A simple method to determine patterns of wet and dry seasons

B I Setiawan
Professor, Dept Civil and Env Engineering, Bogor Agricultural University, Bogor, Indonesia
E-mail: budindra@apps.ipb.ac.id

Abstract. The objective of this paper is to describe a simple method to determine patterns of wet and dry seasons based on historical climate data. Here, the daily rainfall and evapotranspiration were used as input variables, each of which was accumulated over one year. The accumulated data was then estimated using a continuous equation in the form of a 6th order polynomial equation. Nets of the first derivate of the rainfall minus that of evapotranspiration were used to determine wet and dry periods. Here, the wet period occurs when the nets are positive, and the dry period occurs when the nets are negative. Later, algorithms were developed to point the start, end, and peak of, and to calculate the available rainwater in each period. The method was applied here to determine patterns of wet and dry seasons in Serang Regency, Banten Province, Indonesia. The climate data was collected from a local climate station managed by the National Agency for Meteorology, Climatology, and Geophysics from 1978 to 2018 (41 years). There were three wet periods and three dry periods. On average, the dry season started from 107±67 J-day to 263±113 J-day and was followed by the wet season till 121±57 J-day. In the dry season, the rainwater was deficit about -353 mm. Whereas, in the wet season, rainwater was surplus about 576 mm. And, in the whole season, the rainwater was surplus up to 223 mm, which may be conservable to anticipate water deficit in the dry season.

1. Introduction

In the context of climate change, a more precise planting calendar is critical not only to determine the right time to start cultivation but also to make sure that irrigation and drainage structures can anticipate drought and flooding. In the tropics such as Indonesia, the wet season has been traditionally believed to occur between October to March (OKMAR), while the dry season is from April to September (ASEP) [1, 2]. Though there have been considerably seasonal shifting or fluctuations from year to year and as well as from place to place [3], the national agenda on rice plantings all over the regions still unchanged [4]. It is not unusual rice plantings need to be postponed due to unexpected weather, whereas in other areas, harvestings may be delayed because heavy rainfalls are still happening [5]. Moreover, irrigation and drainage facilities are not well prepared to anticipate those situations.

Global maps of climate are available that classify climate type in any region in the world based on a long dataset of monthly precipitation and temperature [6]. In general, rainfall is the primary climate variable to determine the onset and length of the wet or rainy season. Under the Köppen climate classification, for tropical climates, a wet season month is defined as a month where average precipitation is 60 mm or more [7]. Based on the daily precipitation data and plant physiological aspects, fuzzy logics were developed to judge whether the rainy season has already begun [8]. For a practical application, a ten-day moving average is often used to predict the rainfall and categorize it into low (0-50 mm), medium (50-150 mm), and high (150-300) and extreme (>300 mm) [3]. This information is routinely updated and followed to adjust the planting calendars [2]. The wet season had shifted, either delay or earlier, influenced by meteorological and agronomic aspects [9].

Dry season or drought gets more extensive attention because of its direct impacts on vegetations. There are many methods to identify drought. The Standardized Precipitation Index (SPI) applies the probability distribution function to model the precipitation data to characterize meteorological drought on a range of timescales. On short timescales, the SPI is closely related to soil moisture, while at longer timescales, the SPI can be related to groundwater and reservoir storage [10]. The Standardized Precipitation Evapotranspiration Index takes into account both precipitation and potential evapotranspiration (PET) in determining drought and can capture the main impact of increased temperatures on water demand [10]. In some regions of the world, models of PET can have significant effects on the SPEI [11]. Recently, the Standardized Precipitation Evapotranspiration Runoff Index has...
a multi-scalar index that can assess drought conditions in different areas and the impacts of climate change on drought [12, 13]. These previous methods explained before are not able to point out precisely the onset of wet and dry seasons lest to estimate the available rainwater in each season.

A different method has been introduced to point out the start of the dry season [14]. This method was using the 5th order polynomial equation to interpolate the daily cumulative rainfall data, which gained high precision (R^2>0.98). Here, the first derivative of the equation that decreased with time could detect the start and end of the wet/dry season, and the second derivative could find a peak in each season. This method does not consider evapotranspiration, which is the important factor to determine dry season, and consequently, it cannot estimate the available rainwater, whether it is surplus or deficit, in each season.

The objective of this paper is to describe a simple method to determine patterns of wet and dry seasons based on historical climate data. Herewith, the daily evapotranspiration was considered, and its cumulative values were interpolated using another polynomial equation. Now, the first derivative of the rainfall minus the first derivative of the evapotranspiration was then analysed to identify the start, end, and peak of wet and dry seasons. Furthermore, the available rainwater, including the peak rate of the water loss or gain in each season, could be calculated. Based on a historical dataset, patterns of wet and dry seasons then can be determined.

2. Theory
Wet and dry seasons in a specific location related to the rainfall and the evapotranspiration patterns which generally fluctuate from time to time. The wet season occurs when the rates of the rainfall are larger than that of the evapotranspiration over successive days resulting in the surplus of rainwater. Whereas the dry season occurs when the rates of the rainfall smaller than the evapotranspiration over successive days resulting in the deficit of rainwater. This relationship can be expressed in the following equation:

\[
\frac{dN}{dt} = \frac{dR}{dt} - \frac{dET}{dt}
\]

Or, in another form, it is written as follows:

\[
N_t = R_t - ET_t
\]

Where \( N_t \), \( R_t \), and \( ET_t \) are the rates of the net of water balance (mm d\(^{-1}\)), rainfall (mm d\(^{-1}\)), and evapotranspiration (mm d\(^{-1}\)), respectively. Here, \( R(t) \) and \( ET(t) \) are in forms of continuous functions that each represents cumulative rainfall and evapotranspiration over time, such as follows:

\[
R(t) \approx \sum_{i=1}^{t} R_i
\]

\[
ET(t) \approx \sum_{i=1}^{t} ET_i
\]

Where the subscript \( i \) here denotes Julian calendar, which equals 1 for the first January. Thus, \( R_i \) and \( ET_i \) are the daily rainfall and evapotranspiration that generally can be obtained from a climate station. Steps to identify the wet and dry periods are as follows:

- The wet period (W), dry period (D), and transition (T) are defined here as follows:

\[
P = \begin{cases} 
W & \text{if } N_t > 0 \\
D & \text{if } N_t < 0 \\
T & \text{if } N_t = 0 
\end{cases}
\]

- The transition means the Start \( (t_{\text{Start}}) \) of a wet period and the End \( (t_{\text{End}}) \) of its previous dry period, or vice versa.
Length ($t_{Length}$) of each period can be calculated as follows:

$$t_{Length} = t_{End} - t_{Start}$$

(6)

- Peak ($t_{Peak}$) of each period can be found from the second derivative of $N(t)$ as follows:

$$N(t)_{t_{Peak}} = 0$$

(7)

- Available rainwater ($ARW$) in each period is calculated as follows.

$$ARW_{t_{End}} - t_{Start} = [R(t_{End}) - R(t_{Start})] - [ET(t_{End}) - ET(t_{Start})]$$

(8)

3. Materials and Methods

3.1 Climate data

The method here was applied to determine wet and dry periods in the Serang city of Banten Province, Indonesia. The climate data were obtained from a weather station managed by the National Agency of Meteorology, Climatology, and Geophysics (BMKG), which has been registered by the World Meteorological Organization (WMO) with the code of WMO 96737. The Latitude is 6.11185 degrees, Meridian is 106.11 degrees, and Altitude is 100 m from the mean sea level. The station has recorded the data since 1978 and published it online [15]. The data consists:

- Daily Minimum Temperature (Tmn)
- Daily Maximum Temperature (Tmx)
- Daily Averaged Temperature (Tav)
- Daily Averaged Air Relative Humidity (RH)
- Daily Rainfall (R)
- Daily Sunshine Duration (SD)
- Daily Averaged Wind Velocity (AWV)
- Daily Main Wind Direction (WD)
- Daily Maximum Wind Velocity (MWV)

There were, however, quantifiable missing or unrecorded data for SD, AWV, WD, and MWV, which were more than 9% from 1978 to 2018. Whereas, the missed data for Tmn, Tmx, Tav, RH, R, and SD each did not exceed 3%. Thus, reliable data for this study were as follows:

- Daily Minimum Temperature (Tmn)
- Daily Maximum Temperature (Tmx)
- Daily Averaged Temperature (Tav)
- Daily Rainfall (R)

Daily evapotranspiration ($ET$) was estimated from Reference Evapotranspiration ($ETo$) which was calculated using the Hargreaves model as follows [16]:

$$ET = 0.000939 \sqrt{T_{mx} - T_{mn}} (T_{av} + 18.8) Ra(L,J)$$

(9)

Where, $ET$ is the evapotranspiration (mm d<sup>-1</sup>), $Ra$ is the Daily Extraterrestrial Radiation (MJ m<sup>-2</sup>) calculated based on the Latitude ($L$) of the Climate Station and the Julian Calendar ($J$) [16].

3.2 Data Processing

Data processing was carried out using MS Excel. Data of Tmn, Tmx, Tav, R and ET every year was arranged in one different sheet. Computer programs (functions) were developed and written in Visual Basic Editor. Appendix 1 shows source codes of the main functions to calculate Ra and ET; to find the coefficients of the 6<sup>th</sup> order polynomial equation, and to calculate the polynomial equation and its first derivate. Furthermore, algorithms with graphical presentations (Figure 3) were developed to easily
find Start, End, Peak, Length, Available Rainwater and Peak Rate in the wet and dry periods. The complete program is available for free to use but not for any commercial purposes.

4. Results and Discussions

4.1 Annual Climates

Figure 1 shows annual climate variables and their trends from 1978 to 2018. The average and standard deviation (SD) for Tmn was 23.1±0.45 °C, for Tmx was 31.9±0.54 °C, for Tav was 26.7±0.37 °C, and for RH was 81.1±1.42 %. While RH was relatively stable, Tmn, Tav, and Tmn increased with time at 1.1 °C y⁻¹, 0.2 °C y⁻¹, and 0.8 °C y⁻¹, respectively. These trends indicated the air became hotter. The annual rainfall (R) was 1677±370 mm, and ET was 1616±66 mm. Both decreased with time at -5.4 mm y⁻¹ and -1.2 mm y⁻¹, respectively. The highest R was 2914 mm in 2013, whereas the lowest was in 1997 coincident with the first El-Nino in the country. In general, the net of water balance (WB) fluctuated between surplus dan deficit but decreased slightly with time at -4.2 mm y⁻¹, indicating the air became drier.

4.2 Monthly Water Balance

Figure 2 shows the average monthly R, ET, and N over 41 years. While ET was relatively stable at 134±9 mm, R fluctuated widely from the lowest 80 mm in August to the highest 330 mm in March. In general, WB was a positive or rainwater surplus, but from July to September was a deficit, which was the dry period with its peak in August.

4.3 Daily Water Balance

Figure 3(a–d) displays, as an example, a process to find continuous functions $R(t)$ and $ET(t)$, and to determine the Start, End, and Peak of Wet and Dry periods in 1980. Figure 3(a) plots the daily rainfall ($R_i$) and its cumulative and continuous function $R(t)$. The function is the 6th order polynomial equation that in a general form is as follows:

$$Y(t) = a_0 + \sum_{j=1}^{nj} a_j \sum_{i=1}^{nt} X_i^j$$  \hspace{1cm} (10)

Where $Y$ is this case is $R(t)$ (mm), $X$ is $t$ is time (d), $a$ is the coefficient, $nj=6$, and $nt$ is the number of days in the year.

As shown in Figure 3(b), the 6th order polynomial equation gained more precise results for $ET(t)$. The equation also gained precise results for the rest of the years, with the minimum R² was 0.98708.
for $R(t)$. Table 1 lists the coefficients of the 6th order polynomial equations for $R(t)$ and $ET(t)$. Figure 3(c) shows the first derivative for $R(t)$, and $ET(t)$, which is in the general form is as follows:

$$Y_t = a_1 + \sum_{j=2}^{n} a_j \sum_{i=1}^{n-1} x_i^{j-1}$$

(11)

Table 1 Wet and Dry Periods and their Occurrences

| Periods | Prob. in | Prob. in | Start (J-day) | End (J-day) | Length (days) | Water (mm) | Peak (mm) | Peak Rate (mm d⁻¹) |
|---------|----------|----------|---------------|-------------|--------------|------------|-----------|------------------|
| Wet1    | 90%      | 33%      | 1             | 121         | 121          | 395        | 7         | 10.4             |
| Dry1    | 100%     | 44%      | 107           | 263         | 163          | -353       | 198       | -3.6             |
| Wet2    | 85%      | 20%      | 264           | 321         | 73           | 208        | 297       | 5.6              |
| Dry2    | 29%      | 21%      | 322           | 323         | 76           | -152       | 293       | -2.0             |
| Wet3    | 17%      | 16%      | 324           | 354         | 58           | 150        | 352       | 6.5              |
| Dry3    | 10%      | 9%       | 357           | 360         | 32           | -26        | 350       | -1.5             |

4.4 Wet and Dry Seasons

Based on Equation 2, Equation 5 and Equation 7, Figure 3(d) shows there are 2 points when $N_t$ equals nil, which is on 111 J-day and 312 J-day and the peak point on 222 J-day. This period was dry since between those two days; the $N_t$ is negative. Another wet period started from 312 J-day to the year of 1981. Based on Equation 8, the rainwater was deficit amounted to 257 mm, with the peak rate was -1.89 mm d⁻¹ on 222 J-day.

Appendix 2 shows some curves displaying the start, end and peak of the wet and dry seasons, and Appendix 3 shows all the outputs from 1978 to 2018. In 41 years, there were three wet periods (Wet1, Wet2, and Wet3) and three dry periods (Dry1, Dry2, and Dry3). As also shown clearly in Figure 4, in sequence from the first of January (1 J-day):

- Wet1 was from 1 J-day to 121 J-day with $P_{41}=90\%$, $P_{366}=33\%$, ARW=395 mm and the peak rate=10.4 mm d⁻¹;
- Dry1 was from 107 J-day to 263 J-day with $P_{41}=100\%$, $P_{366}=44\%$, ARW=-353 mm and the peak rate=-3.6 mm d⁻¹;
Wet2 was from 264 J-day to 321 J-day with $P_{41}=85\%$, $P_{366}=20\%$, ARW=208 mm, and the peak rate=5.6 mm d$^{-1}$;  
Dry2 was from 322 J-day to 323 J-day with $P_{41}=29\%$, $P_{366}=21\%$, ARW=-152 mm and the peak rate=-2.0 mm d$^{-1}$;  
Wet3 was from 324 J-day to 354 J-day with $P_{41}=17\%$, $P_{366}=16\%$, ARW=150 mm and the peak rate=6.5 mm d$^{-1}$;  
Dry3 was from 357 J-day to 360 J-day with $P_{41}=10\%$, $P_{366}=9\%$, ARW=-26 mm, and the peak rate=-1.5 mm d$^{-1}$.

If divided into two seasons, the dry season may start from 107±67 J-day to 263±113 J-day and follow by the wet season until 121±57 J-day. During the dry season, ARW was -353 mm (rainwater deficit). Whereas, during the wet season, ARW was 576 mm (rainwater surplus). And in the whole season, the rainwater is surplus 223 mm, which may be conservable to anticipate the rainwater deficit in the dry season.

5. Conclusions

A simple method has been developed to determine patterns of wet and dry periods based on the daily data of rainfall and evapotranspiration. The method can point the start, end, and peak, and inform how much rainwater is available in each period. The method was applied here to determine patterns of wet and dry seasons in Serang Regency, Banten Province, Indonesia, based on the climate data from 1978 to 2018. There were three wet periods and three dry periods. On average, the dry season started from 107±67 J-day to 263±113 J-day and was followed by the wet season till 121±57 J-day. In the dry season, the rainwater was deficit about -353 mm. Whereas, in the wet season, rainwater was surplus about 576 mm. And, in the whole season, the rainwater was surplus up to 223 mm, which may be conservable to anticipate water deficit in the dry season.

Acknowledgment

Appreciations convey to the National Agency of Meteorology, Climatology, and Geophysics for providing climate data and to the Ministry of Agriculture for the corporations to disseminate the methods to many regions in Indonesia.

Reference

[1] Puslitbangtan, “Puslitbangtan, Balitbangtan, Kementerian Pertanian Indonesia,” 1 04 2019. [Online]. Available: http://pangan.litbang.pertanian.go.id/berita-1045-rakor-upsus-dalam-rangka-evaluasi-dan-singkrinisasi-itt-okmar-20182019-.html. [Accessed 31 10 2019].

[2] Balitbangtan, Kementerian Pertanian Indonesia, “SI KATAM TERPADU,” 2019. [Online]. Available: http://katam.litbang.pertanian.go.id/. [Accessed 29 10 2019].
[3] BMKG, BMKG, 2019. [Online]. Available: http://www.bmkg.go.id/tag/?tag=prakiraan-hujan-dasarian&lang=ID. [Accessed 29 10 2019].

[4] industrycoid, “Presiden Jokowi Pimpin Gerakan Kawal Musim Tanam OKMAR 2018/2019 di Garut, Jawa Barat,” 2019.

[5] Balittra, Balitbangtan, Kementerian Pertanian Indonesia, “Pergeseran Hujan Saat Musim Tanam,” 12 04 2019. [Online]. Available: http://balittra.litbang.pertanian.go.id/index.php/berita/info-aktual/2296-pergeseran-hujan-saat-musim-tanam. [Accessed 31 10 2019].

[6] M. C. Peel, B. L. Finlayson and T. A. McMahon, “Updated world map of the Köppen-Geiger climate classification,” Hydrol. Earth Syst. Sci., vol. 11, pp. 1633-1644, 2007.

[7] Encyclopaedia Britannica, “Köppen climate classification,” 2019. [Online]. Available: https://www.britannica.com/science/Koppen-climate-classification/World-distribution-of-major-climatic-types. [Accessed 30 10 2019].

[8] P. Laux, H. Kunstmann and A. Bárdossy, “Predicting the Regional Onset of the Rainy Season in West Africa,” International Journal of Climatology, vol. 28, no. 3, pp. 329-342, March 2008.

[9] D. P. Ariyanto, R. P. W. Priswita, Komariah, Sumani and M. Senge, “Determining the wet season onset toward crop water availability under the tropical monsoon climate,” in IOP Conf. Ser.: Earth Environ. Sci. 200 012010, 2018.

[10] NCAR UCAR, “ClimateDataGuide,” 30 10 2019. [Online]. Available: https://climatedataguide.ucar.edu/climate-data/standardized-precipitation-evapotranspiration-index-spei.

[11] S. Beguería, S. M. Vicente-Serrano, F. Reig and B. Latorre, “Standardized precipitation evapotranspiration index (SPEI) revisited: parameter fitting, evapotranspiration models, tools, datasets and drought monitoring,” International Journal of Climatology, vol. 34, p. 3001–3023, 2014.

[12] L. Wang, H. Yua, M. Yang, R. Yang, R. Gao and Y. Wang, “A drought index: The standardized precipitation evapotranspiration runoff index,” Journal of Hydrology, vol. 571, pp. 651-668, April 2019.

[13] S. Khan, H. F. Gabriel and T. Rana, “Standard precipitation index to track drought and assess impact of rainfall on watertables in irrigation areas,” Irrigation and Drainage Systems, vol. 22, no. 2, p. 159–177, June 2008.

[14] F. Irsyad, S. K. Saptomo and B. I. Setiawan, “Determination of Dry Season Onset and Duration using Polynomial Function with Visual Basic For Applications,” Jurnal Agromet Indonesia, vol. 28, no. 1, pp. 40-46, 2014.

[15] BMKG, [Online]. Available: http://dataonline.bmkg.go.id/data_iklim. [Accessed 30 07 2019].

[16] CIGR, CIGR Handbook of Agricultural Engineering Volume I Land and Water Engineering Edited, 1999.
Appendix 1 Computer Programs

| Functions to Calculate Extra-terrestrial Radiation (Ra) |
|------------------------------------------------------|
| Rem Relative distance from earth to the sun          |
| Function Dr(J)                                        |
| Dr = 1 + 0.033 * Cos(0.0172 * J)                     |
| End Function                                         |
| Rem Latitude in rad                                  |
| Function Phi(L)                                      |
| Phi = WorksheetFunction.Pi() * L / 180 'Southern latitude |
| End Function                                         |
| Rem Solar declination                                |
| Function SolarDeclination(J)                         |
| SolarDeclination = 0.409 * Sin(0.0172 * J - 1.39)    |
| End Function                                         |
| Rem Sunset hour angle (Ws)                           |
| Function Ws(L, J)                                    |
| a = Phi(L)                                           |
| b = SolarDeclination(J)                              |
| Ws = WorksheetFunction.Acos(-Tan(a) * Tan(b))        |
| End Function                                         |
| Rem Extraterrestrial radiation                       |
| Function Ra(L, J)                                    |
| a = Dr(J)                                            |
| b = Phi(L)                                           |
| c = SolarDeclination(J)                              |
| d = Ws(L, J)                                         |
| E = d * Sin(b) * Sin(c)                              |
| f = Cos(b) * Cos(c) * Sin(d)                         |
| Ra = 37.6 * a * (E + f) *(MJ m-2 d-1)                |
| End Function                                         |

| Function to Calculate Evapotranspiration (ET)        |
|------------------------------------------------------|
| Rem Daily ETo Hargreaves                             |
| Function Hargreaves(L, J, Tmn, Tmx, Tav)             |
| Co = 0.000939                                        |
| Hargreaves = Co * Sqr(Tmx - Tmn) * (Tav + 17.8) * Ra(L, J) *(mm d-1) |
| End Function                                         |
Functions to find the coefficients (a) of the 6th Order Polynomial Equation

For j=7 To 1 Step -1
    a(j)=WorksheetFunction.Index(WorksheetFunction.LinEst(Range("D8:D372"), Range("F8:K372"),
        True, True), 1, j)
Next j

Functions to calculate the 6th Order Polynomial Equation and Its First Derivative

Rem Polynomial equation
Function Yt(a, t)
    Yt = a(7) + a(6) * t ^ 6 + a(5) * t ^ 5 + a(4) * t ^ 4 + a(3) * t ^ 3 + a(2) * t ^ 2 + a(1) * t
End Function

Rem 1st Derivative
Function dYdt(a, t)
    dYdt = 6 * a(6) * t ^ 5 + 5 * a(5) * t ^ 4 + 4 * a(4) * t ^ 3 + 3 * a(3) * t ^ 2 + 2 * a(2) * t + a(1)
    If dYdt < 0 Then dYdt = 0
End Function
Appendix 2 The Start, End and Peak of the Wet and Dry Seasons for Some Selected Years
## Appendix 3 The Start, End, Length, Water Depth, Peak, and Peak Rate of the Wet and Dry Periods from 1978 to 2018

| Year | Wet Start | Dry Start | Wet End | Dry End | Wet Length | Dry Length | Wet Peak | Dry Peak | Wet Water Depth | Dry Water Depth | Wet Peak Rate | Dry Peak Rate | Wet Water Rate | Dry Water Rate |
|------|-----------|-----------|---------|---------|------------|------------|----------|----------|----------------|----------------|--------------|--------------|---------------|---------------|
| 1978 | 1          | 20        | 20      | 20      | 0          | 0          | 1        | 2        | 1.5            | 1.5            | 0.25         | 0.25         | 0.76          | 0.76          |
| 1979 | 2          | 20        | 20      | 20      | 0          | 0          | 1        | 2        | 1.5            | 1.5            | 0.25         | 0.25         | 0.76          | 0.76          |
| 1980 | 3          | 20        | 20      | 20      | 0          | 0          | 1        | 2        | 1.5            | 1.5            | 0.25         | 0.25         | 0.76          | 0.76          |
| 1981 | 4          | 20        | 20      | 20      | 0          | 0          | 1        | 2        | 1.5            | 1.5            | 0.25         | 0.25         | 0.76          | 0.76          |
| 1982 | 5          | 20        | 20      | 20      | 0          | 0          | 1        | 2        | 1.5            | 1.5            | 0.25         | 0.25         | 0.76          | 0.76          |

Note: The table continues with data for each year from 1978 to 2018.