Can Paddy Growing Phase Produce an Accurate Forecast of Paddy Harvested Area in Indonesia? Analysis of the Area Sampling Frame Results

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Abstract. Our study aims to evaluate the accuracy of the forecasts produced based on the paddy growing phase obtained from the results of the Area Sampling Frame (ASF) Survey and, as a comparison, proposes an alternative forecast method taking into account the seasonal pattern and hierarchical structure of the national paddy harvested area estimation obtained from the ASF to improve the accuracy. In doing so, we calculated the MAPE by comparing the realization of paddy harvested area during the period January to September 2022 with their forecasts produced from the area of generative, late vegetative, and early vegetative phases. We also implemented a Hierarchical forecasting method on monthly data of the harvested area from January 2018 to August 2022 for all provinces. Specifically, we applied the bottom-up method for the reconciliation and the rolling window method to produce a three-consecutive month forecast for the period January to September 2022. We found that the accuracy prediction based on the paddy growing phase is moderately accurate. The combination of the bottom-up reconciliation method and the SARIMA model produces a much better accuracy for the national figure of paddy harvested area as shown by a lower MAPE. Our findings suggest that the Hierarchical forecasting method could be an alternative for the prediction of harvested area based on the ASF results other than the prediction obtained from the standing crops.

1. Introduction

Rice is a very strategic food commodity in Indonesia, which is the main staple food for almost all Indonesians. Therefore, the accuracy of rice production data strongly influenced by the harvested area data is crucial for well-informed rice policies in Indonesia. Since 2018, Statistics Indonesia has implemented the Area Sampling Frame (ASF) method replacing the old one called eye-estimate in estimating the area of paddy in Indonesia. Before the implementation of the ASF method, the paddy harvested area published by BPS was subject to overestimation [1] [2]. [3] found that the harvested area data of Java Island obtained from the eye-estimate method from May 1996 to April 1997 were overestimated by 17 percent. Consequently, the estimates of rice production figures were also overestimated and led to inaccurate information on the rice policy in Indonesia that happened for a dozen years [4] [5].

Besides better accuracy, one of the advantages of implementing this new method is the possibility to provide forecasts of harvested area for the upcoming three months based on the observation results of the paddy growing phase in the current month [6]. The forecast information is crucial for the rice policy in Indonesia. Through the ASF Survey, observation of the paddy growing phase is conducted monthly on sample areas called land segments that are selected randomly [7]. From the observation, six possible outcomes are expected regarding the state of the paddy growing phase at a point of observation, including early vegetative, late vegetative, generative, harvested, damaged, and non-paddy areas. BPS estimates the area for the associated growing phase by multiplying the proportion of each outcome of the total samples with the area of the wetland paddy. The estimation is performed at the sub-district level and then is aggregated to obtain the estimation for the district, provincial, and national levels (bottom-up process) [8].

Besides producing an estimation of the harvested area, BPS uses the estimation of generative, early vegetative, and late vegetative areas in the current month to make predictions of paddy-harvested areas for the next three months. Technically, the forecast of the harvested area for one month ahead is obtained from the area of paddy with a generative phase in the current month while forecasts for the second and third months ahead are obtained from the area of paddy with late and early vegetative phases in the current month, respectively [9]. The predictions are very important to inform rice policy in Indonesia. The Ministry of Agriculture uses the predictions in maintaining rice production in the next three months through some intervention policies, while the State Logistic Agency uses the information for the procurement of national buffer stocks in the next three months. Therefore, the accuracy of the prediction does matter to ensure accurate rice policy interventions.

To the best of our knowledge, well-documented studies focusing on evaluating the accuracy of the harvested area predictions obtained from the ASF paddy growing phases' estimation results are still very limited. Most studies only aimed to evaluate the accuracy of harvested area estimation obtained from the ASF observations, such as [10] and [11]. In this paper, we call it "a realization". Among those limited studies focusing on evaluating the accuracy of the ASF harvested area predictions are [6] and [12]. However, the two studies did not consider the fact that the national paddy harvested area figures obtained from the ASF are the results of aggregation from estimations at the sub-national level. Based on our review, there is no well-documented study dedicated to addressing this issue.

Our study aims to address the gap by evaluating the accuracy of ASF predictions based on the paddy growing phase and proposing an alternative forecast method for comparison. Our study improves what has been done [12] by using an alternative forecast method considering the hierarchical structure of the national paddy harvested area estimation obtained from the ASF. Hence, this study is expected to provide better input for the improvement of the harvested area predictions from the ASF observation results.

2. Methodology

Our study used the monthly observation results of the ASF Survey from January 2018 to September 2022 published by the Indonesian Statistical Agency or Statistics Indonesia (BPS). The observation results consist of the estimation of harvested area, generative area, early vegetative area, and late vegetative area. We split our dataset into the training set covering January 2018 to December 2021 and the test set covering January to September 2022.

In evaluating the harvested area predictions based on the paddy growing phase observed in the ASF Survey, we compared the harvested area realization with the ASF predictions from January to September 2022. Using the data set, as described earlier, the ASF predictions for three consecutive months based on the observation results of the paddy growing phase in the current month follow the patterns in Figure 1 below.

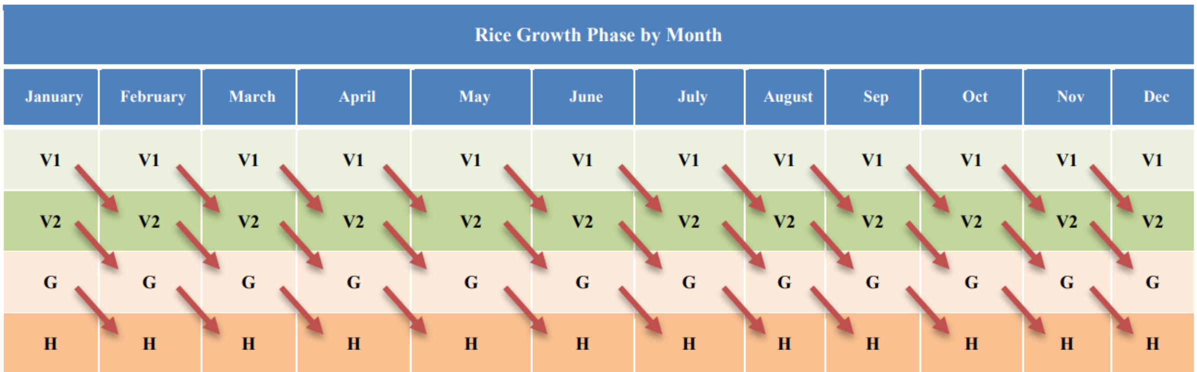

Figure 1. Paddy growing phase calendar

We then computed the forecast errors and Mean Absolute Percentage Errors (MAPE) for one-month, two-month, and three-month ahead predictions. The formula used is as follows

$$MAPE = \frac{\sum_{i=1}^{n}\left(\frac{|e_i|}{y_i}\right)\times 100}{n} = \frac{\sum_{i=1}^{n}\left(\frac{|y_i-\widehat{y_i}|}{y_i}\right)\times 100}{n} \tag{1}$$

In Equation (1), e_i is the forecast error, which is the deviation of paddy harvested area prediction or forecast ($\hat{y}$) from the ASF estimation or the paddy harvested area realization in the current month ($\widehat{y_i}$), and n is the number of out-of-sample forecasts. Using the results of MAPE computations for each prediction, we evaluated the accuracy by following [13]. The accuracy is considered highly accurate when the MAPE value is less than 10 percent. When the value of MAPE falls between 10 percent and 20 percent, the prediction is considered a good forecast; and if the MAPE is greater than 20 percent and less than 50, the prediction is considered a reasonable forecast. Moreover, the MAPE of greater than 50 percent means that the prediction is a poor forecast.

Besides evaluating the accuracy of ASF predictions, we also do out-of-sample forecasts [14] for the test set as an alternative comparison. In doing so, we implemented a Hierarchical forecasting method [15] on monthly data of the harvested area from January 2018 to August 2022 for all provinces. By structure, our data could be considered as a hierarchical time series which is a collection of several time series linked together in a hierarchical structure [15]. Figure 2 shows an example of a two-level hierarchical structure [15] that reflects our data structure. Specifically, we applied the bottom-up method for the reconciliation and the rolling-window method, which is recursive with an expanding window [14] to produce a three-consecutive month forecast for the period January to September 2022.

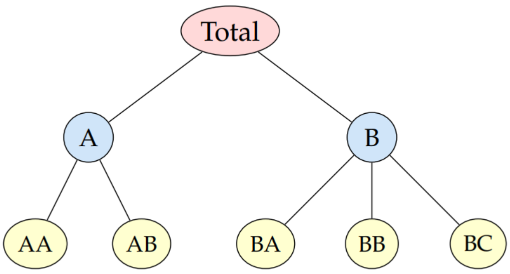

Figure 2. A simple two-level hierarchical structure

When using the bottom-up reconciliation method, we initially forecast the lowest level of the hierarchy and then use the aggregation to obtain forecasts for the higher hierarchy until we end up with the highest level of the hierarchy or called revised forecasts [16]. Referring to Figure 1, the h-step-ahead base forecasts for the bottom-level series are $\hat{y}_{AA,h}$, $\hat{y}_{AB,h}$, $\hat{y}_{BA,h}$, $\hat{y}_{BB,h}$, and $\hat{y}_{BC,h}$. The h-step-ahead forecasts for the next up level are given by $\tilde{y}_{A,h} = \hat{y}_{AA,h} + \hat{y}_{AB,h}$, $\tilde{y}_{B,h} = \hat{y}_{BA,h} + \hat{y}_{BB,h} + \hat{y}_{BC,h}$, and

$\tilde{y}_h = \tilde{y}_{A,h} + \tilde{y}_{B,h}$. The main advantage of using the bottom-up method is there is no lost in information because of the aggregation [16].

The use of the bottom-up method considered the fact that the national figure of paddy harvested area obtained from ASF is the aggregation of all 34 provinces' estimations. In our study, we have two levels of hierarchy. The lowest hierarchy consists of 34 provinces. The second hierarchy consists of 6 islands, which are the groups of all corresponding provinces. The national figure is the aggregation of all islands' forecasts obtained by aggregating the forecasts of corresponding provinces.

The method of forecasting used is the Error, Trend, Seasonal (ETS) model, which is developed from the exponential smoothing method by taking into account the stochastic feature of the data [17], and the Autoregressive Integrated Moving Average (SARIMA) model that also taking into account the seasonality in the data or called Seasonal ARIMA (SARIMA). The general form of the ETS model can be formulated as follows

$$y_t = w(\mathbf{v}_{t-1}) + r(\mathbf{v}_{t-1})\varepsilon_t, \mathbf{v}_t = f(\mathbf{v}_{t-1}) + g(\mathbf{v}_{t-1})\varepsilon_t \quad (2)$$

where $\mathbf{v}_{t-1}$ is the state vector that contains the time series components (level, trend, and seasonal), $w(.)$ is the measurement, $r(.)$ is the error, $f(.)$ is the transition, and $g(.)$ is the persistence functions. The values for these functions will follow the types of components. The general form of SARIMA model employed can expressed as follows

$$\phi(B)\Phi(B^s)\nabla^d\nabla_s^D y_t^{(\lambda)} = \theta(B)\Theta(B^s)\varepsilon_t \quad (3)$$

where $\phi(B)$ and $\Phi(B^s)$ are the lag operators for the non-seasonal autoregressive and seasonal autoregressive. $\theta(B)$ and $\Theta(B^s)$ are the lag operators for the non-seasonal moving average and seasonal moving average. The specification of equation (3) follows the feature of the data.

The use of these methods considered that the seasonal component may exist in the series of harvested area data. In applying the Hierarchical forecasting method, we used the *hts* package in R developed by [18]. By using the package, the specifications of both ETS and SARIMA models in equations (2) and (3) are determined automatically which guarantees the validity of the model and optimizes the goodness of fit. We also computed the MAPE for the harvested area forecasts obtained from the Hierarchical method. We then compare them with the ASF prediction's MAPE to determine which produces a better prediction.

3. Results and discussion

3.1. The evaluation of the ASF predictions

In evaluating the accuracy of ASF's predictions, we start by plotting the ASF's predictions against the realization of the paddy harvested area obtained from the ASF results. It gives us an initial description of the nature of the data from time to time as well as the deviation of the prediction from the realization and its pattern during the period of analysis.

The plots point out that the harvested area data and its predictions have a strong seasonal pattern. In the whole year, there are two peak harvest seasons: March-April and August-September. The highest one happens in March most of the time. The low season always happens in the early (January-February) and end (October-December) of the year. Moreover, as shown by Figures 3,4, and 5, there are strong indications of systematic error patterns of the ASF prediction based on the state of the paddy growing phase. Those are quite evident in both the two-month ahead and three-month ahead predictions.

Figure 3 shows that the generative area in the current month could be a good prediction for the harvested area in the one month ahead. However, although it seems to produce a quite good prediction, the one-month ahead harvested area prediction using the generative area at the current month has been higher than the realization for all months since the middle of the year 2021.

In contrast, the two-month ahead prediction using the vegetative area has been lower than the realization for most of the time from March 2018 to September 2022. It shows that the two-month ahead prediction tends to be downward bias in predicting the harvested area. Figure 4 also points out that the accuracy of the two-month ahead prediction is lower than the one-month ahead prediction. However, the indication of systematic errors on the ASF's two-month ahead prediction could also be useful information to conduct a systematic correction, for instance by adding or subtracting the prediction with the average deviation during the observation period.

Figure 5 shows that in the period April 2018 to 2022, most of the time the three-month ahead prediction using the early vegetative area tends to be higher than the realization. It seems that the three-month ahead prediction tends to be an upward bias in predicting the harvested area. This systematic error could also be a piece of useful information to conduct a systematic correction as in the case of the two-month ahead prediction. However, its accuracy is relatively better than the two-month ahead prediction.

In general, the ASF's one-month prediction using the generative area produces the best prediction, especially during the period before the year 2021. Moreover, the ASF's two-month ahead prediction produces the worst accuracy among the three predictions. It is also evident from Figure 3 that the accuracy of the ASF's two-month ahead prediction is quite poor during the years 2018 and 2019.

The deviation patterns in Figures 3,4, and 5 confirm that the accuracy of the ASF predictions needs to be improved. Besides conducting a systematic correction, one alternative that can be pursued is by applying the forecasting method to the harvested area data directly instead of using predictions based on the paddy growing phases calendar framework that tends to suffer from a systematic bias. It is possible to be done since the data availability is sufficient enough for forecasting. In this regard, whatever forecast method to be used should take into account the seasonal component of the harvested area data, as highlighted before.

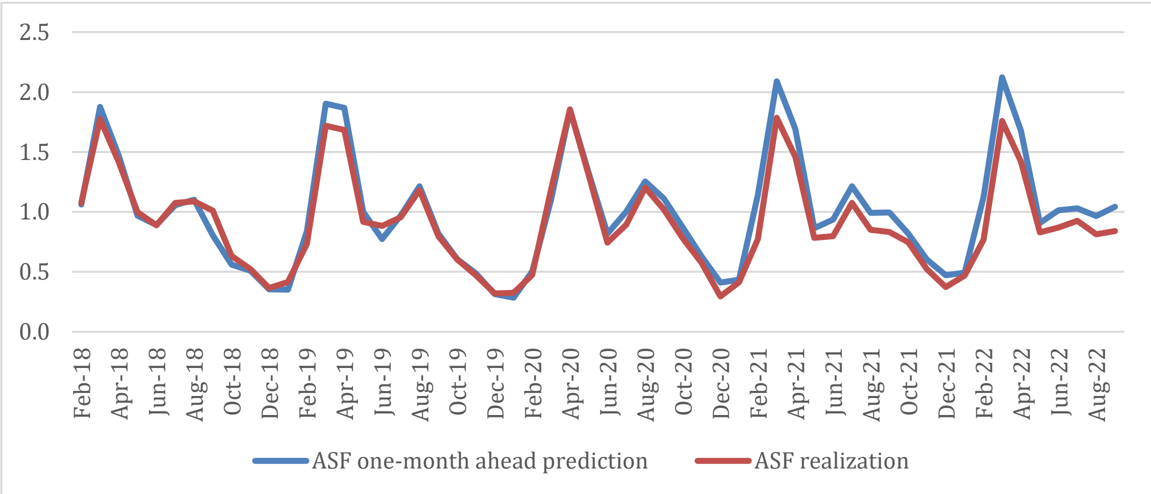

Figure 3. ASF one-month ahead prediction versus harvested area realization, February 2018 - September 2022 (millions of hectares)

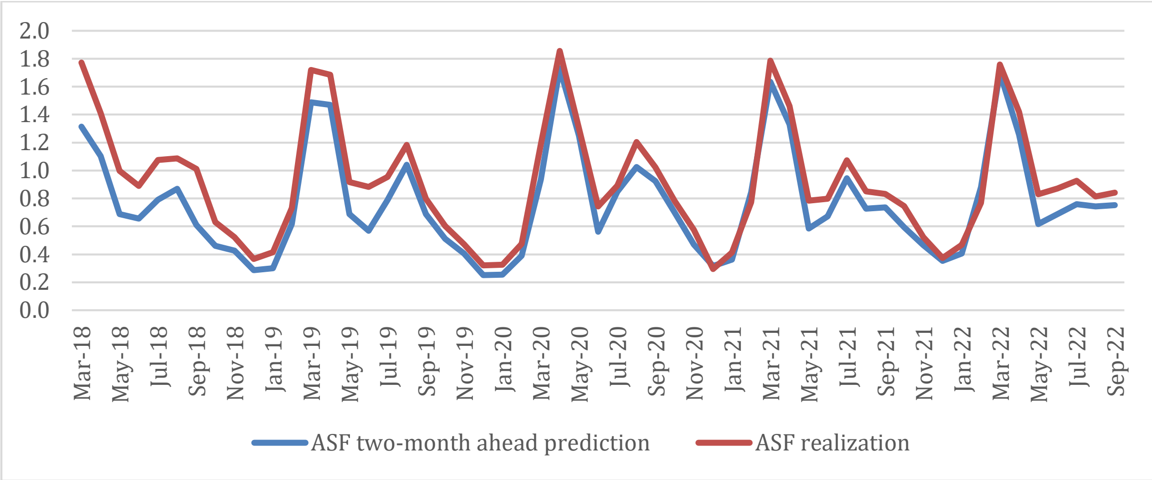

Figure 4. ASF two-month ahead prediction versus harvested area realization, March 2018 – September 2022 (millions of hectares)

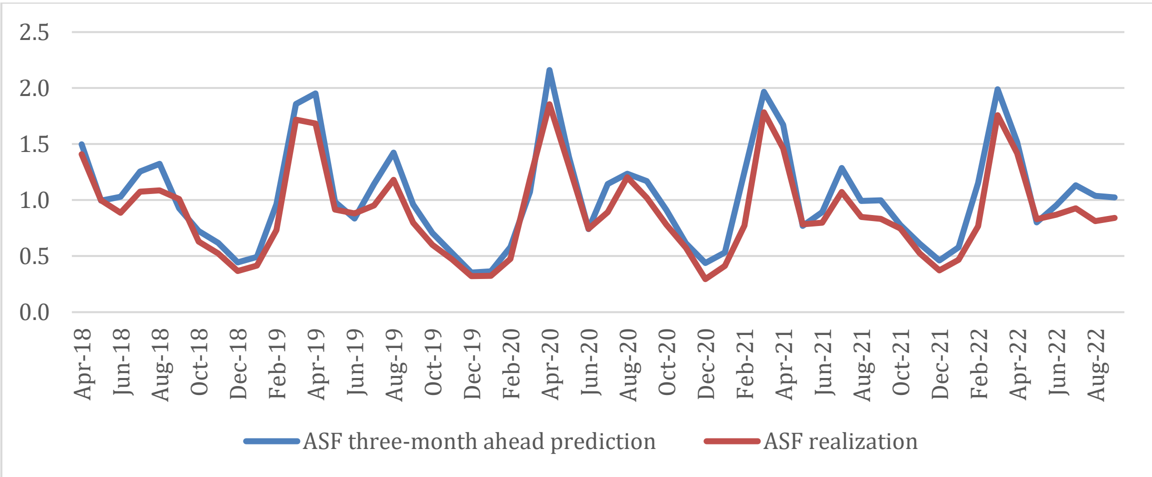

Figure 5. ASF three-month ahead prediction versus harvested area realization, January 2018 - September 2022 (millions of hectares)

Figures 3, 4, and 5 only gave us rough indications regarding the accuracy of the ASF's predictions. To obtain a more precise picture of the accuracy, we quantify the deviation of the ASF's predictions from the realization by computing the MAPE in Equation (1). We found that the accuracy of prediction based on the paddy growing phase is moderately accurate. It is shown by the MAPE of the forecasts that are below 20 percent. The values of MAPE presented in Table 1 are coherent with the patterns in Figures 3, 4, and 5.

As anticipated from Figure 3, from February 2018 to September 2022, the ASF's one-month ahead prediction produces the best accuracy. However, from January to September 2022, it produced relatively worse accuracy, indicated by the value of MAPE, which is close to 20 percent. It is coherent with the pattern in Figure 3, showing a quite substantial deviation of the prediction from the realization from January to September 2022.

The deviation is relatively large in both March and April, which are the period of peak seasons of paddy harvest in Indonesia. It seems that these deviations have given a substantial contribution to the inaccuracy of the one-month ahead prediction. Therefore, the improvement in the one-month ahead prediction must be taken seriously by BPS since it is very important for rice policy-making. Moreover, in general, the ASF two-month and three-month ahead produce quite similar accuracy for both the training set and the test set, shown by the values of the MAPE that are not significantly different between the two.

Table 1. Mean Absolute Percentage Errors (MAPE) of the ASF Prediction

Period	One-month ahead	Two-month ahead	Three-month ahead
February 2018 to September 2022	11.34	-	-
January to September 2022	18.28	-	-
March 2018 to September 2022	-	16.83	-
February to September 2022	-	14.55	-
April 2018 to September 2022	-	-	16.78
March to September 2022	-	-	19.64

Source: *author calculation*

3.2. Alternative forecasts

In this section, we discuss the results of forecasting using the Hierarchical model and their accuracy. We only discuss the results in more detail on the national level. Our findings pointed out that the Hierarchical forecasting method produces a better accuracy than the ASF's predictions for the national figure of the paddy harvested area as shown by a lower MAPE (Table 2). Both ETS and SARIMA models with the bottom-up reconciliation method produce lower MAPEs. The MAPEs of the SARIMA model are even much lower reaching less than ten percent compared to the ASF results. It means that the SARIMA model with a bottom-up reconciliation provides highly accurate forecasts of paddy-harvested areas from January to September 2022. As expected, the best accuracy is for the one-month ahead forecast with a value of MAPE of only 6.12 percent, followed by the two-month ahead and three-month ahead forecasts with the value of MAPEs are 6.61 percent and 7.61 percent respectively. It can be seen even for the three-month forecast our proposed method on average still produces a highly accurate prediction. Our forecast results insist that the forecasting model could be an alternative to improve the accuracy of the ASF's predictions up to the three-month ahead forecast.

Table 2. MAPE of Hierarchical Forecast Method

Period	One-month ahead	Two-month ahead	Three-month ahead
ETS model			
January to September 2022	12.81	-	-
February to September 2022	-	12.18	-
March to September 2022	-	-	13.45
SARIMA model			
January to September 2022	**6.12**	-	-
February to September 2022	-	**6.61**	-
March to September 2022	-	-	**7.61**

Source: *author calculation*

The plot of our forecast results using the Hierarchical model and the harvested area realization are presented in Figures 6, 7, and 8. These plots point out the main drawback of the ETS method that we applied, which did not capture the sifting of peak harvest during the period 2020 to 2022 very well. Based on the ASF historical data, the peak harvest from 2018 to 2022 always happens in March, except in 2020 where there is a shift from March to April due to weather anomalies. At that time, the harvest area in April was the highest ever recorded since 2018. It seems that the shifting impacted the accuracy of the April 2022 harvested area forecast. However, the issue was addressed very well by the SARIMA method which could mimic the seasonal pattern of the harvested data very well, including the peak harvests in March and July. As a result, the method produced a highly accurate forecast as discussed previously.

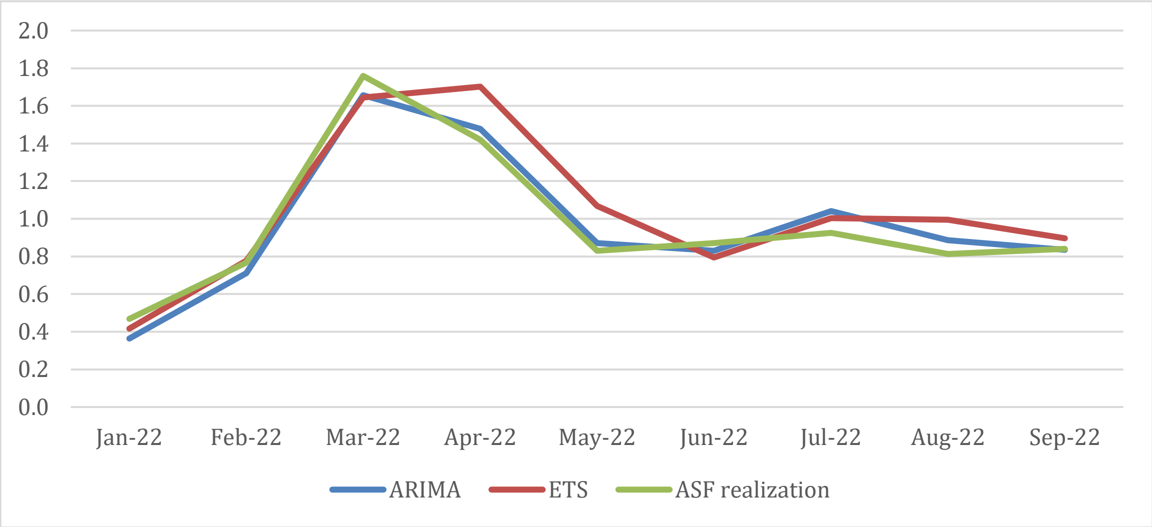

Figure 6. One-month ahead forecast of Hierarchical forecasting model versus harvested area realization, January 2022 - September 2022 (millions of hectares)

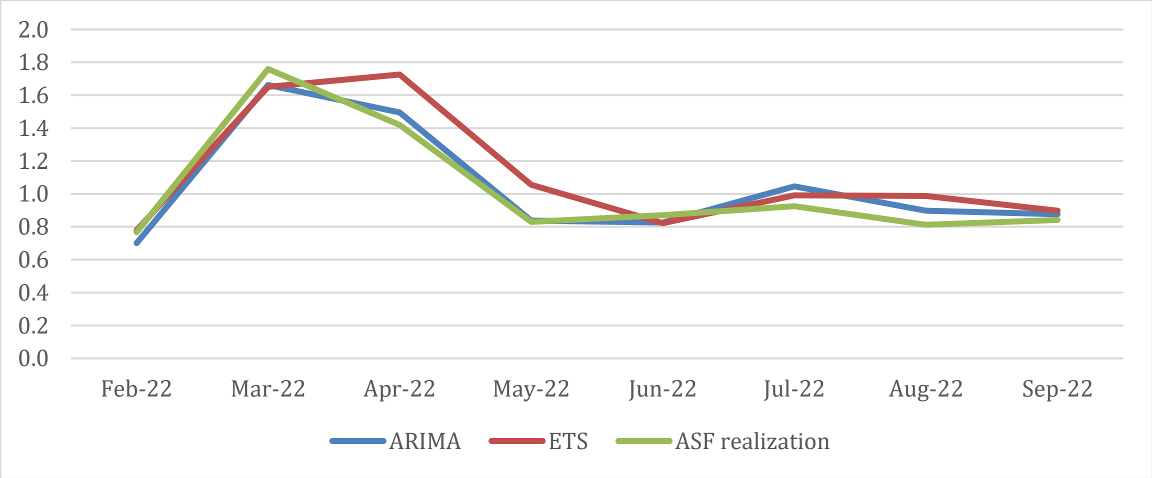

Figure 7. Two-month ahead forecast of Hierarchical forecasting model versus harvested area realization, February 2022 - September 2022 (millions of hectares)

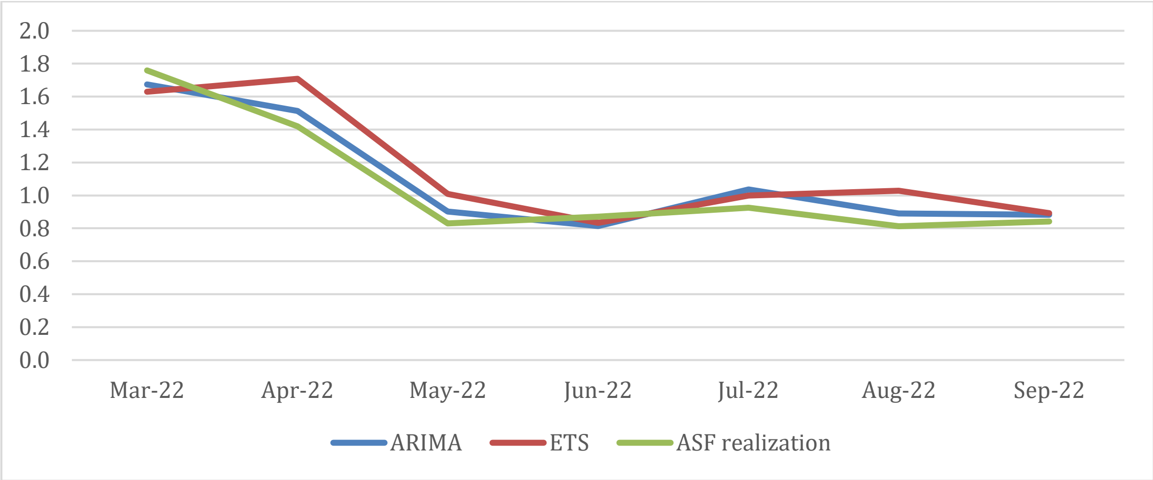

Figure 8. Three-month ahead forecast of Hierarchical forecasting model versus harvested area realization, March 2022 - September 2022 (millions of hectares)

It is important to notice that the Hierarchical method applied only produced a highly accurate forecast for the national level. At the provincial level, we found that the accuracy is quite poor for some provinces. It could be considered as the drawbacks of the Hierarchical model compared to the ASF prediction that produced a quite reasonable forecast at sub-national levels.

4. Conclusion

Our study aims to evaluate the accuracy of the ASF prediction for the paddy harvested area obtained from the standing crops in a current month and exercise an alternative forecast using the Hierarchical forecast method. We found that there are systematic error patterns of the ASF prediction based on the state of the paddy growing phase. It could be a piece of useful information in conducting a systematic correction of ASF predictions. However, the accuracy of the ASF prediction up to three months ahead could be considered moderately accurate based on MAPE values. Our proposed forecast method, which is the SARIMA model with a bottom-up reconciliation method, produces a more accurate prediction of the harvested area for three months ahead at the national level than the ASF predictions. Based on the value of MAPEs, it could be considered that our proposed method produced a highly accurate forecast. The forecast results obtained from the method also can mimic the seasonal pattern of the harvested area data very well. Therefore, it could be an alternative other than the use of a paddy growing phase area for harvested area prediction (standing crops). Moreover, our findings suggest that in the Indonesian context, there is plenty of room for improvement in the paddy-harvested area forecast obtained from the ASF estimation. Other forecast methods such as machine learning and other reconciliation methods like Middle-Out and OptimalMinT could be considered to improve the forecast accuracy.

References

[1] Ruslan K 2019 *Improving Indonesia's Food Statistics through the Area Sampling Frame Method* (Center for Indonesian Policy Studies). https://doi.org/10.35497/287781

[2] Sawit MH 2014 *Analisa Hasil Sensus Penggilingan Padi 2012*. *Jurnal PANGAN*. **23** 3 208-219

[3] Maksum C and Sastrotaruno S 1998 *Evaluasi Luas Tanaman Padi Dengan Pendekatan Rumah Tangga* (Badan Pusat Statistik)

[4] Rosner LP and McCulloch N 2008 *A Note on Rice Production, Consumption and Import Data in Indonesia*. *Bulletin of Indonesian Economic Studies*. **44** 1 81-91

[5] Khudori 2019 *Kaji Ulang Kebijakan Perberasan*. *Jurnal PANGAN*. **28** 1 57-72

[6] Kadir K & Prasetyo OR 2021 *Peramalan Luas Panen Padi Indonesia Dengan Model ETS (Error, Trend, Seasonal)*. *Jurnal MSA (Matematika Dan Statistika Serta Aplikasinya)*. **9** 1 715. https://doi.org/10.24252/msa.v9i1.19666

[7] Mubekti & Sumargana L 2016 *Pendekatan Kerangka Sampel Area untuk Estimasi dan Peramalan Produksi Padi*. *Jurnal PANGAN*. **25** 2 71 – 82
[8] Badan Pusat Statistik 2018 *Pedoman Teknis Pendataan Statistik Pertanian Tanaman Pangan Terintegrasi dengan Metode Kerangka Sampel Area (KSA) 2018* (Badan Pusat Statistik)
[9] Amalia RR and Kadir 2019 *Improving Paddy Statistics in Indonesia: Developing Crop Cutting Survey Using Area Sampling Frame* (*pre-print*)
[10] Gandharum L, Mulyani ME, Hartono DM, Karsidi A, & Ahmad M 2021 *Remote sensing versus the area sampling frame method in paddy rice acreage estimation in regency, West Java province, Indonesia*. *International Journal of Remote Sensing*. **42** 5 1738-1767 DOI: 10.1080/01431161.2020.1842541
[11] Raharjo M, Kurnia A, & Wijayanto H 2022 *A Study on Accuracy of Paddy Harvest Area Estimation on Area Sampling Frame Method*. *Indonesian Journal of Statistics and Its Applications*. **6** 1 41–49. https://doi.org/10.29244/ijsa.v6i1p41-49
[12] Prasetyo OR, Kadir, and Amalia RR 2019 *Evaluasi Akurasi Data Potensi Luas Panen Padi di Indonesia* (*pre-print*)
[13] Lewis C D 1982 *Industrial and business forecasting methods: A practical guide to exponential smoothing and curve fitting* (Butterworth-Heinemann)
[14] Tashman LJ 2000 *Out-of-sample tests of forecasting accuracy: an analysis and review International Journal of Forecasting.* **16** 4 437–450
[15] Athanasopoulos G, Ahmed RA, and Hyndman RJ 2009 *Hierarchical forecasts for Australian domestic tourism*. *International Journal of Forecasting*. **25** 1 146–166
[16] Kahn KB 1998 *Revisiting top-down versus bottom-up forecasting. The Journal of Business Forecasting*. **17** 2 14–19
[17] Hyndman RJ and Athanasopoulos G 2018 *Forecasting: principles and practice. 2nd ed* (Melbourne, Australia: OTexts. OTexts.org/fpp2/)
[18] Hyndman RJ, Ahmed RA, Shang HL, Wang E 2014 *hts: Hierarchical and grouped time series. R package version 4.00*, URL http://CRAN.R-project.org/package=hts