The Role of SST Time Lag for Improving the Ensemble Prediction System Model Output of Monthly Rainfall Total Prediction in Indramayu District of Indonesia

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Abstract

The Japan Re-Analysis 25 years (JRA-25) Sea Surface Temperature (SST) of Japan Meteorological Agency (JMA) with 1° x 1° resolution had been regressed with monthly rainfall prediction in Indramayu District area of West Java Province, Indonesia. This method was used to improve the quality of Weighted Ensemble Prediction System (WEPS) model output that has been run for Indramayu District area to provide monthly rainfall prediction by inserting the fluctuation of SST dynamics. Processing technique done between JRA-25 SST and monthly rainfall prediction was Partial Least Square Regression (PLSR) method. This model was so called as WEPS-PLSR. Those JRA-25 SST data were computed based on preceded time lag of 1 and 2 months ahead because the effect of SST JRA-25 did not occur directly into the atmosphere. Results of WEPS-PLSR model outputs show significantly better in quality comparing to the WEPS model output itself.

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The WEPS-PLSR model outputs show spatially better in minimum Pearson correlation coefficient (r) value, r average, maximum RMSE, and RMSE average comparing to the WEPS model output itself.

Keywords: correlation coefficient; ensemble; PLSR; sea surface temperature

1. Introduction

Rainfall is one of the important climate element which has play a role in tropical region [8,10]. Geographically, the tropical region is defined as region where are located between latitudes of 23.5 °N - 23.5 °S. Astronomically, this region is also famous to be called as region along the *Tropics of Cancer* to *Tropics of Capricorn*. Tropical region is denoted as region which has relatively homogenous of atmospheric condition. But, the occurrences of weather/climate which have relationship with rainfall, are able to happen differently on the earth surface. For example, there is the most wetest place in Kasi Hill of India weather the most driest place in the Shore of Chili [29]. The Indonesian region can be seen as a *maritime continent* as mentioned by Ramage [13] with surface condition surrounded by waters. Surrounding water surface in this region is more significant and only around 30% of them is surrounded by earth surface. Part of land in Indonesian region has complex topography as mountainous area [11]. Indonesian region spread out in equatorial line has also had high variability of rainfall condition [4,17].

Many locations in Indonesian region are very susceptibility to the rainfall condition [1,18]. Above normal rainfall condition tends to cause flood and landslides as well. In opposite, below normal rainfall condition causes drought. Both extreme rainfall conditions affects to the decreasing of food production. For these susceptibility locations, water management is very important to be provided [15] especially for location without any or minimum of technical irrigation facilities so consequently that these location are absolutely depending upon the availability of rainfall occurrences. In relation to the issue of water management, it is very important to provide the rainfall prediction in such susceptibility locations. This rainfall prediction is able to be used to anticipate the achieved water availability in certain locations. The usefulness of rainfall prediction is to be used for arranging planning several months ahead for miscellaneous sectors. Commonly the sector of agriculture is the most sectors to use the output of monthly rainfall prediction.

The output of WEPS model in Indramayu District, West Java, Indonesia [21] was then regressed to the JRA-25 SST data of 1° x 1° resolution (4° - 10°S, 106° - 111°E) and using the Partial Least Square Regression (PLSR) technique in order to know the play a role of fluctuation of JRA-25 SST surrounding the research domain to improve the quality of monthly rainfall prediction output. The grid of JRA-25 SST used in this research was shown in Fig. 1. The time lag used in these cases were 1 and 2 months ahead. The time lag chosen here has correlation with the contribution of water vapor into the atmosphere within Indramayu District area of Indonesia. The output of this model is so called as WEPS-PLSR. A better quality of the model output was denoted with the higher level of r value in the same phase and the lower level of RMSE value. Both values are able to be used to understand the performance of the model output. The higher level of r values mean the better agreement between model output and observed data. Meanwhile, the lower values of RMSE mean the better level of model output comparing to the observed data itself.
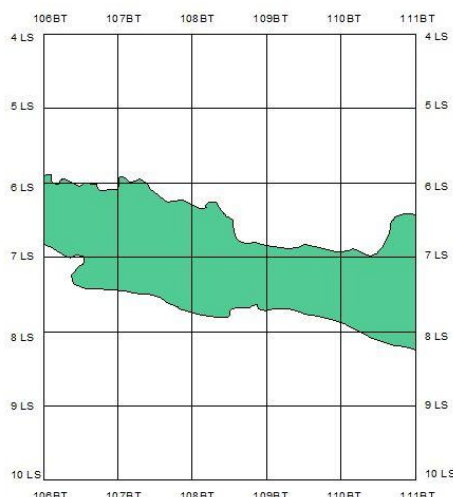
Figure 1: The JRA-25 SST gridded data of 1° x 1° resolution used in data processing of PLSR technique

In order to know and better understanding about the quality of the model output especially for monthly rainfall total prediction, so that the evaluation of the model outputs were done [9,22,25]. Further, the evaluation of the model output was done using r and as well as RMSE values.

The goals of this research are: (1) to understand the quality of the WEPS-PLSR model output comparing to the WEPS model output itself in Indramayu District area of Indonesia; and (2) to understand the play a role of the JRA-25 SST data as predictors to improve the quality WEPS-PLSR model output within Indramayu District area.

2. Data and Analysis

In tropical region such as Indonesian maritime continent [13], the high accuracy of prediction for rainfall cannot be done easily especially when the predictions are purposed for getting deterministic values [5]. Instead of variability and changing on climate signal are various in tropical region, the difficulty of predictions are caused by the condition of spatial variability with complex topography [12]. The orography in tropical region is also variously pictured by the shape of island, orientation of island, environment of island, and others [27]. Those are giving the contribution to special characteristic of different weather/ climate conditions.

The location of Indonesian region is in between the low latitudes of 6°N - 9°S where there are almost no differences in the length of day time every month. This condition is causing a lot of energy taking from the sunshine along the years reaching the earth surface [26] so consequently that this region becomes the convergence area of air mass.

But for the operational use of forehead planning, the rainfall prediction as one of climate elements for certain location has neccessarily been provided. One of prediction models which can be used to predict the monthly rainfall prediction within Indramayu District area, is so called as WEPS model.

The output of WEPS model in this research is eliminated its multi-collinearity properties using the PLSR technique to the JRA-25 SST data surrounding of Indramayu District area of Indonesia [3][19]. These JRA-25 SST data used in this research have time lag of 1 and 2 months ahead [3,16]. These time lags are chosen in corresponding to anticipate the releasing time of energy from the ocean surface. Further, this energy will be released from the ocean surface to the atmosphere during a little bit slower comparing to the energy released from the land surface.

The PLSR technique here is used to extract a number of components [24]. These components are so called as latent variables. Taking from predictor variables (X) will be chosen a number of relevant components with a number of response variables (Y). The method of processing is by simultaneously decomposition X change and Y change by setting a limit that the components can explain as much as varieties between X predictor change and Y response change. This decomposition process is to be followed by regression stage. In this case, decomposition result of X predictor change used to predict Y response change. The result of conducting data management process by this PLSR technique has included *Principal Component Analysis* (PCA) and Double Regression techniques.

In data management, X predictor change has measurement of N*K. In this case N = total data and K = total predictor change, therefore X predictor change can be written as X_k in which k = 1, 2, 3,…, K. Meanwhile Y response change has measurement of N*M. In this case N = total data and M = total response change, then response change can be written as Y_m, in which m = 1, 2, 3,..., M.

Model output using PLSR technique will get a number of new components to be model as X and Y in such way that X and Y connected. The new components to be called as X score, it will be recorded as t_a, in which a = 1, 2, 3, …., A.

$X(t_a)$ score is linear combination of the initially x_k changes with coefficient called determiner that recorded as w_{ka} (a = 1, 2, 3,…, A). The process can be formulated [23] as follows:

$$\begin{cases} t_{ia} = \sum_k x_{ik} w_{ka}; i = 1, 2, 3, .., N \\ \qquad T = XW \end{cases} \quad \text{......................... (1)}$$

X score used as predictor for X as well as Y, as follows:

a.   X score as predictor for X:

$$\begin{cases} x_{ik} = \sum_a t_{ia} p_{ak} + e_{ik} \\ \qquad X = TP' + E \end{cases} \quad \text{……….................. (2)}$$

b.   Y score as predictor for Y:

$$\begin{cases} y_{im} = \sum_a t_{ia} r_{am} + f_{im} \\ \qquad X = TR' + F \end{cases} \quad \text{……….................. (3)}$$

Y residue is f_{im} stating deviation between observation response and prediction response. Based on the equation (1), then equation (3) can be written as double regression model as follows:

$$\begin{cases} y_{im} = \sum_a r_{ma} \sum_k w_{ka}\, x_{ik} + f_{im} \\ \qquad = \sum_k b_{mk} x_{ik} + f_{im} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (4) \\ \quad Y = XWR' + F = XB + F \end{cases}$$

Coefficient of PLSR model, b_{mk}(B) can be written as follows:

$$\begin{cases} b_{mk} = \sum_a r_{ma}\, w_{ma} \\ \qquad B = WR' \end{cases} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

Prediction for new observation data can be obtained based on X data and coefficient matrix of B.

This PLSR technique applied to the WEPS model output meant to include dynamic element into the prediction of WEPS model output on statistics based approach. Output of this stage is so called as WEPS-PLSR. This last result acts as monthly rainfall prediction result for operation purpose. Then this result will be evaluated using available field observed data.

Monthly rainfall prediction value result for operation purpose must be evaluated using observed data in several methods [7]. In order to find out the reliability prediction of this WEPS-PLSR model output, Pearson coefficient correlation value (r) is used [9][22]. For this purpose the following equation is able to be written as:

$$r(F_e, O) = \frac{\sum F_e . O}{[\sum F_e{}^2 . \sum O^2]^{1/2}} \qquad \ldots\ldots\ldots\ldots\ldots\ldots (6)$$

In which:

r(F_e,O) = Pearson coefficient correlation value between WEPS-PLSR model output to field observation data; F_e = prediction value of WEPS-PLSR model output (mm); and O = observed data (mm).

To calculate the total bias value of prediction output to its observed data, RMSE [2,25] value can be used. Equation used is as follows:

$$RMSE = \sqrt{\frac{1}{N} \sum_{i=1}^{i=N} (F_e - O)^2} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots . (7)$$

In which:\

RMSE = *root mean square error (mm/month)*; N = number of data used; Fe = prediction value of WEPS-PLSR model ouput (mm); and O = observed data (mm).

Research conducted in Indramayu district area as research domain. Indramayu district has orography facing Java Sea. Topography of research domain area in general is relatively lower in northern part facing Java Sea and relatively higher in southern part closed to middle limestone mountain in the middle of Java Island plateau [28].

Geographically, Indramayu district area lies between 107° 52' - 108° 36' East Longitude and 6° 15' - 6° 40' South Latitude [14]. This district has an area of 204,11 hectares with average land slope of 0 - 2%. Mainly the type of the land is Alluvial (63%), the rest is Clay Grumosol (24%) and Podsolic (12%).

Rainy Season is between October-March, on the other hand, Dry Season is between April-September. Average air temperature is between 18° - 28 °C. Meanwhile, average rainfall per year reaches 1.418 mm. Total of maximum rainfall occurs in January reaching up to 364 mm/month, whereas total of minimum rain occurs in August reaching up to 10 mm/month. Furthermore, monthly rainfall condition in 1981-2000 for Indramayu districts shown in Fig. 2b. Monthly rainfall pattern in Indramayu district is monsoonal pattern where the rainfall peak occurs in Rainy Season and a rain gap occurs in Dry Season.

In order to know better about the climatological of rainfall condition over here, there are 2 (two) locations used as examples. *Anjatan* location represents western part and *Juntinyuat* location represents eastern part of Indramayu District area. Anjatan location experiences relatively wetter Rainy Season, especially during January-March and September-October, comparing to the eastern part of Juntinyuat one. However, in Dry Season the eastern part is a little bit wetter, especially in April-July, than the western part (Fig. 2).
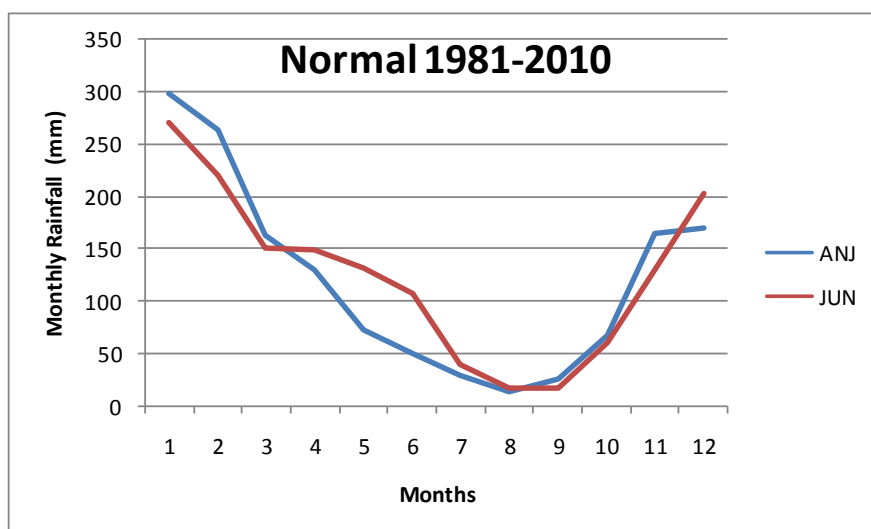

Figure 2: Normal monthly rainfall of 1981-2010 for Anjatan (ANJ) and Juntinyuat (JUN), Indramayu District area of Indonesia

Data used in this research is daily rainfall data taken from observation result of 16 rainfall stations in Indramayu District area. Daily data transformed into monthly rainfall data format. The series data used here is in a good condition. No missing value is available. Location of rainfall stations include such namely as: Anjatan, Bangkir, Bantarhuni, Bondan, Bugis, Bulak, Cidempet, Cikedung, Jatibarang, Juntinyuat, Kedokanbunder, Sudimampir, Sumurwatu, Tugu, Ujungaris, and Wanguk [19].

The rainfall data obtained from the Head Office of BMKG, Class I Climatology Station of Darmaga Bogor, Irrigation Unit of Indramayu District, Agriculture and Husbandry Unit of Indramayu District, and Jasa Tirta II General Company in Patrol, West Java, Indonesia.

The JRA-25 SST data can be accessed through the official JMA website address [6]. This data accessed uses *user name* and *password* especially for BMKG. The mentioned data are in the form of monthly data for each wanted *grid box*. The JRA-25 SST data value will appear after inserting the *longitude* and *latitude* in the center of each *grid box*. Data resolution used in this paper is 1° x 1°. The JRA-25 SST data coverage includes 106° - 111° E and 4° - 10° S. Total of JRA-25 SST *grid box* used in data management of this research is 30 *grid boxes*.

The activity order in the implementation of this research is first collecting monthly rainfall data of WEPS model output series of 2001-2009 [20], collected monthly JRA-25 SST data obtained from official JMA website. Then, conducting monthly rainfall prediction of Indramayu District area with series of 2001-2009 and regressing this WEPS model output series of 2001-2009 with JRA-25 SST data using *time lag* of 1 and 2 month ahead by PLSR technique. Afterward, calculating r value and RMSE for WEPS-PLSR model output series of 2006-2009, preparing r and RMSE spatial field based on WEPS-PLSR model output of monthly rainfall prediction for Indramayu District area, and analyzing result of WEPS-PLSR model output in the form of monthly rainfall prediction to previously calculated WEPS data and its field observation data.

3. Result and Discussion

Data management result based on series of 1991-2000 generates WEPS model output series of 2001-2009. Afterward, WEPS model output regressed with JRA-25 SST data using *time lag* of 1 and 2 months ahead. This *Time lag* meant to anticipate sea response in keeping and releasing energy originated coming from the sun radiation to the atmosphere that takes time lag. The data management result can be seen in the following figures.
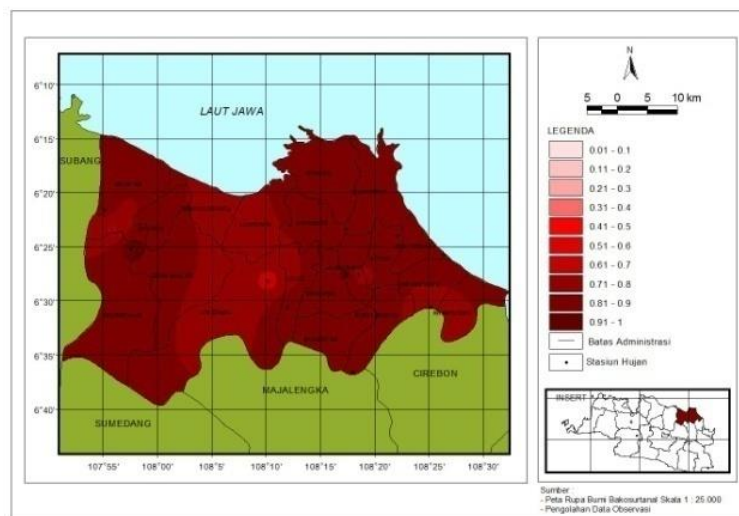

Figure 3: The r coverage of WEPS model output in Indramayu District area of Indonesia with 1 month time lag ahead of JRA-25 SST data
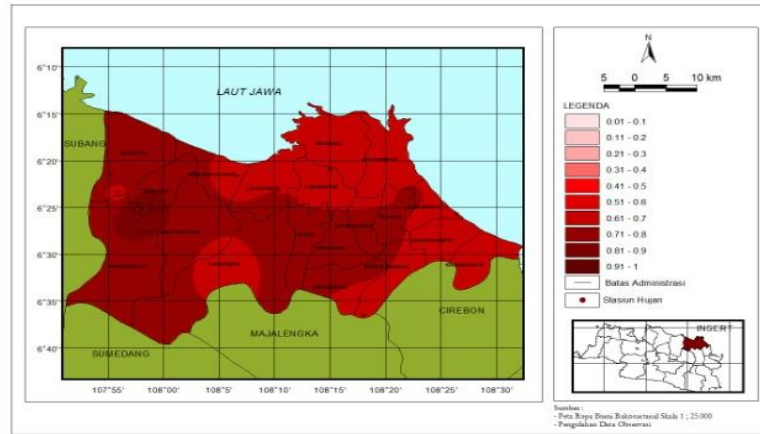
Figure 4: The r coverage of WEPS-PLSR model output in Indramayu District area of Indonesia with 1 month time lag ahead of JRA-25 SST data
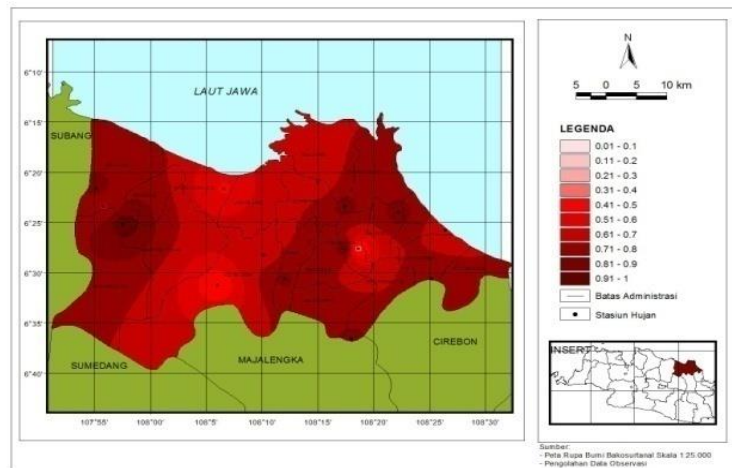

Figure 5: The r coverage of WEPS model output in Indramayu District area of Indonesia with 2 months time lag ahead of JRA-25 SST data
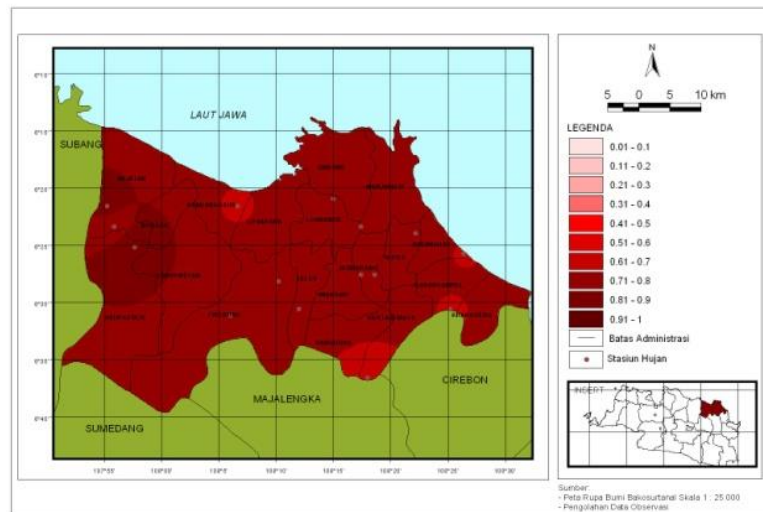

Figure 6: The r coverage of WEPS-PLSR model output in Indramayu District area of Indonesia with 2 months time lag ahead of JRA-25 SST data

The r coverage value for WEPS and WEPS-PLSR model outputs with *time lag* ahead of 1 month of JRA-25 SST data presented in Fig. 3 and Fig. 4. The highest value of WEPS model output with r = +0.94 occurred in Wanguk location, in the meantime, the lowest r = +0.68 occurred in Cikedung location. Average spatial value of r = +0.82 was depicted in Fig. 3. The highest value of WEPS-PLSR model output with r = +0.92 occurred in Wanguk location, on the other hand the lowest of r = +0.64 occurred in Kedokanbunder location. The average value of spatial r = +0.72 was depicted in Fig. 4. Spatial coverage of Indramayu District area with darker color shade appears to be larger for WEPS model output compared to WEPS-PLSR model output.

Even though both WEPS and WEPS-PLSR models output generate r value that relatively is always good > +0.5 but the result above shows that WEPS model output has r value that is relatively better compared to WEPS-PLSR model output for 1 month *time lag* ahead of JRA-25 SST in maximum, minimum and also the average of r values.

The r value for WEPS and WEPS-PLSR models output with 2 months *time lag* ahead of JRA-25 SST data presented in Fig. 5 and Fig. 6. The highest value of WEPS model output with r = +0.96 occurred in Wanguk location, whereas the lowest r = +0.37 happened in Jatibarang location. The average spatial value r = +0.72 (Fig. 5). In the meantime, the highest value of WEPS-PLSR model output with r = +0.90 happened in Wanguk location, whereas the lowest r = +0.64 occurred in Bondan location. The spatial average value r = +0.75 (Fig. 6). Spatially Indramayu District area with darker color shade is larger for WEPS-PLSR model output compared to WEPS model output.

The result above shows that WEPS model ouput generates weak coefficient correlation value in Jatibarang location. This location is in eastern part of Indramayu District area that has relatively climatologically drier. Meanwhile, for other location, both WEPS and WEPS-PLSR models output generate a relatively good coefficient correlation value with r > +0.5. In general WEPS-PLSR model output has better in r value compared to WEPS model output for 2 months *time la*g ahead of JRA-25 SST data in maximum, minimum and its also average of r values.
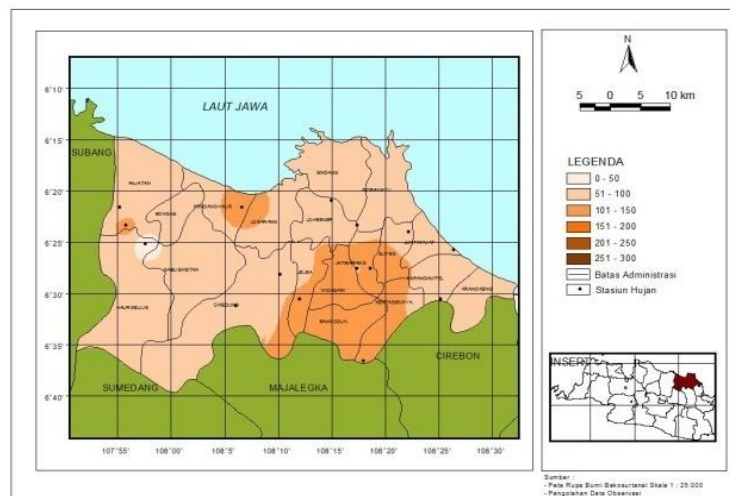

Figure 7: The RMSE coverage of WEPS model output in Indramayu District area of Indonesia with 1 month *time lag* ahead of JRA-25 SST data

T he RMSE value area for WEPS and WEPS-PLSR models output with 1 month *time lag* ahead of JRA-25 SST data presented in Fig. 7 and Fig. 8. The highest value of WEPS model output with RMSE = 143 mm/month occurred in Jatibarang location, whereas the lowest value of RMSE = 32 mm/month occurred in Wanguk location. The average spatial value of RMSE = 96 mm/month (Fig. 7). The highest value of WEPS-PLSR model output with RMSE = 137 mm/month occurred in Bondan location, on the other hand, the lowest value of RMSE = 35 mm/month occurred in Wanguk location. The average spatial value of RMSE = 97 mm/month (Fig. 8).
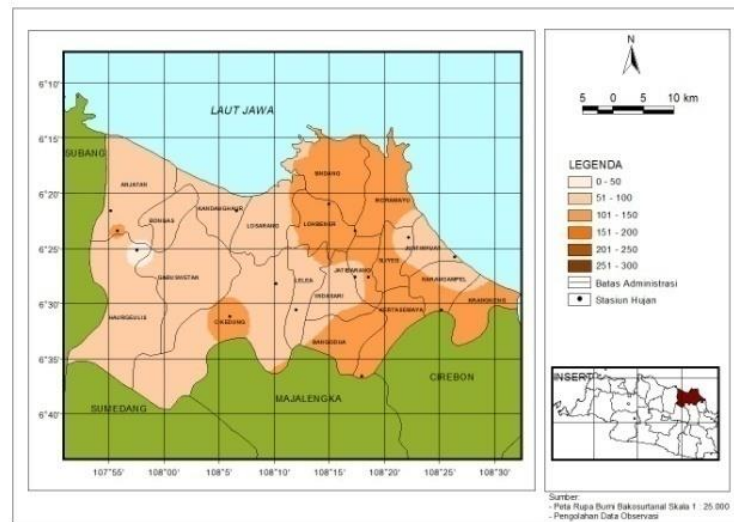

Figure 8: The RMSE coverage of WEPS-PLSR model output in Indramayu District area of Indonesia with 1 month *time lag* ahead of JRA-25 SST data

The average value of RMSE is not too far different between WEPS model and WEPS-PLSR model outputs for 1 month *time lag* ahead of JRA-25 SST data. It only has 1 mm/month gap. This condition shows that WEPS model output is a little bit better than WEPS-PLSR model output. However, the maximum RMSE value appears to be relatively better for WEPS-PLSR model output than WEPS model output. Meanwhile, for minimum RMSE, then WEPS model output shows better result comparing to WEPS-PLSR model output.

Spatially Indramayu District area has softer color shade almost similar to WEPS model output and WEPS-PLSR model output. Area with softer color shade shows the lower RMSE value gained. Considering the best RMSE result has small value or close to zero, it means the better the related output. For WEPS model output it appears to be better than WEPS-PLSR model output in this case. This result represents that WEPS model output has relatively better RMSE value compared to WEPS-PLSR model output for 1 month *time lag* ahead of JRA-25 SST data.

The value area of RMSE for WEPS model output and WEPS-PLSR model output with 2 months *time lag* ahead of JRA-25 SST data presented in Fig. 9 and Fig. 10. The highest value of WEPS model output with RMSE = 181 mm/month occurred in Jatibarang location, whereas the lowest value of RMSE = 32 mm/month occurred in Wanguk location. The average spatial value of RMSE = 108 mm/month (Fig. 9).

The highest value of WEPS-PLSR model output with RMSE = 142 mm/month occurred in Bondan location, on the other hand, the lowest value of RMSE = 37 mm/month occurred in Wanguk location. The average spatial of RMSE = 92 mm/month is shown in Fig. 10.
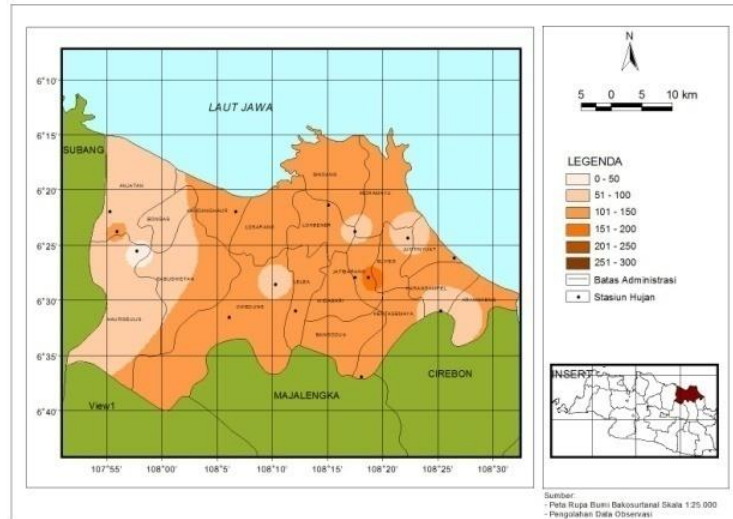

Figure 9: The RMSE coverage of WEPS model output in Indramayu District area of Indonesia with 2 months *time lag* ahead of JRA-25 SST data
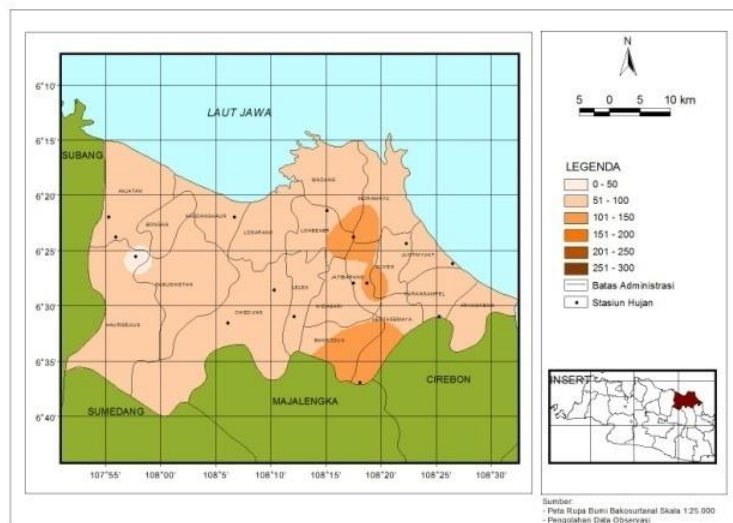

Figure 10: The RMSE coverage of WEPS-PLSR model output in Indramayu District area of Indonesia with 2 months *time lag* ahead of JRA-25 SST data

The average RMSE value is so different between WEPS model and WEPS-PLSR model outputs for this 2 months *time lag* ahead of JRA-25 SST data. It has 16 mm/month gap with WEPS-PLSR model output which is relatively better than WEPS model output results. The value of maximum RMSE appears to be lower for WEPS-PLSR model output comparing to WEPS model output that has difference in value of RMSE = 39 mm/month.

Whereas, for minimum RMSE, then WEPS model output shows relatively better than WEPS-PLSR model output with the difference of RMSE value = 5 mm/month.

Spatially the coverage of Indramayu District area that has softer color shade appears to be larger for WEPS-PLSR model output compared to WEPS model output. Area with softer color shade has lower RMSE value. It means the better is the related model output. Thus, WEPS-PLSR model output appears to have better result than WEPS model output. This result shows that WEPS-PLSR model output has RMSE value that is relatively better than WEPS model output for 2 months *time lag* ahead of JRA-25 SST data.

4. Conclusion

Based on the description in the chapters above, it can be drawn several conclusions, that JRA-25 SST data can be used to improve quality (increase r value, decrease RMSE value) of WEPS model output of monthly rainfall prediction in Indramayu District area uses PLSR technique especially for 2 months *time la*g ahead of JRA-25 SST data. WEPS model output generates value of r = +0.72 whereas WEPS-PLSR model output generates value of r = +0.75. WEPS model output generates value of RMSE = 108 mm/month in the meantime WEPS-PLSR model output generates value of RMSE = 94 mm/month. Result of WEPS-PLSR model output shows maximum value of RMSE is smaller than WEPS model output of 1 month *time lag* and 2 months *time lag* ahead. This also occurs to the average value of r and minimum value of r that is bigger, and maximum value of RMSE is smaller than 2 months *time lag* ahead result. In general spatial JRA-25 SST data plays a significant role for 2 months *time lag* ahead in conducting monthly rainfall in Indramayu District area uses WEPS-PLSR model output. The 2 months time lag ahead of JRA-25 SST data provides more contributions in supplying water vapor into the atmosphere comparing to 1 month time lag ahead of JRA-25 SST data.

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