International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878 (Online), Volume-8 Issue-4, November 2019

The Scenario of Rainfall-Discharge for Supporting the Optimization of Irrigation Reservoir Operation to Anticipate Extreme Flood

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***Abstract*: This research intends to build a scenario of mathematical modeling that can follow up the information of extreme climate does not give the same impact (mainly rainfall), so the water volume when the extreme rainfall will be happened, can be used for the irrigation and the water that cannot be used can be removed from the reservoir before flooding is happened, therefore, the function of reservoir to reduce flood can be increasing. The methodology consists of to obtain the rainfall due to the weather anomaly, the relation between rainfall and reservoir inflow, the decreasing of irrigation water requirement when the rainfall is high, the usage of crop intensity increasing, design flood, and the outlet capacity, the pattern of reservoir operation, the comparison of crop intensity, and the decreasing of flood risk. The result is hoped to be able to increase the available infrastructure (dam) by increasing the function of flood control and it remains to give priority for irrigation through the reservoir**

***Keywords* : extreme climate, reservoir operation, irrigation, flood**

I. INTRODUCTION

The climate change does not give the same impact on reservoir although there is close together, the effect difference is also influenced by the other factors like the watershed slope difference and the soil type [1][2][3]. Partk *et.al* [1] suggested that the adaptation of agriculture reservoir to the climate change impact is by using the adjustment of crop schedule.

Manuscript published on November 30, 2019.
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Hai *et.al* [4] expressed that the climate change is not only influencing the total of yearly discharge volume, however, it also changes the monthly distribution pattern in a year and there will be happened more flood peak [5]. The reservoir operation pattern due to the real time can give the high reliability in protecting drought and flood control. Uysal *et.al* [6] developed the Decision Support System of reservoir operation pattern [7] due to the real time for determining the water volume that is saved or released by operating the available radial gate. An amount of water volume is released before the flood is happened without exceeding the river capacity in the downstream reservoir emptying as the function for reducing flood and after that the gate is closed back so the reservoir can be full back to fulfill the function as the raw water supplier. It is developed with the integrated methodology of flood and hydrology (HEC-HMS) and the reservoir simulation model (HEC-ResSim).

The HEC-HMS is united with the climate prediction data that is used for estimating the real time run-off. The operation pattern is developed for maintaining the reliability of water availability together with the flood protection by regulating it every day and every time depended on the estimation of real time run-off. To determine the minimum volume of reservoir for fulfilling the main objective (raw water) until the period year end, the inflow that is used regarding to the inflow trend that can be hoped (dependable discharge) and due to the consideration the allotment of water saving for the raw water, so it is used the minimum inflow (Q_{min}). The evolution of reservoir function from single becomes some objectives is necessary to be considered, remembering that there is the increasing of water requirement and the limitation in developing the new water resources. Song *et.al* [8] developed the pattern of reservoir operation by using three levels Tank Model with 2 sides outlet on the upper layer and 1 side outlet on the second and third layer. In this research, the tank model that is modified is calibrated by relating the model parameter with the watershed characteristic by using the regression equation. Evaporation is analyzed by using the formula of FAO Penman-Monteich and the reservoir storage is analyzed by using the water balance equation. This study enters the flood control and efficiency of irrigation. The space for flood control is increasing by decreasing the volume of storage for irrigation supply theorugh the efficiency of water supply for irrigation.

There are 4 variables in this study such as maximum inundation depth (PD_{max}), minimum inundation depth (PD_{min}), percolation depth (DP), and efficiency of irrigation (Es). Irrigation water supply is decreasing if DP and PD_{min} is decreasing. The supply is also decreasing if Es and PD_{max} is increasing. PD min is very influenced by the management habit of DP that is very depended on the agriculture soil type. However, the efficiency of irrigation is very influenced by the available infrastructure. The PD_{max} is very determined by the barrier wall of irrigation area block; PD_{max} is functioned to store the rainfall which is dropped in the agriculture area.

This research will see the climate change (extreme rainfall) from the side of potency and risk. So the water volume more than normal will be used by increasing the decorative plant or to advance the crop area or crop schedule so that the water volume can be used as much as possible. The water volume that cannot be used is removed from the reservoir so the function to reduce flood control can be increased. This research intends to optimize the irrigation reservoir operation for anticipating the extreme flood.

II. MATERIAL AND METHOD

A. Research Location

This research is conducted in yearly reservoir/ dam, the main function is for irrigation and there are flood prone area in the downstream that experiences the yearly flood risk. This study is carried out in Way Rarem Dam. The detail of Way Rarem Dam is as follow: as fill type dam and it is located in Lampung Province, Lampung Utara Regency, Abun Pekurun District, Pekurun Village. The coordinate is 4^o 55'29,01" - 104^{o}47'01,76"; The river area unit is: Mesuji - Tulang Bawang, and Sungai Induk: Way Rarem. Map of location is presented as in the Fig. 1.

Fig. 1. Location of Way Rarem Dam

B. Rainfall

Rainfall is one of the precipitation forms that is the most happened in Indonesia. There are 5 unsure that are necessary to be reviewing in the rainfall discussion [9] such as rainfall intensity, rainfall duration, rainfall depth, rainfall frequency, and rainfall geography area. The rainfall depth, number of rainfall day, and watershed area will give the effect to the number of water availability, however, the rainfall depth and number of rainfall day will give the effect to the water volume that is needed to support the crop period.

The availability of rainfall data is obtained from the recording of rainfall station besides it and from the TRMM (Tropical Rainfall Measuring Mission). The both rainfall data ia necessary to be used because there are some reasons that can cause the error in measuring or recording the rainfall with the real rainfall data. The TRMM data is used as the comparison data from the recording one.

The rainfall data of TRMM has the various type and form. It is beginning from level 1 until level 3. The level 1 is the data that is still in raw form and it has calibrated and geometric corrected. The level 2 is the data that has the geophysics parameter illustration on the same spatial resolution; however, it is still in the original condition of the rainfall when the satellite is through the area that is recorded. The level 3 is the data that has rainfall values, especially the daily rainfall condition that is as the union of level 2 rainfall condition. To obtain the rainfall data in millimeter form (mm), it should use the level 3 with the spatial resolution 0.25° x 0.25°and the temporal resolution every 3 hours [10].

Level 3 TRMM data (3B42RT) that is as the daily precipitation form has been archive available in situs NASA and can be download in*ftp://disc2.nascom.nasa.gov/data/TRMM/ Gridded/3B42RT/*. This data is usually known as TRMM Giovanni. Meanwhile, the Japan Aerospace Exploration Agency (JAXA) has also produced TRMM data. The dataset that is prepared ia near real time and the file transfer protocol (ftp) is in the *ftp://hokushai.eorc.jaxa.jp*.

\C. River flow

According to Sosrodarsono [11], river flow is depended on the same factors in the same time. The factors can be divided into 2 groups that are climate that is represented by rainfall and element of watershed that expresses the characteristic of watershed. The elements of watershed are consisting of land use, watershed area, topography condition, soil type and the other factor like synthetic drainage etc.

In this study, to estimate the flow/ discharge will be used F.J. Mock method. The F.J. Mock method is a monthly water balance simulation for watershed based on the transformation of monthly rainfall data, evapotranspiration, soil moisture, and groundwater storage. The principal of this method is that the rainfall that is dropped in the catchment area will be divided into evapotranspiration, part of them directly becomes as surface run-off and the others enter into soil as the infiltration. The infiltration is beginning with the saturation of soil surface, then there is happened the percolation into groundwater. The amount of water that is saved in groundwater, part of them is going out as the base flow and the others will influence the content of groundwater on the next period. The flow in the river is directly in the soil surface and base flow.

The discharge in the river by using F.J. moch method is analyzed by using the steps as follow:

C.1. Limited Evapotranspiration

$$\Delta S = P - E_t \quad (1)$$

$$\Delta E/E_p = (m/20)\,.\,(18 - n) \quad (2)$$

$$\Delta E = E_p\,.\,(m/20)\,.\,(18\text{-}h) \quad (3)$$

$$E_t = E_p - \Delta E \quad (4)$$

Where: ΔS = net rainfall (mm), P = rainfall (mm), E_t = potential evapotranspiration (mm), n = number of day in a month, m = area that is not covered by vegetation ($0 < m < 50$ %), E_t = limited evapotranspiration (mm)

C.2. Water Balance

$$WS = \Delta S - SS \quad (5)$$

$$SS = SMC_n - SMC_{n-1} \quad (6)$$

$$SMC_n = SMC_{n-1} + P_1 \quad (7)$$

Where: WS = water deficit (mm), P = rainfall (mm), SS = groundwater content (mm), ΔS = net rainfall (mm), SMC = soil moisture (mm)

C.3. Sub-surface water balance

$$V_n' = V_n - V_{n}\text{-}_1 \quad 8)$$

$$I = i\,.\,WS \quad (9)$$

$$V_n = 1/2\,.\,(1 + k)\,.\,I + k\,.\,V_{n-1} \quad (10)$$

Where: V' = groundwater content change (mm), V = groundwater content (mm), WS = water deficit (mm), I = infiltration rate (mm/s), i = coefficient of infiltration (<1), k = recession coefficient of groundwater (<1)

C.4. Surface-run-off

$$R_o = BF + DR_o \quad (11)$$

$$BF = I - V_n' \quad (12)$$

$$DR_o = WS - I \quad (13)$$

Where: DR_o = surface run-off (mm), BF = base flow (mm), I = infiltration rate (mm/s), V_n' = groundwater content change (mm), WS = water deficit (mm)

III. RESULT AND DISCUSSION

To compare this study with the existing condition, it is needed to set the reservoir operation pattern in normal year and the same pattern by using the rainfall that is more than in the dry season due to the climate anomaly. The addition rainfall due to the climate anomaly is happened in the dry season (May-October) and the first crop season (MT I) that is usually carried out on November – March, so the second crop season (MT II) is carried out on March-July. Therefore, it can be determined that the climate anomaly will influence the second crop season (MT II). Besides it, the whole irrigation area on the first crop season (MT I) has cropped paddy so it may not be additional crop area. The difference between the two simulations is presented as in the Table- I.

Tabel- I. Simulation of operation

Item	Operation pattern	
	Normal	Climate anomaly
Volume of storage	To allow until Normal Water Level (NWL)	To be limited until the certain storage volume to reduce flood
Inflow	Dependable discharge with probability of 50%	The estimation discharge due to the climate anomaly
Crop schedule MT I MT II	November-March March-July	November-March March-July etc
Classification	Regarding to habit	May be increasing

A. **The relation of rainfall-discharge**

The F.J. Mock modeling (1973) translated the watershed elements into some coefficients as follow:

a. Coefficient of land cover (*m*)

Coefficient of land cover (m) is determined based on the area that is covered by vegetation. According to F.J. Mock, the value of m for dense forest is 0% and for the agriculture area by preparation is 20 % until 50%. This coefficient will increase 10% every dry month. The land cover in the study area is dominated by oil palm plantation, rubber, and pepper, only little part is still as forest and residence. Based on this case, the coefficient of land cover (m) in this study is taken 20% until 50%.

b. Soil Moisture Capacity (SMC)

Soil Moisture Capacity is the capacity of water content on the residence land layer. The value of SMC is estimated through the observation of porosity condition on surface soil layer in the watershed and the thickness of soil layer. To obtain the value of SMC is needed the long time and the very big effort. The accuracy of SMC value that is obtained will be very determined by the density of soil investigation. In the F.J. Mock model, there are illustrated something as follow: water that enters into aquifer is ignored, the rainfall that is dropped Is classified into 3 parts such as evapotranspiration, base flow, and surface run-off, when the rainfall is less than the evapotranspiration (ΔS) so the water content in soil can be evapotranspiration in amount of the difference and the happening of base flow is due to there is water that is saved in soil.

c. Coefficient of infiltration (*i*) and recession coefficient of groundwater (*k*).

By using the rainfall data, monthly climate data, and F.J. Mock method, there is obtained the estimation of discharge ($Q_{calculated}$). By trial the infiltration coefficient (i) and recession factor of groundwater (k), there is obtained the correlation coefficient between $Q_{calculated}$ and $Q_{observed.}$ The trial is carried out until there is obtained the bigger correlation coefficient that illustrates the close relation (least deviation) between the observed discharge and the discharge that is produced by the F,J, Mock Model.

When $\Delta S \leq 0$, the water content in the surface soil layer (SMC) will be decreasing in amount of |Δs|, and if there is happened in some months consecutively, so the Soil Moisture (SM) will reach minimum value. The difference between $SMC_{Max.}$ and SMC_{Min} is the same or more than the number of ΔS during the $\Delta S \leq 0$.

$$SMC_{Mak.} - SMC_{Min.} = \sum_{n=1}^{t} \Delta S \quad (14)$$

Where: t = number of month when $\Delta s \leq 0$ consecutively until the soil moisture (SM) is close to the SM_{min}

The longer dry season where $\Delta S \leq 0$, so the longer difference of SMC_{Max} and $SMC_{Min,}$ so if there is the discharge and rainfall data are long enough in a region and in this period is happened the long dry season, so the value of $SMC_{Mak.}$ - SMC_{Min} can be estimated.

In the model of FJ Mock, if in determining ΔSMC is less than the number of ΔS during the long dry season above, so in this period the analysis of discharge total will be more than net rainfall total. On the contrary if ΔSMC is more than or the same with the number of ΔS during the long dry season, so the discharge total will be the same with the net rainfall total minus the soil moisture change (the beginning and the end of analysis) and minus thw water which is saved in the soil (the end of analysis).

If

$$SMC_{Mak.} - SMC_{Min.} \leq \sum_{n=1}^{t} \Delta S \quad (15)$$

So it will produce:

$$\sum_{n=1}^{t} Aliran > \sum_{n=1}^{t} \Delta S \quad (16)$$

If:

$$SMC_{Mak.} - SMC_{Min.} = \sum_{n=1}^{t} \Delta S \quad (17)$$

So it can produce:

$$\sum_{n=1}^{t} Aliran > \sum_{n=1}^{t} \Delta S - (SM_1 - SM_{tz}) - V_{tz} \quad (18)$$

Where: SMC_{max} = maximum water content in surface soil layer; SMC_{min} = minimum water content in surface soil layer; ΔS = net rainfall; n = month where $\Delta s < 0$; t = number of month consecutively where $\Delta s < 0$; SM_1 = water content in soil layer when the beginning of analysis; SM_{tz} = water content in soil layer when the end of analysis; V_{tz} = water that is saved in the soil at the end of analysis

After SMC_{max} can be estimated, so it is carried out trial and error to obtain the infiltration coefficient (i) and groundwater recession coefficient (k). The trial of I and k is carried out until there is obtained the close relation between observed discharge and discharge that is produced by the F.J. Mock model.

Based on the rainfall (P) and potential evapotraspiration (Et), there are 2 possibilities as follow:

a. Rainfall is more than evapotranspiration ($P \geq Et$; Hujan Netto $\Delta S \geq 0$): water content recharge in soil moisture until reaching the maximum value, the rest is divided as surface run-off and infiltration. By the recession coefficient, infiltration will be increasing/ decreasing the water that is saved in soil (V_n). If the water that is saved in this month (V_n) is more than the previous month (V_{n-1}), so part of infiltration is saved in the soil and the rest becomes as the base flow. On the contrary, if the water that is saved in this month (V_n) is less than the previous month (V_{n-1}), so the water that is saved in soil becomes as the base flow.

Base flow $= I - V_n'$ (19)

$V_n' = V_n - V_{n-1}$ (20)

However, discharge/ flow is the amount of surface-run-off and base flow.

b. Rainfall is less than potential evapotranspiration ($P \leq Et$; Net rainfall $\Delta S \leq 0$): water content in soil layer (soil moisture) is decreasing in amount of P – Et, there is no surface run-off (= 0) and no infiltration (= 0), water that is saved in soil (V_n) will be decreasing. The base flow is as the decreasing of water that is saved in soil ($V_{n-1} - V_n$). Discharge/ flow is as the amount of surface run-off and base flow.

Remembering on the rainy season that the rainfall is more than the potential evapotranspiration ($P \geq Et$), so on the beginning of rainy season, the water content in soil (soil moisture) may be has not reached maximum, however, on the next month until the end of rainy season, the soil moisture will reach the maximum value ($SMC_{Max.}$).

When there is happened the climate anomaly (negative ENSO or negative mode Dipol), so the rainfall on dry season will be also high. Water content in soil layer (soil moisture) on previous month and this month reach the maximum value ($SMC_{Max.}$), so there is no addition for the water content in soil layer, the whole net rainfall will become as surface run-off and infiltration

Water surplus (WS) = ΔS; I = i x ΔS; Surface run-off = WS – I = (1-i) x ΔS; Base flow = I - V_n'; $V_n' = V_n - V_{n-1}$; Flow/ Discharge = surface run-off + base flow = WS – I + I - V_n'= WS - V_n'; due to $WS_n = \Delta S_n$; $I_n = i \times \Delta S_n$; $V_n' = Vn - V_{n-1}$; $V_n = 1/2 \times (1+k) \times I + k \times V_{n-1}$; $V_n = 1/2 \times (1+k) \times (i \times \Delta S_n) + k \times V_{n-1}$; $V_n = F \times \Delta S_n + k \times V_{n-1}$. If F =1/2 x (1+k) x I, so

$$V_1 = F \times \Delta S_1 + k \times V_0 \quad (21)$$

$$V_2 = F \times \Delta S_2 + k \times V_1$$
$$= F \times \Delta S_2 + k \times (F \times \Delta S_1 + k \times V_0)$$
$$= F \times \Delta S_2 + k \times F \times \Delta S_1 + k^2 \times V_0 \quad (22)$$

$$V_3 = F \times \Delta S_3 + k \times V_2$$
$$= F \times \Delta S_3 + k \times (F \times \Delta S_2 + k \times F \times \Delta S_1 + k^2 \times V_0)$$
$$= F \times \Delta S_3 + k \times F \times \Delta S_2 + k^2 \times F \times \Delta S_1 + k^3 \times V_0 \quad (23)$$

$$V_4 = F \times \Delta S_4 + k \times V_3$$
$$= F \times \Delta S_4 + k \times (F \times \Delta S_3 + k \times F \times \Delta S_2 + k^2 \times F \times \Delta S_1 + k^3 \times V_0)$$
$$= F \times \Delta S_4 + k \times F \times \Delta S_3 + k^2 \times F \times \Delta S_2 + k^3 \times F \times \Delta S_1 + k^4 \times V_0$$

Retrieval Number: D8387118419/2019©BEIESP
DOI:10.35940/ijrte.D8387.118419
Journal Website: www.ijrte.org

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

Therefore,

Flow/discharge = WS_n - V_n'

$= \Delta S_n - (V_n - V_{-1})$

Flow/ discharge: $Q = \Delta S_n - (V_n - V_{n-1})$

$$Q_1 = \Delta S_1 - (V_1 - V_0) \quad (24)$$

$$Q_2 = \Delta S_2 - (V_2 - V_1) \quad (25)$$

$$Q_3 = \Delta S_3 - (V_3 - V_2) \quad (26)$$

Where Q_n = flow/ discharge n^{th} month; ΔS_n = net rainfall n^{th} month; V_n = water that is saved in soil on n^{th} month.

Based on the something above, it indicates that if the water that is saved in soil (V_n) on the previous month that is happened climate anomaly rainfall and it can be known, so the discharge/ flow that will be happened can be estimated after the net rainfall (ΔS) can be estimated as follow

- Q_1 can be estimated after V_0 and ΔS_1 can be estimated.
- Q_2 can be estimated after V_0, ΔS_1 and ΔS_2 can be estimated.
- Q_3 can be estimated after V_0, ΔS_1, ΔS_2 and ΔS_3 can be estimated.
- Etc.

Table- II presents the effect of V_n to discharge

Table- II The effect of V_0 to discharge

Month-	Effect of V_n	Note
1	k V_0	- If k < 1,the effect of V_0 to the next monthly discharge will be more decreasing - If recession coefficient (k) is getting smaller, so the effect of V_0 is getting smaller too.
2	(1-k) k V_0	
3	(1-k) k^2 V_0	
4	(1-k) k^3 V_0	

IV. CONCLUSION

Four unsure of catchment area factor (V_n, i, k, dan SM) each gives effect to the discharge, however, when there is happened the climate anomaly ($P \geq Et$; net rainfall $\Delta S \geq 0$), so the unsure of V_0 gives the getting smaller effect on next months.

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