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Identification of Irrigation Performance Indicator Using Remote Sensing

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Abstract

Irrigation system is one of the important physical infrastructures for achieving the objectives of the Sustainable Development Goals program in 2030. Good performance of the irrigation system will positively contribute to the agricultural sector and improve the farmer welfare. Indonesia has a modern irrigation management unit which is responsible for the operation and maintenance of irrigation in an irrigation area with participatory, needs-based, effective, efficient and sustainable principles that guarantee a better level of service for water-using farmers. Remote sensing technology has the potential to assist in the new assessment process on existing irrigation systems to improve agricultural quality. Therefore this paper aimed to identify irrigation performance indicators that can be measured using remote sensing to help the development and the operation & maintenance of modern irrigation systems in Indonesia become more effective, efficient, and sustainable. The method used the Simplified Surface Energy Balance (SSEBop) model to calculate the actual evapo-transpiration value. The study case was on Balai Besar Wilayah Sungai Cimanuk-Cisanggarung West Java irrigation area produces actual evapo-transpiration values that were described spatially of 1.59 to 5.99 mm per day. Low levels of actual evapo-transpiration indicated that plants lack of water or deficit irrigation. Therefore, the actual evapo-transpiration values can be used to improve service level performance on modern irrigation systems in Indonesia such as water loss, water supply, irrigation water allocation, and water allocation interval.

Key words: *Indicator; Remote Sensing; SSEBop Model; Actual Evapo-transpiration; Irrigation Performance*

Abstrak

Sistem irigasi merupakan salah satu infrastruktur fisik yang penting untuk mencapai tujuan program Tujuan Pembangunan Berkelanjutan pada tahun 2030. Kinerja sistem irigasi yang baik akan memberikan kontribusi positif bagi sektor pertanian dan meningkatkan kesejahteraan petani. Indonesia memiliki unit pengelolaan irigasi modern yang bertanggung jawab atas pengoperasian dan pemeliharaan irigasi pada suatu daerah irigasi dengan prinsip partisipatif, berbasis kebutuhan, efektif, efisien, dan berkelanjutan yang menjamin tingkat pelayanan yang lebih baik bagi petani pemakai air. Teknologi penginderaan jauh berpotensi membantu proses penilaian baru pada sistem irigasi yang ada untuk meningkatkan kualitas pertanian. Oleh karena itu makalah ini bertujuan untuk mengidentifikasi indikator kinerja irigasi yang dapat diukur menggunakan penginderaan jauh untuk membantu pengembangan dan pengoperasian & pemeliharaan sistem irigasi modern di Indonesia menjadi lebih efektif, efisien, dan berkelanjutan. Metode tersebut menggunakan model Simplified Surface Energy Balance (SSEBop) untuk menghitung nilai evapo-transpirasi yang sebenarnya. Studi kasus di wilayah irigasi Balai Besar Wilayah Sungai Cimanuk-Cisagarung Jawa Barat menghasilkan nilai evapo-transpirasi aktual yang digambarkan secara spasial sebesar 1,59 hingga 5,99 mm per hari. Rendahnya tingkat evapo-transpirasi aktual mengindikasikan tanaman kekurangan air. Untuk itu tingkat evapo-transpirasi aktual dapat digunakan untuk meningkatkan kinerja tingkat pelayanan pada sistem irigasi modern di Indonesia seperti kehilangan air, penyediaan air, alokasi air irigasi, dan interval alokasi air.

Kata kunci: Indikator; Penginderaan Jauh; Model SSEBop; Evapotranspirasi Aktual; Kinerja Irigasi.

INTRODUCTION

The irrigation system is one of the important physical infrastructures for the achievement of the objectives of the Sustainable Development Goals (SDGs) program in 2030 (Kementrian Pertanian Republik Indonesia, 2017, 2019). Through a well-operated irrigation system, it will naturally contribute positively to agriculture, which will provide prosperity to the Indonesian people in the form of achieving better food security and nutrition acquisition. One of the keys to achieving these targets and goals is to make the irrigation system operating better.

The process of evaluating irrigation systems applied by Indonesia is still conventional so that it does not yet have a good level of accuracy. One reason is the assessment process carried out by workers who are in the field. These workers take inadequate samples resulting in inaccurate assessments. In addition, workers in different places will have different assessments so as to produce different conclusions, so there is a need for other efforts in the assessment of existing irrigation systems. There are 5 pillars that must be considered in the process of evaluating the new irrigation system, namely the reliability of water supply, reliability of river networks, water management, institutions, and human resources (Liputan6, 2019). It is hoped that this new assessment approach can make the existing irrigation system more effective, efficient and sustainable.

Remote sensing is a technology used to obtain information from an object, area, or event without having to make direct contact. Remote sensing gets information about the surface of the earth and water by using electromagnetic energy reflection. The method used in remote sensing is taking pictures from the recording of electromagnetic energy that occurs on the surface of the earth and water from a distance and the processing of image data (Buiten & Clevers, 1993; Janssen, et.al., 2001; Campbell, 2011). Remote sensing technology can be used as a first step in the new assessment process in the field of irrigation. Comprehensive reviews on remote sensing applications for agricultural water management were presented by Choudhury et al. (1994), Vidal & Sagardoy (1995), Rango & Shalaby (1998), Bastiaanssen (1998) & Stewart et al. (1999), Nandi, et.al., (2016), Waghmare & Suryawanshi (2017). Remote sensing can provide a lot of information with varying degrees of success and accuracy in various fields, including; irrigation area, type of harvest, biomass development, crop yields, crop water requirements, evapotranspiration, salt content, water logging. There are several advantages in using remote sensing that can be linked to field measurements.

Remote sensing technology has the potential to assist in the new assessment process on existing irrigation systems to improve agricultural service quality. Through Simplified Surface Energy Balance (SSEBop) Model which take the Normalized difference vegetation index (NDVI) as product of remote sensing, the value of actual evapo-transpiration (ETa) can be obtained. Sulistyono et al (2005) state that actual evapo-transpiration is a very important variable related to crop production. In conditions of water deficit, crop production decreases proportionaly to the decrease in evapo-transpiration. Threfore the higher the total evapo-transpiration deficit causing a greater decline in crop production. In light with those understanding, this research conducted to identify irrigation performance indicators based of one time monitoring data which can be measured using remote sensing, in order to help the development of operation & maintenance of modern irrigation systems in Indonesia become more effective, efficient, and sustainable. This is in accordance with the aim of modernizing irrigation in Indonesia, namely to support the productivity of farming by increasing agricultural production to achieve national food security and the welfare of Indonesian farmers.

Modernization of irrigation is an effort to realize a participatory irrigation management system that is oriented to meeting the level of irrigation services in an effective, efficient, and sustainable manner in order to support food and water security, through increasing the reliability of water supply, infrastructure, irrigation management, management institutions, and human resources. The purpose of irrigation modernization in Indonesia is to realize the irrigation management system in meeting the predetermined level of irrigation services effectively, efficiently and sustainably. The objective of irrigation modernization in Indonesia is to support the productivity of farming by increasing agricultural production to achieve national food security and farmers welfare (Kementerian Pekerjaan Umum, 2011).

Nowadays, Indonesia is in a transition period from traditional irrigation approach to technological approaches towards precision agriculture (Sulistiawan, et al., 2020). Therefore one of the goal of Indonesia's National Medium Term Development Plan 2015-2019 (RPJMN 2015-2019) is modernization of irrigation. Thus, since then Indonesia Government tried to establish modern irrigation management unit named Unit Pengelola Irigasi Modern (UPIM) along with the modernization project. The UPIM establishment depend on the readiness index score (IKMI) of irrigation area management agency, such as BBWS of Cimanuk-Cisanggarung. Based on training module prepared by Ministry Of Public Works Directorate General of Water Resources on 2019, the management agency are considered as ready when they reach the minimal score 80. The level of readiness asses based on five pilars namely: reliability improvement of irrigation water supply, infrastructure and facilities, irrigation management system, institution management and human resources management. Therefore, to fulfil one of the pilar the Rentang Irrigation Modernization Project (RIMP) as part of Cimanuk-Cisanggarung BBWS irrigation area has been setup since 2017 and until June 2023 the progress just reached 52%.

Moreover, the UPIM which is responsible for the operation and maintenance of irrigation in an irrigation area with participatory approach, needs-based, effective, efficient and sustainable principles that guarantee a better level of service for water-using farmers (Angguniko & Hidayah, 2017). There are 12 service level indicators can be measured by UPIM such as cropping index, water loss, water allocation interval, water productivity, water supply, water flow system, irrigation water allocation, water level control, method of using water, water usage, right of water use, and drainage.

Possible performance indicators that can be quantified by use of remote sensing are divided into 5 groups, namely adequacy, equity, reliability, productivity, and sustainability. Table 1 shows performance indicators that can be measured by remote sensing. Each of these groups has its own requirements for frequency of images and time constraints between image acquisition and availability at the door of the irrigation manager. (Bastiaanssen & Bos, 1999).

RESEARCH METHODOLOGY

The data needed to take measurements in this research are the irrigation area image from the Landsat 8 OLI / TIRS C1 Level-1 satellite obtained from the website https://earthexplorer.usgs.gov/, the BMKG daily climate data obtained from the website http://dataonline.bmkg.go.id/, and the Cimanuk-Cisanggarung BBWS irrigation system data.

Furthermore the irrigation area image data was analyzed using ArcMap dan BMKG daily climate data was analyzed using Cropwat to get evapo-transpiration value. Evapo-transpiration is a process of evaporation or loss of water that comes from the soil surface and surface of plants caused by the sun's irradiating activity. Evapo-transpiration has several types including reference evapo-transpiration (ETo) and actual evapo-transpiration (ETa). Reference Evapo-transpiration (ETo) is an estimate of the value of evapotranspiration originating from the reference land, where the reference land is grass with a height of 0.12 m. Actual evapo-transpiration (ETa) is the rate of actual absorption of water by plants, which is determined by the level of water available in the soil and combines simultaneously water loss by evaporation from the soil surface and transpiration from the plant surface. Singh, et. al. (2014) found at least eleven remote sensing model for estimating actual evapotranspiration (ETa), such as the surface energy balance index (SEBI), two source model (TSM), surface energy balance algorithm for land (SEBAL) and others. Operational simplified surface energy balance (SSEBop) is one of them. The SSEBop developed based on the he surface energy balance (SEB) as one of the five widely used method (Wagle, et al., 2017). Moreover, Wagle, et al. (2017) also stated that SSEBop estimate ET at a daily scale with no need to compute instantaneous energy balance parameters. Meanwhile, Savoca et al. (2013) state the advantage of SSEBop model that provide more spatial detail and accuracy.

The SSEBop model approach which limits conditions based on the principle of clear-sky net radiation balance, where the SSEBop model approaches by distinguishing the values of hot/dry and cold/wet from each pixel (Senay, et.al. 2016; Avdan & Jovanovska, 2016; Hashim, et.al. 2019). Calculating actual evapotranspiration using the SSEBop method requires Surface Temperature (Ts, ˚C), air temperature (Ta, ˚C), and Reference Evapotranspiration (ETo, mm) data.

The data can be used to calculate the actual evapotranspiration (ETa, mm) using equation (1).

$$ETa = ETf * k * ETo \quad (1)$$

ETo is a grass reference evapotranspiration at the location; while k is the scale coefficient for ETo in order to adjust the maximum level of evapotranspiration that occurs in plants. The recommended k value used is 1. Senay, et. al. (2016) stated that the Evapotranspiration Fraction (ETf) value between 0 to 1.05; The negative ETf value is set to 0 and the maximum ETf value is limited to the value 1.05 or is considered "no data" for cloudy pixels.

The Simplified Surface Energy Balance (SSEBop) model will generally be explained in the flow diagram shown in Figure 1.

The actual evapo-transpiration value obtained from the SSEBop method is examined in relation to the service level indicator UPIM in Indonesia to determine possible performance indicators that can be quantified by use of remote sensing of the of BBWS Cimanuk-Cisanggarung irrigation system.

Table 1. Possible Performance Indicators That Can Be Quantified by Use of Remote Sensing

Performance Indicator	Remote Sensing Principle
Adequacy	
Crop water stress index	Surface energy balance
Relative water supply	Crop water requirements
Water deficit index	Surface energy balance
Evaporative fraction	Surface energy balance
Soil moisture	Microwave techniques
Equity	
Water application per unit area	Vegetation index
CV of evapo-transpiration	Surface energy balance
CV of evaporative fraction	Surface energy balance
CV of depleted fraction	Surface energy balance
Spatial geometry of crop yield	Vegetation index
Spatial geometry of actual evapo-transpiration	Surface energy balance
Reliability	
Temporal variation of the evaporative fraction	Time series evaporative fraction
Productivity	
Actual evapo-transpiration over water applied	Water balance
Yield over water applied	Vegetation index
Yield over evapo-transpiration	Vegetation index and Surface energy balance
Sustainability	
Irrigation intensity	Multi-spectral classification
Rice intensity	Multi-spectral classification
Wheat intensity	Multi-spectral classification
Water-logging	Surface albedo
Salinity of top soil	False color composite

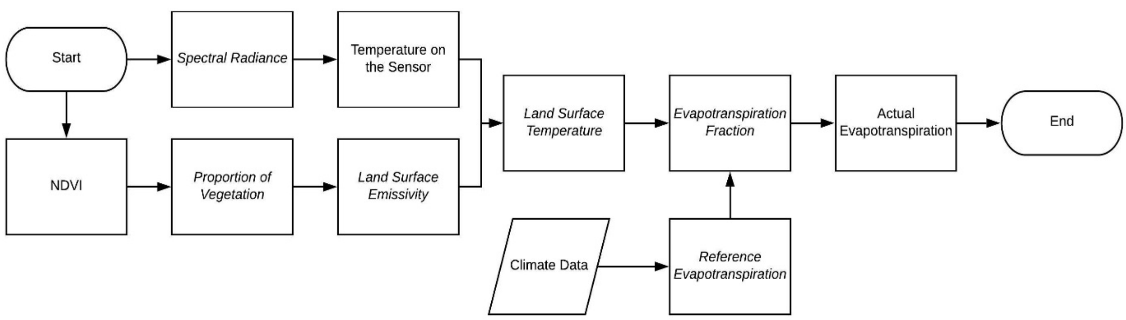

Figure 1. Simplified Surface Energy Balance (SSEBop) Model (Senay, et.al., 2016)

ANALYSIS AND DISCUSSION

This research was conducted at Balai Besar Wilayah Sungai (BBWS) Cimanuk-Cisanggarung, West Java, Indonesia. It consisted of Cirebon District, Majalengka District, and Cirebon District. The total service area of the BBWS Cimanuk-Cisanggarung functional irrigation area is 87,840 ha consisting of 1,094 ha for Majalengka District, 20,571 ha for Cirebon District, and 66,157 ha for Indramayu District (BBWS Cimancis, 2020). Figure 2 shows the location of the irrigation area on BBWS Cimanuk-Cisanggarung.

The actual evapo-transpiration calculation method uses the Simplified Surface Energy Balance (SSEBop) model is consist of: 1) Normalized difference vegetation index (NDVI), 2) Spectral radiance ($L\lambda$), 3) Temperature on the sensor (BT), 4) Proportion of vegetation (Pv), 5) Land surface emissivity (LSE), 6) Land surface temperature (LST), 7) Evapo-transpiration fraction (ET_f), 8) Reference evapo-transpiration (ETo), and 9) Actual evapo-transpiration (ETa). The results of this process will produce an image that has a parameter from the value and color of the image. Table 2 shows the result of the actual evapo-tranpiration calculation for Cirebon District, Majalengka District, and Indramayu District.

NDVI has 2 components, namely the near infrared band (NIR) where vegetation reflects this wave and the red band where vegetation absorbs these waves. A negative value means there is a high probability of water in the area. A positive value means there is vegetation in the area, while a value close to +1 means that there is dense vegetation. A value close to 0 means the absence of vegetation or that the area may have turned into an urbanized area.

Spectral radiance is a unit used to correct the readable wave value of each pixel in the image into International System units for each new pixel. The yield of this spectral radiance is a unit used for correction. The results of this spectral radiance will be used to process the temperature value on the sensor.

The temperature on the sensor is the temperature in the atmosphere from different heights. The meanings of these different heights are the same as sea temperature and surface temperature obtained from radiometric measurements. The results of the temperature on this sensor may experience problems due to noise or interference caused by clouds in the image, so it is necessary to assume or it can be said that no data can be obtained in areas disturbed by these clouds.

A proportion of vegetation is the ratio of the vertical projection area of vegetation on the ground (leaves, stems and twigs) to the total area of existing vegetation. Land surface emissivity is the ratio of the energy radiated by a particular material on the surface radiated by a black body at the same temperature. This is the ability of an object to radiate the energy it absorbs.

Land surface temperature is the temperature on the surface that comes from solar radiation. The parable of the land surface temperature is how hot the surface is on the earth in a certain location. The surface referred to by the satellite is the surface of the land, ice, snow, water, grass, or the roof of a building. This land surface temperature is different from the air temperature.

Evapo-transpiration fraction is a ratio or correction factor used to improve an existing reference evapo-transpiration (ETo). This evapo-transpiration fraction has a range or limit of values that need to be considered, namely a value of 0 to 1.05. If this upper limit of the evapo-transpiration fraction is passed, the area that exceeds the 1.05 value can be considered the same as the value of 1.05 or it can be assumed that there is no data in that area.

Reference evapo-transpiration is a reference for estimating evapo-transpiration that is used to determine water loss caused by evaporation and absorption of water by the soil in an area. Reference evapo-transpiration can be searched using available climatic data in the area. In this case the reference evapotranspiration value is 6.05.

Actual evapo-transpiration is the amount of water lost from the surface due to evaporation due to solar radiation and transpiration or absorption of water into the soil or plants. Actual evapo-transpiration has an upper limit value due to 1.05 times the reference evapo-transpiration value. Therefore, the upper limit value is equal to 6.3525 mm per day.

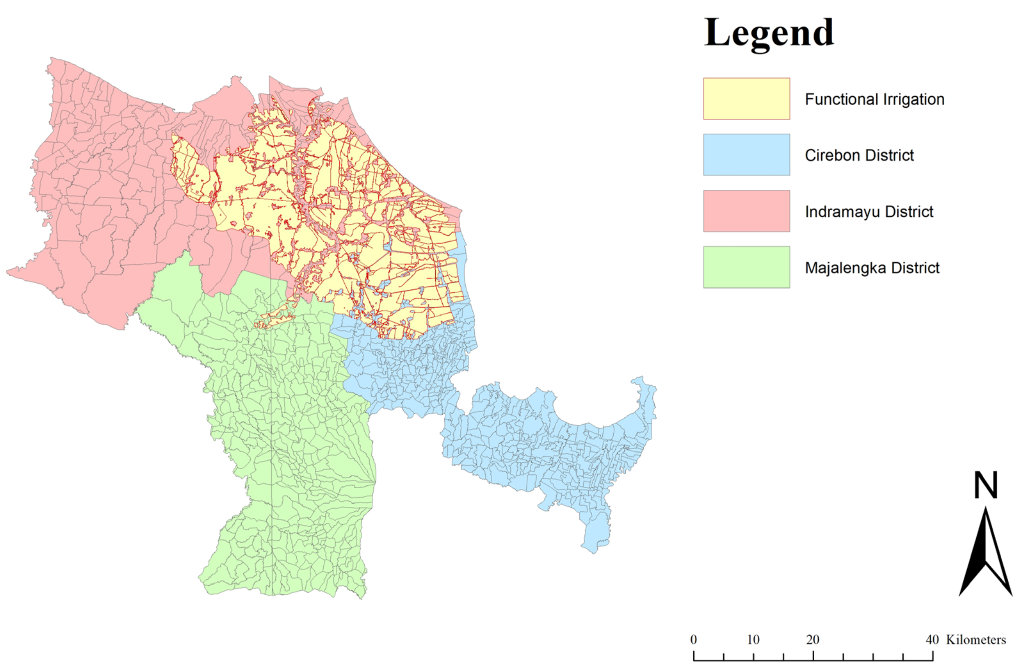

Figure 2. Location of BBWS Cimanuk-Cisanggarung Irrigation Area

Table 2. Value of Measurement Process

Process	Cirebon District	Majalengka District	Indramayu District
Normalized difference vegetation index (NDVI)	-0,225222 - 0,533037	-0,218689 - 0,581001	-0,265448 - 0,568966
Spectral radiance (Lλ) (Band 10)	8,66521 - 11,4377	7,5804 - 11,3381	8,39184 - 11,3722
Spectral radiance (Lλ) (Band 11)	7,76154 - 9,88103	7,21913 - 9,80216	7,71174 - 10,0896
Temperature on the sensor (BT) (Band 10)	20,1286 - 39,1286	11,7566 - 38,4937	18,0786 - 38,7113
Temperature on the sensor (BT) (Band 11)	16,8682 - 34,4126	11,8995 - 33,7954	16,3655 - 36,0325
Temperature on the sensor (BT) (Average)	18,4746 - 36,7706	11,853 - 36,418	17,2622 - 37,2608
Proportion of vegetation (Pv)	$3{,}74956 \times 10^{-14}$ - 2,14142	$9{,}64121 \times 10^{-15}$ - 3,0595	$1{,}69151 \times 10^{-15}$ - 1,4573
Land surface emissivity (LSE)	0,986 - 0,994566	0,986 - 0,998238	0,986 - 0,991829
Land surface temperature (LST) (Band 10)	20,133 - 39,1447	11,7579 - 38,5086	18,0821 - 38,7282
Land surface temperature (LST) (Band 11)	16,8111 - 34,4251	11,9008 - 33,8076	16,3684 - 36,0471
Land surface temperature (LST) (Average)	18,4782 - 36,7849	11,853 - 36,1118	17,2654 - 37,2765
Evapotranspiration fraction (ETf)	0 - 1,32803	0 - 1,85015	0 - 1,40168
Reference evapotranspiration (ETo)	6,05	6,05	6,05
Actual evapotranspiration (ETa)	0 - 8,03456	0 - 11,1934	0 - 8,48017

The actual evapo-transpiration results for Cirebon District, Majalengka District, and Indramayu District can represent Cimanuk-Cisanggarung BBWS. The actual evapo-transpiration value results obtained after the three districts were 0.0112509 to 11.1934 mm per day. The actual evapotranspiration value that exceeds the upper limit value will be considered as having no data due to inaccurate values in the area caused by interference such as cloudy pixels. Figure 3 shows the actual evapotranspiration results of the BBWS Cimanuk-Cisanggarung irrigation area.

Based on the results of the BBWS Cimanuk-Cisanggarung irrigation area, focusing on the existing functional irrigation area, it will produce an actual evapo-transpiration value of 1.59372 to 5.99795 mm per day. Meanwhile the upper limit value of evapo-transpiration actual is 6.3525 mm per day. It means the results of the actual evapotranspiration processing in functional irrigation areas have good data because in this area there are no disturbances that can lead to inaccurate data. Fig. 4 shows the actual evapotranspiration results of the BBWS Cimanuk-Cisanggarung functional irrigation area.

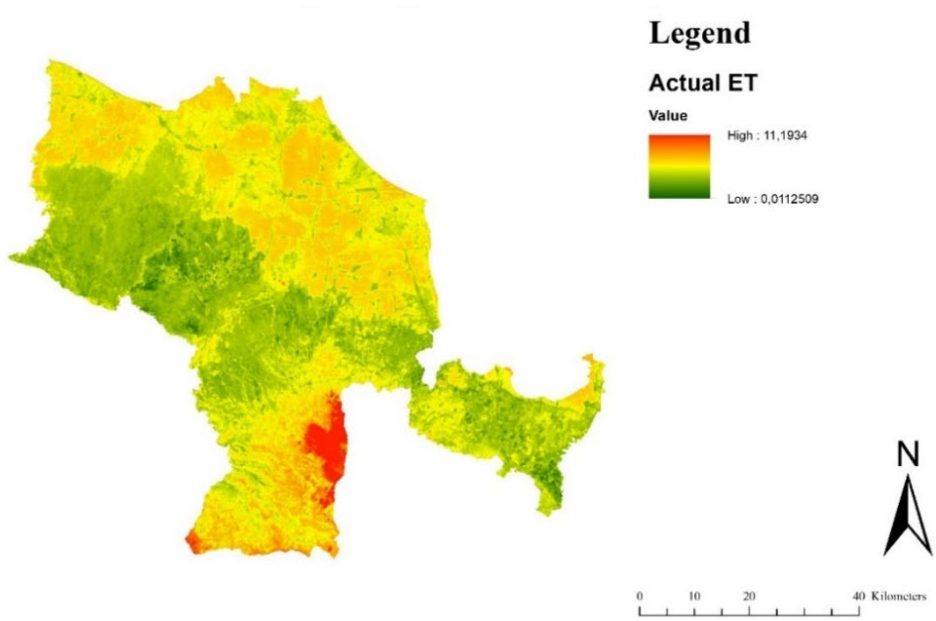

Figure 3. Result of Actual Evapo-transpiration of BBWS Cimanuk-Cisanggarung Irrigation Area

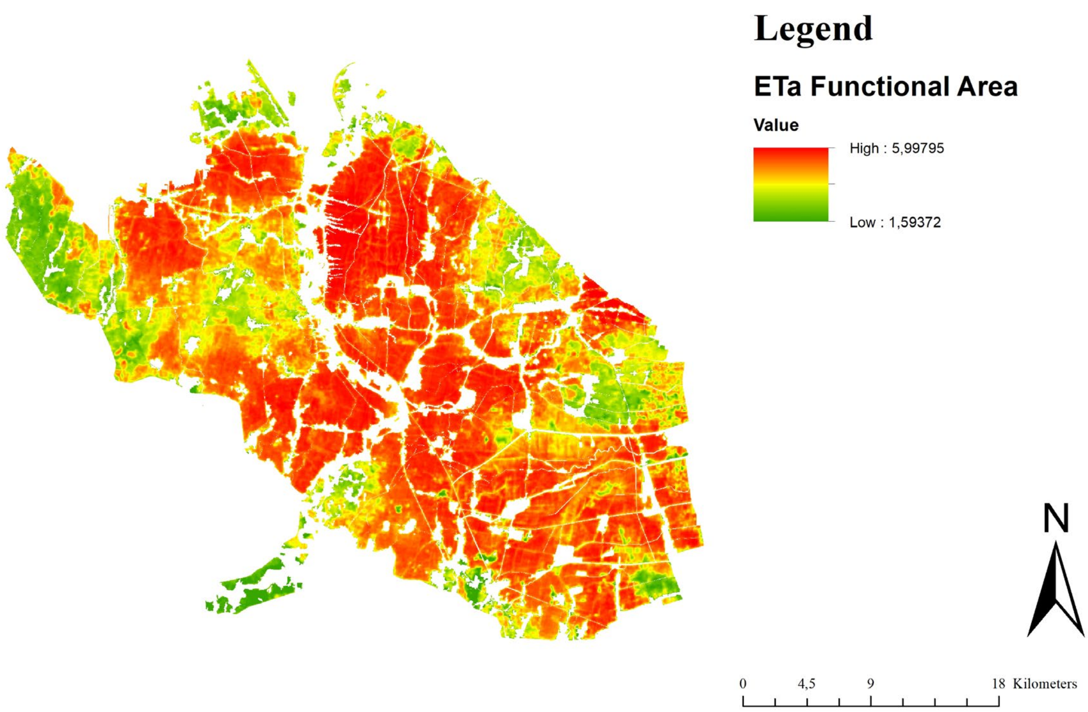

Figure 4. Result of Actual Evapo-transpiration of BBWS Cimanuk-Cisanggarung Functional Irrigation Area

The use of remote sensing can help demonstrate irrigation system performance which in turn is beneficial for improving irrigation performance. Measurement of irrigation performance indicators in Indonesia using remote sensing can manage service level indicators of UPIM such as cropping index, water loss, irrigation water allocation, water supply, and water allocation interval. Indicators that can be quantified by use of remote sensing related to irrigation performance indicators in Indonesia are measurements of relative water supply, water deficit index, evaporative fraction, to compute *adequacy*; Coefficients of Variation (CV) of evapo-transpiration, CV of evaporative fraction, spatial geometry of actual evapo-transpiration, spatial geometry of crop yield, being a suitable indicator for *equity*; actual evapotranspiration over water applied, to indicate the *productivity*; rice intensity, and wheat intensity, to investigate whether the intervention was *sustainable*. Not all indicators that can be measured by remote sensing can help irrigation performance indicators in Indonesia. It needs to be compared to find out what indicators have a relationship to the two existing indicators. Measurement of relative water supply using remote sensing can improve service level indicator of water supply and irrigation water allocation. Measurement of water deficit index using remote sensing can improve service level indicator of water loss and irrigation water allocation. Measurement of evaporative fraction, CV of evapo-transpiration, and CV of evaporative fraction, using remote sensing can improve service level indicator of water loss. Measurement of spatial geometry of actual evapo-transpiration and actual eva-potranspiration over water applied, using remote sensing can improve service level indicator of water loss, water supply, and irrigation water allocation. Measurement of spatial geometry of crop yield, rice intensity, and wheat intensity, using remote sensing can improve service level indicator of cropping index. The use of remote sensing indirectly helps the allocation interval indicator because the use of remote sensing shortens the time for surveying, remote sensing has many choices of time and resolution on each different satellite so it needs to be considered and adjusted to use satellites to help the allocation interval indicator on the irrigation system.

The actual evapotranspiration value (ETa) in this study was 1.59372 to 5.99795 mm per day indicating the amount of water loss in the functional irrigation area in the BBWS Cimanuk-Cisanggarung irrigation system. The value of water loss can be used to improve some irrigation system performance. The performance of the irrigation system is the performance of water loss, water supply, irrigation water allocation, and water allocation interval for modern irrigation systems. Desired water loss in functional irrigation areas is not more than 10% to 30%. The actual evapotranspiration value can be used for irrigation water allocation in the irrigation system so that the water loss is not more than 10% to 30% by adjusting the door openings for each irrigation area according to water loss. The allocation interval can be set with the use of certain satellites that have a certain return period, the allocation interval is used to adjust the water needs of the irrigation system within a specified time period, in this analysis a 16-day return period is obtained from Landsat 8 satellites. Using the actual evapotranspiration value to improve performance water loss, water allocation, and irrigation water allocation interval in the irrigation system will make the performance of water supply for irrigation systems more reliable.

The use of remote sensing as a whole has a positive impact on the irrigation system. The result is objective, not based on opinion. Remote sensing covers a large area. Field studies are often limited to small sample areas because of costs and logistics. The measurements can be done repeatedly, making it possible to oversee water management practices and evaluate the impact of disturbances. (Bastiaanssen & Bos, 1999). However, remote sensing has a limitation where satellites that take pictures from a distance have a return period of several days so that it cannot be done repeatedly for each day. In addition, a very difficult problem to be faced by remote sensing is the disturbance of the cloud in the area to be analyzed because the cloud is block everything that is underneath and the waves emitted by satellites cannot penetrate it, so we need an alternative to deal with this problem such as the use of equipment which can measure in the field directly. Remote sensing also has a dependency on other data that cannot be obtained by satellites such as climate data, where if the climate data is incomplete then analysis of the area cannot be done. Overall the use of remote sensing will improve the operating performance of existing irrigation systems.

CONCLUSION

The actual evapotranspiration (ETa) value of 1.59372 to 5.99795 mm per day can be used to improve service level performance indicators on modern irrigation systems in BBWS Cimanuk-Cisanggarung West Java Indonesia. The service level indicators are water loss, water supply, irrigation water allocation, and water allocation interval.

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