Rainfall modeling based on early predicted and season zone characteristic in the BMKG season zone over Lombok river basin

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Abstract. Planning water resources for long-term (annual, monthly) and operational (daily) requires a more accurate analysis of water availability calculations. The Meteorology, Climatology and Geophysics Agency (BMKG) publishes bulletin of forecasting every year in the form of the early wet season and the characteristics of the wet and dry season in each Season Zone (ZOM). BMKG conducts analysis and forecasting with complex climate parameters. Thomas Fiering analysis with the help of Excel Visual Basic Application (VBA) software is used to forecast rainfall at each rainfall station in BMKG Season Zone. The average error of forecasting rainfall during the wet season on the BMKG season zone in 2015/2016, 2016/2017 and 2017/2018 were 20%, 30% and 26%. While the average error for the dry season on the BMKG season zone is 44%, 34% and 52%. The existence of this deviation is caused by several factors including the uncertain season changes every year, as well as the influence of “El Nino.”.

1. Introduction
In terms of planning, an appropriate method is needed to calculate the debit of water availability so that it can be used as the basis of water resource planning. Among them are temporal planning (basic / monthly / annual) and daily operations. The Availability of Water on the surface or surface runoff is strongly influenced by the infiltration value indicated by the C value and amount of rainfall [1]. Calculations for water availability are generally based on rain input probability or reliability is wet probability (20% probability), normal (50% probability) and dry (80% probability) while the rainfall pattern changes annually. Water availability generally uses a calculation of 80% reliability using the ranking formula [2]. Besides that, the Thomas Fiering method is also used to predict monthly rainfall patterns in the Sleman district [3]

Based on previous research that the calculation results get results that are too high (wet probability) or too low (dry probability). So, a study of methods could be used to make the calculation of water availability for planning more accurate. In this case we can use the weather forecast according to Government Regulation of Indonesian No. 11 of 2016 on the services of Meteorology, Climatology and Geophysics located at the Meteorology, Climatology and Geophysics Agency (BMKG) [4]. BMKG conducts hydrological analysis and forecasting every year for rainfall in the form of preliminary maps and the nature of the rainy and dry seasons in each Season Zone (ZOM), so that the climate parameters used by BMKG which are
quite complex. The neural network model can be used as an alternative in predicting rainfall with correlation 88.43% and RMSE 83.76 [5]. And the Thomas Fiering method is better than ANFIS for short-term (1 year) forecasting [6]. Furthermore, the stochastic model to generate monthly rainfall data is the Thomas Fiering model where the results of synthetic monthly rainfall generation have characteristics that are not much different from the history data [7]. Then the WRF model got the result that the ability (accuracy) of the prediction method that was operational at BMKG in predicting dichotomous rains was good compared to the prediction of heavy rainfall and very heavy rain [8]. This study aims to predict the discharge that will occur in the following hydrological year which begins with the collection of rain data from 17 Rain Stations or ARR (automatic rainfall recorder) managed by BWS NT1 for 13 years. The rain data will be used to forecast rain using the Thomas Fiering method [9] to find out the height of rain in the next year at each ARR Station. Then This study aims to provide a quantitative discharge forecast that can be used for planning related to water resources as well as assisting the management of natural resources to carry out wet, normal and dry probability-based calculations to develop more accurate data-based calculations based on BMKG forecasting.

2. Method

2.1 Study Area
This research was conducted at ARR (Automatic Rainfall Recorder) stations in the Lombok River Basin. The 17 Stations are: Gunung Sari ARR, Ijobalit ARR, Jurang Sate ARR, Kabul ARR, Keru ARR, Kuripan ARR, Lingkok Lime ARR, Loang Make ARR, Mangkung ARR, Pemgadang ARR, Perian ARR, Pringgabaya ARR, Rembitan ARR, Santong ARR, Sapit ARR, Sepit ARR, and Sesaot ARR [10].

![Map of the ARR Station in the Lombok River Basin](image)

**Figure 1.** Map of the ARR Station in the Lombok River Basin

2.2 Season Zone (ZOM)
ZOM is an area where the rain pattern has a clear difference between the rainy season and the dry season. ZOM is not always the same as the area of government administration, and thus
one district can consist of several ZOMs and vice versa one ZOM can consist of several
districts or parts of a district [11]

**Table 1. Season Zone Area BMKG [11]**

| No | ZOM | Regency                    | No | ZOM                          |
|----|-----|----------------------------|----|------------------------------|
| 1  | 220 | West Lombok / South Central Lombok | 6  | 225 | Northern Lombok |
| 2  | 221 | Central Lombok              | 7  | 226 | West Lombok Central part, Northern Central Lombok |
| 3  | 222 | Mataram City, Western Lombok | 8  | 227 | Western East Lombok, Middle East Lombok |
| 4  | 223 | Northern West Lombok        | 9  | 228 | Eastern East Lombok |
| 5  | 224 | Northern North Lombok       | 10 | 229 | Southern East Lombok |

2.3 **Map of Rainy Season Properties, Dry Season Properties, Early Rainy Season and Early Dry Season**

Rainy property is a comparison between the amount of rainfall that occurs during a month with
the average or normal value of the month in a place [11]. So that the nature of the above normal
rain does not mean an abundant amount of rainfall or vice versa if the Above Normal rain
nature does not mean there is no rain. The nature of rain is divided into 3 (three) criteria, namely:

a. Above Normal (AN), if the value of the comparison of the amount of rainfall for 1 month
   against the average is greater than 115%.

b. Normal (N), if the comparison value of the amount of rainfall for 1 month against the
   average is between 85% - 115%.

c. Below Normal (BN), if the value of the comparison of the amount of rainfall for 1 month
   against the average is greater than 85%.

Early of the Dry Season. Determined based on the amount of rainfall in one decade (10
days) less than 50 millimeters and followed by several subsequent Dasarians. The beginning
of the dry season, can occur earlier (forward), same or slower (backward) than normal [11].

Early of the rain season. The rainy season is determined based on the amount of rainfall in
one dasarian (10 days) equal to or more than 50 mm and is followed by the next several
decades. The beginning of the rainy season, can occur earlier (forward), same or slower
(backward) than normal [11].

2.4 **Rainfall Forecasting uses the Thomas Fiering method**

Rainfall in every station will be calculated using Thomas Fiering forecasting with the
conditions that meet the requirements of the nature of the rainy season, the beginning of the
rainy season and the beginning of the dry season from BMKG. Each rainfall station has
different statistical parameters so the calculations are carried out by each dasarian.
3. Result and Discussion

3.1 Overlaid location of rain stations in the BMKG Season Zone (ZOM)

![Figure 2. Rainfall station overlayed maps and BMKG Season Zone Maps](image)

| No | Rain Station | ZOM | No | Rain Station | ZOM |
|----|--------------|-----|----|--------------|-----|
| 1  | Gunung sari  | ZOM 222 | 10 | Pengadang    | ZOM 221 |
| 2  | Ijobalit     | ZOM 228 | 11 | Perian       | ZOM 226 |
| 3  | Jurang Sate  | ZOM 226 | 12 | Pringgabaya  | ZOM 228 |
| 4  | Kabul        | ZOM 220 | 13 | Rembitan     | ZOM 221 |
| 5  | Keru         | ZOM 226 | 14 | Santong      | ZOM 223 |
| 6  | Kuripan      | ZOM 222 | 15 | Sapit        | ZOM 227 |
| 7  | Lingkok Lime | ZOM 226 | 16 | Sepit        | ZOM 229 |
| 8  | Loang Make   | ZOM 229 | 17 | Sesaot       | ZOM 226 |
| 9  | Mangkung     | ZOM 220 |    |              |     |
3.2 Maps of Rainy Season Characteristics and Early Rainy Season BMKG

(a) (2015/2016)  
(b) (2016/2017)  
(c) (2017/2018)

**Figure 3.** Map of Rainy Season Characteristics BMKG: (a) 2015/2016, (b) 2016/2017, and (c) 2017/2018
Figure 4. Map of Early Rainy Season BMKG: (a) 2015/2016, (b) 2016/2017, and (c) 2017/2018
3.3 Maps of Dry Season Characteristic and Early Dry Season BMKG

Figure 5. Maps of Dry Season Characteristic BMKG: (a) 2016, (b) 2017, and (c) 2018
Figure 6. Maps of Early Dry Season BMKG: (a) 2016, (b) 2017, and (c) 2018

3.4 Rainfall forecasting uses the Thomas Fiering Method

Thomas Fiering Model is a statistical model that uses random numbers. Thomas fiering is a stochastic formulation. This research will predict the discharge by building a Thomas Fiering model from the hydrological year 1993/1994 to 2013/2014. The following is the recapitulation rainfall data of Gunung Sari ARR Station for Dasarian Oct II.

Table 3. Gunung Sari ARR Station Rainfall Data.

| No | Years     | Oct II (mm) | No | Years     | Oct II (mm) |
|----|-----------|-------------|----|-----------|-------------|
| 1  | 1993/1994 | -           | 12 | 2004/2005 | 0.50        |
| 2  | 1994/1995 | 41.00       | 13 | 2005/2006 | 134.00      |
| 3  | 1995/1996 | 26.80       | 14 | 2006/2007 | 20.00       |
| No | Years   | Oct II (mm) | No | Years   | Oct II (mm) |
|----|---------|-------------|----|---------|-------------|
| 4  | 1996/1997 | 43.73       | 15 | 2007/2008 | 26.70       |
| 5  | 1997/1998 | 0.00        | 16 | 2008/2009 | 47.20       |
| 6  | 1998/1999 | 66.70       | 17 | 2009/2010 | 60.50       |
| 7  | 1999/2000 | 83.40       | 18 | 2010/2011 | 10.10       |
| 8  | 2000/2001 | 57.20       | 19 | 2011/2012 | 29.40       |
| 9  | 2001/2002 | 0.00        | 20 | 2012/2013 | 27.10       |
| 10 | 2002/2003 | 0.00        | 21 | 2013/2014 | 124.20      |
| 11 | 2003/2004 | 0.00        | 22 | 2014/2015 | 1.00        |

Statistical parameter calculation:
- Average Rainfall in OCT II = Amount of rainfall data / Amount of data = 800 mm / 21 = 38.07 mm
- Data with the largest value (maximum) in OCT I = 134.00 mm, namely in the 2005/2006 hydrological year
- Data with the smallest (minimum) value in OKT II = 0 mm, namely in the 1997/1998 hydrological year, 2001/2002, 2002/2003, 2003/2004 and 2015/2016.
- The minimum Upper Normal (AN) threshold value is 115% of the average rainfall data. Then the value of AN = 115% x 38.07 mm = 43.78 mm
- The maximum Lower Normal (BN) threshold value is 85% of the average rainfall data. Then the value of BN = 85% x 38.07 mm = 32.36 mm
- Calculate the Standard Deviation (SD)

**Table 4. Calculation of Standard Deviation (SD)**

| Years | Rainfall (Xi) | Xi-X Average | (Xi - X Average)² |
|-------|---------------|--------------|-------------------|
| 1993/1994 | 41.0         | 2.9          | 8.6               |
| 1994/1995 | 26.8         | -11.3        | 127.1             |
| 1995/1996 | 43.7         | 5.7          | 32.1              |
| 1996/1997 | 0.0          | -38.1        | 1449.6            |
| 1997/1998 | 66.7         | 28.6         | 819.5             |
| 1999/2000 | 83.4         | 45.3         | 2054.5            |
| 2000/2001 | 57.2         | 19.1         | 365.8             |
| 2001/2002 | 0.0          | -38.1        | 1449.6            |
| 2002/2003 | 0.0          | -38.1        | 1449.6            |
| 2003/2004 | 0.0          | -38.1        | 1449.6            |
| 2004/2005 | 0.5          | -37.6        | 1411.7            |
| 2005/2006 | 134.0        | 95.9         | 9202.0            |
| 2006/2007 | 20.0         | -18.1        | 326.6             |
| 2007/2008 | 26.7         | -11.4        | 129.3             |
| 2008/2009 | 47.2         | 9.1          | 83.3              |
| 2009/2010 | 60.5         | 22.4         | 503.0             |
| 2010/2011 | 10.1         | -28.0        | 782.5             |
| 2011/2012 | 29.4         | -8.7         | 75.2              |
| 2012/2013 | 27.1         | -11.0        | 120.4             |
| 2013/2014 | 124.2        | 86.1         | 7417.8            |
| 2014/2015 | 1.0          | -37.1        | 1374.4            |
Statistical parameter calculation:

\[ (X_i - \bar{X})^2 = 30632.15 \]

The amount of data \( (n) = 21 \)

Standard Deviation (SD) = \[ \sqrt{\frac{\sum(X_i - \bar{X})^2}{n-1}} = \sqrt{\frac{30632.15}{21}} = 39.14 \]

Calculation of \( r \) (Lag Correlation) = Correlation between OKT II and OKT I values

\[ r = -0.09 \text{ or } -9\% \]

Calculation of coefficients \( b = \frac{\text{SD}_{OKT I}}{\text{SD}_{OKT II}} = -0.09 \times \frac{24.66}{39.14} = -0.06 \)

where \( t_1 \) and \( t_2 \) are random numbers

\( t_1 = 0.18; t_2 = 0.48 \)

Calculation \( t^* = \sqrt{2 \times L_n(t_2 \times \cos 2\pi t_1) = \sqrt{2 \times L_n 0.48 \times \cos(2 \times \pi \times 0.18)}} = 0.49 \)

Rainfall calculation \( R_{OCT II} \)

\[ R_{OCT II} = X_{\text{avg}_{OCT II}} + b_{OCT II} \times (R_{OCT I} - X_{\text{avg}_{OCT I}}) + t^*_{OCT II} \times SD_{OCT II} \times (\sqrt{1 - r^2}) \]

\[ R_{OCT II} = 38.07 + (-0.06) \times (0 - 17.40) + (0.49) \times 39.14 \times (\sqrt{1 - (-0.09)^2}) \]

\[ = 58.33 \text{ mm} \]

| No | Years | 10 days | Rainfall (mm) | No | Years | 10 days | Rainfall (mm) |
|----|-------|---------|---------------|----|-------|---------|---------------|
| 1  | 2015  | OCT I   | 0.00          | 19 | 2016  | APR I   | 21.63         |
| 2  |       | OCT II  | 58.33         | 20 |       | APR II  | 27.58         |
| 3  |       | OCT III | 122.91        | 21 |       | APR III | 18.84         |
| 4  |       | NOV I   | 16.22         | 22 |       | MAY I   | 0.00          |
| 5  |       | NOV II  | 106.33        | 23 |       | MAY II  | 37.24         |
| 6  |       | NOV III | 119.04        | 24 |       | MAY III | 0.00          |
| 7  |       | DEC I   | 74.81         | 25 |       | JUN I   | 6.59          |
| 8  |       | DEC II  | 59.74         | 26 |       | JUN II  | 0.65          |
| 9  |       | DEC III | 77.41         | 27 |       | JUN III | 24.76         |
| 10 | 2016  | JAN I   | 41.11         | 28 |       | JUL I   | 54.22         |
| 11 |       | JAN II  | 30.30         | 29 |       | JUL II  | 6.93          |
| 12 |       | JAN III | 41.72         | 30 |       | JUL III | 8.42          |
| 13 |       | FEB I   | 112.27        | 31 |       | AUG I   | 8.38          |
| 14 |       | FEB II  | 88.60         | 32 |       | AUG II  | 0.00          |
| 15 |       | FEB III | 70.02         | 33 |       | AUG III | 4.98          |
| 16 |       | MAR I   | 47.23         | 34 |       | SEP I   | 13.39         |
| 17 |       | MAR II  | 68.72         | 35 |       | SEP II  | 0.00          |
| 18 |       | MAR III | 102.55        | 36 |       | SEP III | 33.01         |

**Total** 1503.90
Verification of Annual Rain Against BMKG Forecast
a. The Gunung Sari Station is in the Season Zone (ZOM) 222 where the Beginning of the Rainy Season is located at DES I
   The forecast results show that:
   DEC I = 74.81 mm > 50 mm …… (Ok)
   DEC II = 59.74 mm > 50 mm …… (Ok)
   DEC III = 59.74 mm > 50 mm …… (Ok)
   The total rainfall on 3 Dasarians is 211.95 mm > 150 mm …… (Ok)

b. Gunung Sari ARR it is in season zone (ZOM) 222 where the nature of the rainy season in Normal (N) with the forecast annual rain is 1237 mm. 978 mm (Normal lower limit) < 1237 mm (Forecast) < 1323 mm (Normal upper limit).

3.5 Rainfall Forecasting of BMKG Season Zone on Field Realization
Rainfall forecasting results based on the 2015/2016 BMKG Season Zone show an average error of 20%, where the maximum error is 37% at the Pringgabaya rainfall station (Season Zone 228) and a minimum error of 1% at the Sapit rainfall station (Season Zone 227). Based on the results also found that there are 4 rain stations that have an error rate above 30%, namely Gunung Sari station in the Season Zone 222 (40%), Mangkung in the Season Zone 220 (46%), Perian in the Season Zone 226 (32%), and Pringgabaya in the Season Zone 228 (37%). Whereas in the dry season it shows an average error of 44%, where a maximum error of 77% is at the Sesaot rainfall station (Season Zone 226) and a minimum error of 11% at the Ijobalit rainfall station (Season Zone 228).

The results of rainfall forecasting in the 2016/2017 rainy season show an average error of 30%, where a maximum error of 156% is at the Loang Make rainfall station (Season Zone 229) and a minimum error of 12% at the Lingkok Lime rainfall station (Season Zone 226). Based on the results also found that there are 4 rain stations that have an error rate above 30%, namely Gunung Sari station in the Season Zone 222 (32%), Loang Make in the Season Zone 229 (156%), Rembitan in the Season Zone 221 (32%), and Pringgabaya in the Season Zone 228 (50%). Whereas in the dry season it shows an average error of 34%, where the maximum error is 65% at the Santong rainfall station in the Season Zone 223 and a minimum error of 0% at the Ijobalit rainfall station in the Season Zone 228.

Rainfall forecasting results in the 2017/2018 rainy season show an average error of 26%, where the maximum error is 104% at the Loang Make rainfall station (Season Zone 229) and a minimum error of 4% at the Pengadang rainfall station (Season Zone 221) and Perian (Season Zone 226). Based on the results also found that there are 4 rain stations that have an error rate above 30%, namely Kabul station in the Season Zone 220 (53%), Loang Make in the Season Zone 229 (104%), Santong in the Season Zone 223 (35%), and Sapit (48%) in the Season Zone 227. While in the dry season shows an average error of 52%, where the maximum error is 92% at the Sepit rainfall station (Season Zone 229) and a minimum error of 9% at the Sesaot rainfall station (Season Zone 226).

Based on the results of rainfall it is found that there are some rain stations that have high error rates such as the Rainfall Make station in 2016/2017 where the error is 156%. That is because BMKG forecasting for the Loang make station which is located in the Season Zone (ZOM) 229 has the upper normal rainy season where the normal upper limit (AN) is 1055 mm and the lower normal limit (BN) is 780 mm. While the observation in 2016/2017 is 422 mm
which is below normal (BN). This causes a large enough deviation because the range between the upper limit of normal and observation is 633 mm.

Forecast differences that occur are also caused by seasonal changes that change each year, both from the beginning of the rainy and dry seasons and the nature of the rainy and dry seasons. The BMKG Website (BMKG.go.id) provides information related to El Nino which shows the level of drought, where the greater the El Nino number (the stronger El Nino), the greater the level of drought. Figure 7 shows the irregular seasonal changes from year to year so that forecast accuracy is very difficult to predict.

![Figure 7. El Nino Index Information Graph [11]](image)

4. Conclusion
From the analysis of the data conducted in this study, several conclusions can be drawn, namely the forecasting of rainfall at each rainfall station in the BMKG Season Zone during the rainy season for 2015/2016, 2016/2017, and 2017/2018 are 20%, 30% and 26%, respectively. This shows that the average error for 3 years is a maximum of 30%. While the average rainfall errors at each rainfall station in the BMKG Season Zone for the dry season are 44%, 34%, and 52%, respectively. However, there are some rainfall stations that have high errors, namely the rainfall Loang Make ARR station which is in the Season Zone number 229 in the 2016/2017 rainy season by 156% and in 2017/2018 at 104%. This is caused by several factors including the change in season each year that is not certain so that the estimated season has the Above Normal to Lower Normal or vice versa. El Nino figures indicate the degree of seasonal change, if the Nino 3.4 number is strong or high causes low rainfall (drought) and if El Nino weakens it causes high rainfall (flood).

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