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Surface Ozone Trend in Major Rice Growing Areas in Malaysia
(Tren Ozon Permukaan di Kawasan Penanaman Padi Utama di Malaysia)

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ABSTRACT

Surface ozone or tropospheric ozone has been recognized as one of the major factors that can give adverse impact on crops including rice plants. Effects of ozone on rice plants could be seen in decreased of biochemical activities and physiological performance which contribute to yield reduction. In Malaysia, surface ozone is on the rise due to increment anthropogenic sources i.e. urbanization, transportation and also industrialization process. This condition is alarming due to the facts that rice is the major staple food to the majority of Malaysian population. In this study, exceedence of ozone exposure above an hourly threshold concentration of 40 ppb (AOT40) and ozone trends in four major rice growing areas in Malaysia were assessed using time series analysis of ozone data recorded in each area from January 2000 until December 2010 with a total of 132 readings. The results showed a steady increase in exceedence ozone of yearly AOT40 and statistical significant upward trend for ozone concentrations in each rice growing area in Malaysia. This finding was particularly alarming because ozone is able to inhibit production of rice yields. Preventive actions need to be implemented as soon as possible in order to alleviate ozone threat to our national food security agenda.

Keywords: Accumulate ozone exposure above an hourly threshold concentration of 40 ppb; rice growing area; surface ozone; trend analysis

ABSTRAK

Ozon permukaan atau ozon troposfera telah dikenal pasti sebagai salah satu faktor utama yang boleh memberi kesan buruk kepada tanaman termasuk padi. Kesan ozon pada tanaman padi boleh dilihat dalam penurunan aktiviti biokimia dan prestasi fisiologi yang menyumbang kepada pengurangan hasil. Di Malaysia, ozon permukaan semakin meningkat disebabkan peningkatan sumber antropogenik iaitu perbandaran, pengangkutan dan juga proses perindustrian. Keadaan ini adalah membimbangkan kerana berdasarkan fakta, beras adalah makanan ruji utama kepada majoriti penduduk Malaysia. Dalam kajian ini, kepekatan pendedahan ozon di atas kepekatan ambang jam 40 ppb (AOT40) dan tren ozon di empat kawasan utama tanaman padi di Malaysia telah dinilai menggunakan analisis siri masa data ozon yang direkodkan pada setiap kawasan dari Januari 2000 hingga Disember 2010 dengan sebanyak 132 bacaan. Keputusan menunjukkan peningkatan yang stabil dalam lebihan ozon daripada AOT40 tahunan dan tren menaik yang ketara secara statistik untuk kepekatan ozon di setiap kawasan penanaman padi di Malaysia. Penemuan ini amat membimbangkan kerana ozon dapat menghalang pengeluaran hasil padi. Tindakan pencegahan perlu dilaksanakan secepat mungkin untuk mengurangkan ancaman ozon terhadap agenda keselamatan makanan negara.

Kata kunci: Analisis tren; kawasan tanaman padi; pendedahan ozon yang terkumpul di atas kepekatan ambang 40 ppb per jam; ozon permukaan

INTRODUCTION

Surface ozone constitutes a threat to human health (WHO 2003) and is causing damage to vegetation in regions with elevated concentrations (Emberson et al. 2003). Ozone concentrations are increasing in Asia because of rapid increases in emissions of the main critical ozone precursors, nitrogen oxides and volatile organic compounds particularly from motor vehicles and industries (Latif et al. 2012; Naja & Akimoto 2004; Permadi & Kim Oanh 2008). Phototoxicity and availability of the ozone all over the entire agricultural areas of North America, Europe and Asia has shown that the rise of this pollutant would globally become a threat to food production status (Fuhrer & Brooker 2003). Therefore, assessments of ozone impacts on crops especially rice, which is the staple food for the vast majority of the population, have become very significant in Malaysia. An assessment approach using AOT40 has the advantage of being simple because only atmospheric ozone concentration data are needed.

In recent years, many statistical analyses have been used to study the air pollution pattern (Ghazali et al. 2012; Lee 2002) and many investigators have used probability models to explain temporal distribution of air pollutants (Bencala & Seinfield 1979; Yee & Chen 1997). Time series analysis is a useful tool for better understanding of cause and effect relationship in environmental pollution (Kyriakidis & Journal 2001; Salcedo et al. 1999; Schwartz & Marcus 1990). The main aim of time series analysis is to describe movement history of a particular variable in time. Many authors have undertaken to relate air pollution to human health through time series analysis (Gouveia & Fletcher 2000; Roberts 2003; Touloumi et al. 2004).

There were two objectives for this study. First, effects of ozone were investigated using AOT40 while the second objective was to predict the ozone concentrations in four rice granary areas i.e. Muda Irrigation Development Area (MADA), Kemubu Agricultural Development Authority (KADA), Seberang Perak and Sabak Bernam using time series analysis of ozone data recorded in each area from January 2000 until December 2010 with a total of 132 readings. The ozone concentration pattern in these four granary areas are of upmost importance since they produce the bulk of the national rice output in Malaysia.

METHODS

STUDY AREA

The study was conducted utilizing data from four air monitoring stations located at four selected rice granary areas in Peninsular Malaysia (Figure 1). The stations are located at Sekolah Menengah Jalan Pegoh, Ipoh, Sekolah Menengah Kebangsaan Bakar Arang, Sungai Petani, Maktab Sultan Ismail, Kota Bharu and Universiti Pendidikan Sultan Idris in lieu of four major agricultural areas namely Seberang Perak, Muda Irrigation Development Authority (MADA), Kemubu Agriculture Development Area (KADA) and Sabak Bernam, respectively. All the monitoring stations were installed, operated and maintained by Alam Sekitar Malaysia Sdn. Bhd. (ASMA) under concession by the Department of Environment Malaysia (Afroz et al. 2003). The surface ozone concentrations data was recorded using a system based on Beer-Lambert law for measuring low ranges of ozone in ambient air manufactured by Teledyne Technologies Incorporated (Model 400E). A 254 nm UV light signal is passed through the sample cell where it is absorbed in proportion to the amount of ozone at present (ASMA 2008). Ozone trend for these four rice granary areas was examined using ozone data consisting of 132 monthly observations from January 2000 until December 2010.

CALCULATION OF AOT40

The AOT40 was calculated using the formula by Mills et al. 2007 as in (1).

$$AOT40 = \sum^{n} [C_{o3} - 40], \tag{1}$$

where C_{o3} is hourly concentration of ozone expressed in parts per billion (ppb) while n is the number of hours with ozone exceedance of 40 ppb. In this study, AOT40 was calculated over daylight hours (0700 until 1900) as the tropospheric ozone is only formed with the presence

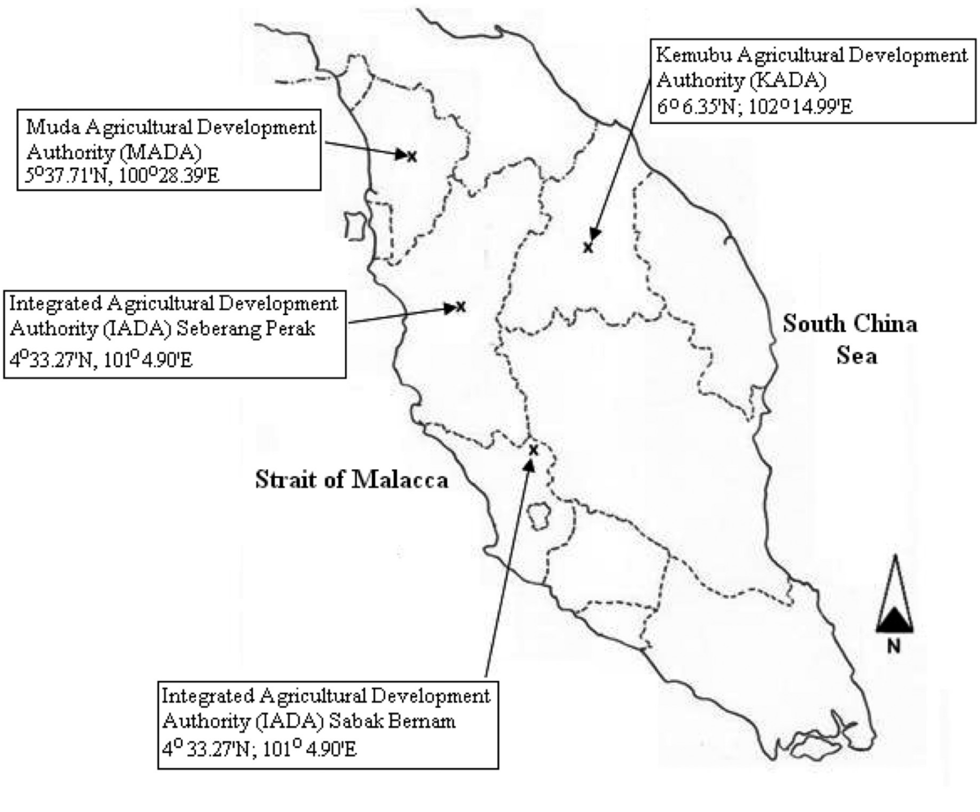

FIGURE 1. Locations of selected air monitoring stations

of sunlight (EPA 2011), throughout the year since the rice growing seasons occurred all year long at all of the selected areas. Then, single classification analysis of variance (ANOVA) *F* test was performed at 95% confidence level to determine the significant difference of AOT40 between each selected rice growing area.

TREND ANALYSIS

In trend analysis, Box-Jenkins autoregressive integrated moving average (ARIMA) model was applied to model the time series behavior in generating the forecasting trend. The methods were done by application of ARIMA model based on four steps:- identification, estimation of identified parameters, diagnostic check on adequacy of identified model and establishment of time series forecasting by using selected model.

In model identification (Step 1), the data was examined to check for the most appropriate class of ARIMA processes through selecting the order of the consecutive and seasonal differencing required to make series stationary, as well as specifying the order of the regular and seasonal auto regressive and moving average polynomials necessary to adequately represent the time series model. The autocorrelation function (ACF) and the partial autocorrelation function (PACF) are the most important elements of time series analysis and forecasting. The ACF measures the amount of linear dependence between observations in a time series that are separated by a lag k. The PACF plot helps to determine how many auto regressive terms are necessary to reveal one or more of the following characteristics: Time lags where high correlations appear, seasonality of the series or trend either in the mean level or in the variance of the series. The general model introduced by Box- Jenkins includes autoregressive and moving average parameters as well as differencing in the formulation of the model.

The three types of parameters in the model are: The autoregressive parameters (p), the number of differencing passes (d) and moving average parameters (q). Box-Jenkins model are summarized as ARIMA (p, d, q). In addition to the non-seasonal ARIMA (p, d, q) model introduced above, we could identify seasonal ARIMA (P, D, Q) parameters for our data. These parameters are: Seasonal autoregressive (P), seasonal differencing (D) and seasonal moving average (Q). Seasonality is defined as a pattern that repeats itself over fixed interval of time. In general, seasonality can be found by identifying a large autocorrelation coefficient or large partial autocorrelation coefficient at a seasonal lag. The general form of the above model describing the current value Z_t of a time series by its own past is:

$$(1-\phi_1 B)(1-\alpha_1 B^{12})(1-B)(1-B^{12})\, Z_\tau = (1-\theta_1 B)\,(1-\gamma_1 B^{12})\, \varepsilon_\tau . \tag{2}$$

Where $1-\phi_1 B$ = non seasonal autoregressive of order *1*; $1-\alpha_1 B^{12}$ = seasonal autoregressive of order 1; Z_τ = the current value of the time series examined; B = the backward shift operator $BZ_\tau = Z_{\tau-1}$ and $B^{12}Z_\tau = Z_{\tau-12}$; $1-B$ = 1st order non-seasonal difference; $1-B^{12}$ = seasonal difference of order 1; $1-\theta_1 B$ = non seasonal moving average of order 1 and $1-\gamma_1 B^{12}$ is the seasonal moving average of order 1.

For the seasonal model, we used the Akaike information criterion (AIC) for model selection. The AIC is a combination of two conflicting factors; the mean square error and the number of estimated parameters of a model. Generally, the model with the smallest value of AIC is chosen as the best model (Hong 1997). After choosing the most appropriate model, the model parameters were estimated (Step 2) - the plot of the ACF and PACF of the stationary data was examined to identify what autoregressive or moving average terms are suggested. Here, values of the parameters are chosen using the least square method to make the sum of the squared residuals (SSR) between the real data and the estimated values as small as possible. In most cases, nonlinear estimation method is used to estimate the above identified parameters to maximize the likelihood (probability) of the observed series, given the parameter values (Naill & Momani 2009).

In diagnose checking step (Step 3), the residuals from the fitted model was examined against adequacy. This is usually done by correlation analysis through the residual ACF plots and the goodness-of-fit test by means of Chi-square statistics c^2. If the residuals are correlated, then the model should be refined as in Step 1 above. Otherwise, the autocorrelations are white noise and the model is adequate to represent our time series. The final stage for the modeling process (Step 4) was forecasting, which gives results as three different options: Forecasted values, upper and lower limits that provide a confidence interval of 95%. Any forecasted values within the confidence limit are satisfactory. Finally, the accuracy of the model was checked with the mean-square error (MS) to compare fits of different ARIMA models. A lower MS value corresponds to a better fitting model.

RESULTS AND DISCUSSION

OZONE EXCEEDANCES

Exceedances of hourly average concentration of 40 ppb (AOT40) occurred many times in each year for all the major rice growing areas. IADA Sabak Bernam recorded the highest number of hourly average concentration ozone exceedences for the 11 years period followed by Seberang Perak, MADA and KADA, respectively. Cumulative frequency distribution of number of hours greater than threshold for each area is listed in Figure 2. In IADA Sabak Bernam, year 2007 showed the lowest AOT40 of 6976 ppb and the highest was in year 2009 (21053 ppb). In Seberang Perak, the lowest AOT40 was recorded in year 2001 (3802 ppb) and the highest was in year 2009 (21074 ppb). In MADA, the lowest AOT40 was in year 2000 (7645 ppb) and the highest value was 20106 ppb in year 2005. AOT40 in KADA showed the lowest value among these four rice granary areas with the lowest was 52 ppb in year 2009 and the highest value of 1127 ppb in year 2004, respectively. Analysis of variance showed that there exists significant difference (p<0.05) on AOT40 among those 4 rice growing areas and it can be seen from the figure that the AOT40 at KADA area was lower than AOT40 at MADA, IADA Seberang Perak and IADA Sabak Bernam, respectively. Overall, AOT40 exceedance are much greater in rice growing areas located in the west coast i.e. MADA, Seberang Perak and Sabak Bernam comparative to KADA which is in the east coast of Peninsular Malaysia. These findings coincide with much higher number of motor vehicles and industries in the west coast in comparison to the east coast of Peninsular Malaysia. Motor vehicle exhaust, industrial emissions and chemical solvents are the major anthropogenic sources of nitrogen dioxide and volatile organic compounds. Ground level ozone is produced mainly by these two chemicals via photochemical reactions in sunlight produced (Seinfeld 1989). The scenario is detrimental for rice production in Malaysia as study done by Ishii et al. (2004) found that there was significant grain yield reduction of locally grown rice cultivar which are exposed to AOT40.

TIME-SERIES ANALYSIS

The appropriate ARIMA models were selected based on the smallest value of AIC for each rice growing area in the study is shown in Table 1. The model was utilized for forecasting the ozone concentration as shown in Figure 3. In addition, the models assumed that the best prediction for future data was given by model parametric which relates the most recent data to the previous data and previous noise (Marzuki 2011). In Table 2, it was shown that the parameters AR term, MA term, SAR term and SMA term are less than 0.05 which all of them are significantly different from 0. Meanwhile, the estimated standard deviation of the input white noise was equal to 2.49579 (Sabak Bernam); 2.65933 (Seberang Perak); 2.58493 (KADA) and 3.66434 (MADA). There is no test which statistically significant at 5% significant level, thus all the selected current models are sufficient to represent the data and could be used to predict the upcoming ozone concentrations. For the residual test, Ljung-Box test was used in order to test white noise for each model as shown in Table 3. In this test, it shows that p-value of each model for up to lag 12 and 24 are greater than 0.05. Thus, each model is good because a good model will be formed if there is no correlation or pattern shown

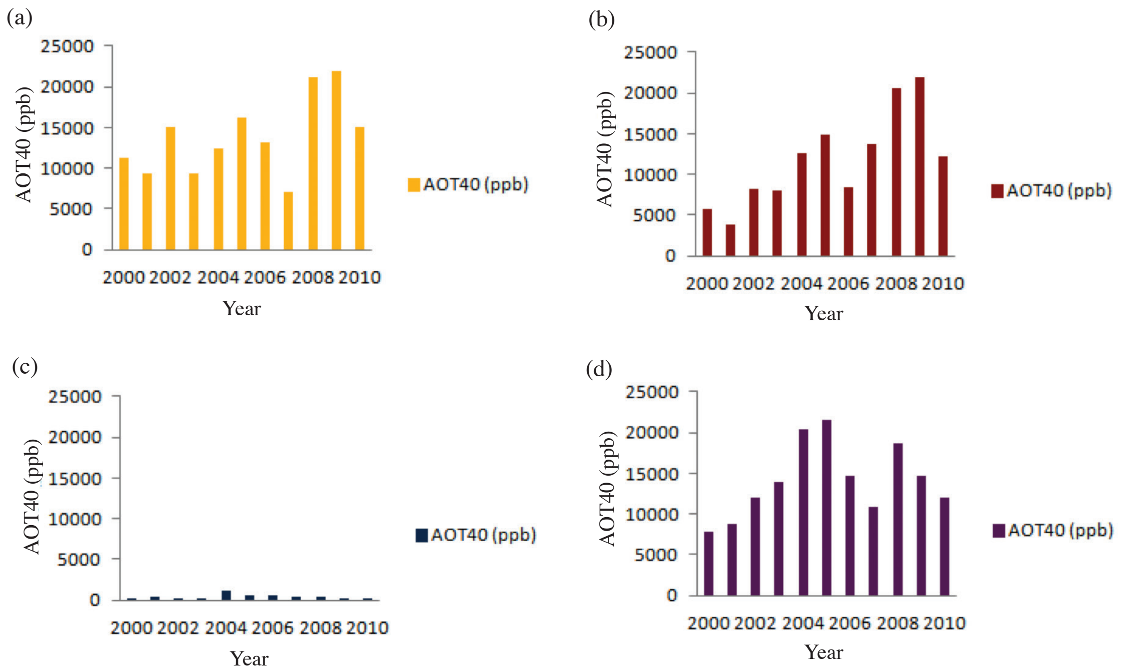

FIGURE 2. AOT40 at all of the selected rice growing areas (a) Sabak Bernam, (b) Seberang Perak, (c) KADA and (d) MADA

TABLE 1. Selected model with value of AIC for each area (a) Sabak Bernam, (b) Seberang Perak, (c) KADA and (d) MADA

Location	ARIMA model	Akaike information criterion (AIC)
KADA	$(2,0,0)\times(2,0,1)^{12}$ with constant	-11.8768
Seberang Perak	$(0,0,1)\times(2,1,2)^{12}$ with constant	-11.9312
MADA	$(1,0,1)\times(1,1,2)^{12}$	-11.2505
Sabak Bernam	$(2,0,2)\times(1,1,2)^{12}$ with constant	-11.7528

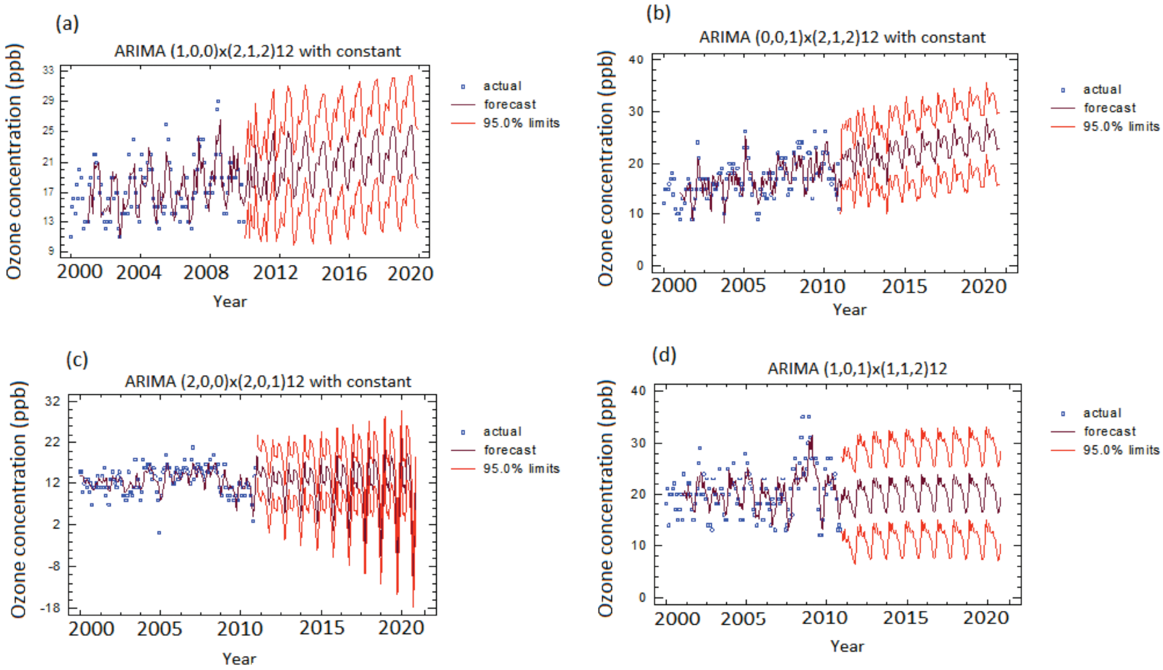

FIGURE 3. Predicted model of ozone concentration at 4 selected rice growing areas (a) Sabak Bernam, (b) Seberang Perak, (c) KADA dan (d) MADA

TABLE 2. ARIMA model summary for each area (a) Sabak Bernam, (b) Seberang Perak, (c) KADA and (d) MADA

(a) ARIMA model summary

Parameter	Estimate	Std. Error	t	*p*-value
AR(1)	0.404451	0.0900398	4.49191	0.000019
SAR(1)	0.553363	0.0955562	5.79098	0
SAR(2)	-0.528173	0.0745441	-7.08537	0
SMA(1)	1.63588	0.0478615	34.1795	0
SMA(2)	-0.71333	0.0421198	-16.9357	0
Mean	0.364977	0.0938552	3.88873	0.00018
Constant	0.211887			

Back forecasting: yes
Estimated white noise variance = 6.22895 with 102 degrees of freedom
Estimated white noise standard deviation = 2.49579
Number of iterations:17

(b) ARIMA model summary

Parameter	Estimate	Std. Error	t	*p*-value
MA(1)	-0.432163	0.0877123	-4.92705	0.000003
SAR(1)	-1.04846	0.0875716	-11.9726	0
SAR(2)	-0.507162	0.0835588	-6.06953	0
SMA(1)	-0.069233	0.041483	-1.66895	0.097872
SMA(2)	0.764393	0.0389459	19.6271	0
Mean	0.556147	0.0918574	6.05446	0
Constant	1.4213			

Back forecasting: yes
Estimated white noise variance = 7.07203 with 114 degrees of freedom
Estimated white noise standard deviation = 2.65933
Number of iterations:14

(c) ARIMA model summary

Parameter	Estimate	Std. Error	t	*p*-value
AR(1)	0.401103	0.0850751	4.7147	0.000006
AR(2)	0.29669	0.085032	3.48915	0.000668
SAR(1)	1.01159	0.0919694	10.9992	0
SAR(2)	0.151617	0.100699	1.50565	0.134661
SMA(1)	1.11055	0.0555708	19.9844	0
Mean	13.2252	1.32197	10.0041	0
Constant	-0.652281			

Back forecasting: yes
Estimated white noise variance = 6.68184 with 126 degrees of freedom
Estimated white noise standard deviation = 2.58493
Number of iterations:10

(d) ARIMA model summary

Parameter	Estimate	Std. Error	t	*p*-value
AR(1)	0.869005	0.0726305	11.9647	0
MA(1)	0.514531	0.127048	4.0499	0.000094
SAR(1)	0.731978	0.151344	4.83653	0.000004
SMA(1)	1.82157	0.0819338	22.2322	0
SMA(2)	-0.854814	0.0763693	-11.1932	0

Back forecasting: yes
Estimated white noise variance = 13.4274 with 114 degrees of freedom
Estimated white noise standard deviation = 3.66434
Number of iterations:12

by the residuals which is plain just plain white noise and the plots of residuals ACF and PACF are shown as in Figures 4 and 5 as to confirm the Ljung-Box test. In addition, Figure 6 also shows the normal probability plot which is the residuals of the models is normal.

Therefore based on the results obtained from the time series analysis, it shows that there were statistically significant (95% confidence level) upward trend in forecasted concentrations of the ground level ozone in those 4 areas till year 2020. The accuracy of each model

TABLE 3. Modified Box-Pierce (Ljung-Box) chi-square statistic for each area (a) Sabak Bernam, (b) Seberang Perak, (c) KADA and (d) MADA

(a) Modified Box-Pierce (Ljung -Box) Chi-Square statistic					(b) Modified Box-Pierce (Ljung-Box) Chi-Square statistic				
Lag	12	24	36	48	Lag	12	24	36	48
Chi-Square	8.1	14.9	23	37.7	Chi-Square	11.0	29.4	41.2	47.6
DF	6	18	30	42	DF	6	18	30	42
p-Value	0.231	0.671	0.817	0.659	*p*-Value	0.089	0.043	0.084	0.255
(c)Modified Box-Pierce (Ljung-Box) Chi-Square statistic					(d) Modified Box-Pierce (Ljung-Box) Chi-Square statistic				
Lag	12	24	36	48	Lag	12	24	36	48
Chi-Square	5.5	21.6	31.7	48.7	Chi-Square	9.7	16.5	28.4	33.9
DF	6	18	30	42	DF	6	18	30	42
p-Value	0.481	0.25	0.38	0.222	*p*-Value	0.139	0.56	0.548	0.808

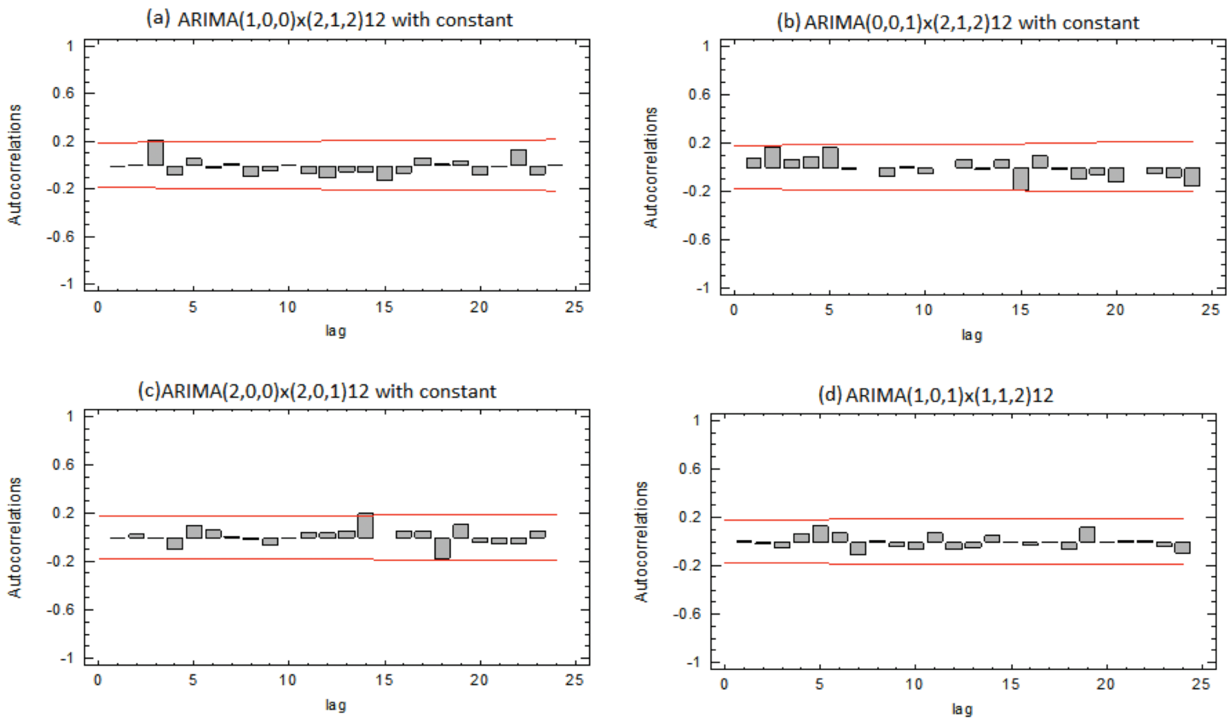

FIGURE 4. Residual autocorrelation functions (ACF) plots for each area (a) Sabak Bernam, (b) Seberang Perak, (c) KADA and (d) MADA

was checked with mean-square error (MSE) in order to compare fits of different ARIMA model. A lower MSE value corresponds to better-fitting model as shown in Table 4. Sungai Petani showes the highest range of ozone concentrations (25 to 28 ppb) followed by Seberang Perak (23 to 28 ppb), Sabak Bernam (12.5 to 18 ppb) and KADA area (13 to 15 ppb), respectively. This circumstances is due to increment in anthropogenic activities such as industrial activities, urbanization and traffic density which contributes to the formation of the secondary air pollutant i.e. ground level ozone (Marzuki 2011).

CONCLUSION

The study has found that forecasted concentration of ground level ozone up to year 2020 in all of the rice growing areas i.e. Muda Irrigation Development Area (MADA), Kemubu Agricultural Development Authority (KADA), IADA Seberang Perak and IADA Sabak Bernam shows a statistically-significant upward trend. Our analysis also showed that, as a whole, ozone concentrations in the west coast areas were greater than those in the east coast of Peninsular Malaysia. On top of that, the exposure-plant response index of 40 ppb was regularly surpassed each

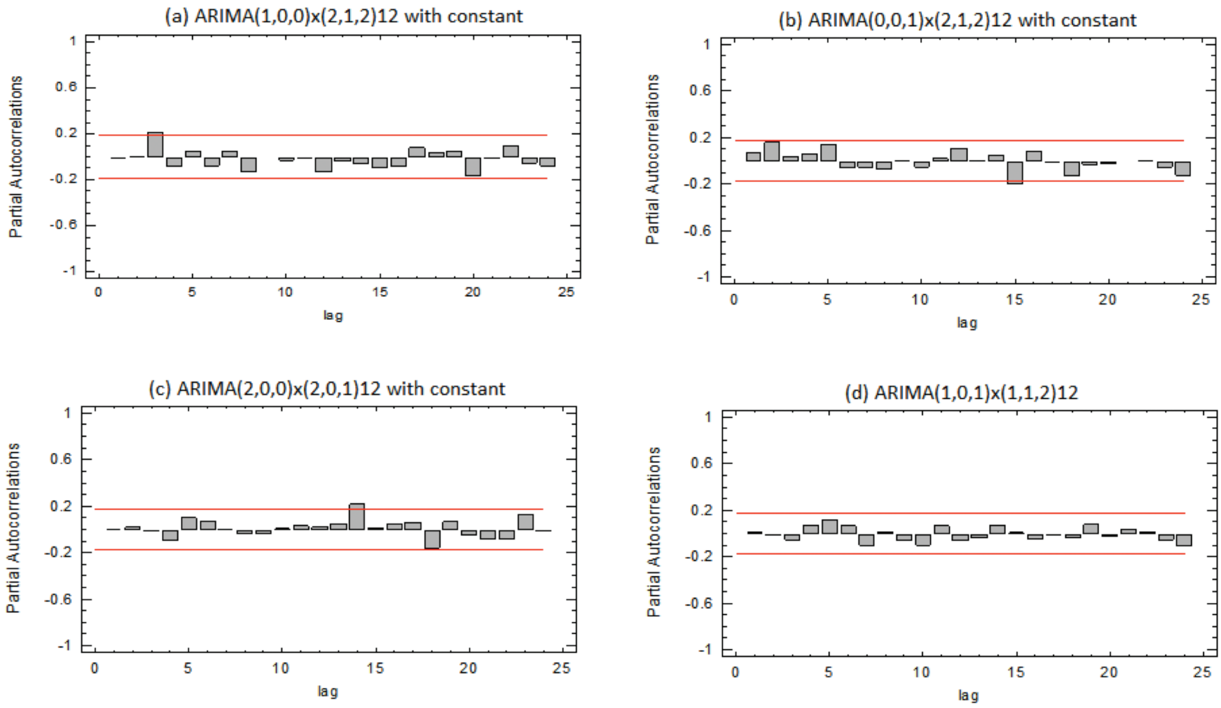

FIGURE 5. Residual partial autocorrelation functions (PACF) plots for each area (a) Sabak Bernam, (b) Seberang Perak, (c) KADA and (d) MADA

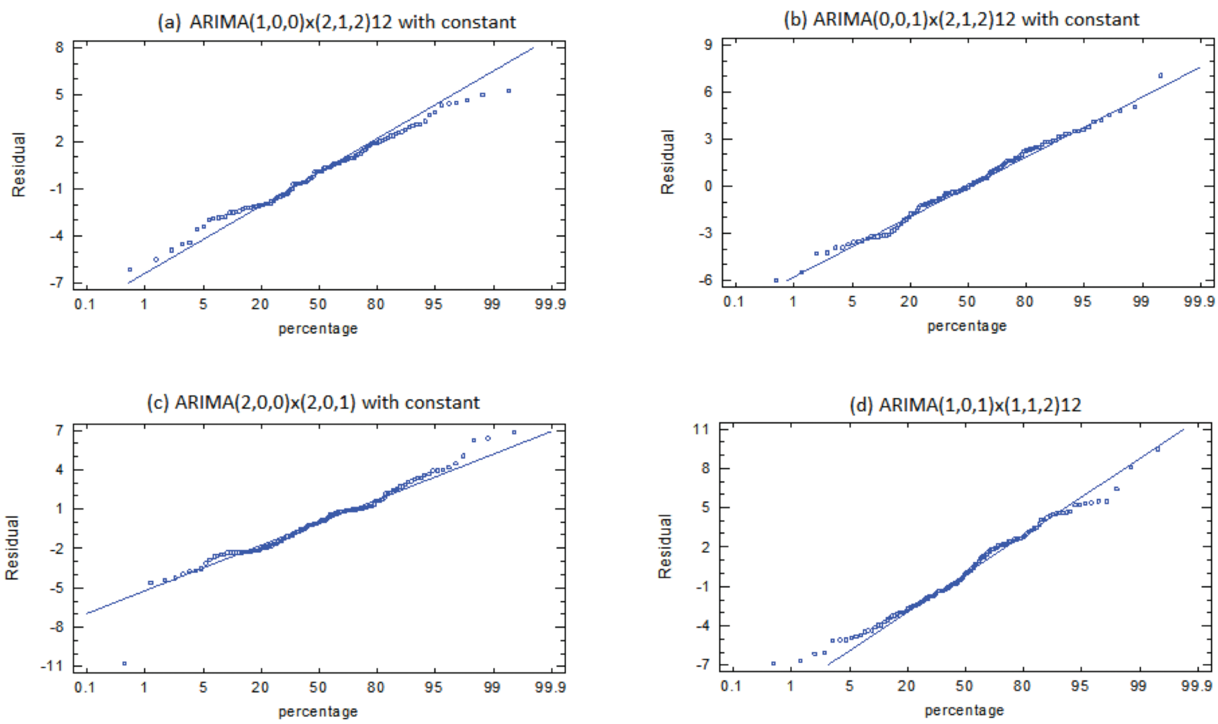

FIGURE 6. Residual normal probability plot for each area (a) Sabak Bernam, (b) Seberang Perak, (c) KADA and (d) MADA

TABLE 4. Forecast summary for each area (a) Sabak Bernam, (b) Seberang Perak, (c) KADA and (d) MADA

(a) Forecast summary

Seasonal differencing of order: 1
Forecast model selected: ARIMA (1,0,0)×(2,1,2)12 with constant
Number of forecasts generated: 120
Number of periods withheld for validation: 0

Statistic	Estimation Period	Validation Period
RMSE	2.43898	
MAE	1.93418	
MAPE	11.194	
ME	0.0105149	
MPE	-1.50682	

(b) Forecast summary

Seasonal differencing of order: 1
Forecast model selected: ARIMA (0,0,1)×(2,1,2)12 with constant
Number of forecasts generated: 120
Number of periods withheld for validation: 0

Statistic	Estimation Period	Validation Period
RMSE	2.52174	
MAE	1.98421	
MAPE	12.4077	
ME	0.0856409	
MPE	-1.45	

(c) Forecast summary

Forecast model selected: ARIMA (2,0,0)×(2,0,1)12 with constant
Number of forecasts generated: 120
Number of periods withheld for validation: 0

Statistic	Estimation Period	Validation Period
RMSE	2.54764	
MAE	1.9148	
MAPE		
ME	0.0362109	
MPE		

(d) Forecast summary

Seasonal differencing of order: 1
Forecast model selected: ARIMA (1,0,1)×(1,1,2)12
Number of forecasts generated: 120
Number of periods withheld for validation: 0

Statistic	Estimation Period	Validation Period
RMSE	3.47402	
MAE	2.86555	
MAPE	14.6895	
ME	0.129551	
MPE	-2.22233	

year in each of the rice growing areas and as ozone is harmful to rice plant; one direct effect of increasing ozone is expected to be a decline in domestic rice production. This is dreadfully alarming as those 4 areas contributed more than 50% of the national rice output (MOA 2008). Therefore steps in reducing emissions from industrial facilities and electric utilities, motor vehicle exhaust, gasoline vapors and chemical solvents chemicals must be taken immediately in order to overcome this problem which is a threat to our national food security. Furthermore, new cultivar of rice with high tolerance to surface ozone must be produced in order to ensure less dependence on imported rice from foreign countries.

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