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Research paper

Analysis of the Water Availability to Irrigation Needs in Irrigation Areas Jambo Aye

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Abstract

Jambo Aye Irrigation Area serves cross-district irrigation water needs, namely North Aceh district and East Aceh district with a service area of 19,360 Ha and in accordance with the Regulation of the Minister of Public Works and Public Housing of the Republic of Indonesia Number 14/PRT/M/2015, criteria and determination of the status of irrigation areas is the authority of the Central Government. Complaints of farmers' communities, especially in North Aceh, there is always a shortage of water for the needs of rice fields, this can be caused by a lack of water supply or it could be caused by damage to irrigation infrastructure. In this study, the availability of water was analyzed from sources for irrigation needs by looking at the water balance. The research method uses the Mock method because there is no discharge measurement data in the study area. The results of the study illustrate that monthly water demand is smaller than the available water called monthly reliable discharge. Water shortages experienced by farmers are not due to supply shortages that are considered possible due to damage to irrigation infrastructure

***Keyword**: Water availability, water demand*

1. Introduction

Jambo Aye Irrigation Area is in 2 districts, namely North Aceh District and East Aceh District which is ± 310 Km from Banda Aceh City, Aceh Province. Jambo Aye Dam is located in Jambo Aye River, Langkahan sub-District, and North Aceh District. This dam was built in 1982 with a width of 99.5 m and a service discharge of 27.31 m^3/second. The research location is shown in Figure 1.

Figure 1 Research Location

Geographically, weirs are located at 4˚10'00 "- 5˚15'00" LU and 96˚45'00 "- 97˚45'00" BT. The source of water is the Jambo Aye river with the area of the River reaches 776,383.04 Ha, has a maximum water level of ± 7 meters during floods and a minimum height of surface ± 4.5 meters during the dry season. The Jambo Aye Irrigation Area is divided into five sub-Irrigation area, namely the Lueng Baro sub-Irrigation area, the Lhoksukon sub-irrigation area, the Mon Sukon sub-Irrigation area, the Panton Labu sub-irrigation area, and the Arakundo sub-irrigation area. Irrigation areas serve irrigation in parts of North Aceh and East Aceh amounting to 19,360 Ha based on service area is the authority of the central government (Ministry of Public Works and People's Housing of the Republic of Indonesia, 2015).

The problem in this research is the complaints of farmers who lack water in the process of rice cultivation so as to disrupt the harvest that the results are not maximal. Water shortages can be caused by a lack of discharge available in irrigation water needs, or it could be due to infrastructure damage in irrigation areas. This study aims to evaluate the availability of discharge through the water balance by assessing the adequacy of water in Jambo Aye dam in meeting the needs of irrigation water based on the comparison between mainstay discharges and need discharge.

2. Material and Method

2.1 Water Demand

Agricultural water use accounts for around 70% of the total water that is withdrawn from surface water and groundwater (Wisser et al., 2008). Irrigation water demand is highly dependent on the area of Irrigation Area. The criteria and stipulation of the status of Irrigation Area and its management authority shall be regulated in the legislation of the Indonesian government (Ministry of Public Works and People's Housing of the Republic of Indonesia, 2015)

Based on rainfall data for 11 months from 2006 to 2016 the maximum data is sorted every year from January to December, the largest data is chosen. The rainfall maximum is shown in Table 1

Table 1 Rainfall maximum

Year	Monthly Rainfall Maximum (mm)
2006	388
2007	418
2008	439
2009	372
2010	204.5
2011	326
2012	582
2013	393
2014	214
2015	290
2016	344

2.1.1 Potential evapotranspiration Monthly

Potential evapotranspiration is calculated based on climatologically data using the Modified Penman method (Yulianur, 2005). This formula produces ET_0 from a reference plant of short grass with albedo 0.25. The Penman modification formula of the FAO Method is more commonly used as follows:

$$ET_0 = c\,x\left[W\,x\,R_n + (1-W)\,x\,f(u)\,x(ea-ed)\right]$$

The water requirement for crop consumptive is the depth of water required to meet the evapotranspiration of disease-free crops, grows in agricultural areas under sufficient water conditions from soil fertility with good growth potential and good growth environment levels. To calculate the water needs of consumptive use crop used the equation:

$$ET_c = k_c\,x\,ET_0$$

Where:

ET_0 : Reference plant evapotranspiration (mm/day);

c : Factors that show the effect of the difference in wind speed during the day and night; If there is no data that distinguishes wind speed during the day and night during the day, then the value of c is considered 1

W : Weighting factor;

Rn : Clean radiation energy which results in evaporation (mm/day);

f (u) : the average wind speed function measured at a height of 2 m with a unit of wind speed (km/day);

(ea-ed) : Difference in vapor pressure saturated with actual vapor pressure, (mbar).

f (u) : Wind velocity

ET_c : Water requirements for consumptive use of plants (mm/day);

k_c : coefficient of a plant;

2.1.2 Net Water Requirement (NFR)

Another opinion expressed by (Conferiana, 2010) the water requirement for plants on an irrigation network is the water required for plants for optimal growth without water shortage expressed in Net Field Requirement (NFR). The amount of water needed for crops in the fields is determined by several factors, namely land preparation, consumptive use, percolation and seepage, water change and rainfall. The need for net water (NFR) for rice is calculated by the formula:

$$NFR = ET_c + WLR + P - R_e$$

Where:

NFR : The need for net water

ETc : water requirement for consumptive use of plants (mm/day);

WLR : water requirement for change of water layer (mm/day);

P : water requirement for percolation and seepage (mm/day).

Re : effective rainfall (mm/day);

Water requirements during land preparation are used methods developed by van de Goor and Zijlstra (Goor and Zijlstra, 1968). The method is based on the constant water rate in liter/sec during the land preparation period.

Percolation is the movement of water flowing in the soil that its speed depends on the nature and type of soil. In clay soils, percolation rates and seepage on embankments inflicted with P are estimated to range from 1-3 mm/day. In soils containing lots of sand, the rate of percolation and seepage can reach higher numbers. Changes water layer were performed twice, one month after transplant and two months after transplant. 50 mm change of water layer caused by WLR and can be given:

1) For half a month, the meaning is given

$$WLR = \frac{50\,mm}{15\,hari} = 3{,}3\,mm/day \text{ ; Or} \quad (1)$$

2) for a month, its meaning is given

$$WLR = \frac{50\,mm}{30\,hari} = 1{,}7\,mm/day \quad (2)$$

Rainfall is not fully utilized by plants, some of which may become surface runoff, percolate or evaporate. Only a portion of the rain with high intensity can enter and be stored in the root zone which can then be utilized by the plant. The amount of rainfall is called effective rainfall. Effective rainfall is the rainfall that plummets in an area and is used for crops for growth. The determination of effective rainfall is based on basic month rainfall, with the possibility of 80% (R80) for rice crops. For rice crops, the amount of effective rainfall is estimated at 70% of the monthly rainfall monthly with probability 80% (Directorate General of Irrigation, 2010). Needs intake (DR) is the amount of water needed by one hectare of rice field (liter/sec/ha), calculated by the formula:

$$D_R = \frac{NFR}{ef\;x\,8.64}$$

Where:

DR : Retrieval requirement (liter/sec/ha);

NFR : The need for net water (mm/day);

ef : Efficiency of irrigation, usually taken at 65%;

8.64 : Unit conversion rate mm/day to liter/sec/ha.

The intake discharge for rice is the tapped discharge and then flowed into the irrigation canal to meet the irrigation water requirement when planting the rice. This intake discharge unit is m^3/sec and can be calculated by the formula below:

$$Q = \frac{D_R\,x\,A}{1000} \quad (3)$$

Where:

Q : discharge intake (m^3/sec);

DR : retrieval requirement (liter/sec/ha)

A : Irrigation area (Ha);

1000 : Unit conversion rate liter to m^3.

2.2 Water Availability (Water Supply)

The calculation of water availability is conducted to determine the water available from the main irrigation water source, to meet the planned irrigation water needs. The methods that can be used to calculate water availability include Mock and NRECA methods (Directorate General of Irrigation, 2010). Rainy is an important aspect in analyzing water availability. Rainfall data is needed to calculate the Mainstay Discharge and Water Balance Analysis. The location of the rainfall post is located at Langkahan Rainfall Post North Aceh District. Water availability was analyzed in the Mock method. Using data in the form of Area Catchment (A) and monthly rainfall (Isnin et al., 2012).

2.2.1 Infiltration

For irrigation Storage of soil moisture (SMS) is defined as the total amount of water stored in the soil in the plant root zone. The soil texture and depth of rooting of the plant determine this. Deeper rooting depth means there is a larger volume of water stored in the soil for plants. The amount of infiltration is influenced by water supply and infiltration factors such as the following equation:

$$Infiltation\ n = WS\ x\ IF \quad (6)$$

Where:
WS : Water Surplus
IF : Infiltration factor 0.4

2.2.2 Average monthly discharge

Ground storage at the end of the month (G.STORt) can be calculated using the equation as follows:

$$Q_{base} = Inf - G.STOR_t + G.STOR_{(t-1)} \quad (7)$$

$$Q_{direct} = WS\ x\,(1 - IF) \quad (8)$$

$$Q_{Strom} = R_e\ x\ PF \quad (9)$$

$$Q_{total} = Qbase + Qdirect + QStrom \quad (10)$$

$$Q_S = Qtotal\ x\ A \quad (11)$$

Where:
G.STORt (mm/month) : Groundwater capacity at time t
G.STOR $_{(t-1)}$ (mm/month) : Groundwater capacity at time t-1
Inf : Infiltration
Qbase : Basic runoff
Qdirect : Surface runoff
WS : Water Surplus
IF : Infiltration factor 0.4
QStrom : Rainfall runoff moment
Qtotal : Total Runoff
Qs : Average monthly discharge
A : Area of Watershed

2.2.3 Dependable Discharge

At the weir location, there is no discharge gauge so the average monthly discharge is calculated by the Mock method (Mock and Fao, 1973). The data used are monthly rainfall data, a number of rainy days, potential evapotranspiration value and soil moisture. The rainfall data used is recorded in the raining post in Langkahan area with the data range from 2006 to 2016. A reliable discharge calculation is performed by sorting the average monthly discharge calculation data from a large sequence into a small sequence to determine its probability. The mainstay discharge is calculated for wet discharge conditions (20% probability), normal discharge (50% probability) and dry discharge (80% probability).

2.3 Water Balance

The water balance is conducted to check whether the water available is sufficient to meet the irrigation water needs. Calculations are based on weekly or mid-month periods. Differentiated three main elements: Water Availability, Needs Water and Water balance. In water balance calculations, the yield requirements generated for the planting pattern used will be compared with the mainstay discharge for every half month and the area that can be irrigated. If the river discharge is abundant, the area of irrigation is fixed because the maximum area of the service area (command area) and the project will be planned in accordance with the planting pattern used
According to (Wesli, 2017) the difference between the discharge of water availability and the irrigation water demand is named as the result of water balance. Sustainable use of irrigation water is achieved under conditions of water availability discharge greater than the discharge required for irrigation land. Conditions of water deficit should be avoided at any given time, especially during the cultivation of land on plant growth.

3. Result and Discussion

2.4 Evapotranspiration potential Monthly

The potential evapotranspiration concept was first introduced in the late 1940s and 50s by Penman and it is defined as the amount of water transpired in a given time by a short green crop, completely shading the ground, of uniform height and with adequate water status in the soil profile (Irmak and Haman, 2003). Evapotranspiration potential is the amount of evaporation that would occur if a sufficient water source were available (Fetter, 2018). If the actual evapotranspiration is considered the net result of atmospheric demand for moisture from a surface and the ability of the surface to supply moisture, then Evapotranspiration potential is a measure of the demand side. Evapotranspiration potential monthly data is shown in Table 2.

Table 2 Evapotranspiration potential monthly

Month	evapotranspiration potential (mm/month)	Month	evapotranspiration potential (mm/month)
Jan	156.44	July	154.74
Feb	147.23	August	165.91
March	187.77	Sept	175.57
April	167.50	Oct	163.47
May	156.20	Nov	167.33
June	164.60	Dec	148.59

From Table 2 the potential evapotranspiration average of 162.95 mm/month. The lowest potential evapotranspiration was 147.23 mm/month which occurred in February and the highest was 187.77 mm/month which occurred in March.

2.5 Retrieval Requirement (DR)

The water needed by one hectare of rice fields is calculated using Equation 4. Water needs are calculated every half month and the highest in March II is 1.9 liters /second/ha. Water needs vary, most needs on March 2 are 1.90 liters/second/ha, while on July 2 to September 2 there is no need for water because this period is the harvest period. Water requirement for rice crops seen from the maximum requirement that is at age of rice aged two months (Soumokil and Nara, n.d.). Calculation results as shown in Table 3.

Table 3 Retrieval Requirement (DR)

Month	DR (Liter/Sec/Ha)	Month	DR (Liter/Sec/Ha)
Jan I	0.93	July I	0.15
Jan II	0.84	July II	0.00
Feb I	0.57	August I	0.00
Feb II	0.80	August II	0.00
March I	1.26	Sept I	0.00
March II	1.90	Sept II	0.00
April I	1.69	Oct I	0.52
April II	1.66	Oct II	0.99
May I	1.37	Nov I	1.27

May II	1.25	Nov II	1.11
June I	1.08	Dec I	1.39
June II	0.54	Dec II	0.60

Monthly water requirements every semi-month are shown in Table 4

Table 4 Water Irrigation Needs Monthly

Month	Irrigation Need (m^3/sec)	Month	Irrigation Need (m^3/sec)
Jan I	2.04	July I	0.00
Jan II	7.72	July II	0.00
Feb I	0.00	August I	0.00
Feb II	34.78	August II	0.00
March I	36.81	Sept I	0.00
March II	36.97	Sept II	0.00
April I	29.59	Oct I	30.51
April II	33.05	Oct II	29.06
May I	24.64	Nov I	24.72
May II	18.61	Nov II	18.27
June I	11.92	Dec I	27.52

June II	0.00	Dec II	9.68

2.6 Water Availability (Water Supply)

2.6.1 Average monthly discharge

The average monthly discharge (Qs) is calculated using equation (11) based on the total runoff (Qtot) calculated from equation (10) proportional to the area of the watershed. Total runoff is obtained based on the number of basic runoff (Qbase), surface runoff (Qdirect) and the moment of rain runoff (Qstrom) through equation (10). Determination based on data for 11 years from 2006 to 2016. The average discharge for each month for 11 years shows that the average discharge is 141,045m^3/sec. The maximum average discharge occurs in December of 381.60m^3/sec and the minimum average discharge occurs in October of 77.64 m^3/sec. The results are as shown in Table 5.

Table 5 Monthly averages Discharge

Year	River discharge											
	Jan	Feb	March	Apr	May	Jun	Jul	August	Sept	Oct	Nov	Dec
2006	38.82	47.59	163.11	92.02	44.88	24.61	68.31	131.36	64.44	6.29	289.04	614.47
2007	129.85	89.55	36.45	30.51	296.36	325.20	171.66	99.81	119.90	108.69	109.04	650.44
2008	105.57	89.39	63.91	38.09	14.72	8.95	72.38	129.41	18.69	61.56	535.67	740.10
2009	406.78	103.27	176.54	238.34	233.05	54.99	51.28	69.97	526.65	119.08	314.70	72.52
2010	38.75	37.03	42.63	38.85	30.33	27.71	85.76	0.73	0.44	62.51	75.49	226.49
2011	140.17	57.44	89.32	71.50	119.92	17.62	40.63	41.91	78.75	137.39	434.50	101.84
2012	79.26	53.32	61.80	65.38	981.22	170.16	240.00	67.83	203.68	117.83	155.73	475.38
2013	364.97	262.18	63.82	301.76	71.24	62.78	61.96	190.24	94.42	107.37	95.36	596.49
2014	116.86	42.31	78.74	36.47	68.85	19.02	50.74	92.68	65.00	25.10	117.77	231.26
2015	183.52	25.25	35.75	37.17	40.34	59.77	70.55	92.74	40.85	48.06	58.52	403.57
2016	144.23	529.64	70.09	76.50	69.07	50.83	36.64	256.00	96.23	60.12	162.46	85.09
average	158.98	121.54	80.20	93.33	179.09	74.70	86.36	106.61	119.01	77.64	213.48	381.60

2.6.2 Dependable Discharge

Dependable discharge is the minimum flow for a probability of meeting with probability 80%. The data are sorted from largest to smallest and then given a number as "m". The probability is calculated by the formula P=m/ (1+n) where "n" is the number of data. Values have seen an 80% probability of the sequence number "m". If the value is not exactly 80% probability is the number "m" then do interpolation to get an 80% probability Dependable Discharge (Qa) at 80% by probability is shown in Table 6

Table 6 Dependable Discharge

m	Dependable Discharge												Pr = m/(n+1)
	Jan	Feb	March	Apr	May	Jun	Jul	August	Sept	Oct	Nov	Dec	
1	406.78	529.64	176.54	301.76	981.22	325.20	240.00	256.00	526.65	137.39	535.67	740.10	8.33
2	364.97	262.18	163.11	238.34	296.36	170.16	171.66	190.24	203.68	119.08	434.50	650.44	16.67
3	183.52	103.27	89.32	92.02	233.05	62.78	85.76	131.36	119.90	117.83	314.70	614.47	25.00
4	144.23	89.55	78.74	76.50	119.92	59.77	72.38	129.41	96.23	108.69	289.04	596.49	33.33
5	140.17	89.39	70.09	71.50	71.24	54.99	70.55	99.81	94.42	107.37	162.46	475.38	41.67
6	129.85	57.44	63.91	65.38	69.07	50.83	68.31	92.74	78.75	62.51	155.73	403.57	50.00
7	116.86	53.32	63.82	38.85	68.85	27.71	61.96	92.68	65.00	61.56	117.77	231.26	58.33
8	105.57	47.59	61.80	38.09	44.88	24.61	51.28	69.97	64.44	60.12	109.04	226.49	66.67
9	79.26	42.31	42.63	37.17	40.34	19.02	50.74	67.83	40.85	48.06	95.36	101.84	75.00
10	38.82	37.03	36.45	36.47	30.33	17.62	40.63	41.91	18.69	25.10	75.49	85.09	83.33
11	38.75	25.25	35.75	30.51	14.72	8.95	36.64	0.73	0.44	6.29	58.52	72.52	100.00
Qa (m^3/sec)	55.00	39.14	38.92	36.75	34.33	18.18	44.67	52.28	27.56	34.28	83.44	91.79	

2.7 Water Balance

The water balance is conducted to check whether the water available is sufficient to meet the irrigation water needs. Calculations are based on weekly or mid-month periods. Differentiated three main elements: Water Availability, Needs Water and Water balance.

In water balance calculations, the yield requirements generated for the planting pattern used will be compared with the mainstay discharge for every half month and the area that can be irrigated.

If the river discharge is abundant, the area of irrigation is fixed because the maximum area of the service area (command area) and the project will be planned in accordance with the planting pattern used. Correlation dependable discharge with Irrigation needs water are shown in Table 7

Table 7 Dependable Discharge, Irrigation Need

Month	Dependable Discharge	Irrigation Need	Balance
Jan I	55.00	2.04	52.96
Jan II	55.00	7.72	47.28
Feb I	39.14	-	39.14
Feb II	39.14	34.78	4.36
March I	38.92	36.81	2.11
March II	38.92	36.97	1.95
April I	36.75	29.59	7.16
April II	36.75	33.05	3.70
May I	34.33	24.64	9.69
May II	34.33	18.61	15.72
June I	18.18	11.92	6.26
June II	18.18	-	18.18
July I	44.67	-	44.67
July II	44.67	-	44.67
August I	52.28	-	52.28
August II	52.28	-	52.28
Sept I	27.56	-	27.56
Sept II	27.56	-	27.56
Oct I	34.28	30.51	3.77
Oct II	34.28	29.06	5.22
Nov I	83.44	24.72	58.72
Nov II	83.44	18.27	65.17
Dec I	91.79	27.52	64.27
Dec II	91.79	9.68	82.11

According to (Wesli, 2017) the difference between the discharge of water availability and the irrigation water demand is named as the result of water balance. Sustainable use of irrigation water is achieved under conditions of water availability discharge greater than the discharge required for irrigation land. Conditions of water deficit should be avoided at any given time, especially during the cultivation of land on plant growth.

The main problem with regulating water resources is that the amount of water demand always changes with time and place. Therefore, an arrangement is needed so that the available water can meet the existing needs. In the fulfillment of existing needs, of course, must be determined which needs are more prioritized. If the river discharge is abundant, the area of the irrigation project is fixed because the maximum area of service (command area) and the project will be planned according to the planting pattern used. If the river flow is not abundant and sometimes there is a shortage of discharges then there are 3 options that can be considered (Directorate General of Irrigation, 2010):

a. The total area of irrigation is reduced
b. Modify in cropping pattern
c. Group technical rotation.

The complete water balance is shown in Figure 2

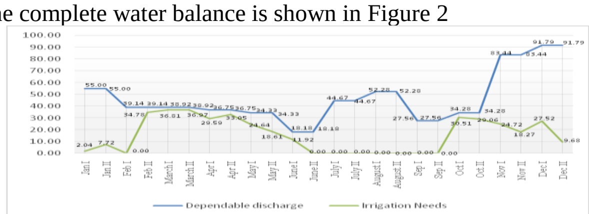

Figure 2 Water Balance

4. Conclusions

Available water is very adequate for the supply of water needs, even water is still excessive. The high water demand is in February until June, according to the applied cropping pattern. The results of the study illustrate that monthly water demand is smaller than the available water called monthly reliable discharge. Water shortages experienced by farmers are not due to supply shortages that are considered possible due to damage to irrigation infrastructure

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