

Rusnam_2021_IOP_Conf._Ser._
Earth_Environ._Sci._757_012041
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by

Submission date: 14-Oct-2022 09:09AM (UTC+0800)

Submission ID: 1924796221

File name: Rusnam_2021_IOP_Conf._Ser._Earth_Environ._Sci._757_012041.pdf (617.36K)

Word count: 2741

Character count: 14439

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To cite this article: R Rusnam and N R Yanti 2021 *IOP Conf. Ser.: Earth Environ. Sci.* **757** 012041

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Potential Evapotranspiration uses Thornthwaite Method to the Water Balance in Padang City

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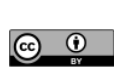
Abstract. Population growth has resulted in many changes in land cover that occurs in the city of Padang. The availability of groundwater which mostly comes from rainfall is an important limiting factor that increased the production of a plant. Limited water availability causes competition for water use in the community both for agricultural activities, residential, industrial and other water uses. The water balance is a method that can be used to see the availability of groundwater for plants at a certain time. This study aims to analyze the water balance using the Thornthwaite method. The data used in this study are rainfall data along with climatological data for the years 2007 - 2018 which represent the Padang City area. The results showed that there was a water surplus every month. The highest excess of water occurred in November at 375.72 mm.

Keywords: Evapotranspiration, Thornthwaite, Water balance

1. Introduction

Water is the most important component in life primarily in agricultural activities. Most of the earth's freshwater remains stored underground in aquifers and not in lakes and rivers. An aquifer is an area that becomes a source of bottom-flow water for rivers if there is no rainfall. Groundwater plays an important role in terms of the economic and social health of the population. The government needs to provide water in various combinations according to the demands of private, public, industrial, and commercial users [1] [2]. Water demand has increased recently due to population growth, where water for agriculture and other needs has become limited [3]. The acceleration of population growth has had two major impacts on groundwater, such as exploitation of aquifers which can destroy natural resources and also be affected by industrial waste [4].

The water balance is a measurement of the amount of each component of the water flow cycle that enters and leaves the plant root layer. The water requirements for different plants require different water balances. Therefore, the dimensions of space, time and water requirements for plants are very prominent in the management of water resources [5]. The availability of water resources is strongly influenced by climatic conditions, topography, soil types, land cover, and geological structure of an area [6]. Estimation of water availability, as well as its uncertainty, will occur in current and future conditions. Using various simulation models, the aim is to increase our understanding of current and future water availability and water pressure on a global scale, with an emphasis on water resources available in major river systems at timescales [7]. The level of groundwater availability is obtained by analyzing groundwater content data. Different types of soil can affect the availability of groundwater content [8].



The ability of soil to hold water is largely determined by soil type (especially texture) and the type of vegetation [9]. Most of the water that is absorbed by plants is released back into the atmosphere through the process of transpiration. The loss of water from the ground occurs not only through the process of transpiration but also through the soil surface which is called evaporation. In the field, the processes of transpiration and evaporation occur simultaneously and are difficult to separate from one another. Therefore, water loss through these two processes is generally used as one called evapotranspiration [5]. Evapotranspiration plays an important role in linking the water and energy cycles but is difficult to predict [10]. Soil evapotranspiration is an important component that provides a link between the atmosphere and the earth's surface [11]. Evapotranspiration is also an important indicator of hydrological variation and the presence of climate change due to anthropogenic disturbances [12] [13]. Several methods are available for estimating evapotranspiration from meteorological observations. One of them is the Thornthwaite method, a simple method developed by Thornthwaite (1948) that uses air temperature and latitude to estimate evapotranspiration [14].

Padang City is the capital city of West Sumatra province where the population growth and land-use changes are quite high every year [15]. Changes in land cover have implications for changes in water systems in a watershed. This is inseparable from the land's ability to accommodate, store, and flow water in an area.

2. Methods

This research was conducted in Padang City, West Sumatra Province. With an altitude of 0–1853 meters above sea level. The materials used in this study include daily and monthly climate data for the period 2007 - 2018 Gn Nago Station, Minangkabau Meteorological Station and Teluk Bayur Maritime Meteorological Station. The method used in the land balance analysis is Thornthwaite and Mather (1957). Soil data is in the form of field capacity and the permanent wilt point of the soil.

The relationship between monthly means of daily averaged temperatures (T) and potential evapotranspiration (PET) is given by Thornthwaite [9].

$$PET = 16 \left(\frac{10T}{I} \right)^a \quad (1)$$

where PET is in mm month^{-1} and a is given by a third-order polynomial in the heat index (I). The heat index is developed for this purpose and has for each year 12 monthly means of daily averaged temperature values as input.

$$I = \sum_{i=1}^{12} \left(\frac{T_i}{5} \right)^{1.514} \quad (2)$$

$$a = 0.657 \times 10^{-6} I^3 - 0.771 \times 10^{-4} I^2 + 0.017921 + 0.49239 \quad (3)$$

The numerical implementation of equation (2) is that $\max(T, 0)$ is taken as input to the summation rather than T . The implementation of the Thornthwaite formula has been modified by Willmot et al 1985 where there is a temperature range parameter [16].

$$PET = \begin{cases} 0 & T \\ 16 \left(\frac{10T}{I} \right)^a & 0^\circ\text{C} \leq T < 25.5^\circ\text{C} \\ -425.85 + 32.24 - 0.43T^2 & T \geq 26.5^\circ\text{C} \end{cases} \quad (4)$$

To calculate the PET correction required the number of days in a month, length of day and latitude

$$PET = PET \left(\frac{\theta}{30} \right) \left(\frac{h}{12} \right) \quad (5)$$

where θ is the length of the month (in days) and h is taken as the duration of daylight (in hours) on the fifteenth day of the month. The latter correction ensures that the Thornthwaite parameterization for PET is related to the latitude of the site considered, next to the monthly means of daily averaged temperatures.

Accumulation Off Potential Water Losses (APWL), the accumulated potential water loss is calculated as a running sum of the daily precipitation P with PET [17].

$$APWL = P - PET \quad (6)$$

when $P - PET$ is negative, actual evapotranspiration AET is equal only to the amount of water that can be extracted from soil moisture SM . When $P - PET$ is positive, the AET equals the PET .

3. Results and Discussion

The water balance assumption is a simple control that rainfall is the only input and evaporation and river flow as the output. Water balance can be simulated with a simple model effective soil storage with evaporation threshold, reflects the balance between the availability of water and energy, and runoff is generated in an excess storage situation [18]. The availability of water is illustrated by levels of water in different soil layers. Excess water or gravity flow quickly from the ground after heavy rain due to force gravity (point of saturation with field capacity). That water available is retained in the soil after excess dried (field capacity for withering point) [19].

Table 1. Water content at field capacity and point permanent wilt in various types of soil in Padang

Type of soil	Wilting point %	Field capacity %	pH
Podsolik of red yellow (Ultisol)	3.51	60.51	4.82
Alluvial ¹	7.29	39.8	7.56
Alluvial ²	8.81	50	5.47

Source : Munir and Herman 2019 [20]

Table 2. Land evapotranspiration

Month	P (mm)	T (°C)	PET (mm)	P-PET (mm)	Surplus/deficit
January	237.91	27.27	152.13	85.79	Surplus
February	233.29	27.40	140.07	93.22	Surplus
March	317.68	27.43	155.87	161.80	Surplus
April	300.82	27.49	152.16	148.66	Surplus
May	266.35	27.54	158.30	108.05	Surplus
June	272.63	26.80	136.45	136.18	Surplus
July	205.43	27.08	146.94	58.50	Surplus
August	288.58	27.10	148.56	140.02	Surplus
September	284.53	26.96	140.88	143.64	Surplus
October	330.15	27.01	146.62	183.53	Surplus
November	518.07	27.04	142.35	375.72	Surplus
December	386.08	27.07	147.94	238.14	Surplus

According to Table 2, the highest rainfall occurred in November at 518 mm with an average temperature of 27.04 °C. The highest evapotranspiration occurred in May 158.3 mm / month with the highest temperature 27.54 °C. The difference in the resulting evapotranspiration value is influenced by the size or the small value of temperature, climate, soil conditions, evaporation, and local vegetation [21]. The availability of water every month is a surplus, which means that water needs can be met every month. Good management is needed so that this excess water can be used optimally. The maximum surplus occurred in November of 375.72 mm. This is consistent with the high rainfall that occurred in November.

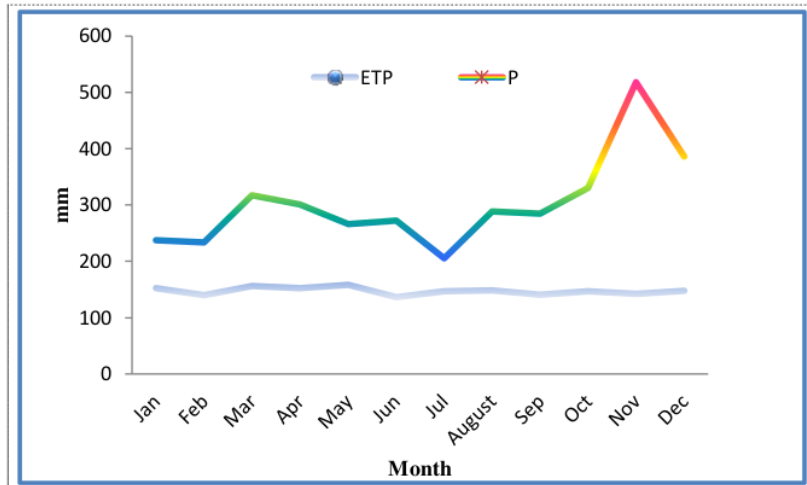


Figure 1. Evapotranspiration and precipitation

Evapotranspiration has a very important role in water balance. water from plant evaporation, surface evaporation, and groundwater funds are consumed by evapotranspiration. According to statistics, in humid areas evapotranspiration accounts for about 50% of annual rainfall, while in dry areas about 90% [22]. In Figure 1, it can be seen that evapotranspiration contributes around 30-70% of the total precipitation.

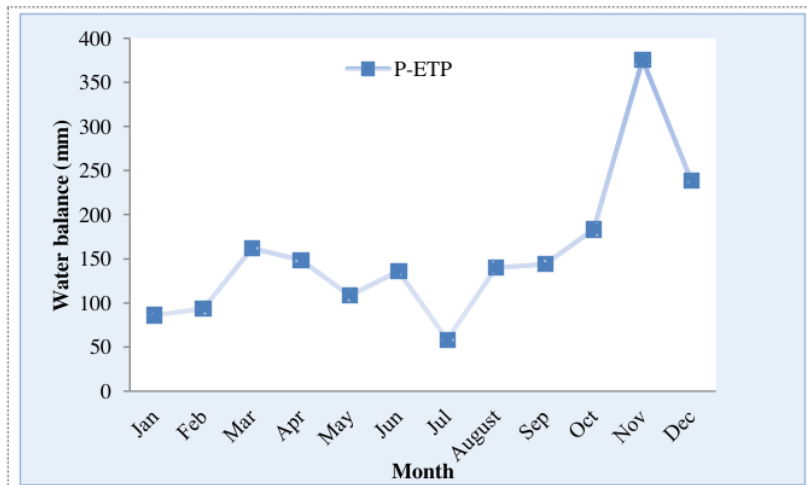


Figure 2. Water balance

4. Conclusion

Padang city is a humid evapotranspiration area, where about 30-70% of the rainfall is consumed by evapotranspiration activities. every month there is a surplus of water which does not allow drought. good management is needed by many parties so that the use of water can run optimally.

Acknowledgments

The author would like to thank the Faculty of Agricultural Technology, Andalas University under the Research Work Implementation Agreement Letter No: 011 / PL / DF-DIPA / FATETA-2020 which has funded this research. The author also expressed gratitude to all who had helped to accomplish the research.

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