Influence Rainy and Dry Season to Daily Rainfall Interpolation in Complex Terrain of Sulawesi

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Abstract. Spatial interpolation widely is used to predict rainfall in ungauged location. There are two methods of spatial interpolation, deterministic method such as Inverse Distance Weighting (IDW) method and geostatistics such as kriging. Daily rainfall in the tropical Indonesian maritime region such as Sulawesi is generally uneven. Although, in a location has heavy rainfall, a zero rainfall can be found in adjacent places. It makes choosing suitable spatial interpolation method for ungauged rainfall prediction is difficult. The aim of this research is evaluate the impacts of the rainy season to the interpolation method. Root mean square (RMSE) and correlation is used as statistical parameter to determine the goodness of interpolation method. The result shows that heavy rain event has big impact to interpolation, both IDW and kriging. Log transformation can little improve in RMSE in rainy season, but not recommended in dry seasons. The most biggest deviation of the interpolation result spreads in south west coast, plain at middle of Sulawesi and north part of the Bone Gulf in January and only south west coast of Sulawesi and north part of the Bone Gulf in dry season July.

Keywords: Interpolation, IDW, Kriging and Maritime Continent.

1. Introduction

Rainfall is very most important component in the modeling of some fields area such as agriculture, ecology, and hydroelectric [1][2][3][4]. Nevertheless rainfall data availability commonly is unsatisfied. Interpolation can be one solution to solve this problem. There are two methods of interpolation [5]. The first is deterministic such as a Thiessen polygon (THP), spline (SPL) and inverse distance weighting (IDW). The second is geostatistics such as kriging. Applied spatial interpolation of rainfall data has itself uniqueness, no one interpolation method is more powerful than others. The goodness of the interpolation result depends on time and place, espesially in daily tropical maritime rainfall interpolation. Interpolation, commonly using rainfall that greater than 0, such as yearly accumulation. Although the preferable uses geostatistics method for yearly and monthly interpolation, occasionally it is found that the deterministic interpolation is the best method in a place [6].

Daily rainfall accumulation is more varied than monthly and yearly. Changing weather conditions are very dynamic, especially in the maritime continent tropical region such Indonesia. Weather global and local circulation influences weather patterns in Indonesia [7][8][9][10][11][12][13][24]. Indonesia has varying of onset and withdrawal rainfall from monsoon in time and place [14]. This condition makes one place in dry with little precipitation, but the other in...
the wet season with a lot of precipitation at the same time. Some research found that geostatistics interpolation such as kriging is the best method [15][16][17][18]. While, sometimes deterministic can also be better than others [5][19][20][21][23].

Daily interpolation of rainfall data in the part of the tropical maritime continent, such as Sulawesi may be more challenging than other regions. Rainfall in the place can vary in a short time and can be different rain event although in nearly place. Comparison research of daily rainfall interpolation methods in this region is limited. In this work, we will investigate the impact of rain season using deterministic (IDW) and geostatistics (kriging) interpolation in Sulawesi. Daily rainfall is chosen because of the incidence that can be different each place in a short time.

2. Theory

2.1. Study Area and Data

Sulawesi Island is located in middle of the Indonesian maritime continent as shown on Figure 1. There are more 291 rain guages in this location in 2015. We remove all missing data or NA data in each day, so that rainfall prediction uses interpolation can do daily without unobserved data. This region has a wide Pacific ocean in the north that has high intensity of tropical cyclones. Even though, in the south of the Sulawesi Island there is Flores Sea that one part of sequences of long sea from the Java Sea to the Banda Sea. There are Makassar Strait, Java Sea and Flores Sea in the west and south part and Bone Bay in the east part. Complex mountain topography whose extends from north to south in Sulawesi Island. This condition makes the spreading of rain event can be different in each place, although in close place.

![Figure 1. Location of Rain Gauge Station in Sulawesi](image)

Besides Asian Monsoon and Australian Monsoon as the most influential to rainfall event in this region, other factors also influence to rainfall event [7][8][9][10]. That makes each region has an own early of beginning of rainfall [14]. Using remote sensing for rainfall estimates in this region, especially in surrounding the Makassar Strait has various results, depents time duration and places [22].

2.2. Rainfall Prediction Use Spatial Interpolation Methods

A rainfall measurement in the surface results point data and sparse, so prediction rainfall in ungauged location ones can use spatial interpolation. There are two methods of spatial interpolation, deterministic and geostatistics. Inverse Distance Weighting (IDW) and kriging commonly is chosen in rainfall estimates [5][15][16][17][18].
2.2.1. *Inverse Distance Weighting (IDW)*

IDW works with the assumption that the nearest location is the most influence, so based on this condition is formed a function of inverse distances. Weights of influence are calculated by opposite of distance as below

\[
\hat{Z}(s_0) = \lambda^T Z(s_i)
\]

(3)

where \( \hat{z} \) is rainfall estimation, \( s_i \) is \( i \) location and, \( s_0 \) is location of interest. The weights of IDW is calculated by

\[
\lambda_i(s_0) = \frac{1}{\sum_{i=0}^{n} \frac{1}{d^\alpha(s_0, s_i)}}, \alpha > 1
\]

(4)

where \( d(s_0, s_i) \) is distance between \( s_0 \) and \( s_i \). Power of distance is very influence to weight of interpolation. Commonly \( \alpha \) is choosed by trial but the most application uses \( \alpha = 2 \) and 3.

2.2.2. *Kriging*

Kriging is geostatistical techniques that use the value of autocorrelation to modeled interpolation. Measurement of a variable in \( n \) points location results \( Z(x_1), Z(x_2), \ldots, Z(x_n) \). Value of variable at a point \( Z(x_0) \) estimated uses

\[
\hat{z}(x_0) = \sum_{i=1}^{N} w_i z(x_i)
\]

(5)

Where \( w_i \) are weights. Kriging assumes station in mean and variance. Expectation of variable \((m)\) is random and it have variance \( \sigma^2 \). Kriging based assumption that on calculation has minimized of differences between estimation and data observation, so that sum of weight is one and model is unbiased. In weight calculation of variance \( ij \) we have

\[
C_{0i} = \sum_{i,j=1}^{n} w_i C_{ij} + \lambda \quad \text{for } \forall i = 1, 2, 3, \ldots, n \text{ and } \sum_{i=1}^{n} w_i = 1
\]

(6)

Equation (6) is formed in matrix and can be solved. In practical it is used experimental semivariance is used to modeling in kriging as shown in Figure 2.

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**Figure 2.** Experimental Variogram Characteristic
Parameters of the semivariogram model are sill, range, and nugget as show in Figure 2. Sill refers to an upper bound condition increasingly semivariogram respect to lag distance. Range refers to the range of spatial correlation or dependence of lag distance autocorrelation. Nugget is the positive intercept on the ordinate of semivariance. Kriging uses theoretical model semivariogram to approach experimental variogram.

2.2.3. Evaluation Method

Evaluation is done by choosing the nearest estimation to rain gauge. This work uses two common statistic indicators, pearson coefficient correlation ($r$) and Root Mean Square Error (RMSE) that formulated as below:

$$
 r = \left( \frac{\sum_{i=1}^{n} (R_r_i - \bar{R}_r)(R_e_i - \bar{R}_e)}{\sqrt{\sum_{i=1}^{n} (R_r_i - \bar{R}_r)^2 \sum_{i=1}^{n} (R_e_i - \bar{R}_e)^2}} \right)^2
$$

$$
RMSE = \sqrt{\frac{\sum_{i=1}^{n} (R_r_i - R_e_i)^2}{n}}
$$

Where $R_r$ refers to rainfall from rain gauge, $\bar{R}_r$ refers to average of $R_r$, $R_e$ refers to interpolation of rainfall estimation, $\bar{R}_e$ refers to average of $R_e$, $n$ refers to total of rain gauge and $i$ is station index.

3. Research Methods

Location of rain gauge station in Sulawesi include South Sulawesi, West Sulawesi and Central Sulawesi with Rainfall data are collected by Indonesian meteorological agency (BMKG). There are more 291 rain guages in this location in 2015. Rainfall prediction use spatial interpolation methods including (a) inverse distance weighting (IDW), (b) kriging and (c) evaluation method. The grid interpolation results 0.05 degree or 5.5 km grid.

4. Result and Discussion

4.1. Daily Rainfall Analysis

The rainy season is not ensuring that the most of the day in this month is always rain. In January 2015, only 54% event is no rain and only 5% rainfall event has greater than 50 mm/day. On the other hand, in dry season the most of no rain event is very dominant. This condition reaches 89% in this region with no heavy rain event as depicted in Figure 3(a) and 3(b). More than 80% correlation is below 0.3, and only 1.4 % its correlation more than 0.6 as depict in Figure 3(c).
4.2. Analysis of Rainfall Interpolation

Heavy rain in a location does not have much effect to other places in IDW method as depicted in Figure 4, conversely heavy rainfall of kriging has an impact the surrounding area with increasing rainfall in the area around heavy rain. As far as the distribution of rain interpolation using kriging more smooth.

Figure 4. IDW and Kriging Result at 01 January 2015.
Based on RMSE and correlation in dependent location, log transformation can little improve in RMSE. Rainfall transformed can minimize RMSE from 17.06 to 16.47, but it cannot improve in correlation where original data get 0.94 than the transformation get 0.92 in January. On the other hand, in dry season, RMSE of original data is better than transformation as shown in Table 1.

| Dependent Location | Kriging | IDW | Independent Location | Kriging | IDW |
|-------------------|---------|-----|----------------------|---------|-----|
| Correl            |         |     | Correl               |         |     |
| Month             | Jan     | Jul | Jan      | Jul     | Jan   |
|                   | Log     |     | Log      |     |     |
|                   | Ori     |     | Ori      |     |     |
| RMSE              |         |     | RMSE     |         |     |
| Month             | Jan     | Jul | Jan      | Jul     | Jan   |
|                   | Log     |     | Log      |     |     |
|                   | Ori     |     | Ori      |     |     |

The difference of both the methods is the RMSE in January and July is very high. There is a possibility this is due to differences in rainfall intensity during the rainy season and high drought. Kriging is better than IDW method mainly in decreasing RMSE, both in rain and dry season. But in correlation, obtained that using of IDW method is much better than kriging. Comparison in 28 independent locations shows that all methods has poor a correlation (< 0.2), while log transformations can reduce RMSE, both methods. During the rainy season, interpolation using IDW is better than kriging. Conversely in the dry season kriging is better than IDW.

Spatial distribution of RMSE of independent location shows that both methods result same pattern as depicted in Figure 4. In January, the biggest RMSE spreads in south west coast, plain in the middle of Sulawesi and north part of the Bone Gulf as depicted in 4(a) and 4(b), while in dry season July different with rain season in January. The most biggest RMSE spreads in south west coast of Sulawesi and north part of the Bone Gulf as depicted Figure 4(c) and 4(d). Spreading of RMSE besides can show how deviation between rainfall prediction and rainfall observed, it can also indicate the variability of interpolation of a rain event. Rainfall in January from Asian monsoon causes a lot of rainfall in the west coast of South West of Sulawesi than east coast. Light or heavy of a rain event in a place influence to rainfall prediction using interpolation.

Figure 5. RMSE in Independent Location at January with IDW (a), Kriging (b) and independent location using IDW(c) and kriging (d).
4.3. Discussion

Inverse distance method interpolation (IDW) in Sulawesi more stable in correlation than kriging, both in rainy season and dry season. While RMSE in this region, kriging little better than IDW as same with previous work [5] [21]. Beside rainfall intensity has influence of the performance of interpolation [21], it may cause IDW better than kriging as shown in this result. Also this condition may answer why deterministic interpolation can be the best method in variable rainfall such as in Africa [5][6][23][24]. Performance of interpolation depends on continuity spreading of a rain event. Trying with independent location shows that performance IDW in rainy season January is more less RMSE than kriging and has poor correlation. It is different with not independent location that have high correlation to interpolation result. Log transformation can little improve in RMSE in rain season and it is not in dry season. Base on distribution of RMSE also shows that in the coast of Sulawesi, plain land in middle of Sulawesi and north part of Bone Gulf have the biggest RMSE, where Asian and Australian monsoon strongly influences rainfall in that places [14].

5. Conclusion

Based on this work, spreading of a rain event in the Sulawesi has a high locality event, where the correlation between gauge locations are not strong. This condition has an impact on the performance of interpolation. IDW interpolation has better performance in the rainy season. Log transformation can be used for improved interpolation, both IDW and kriging. Variation of a rain event in tropical maritime continent region makes interpolation has some difficulty to predict rainfall in ungauged location. Our suggestion for future research to use some transformation to assure best interpolation. Threshold treatment is recommended to avoid a lot of zero rainfall in this region.

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