akbari M, Toomanian N, Droogers P, Bastiaanssen W, Gieske A. Monitoring irrigation performance in Esfahan, Iran, using NOAA satellite imagery. Agricultural water management. 2007;88(1-3):99-109.
2. Allen RG, Pereira LS, Raes D, Smith M. Crop evapotranspiration-Guidelines for computing crop water requirements-FAO Irrigation and drainage paper 56. Fao, Rome. 1998;300(9):D05109.
3. Bazile AC, Vennat B, Venot JP, Costea P. Rôles et place des sociétés d'aménagement dans le développement de l'irrigation en Afrique de l'Ouest (2010, Doctoral dissertation, COSTEA); c2010.
4. Bandara KM. Assessing irrigation performance by using remote sensing. Wageningen University and Research; c2006.
5. Edwards PD, Frenette-Ling C, Palme R, Boonstra R. A mechanism for population self-regulation: social density suppresses GnRH expression and reduces reproductivity in voles. Journal of Animal Ecology. 2021;90(4):784-95.
6. Elshaikh AE, Jiao X, Yang SH. Performance evaluation of irrigation projects: Theories, methods, and techniques. Agricultural water management. 2018;203:87-96.
7. Gerits F, Reubens B, Messely L, Verheyen K. Consistency of landscape compositional effects on microclimate, arthropods and plant performance across different years and regions. Landscape Ecology. 2024;39(8):137.
8. Irmak S, Irmak A, Howell TA, Martin DL, Payero JO, Copeland KS. Variability analyses of alfalfa-reference to grass-reference evapotranspiration ratios in growing and dormant seasons. Journal of Irrigation and Drainage Engineering. 2008;134(2):147-159.
9. Kakani V, Nguyen VH, Kumar BP, Kim H, Pasupuleti VR. A critical review on computer vision and artificial intelligence in food industry. Journal of Agriculture and Food Research. 2020;2:100033.

10. Koussoube Y. Hydrog´eologie des s´eries s´edimentaires de la d´epression pi´ezom´etrique du Gondo (bassin du Sourou): Burkina Faso / Mali. Paris: Universit´e Pierre et Marie Curie - Paris VI, Fran¸ cais; c2013.
11. Sally H, Lévite H, Cour J. Local Water Management of Small Reservoirs: Lessons from Two Case Studies in Burkina Faso. Water Alternatives. 2011;4(3):362-385.
12. Trezza R, Allen RG, Tasumi M. Estimation of actual evapotranspiration along the Middle Rio Grande of New Mexico using MODIS and landsat imagery with the METRIC model. Remote Sensing. 2013;5(10):5397-423.
13. Kakani V, Nguyen VH, Kumar BP, Kim H, Pasupuleti VR. A critical review on computer vision and artificial intelligence in food industry. Journal of Agriculture and Food Research. 2020;2:100033.
14. Burke M, Emerick K. Adaptation to climate change: Evidence from US agriculture. American Economic Journal: Economic Policy. 2016; 8(3):106-40.