Application of three prediction models in pesticide poisoning

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Abstract

To establish a reasonable prediction model of pesticide poisoning and predict the future trend of pesticide poisoning in Jiangsu Province, so as to provide the basis for rational allocation of public health resources and formulation of prevention and control strategies, the number of pesticide poisoning in Jiangsu province from 2006 to 2020 was collected. Grey model (GM(1,1)) model, autoregressive integrated moving average model (ARIMA) model and exponential smoothing model were used for prediction and comparative analysis. Finally, the model with the best fitting effect was selected. The average relative errors of ARIMA(0,1,1)(0,1,0)₁₂ model, Holt-Winters multiplicative model and GM(1,1) were 0.096, 0.058 and 0.274 separately. The fitting effect of GM model is the worst, while the fitting effect of ARIMA(0,1,1) (0,1,0)₁₂ model and Holt-Winters multiplication model is relatively good, which can be basically used for prediction. Holt-Winters multiplicative model has the best fitting effect and the highest accuracy in predicting the number of pesticide poisoning. The numbers of pesticide poisonings in the next 3 years are 454, 410 and 368, with a total of 1232, according to the Holt-Winters multiplicative model. Through the prediction of the number of pesticide poisoning in the next 3 years, this paper also provides a basis for the formulation of pesticide-related policies in the future.

Keywords Prediction models · Pesticides · Pesticide poisoning

Introduction

Pesticide poisoning refers to the use of pesticides in which the amount of agriculture entering the body exceeds the acceptable range, resulting in physiological disorders and toxic reactions (Krakowiak et al. 2019). Pesticide poisoning can be divided into two categories, namely productive poisoning caused by pesticide application on crops and non-productive poisoning caused by accidental poisonings and

suicide attempts (Yuan and Yang 2017). According to WHO statistics, there are as many as 3 million cases of pesticide poisoning in the world each year, and the number of suicides using pesticides is about 360,000, accounting for 30% of the total number of suicides in the world (Moebus and Bodeker 2015). This indicates that pesticide poisoning has become one of the global public health problems.

Agriculture is one of the largest economic sectors in China. Pesticides are also widely used in China, which makes pesticide poisoning one of the main causes of occupational, intentional and accidental poisoning. Suicide by pesticide use is common in rural China. Of the 160,000 suicides each year, most of the deaths are caused by deliberate self-poisoning (Wang et al. 2019). As a traditional land of fish and rice, Jiangsu province straddles two great plains and is one of the main vegetable and rice producing areas in China. This also leads to a large number and various types of pesticides used in this province and a high number of pesticide poisoning, which has long been one of the important reasons for harming the health of local residents (Yu et al. 2015).

At present time, time series models are widely used in the occurrence of various diseases, including novel Coronavirus,

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hand, foot, and mouth disease, tuberculosis and influenza outbreak (Bao et al. 2020; Liu et al. 2016; Yan et al. 2019; Zhang and Nawata 2017). Firstly, the data of pesticide poisonings reported from 2006 to 2020 was fitted by grey model (GM(1,1)) model, autoregressive integrated moving average model (ARIMA(0,1,1)(0,1,0)₁₂) model and Holt-Winters multiplicative model. Then, the model with the best prediction effect was selected to predict the number of cases in the next 3 years.

Data and methods

Data sources

All data are from the health hazard factor monitoring information system of the ‘China disease prevention and control information system’. The entire information system database includes data from all levels and types of health facilities, such as hospitals, clinics and centers for disease control and prevention. All pesticide poisoning cases in this paper were diagnosed by local experts according to relevant standards (Zhang et al. 2013a, b). The use of the database has also been approved by the Jiangsu Provincial Center for Disease Control and Prevention.

Research method and modeling process

In this study, grey model (GM(1,1)), autoregressive integrated moving average model (ARIMA) and exponential smoothing prediction model were established. R^2 , BIC, mean relative error and other indicators were used to determine the optimal model according to the fitting effect of the model, and then the number of cases in the following years was predicted.

GM (1,1) model

The grey dynamic model is a time series model abstractly derived from a system containing both known information and unknown or unascertained information. It can make objective prediction and description of the development trend of things only by using less and incomplete information (Wan-Mei 2009). Its principle is to first establish a dynamic model for a set of given time series, then accumulate the original time series to generate a new cumulative series, and then build a new model on this basis. Finally, the results are reduced to generate a new predicted value (Yang and Yang 2010; Zhang et al. 2013a, b). In this study, the number of pesticide poisoning during 2006–2020 was used as the model fitting data set to establish the model.

ARIMA model

ARIMA model is one of the prediction and analysis methods of time series (Luo et al. 2012). In this model, the data formed by the change of the research object over time are regarded as a random sequence, and individual outliers generated by confounding factors are excluded. The whole set of data is a random variable that has a dependency relationship with the time factor, and the dependency relationship indicates the future development trend of the research object. After this correlation is described by the ARIMA model, the future value of time series can be predicted according to this model (Chen and Xu 2012).

Model identification SPSS software was used to define the time sequence of the number of pesticide poisonings from 2006 to 2020, and the time series diagram, autocorrelation function (ACF) diagram and partial autocorrelation function (PACF) diagram were drawn to analyze the stability of the series. The appropriate model was selected according to the existence of seasonal and periodic changes. Finally, in accordance with the residual ACF diagram and the residual PACF diagram, the value range of p,d,q and P,D,Q was preliminarily determined, and different models were fitted at last.

Model diagnosis The ACF and PACF of the residual series were not statistically significant and were within 95% confidence interval. The Box-Ljung Q statistics of the residual are meaningless ($P = 0.075$), indicating that the residual is random and white noise. Otherwise, it implies that the information in the residual sequence has not been extracted completely and needs to be improved. In addition, there are also indicators such as R^2 , RMSE, MAE, mean percentage error (MPE), mean absolute percentage error (MAPE) and BIC that can be used to determine the fit of the model (Liang et al. 2008).

Incidence prediction The numbers of pesticide poisoning cases from 2006 to 2020 were used to establish a model to predict the number of cases from 2008 to 2020, then the average relative error can be calculated.

Exponential smoothing model

Exponential smoothing model is a time series prediction model based on the weighted moving average method, which gives different weights to different observed values and predicts the future trend combined with the model (Jing et al. 2019). This model takes into account that events in different periods do not have exactly the same impact on the present, so the smoothing constant decreases gradually with the increase of time interval. The

forecasting steps of exponential smoothing are as follows: (1) draw sequence diagram, (2) establish model, (3) model diagnosis and (4) predict the number of pesticide poisoning. In order to select the optimal model, we can evaluate the prediction effect of the model by comparing RMSE, MAPE, MAE and other indicators.

Statistical method

Excel 2019 software is used to collect and sort out pesticide poisoning data from 2006 to 2020. The ARIMA seasonal model and exponential smoothing model are established by SPSS 22.0. The GM (1,1) model is established by python. Test level $\alpha=0.05$, $P < 0.05$ means statistical significance.

Fig. 1 Numbers of pesticide poisoning in Jiangsu Province from 2006 to 2020

Fig. 2 Time series of the number of pesticide poisoning in Jiangsu Province from 2006 to 2020

Results

Data characteristics

The number of pesticide poisoning reported in Jiangsu Province from 2006 to 2020 was 40690, among which the highest annual number of cases is 6448 and the lowest is 574. Since the peak in 2007, the number of cases has been decreasing year by year, as shown in Fig. 1.

ARIMA model

Data preprocessing

The time sequence chart of the number of pesticide poisoning cases from January 2006 to December 2020 was drawn. In Fig. 2, the number of pesticide poisoning showed a long-term trend of decline, and the variance was not large. It can be seen from the original sequence that the data has obvious seasonality and periodicity, so the first-order 12-step seasonal difference is carried out on it, as shown in Fig. 3. Then, through the autocorrelation analysis, the data showed a stable trend, in line with the requirements of ARIMA model.

Model establishment

The processed time series has periodicity and seasonality, indicating that the model $ARIMA(p,d,q) \times (P,D,Q)_s$ is applicable. The periodicity and seasonality of the sequence are significantly eliminated after the first-order and 12-step difference processing, so $d=1$, $D=1$, $s=12$ are obtained.

According to Figs. 4 and 5 obtained from the processed data, the values of p , q , P and Q can be preliminarily

Fig. 3 Differential diagram of the number of pesticide poisoning in Jiangsu Province from 2006 to 2020

Fig. 4 Autocorrelation function (ACF) diagram

Fig. 5 Partial autocorrelation function (PACF) diagram

determined to be within 2. Then, all possible suitable models were fitted, and several combinations conforming to the modeling were screened out. Relevant indicators were used

for comparison, and the results were shown in Table 1. In the end, we chose $ARIMA(0,1,1)(0,1,0)_{12}$ with the best fitting effect.

Model evaluation

The BIC value of this model is 9.466, fitting $R^2=0.381$ and Ljung-Box Q has no statistical significance ($P=0.0195$), indicating that the residual order is classified as white noise. We can also see from Fig. 6 that the residual sequence values basically fall within the confidence interval. The model was used to fit the number of cases from 2006 to 2020, and the trend of the predicted value is basically in line with the actual value, as shown in Fig. 7. The number of pesticide poisonings from 2008 to 2020 was estimated based on the $ARIMA(0,1,1)(0,1,0)_{12}$ prediction model, as shown in Table 5.

Exponential smoothing model

Three exponential smoothing models were used to analyze the time series through SPSS software, and the fitting degree of each model was shown in Table 2. The BIC, RMSE and MAPE of the Holt-Winters multiplicative model were the smallest, and the stable R^2 was the largest. Therefore, the Holt-Winters multiplicative model was considered to be the optimal model. In addition, the Ljung-Box Q of this model is 24.670, $P=0.055$ and the residual is white noise. Table 3 is the analysis and comparison of the statistics of each model. It is found that the initial parameter α (level) of the three models and the δ (season) of the Holt-Winters multiplicative model have statistical significance. The γ (trend) of holt-Winters multiplicative model and Holt-Winters addition model has no statistical significance. The δ (season) values of the simple seasonal model and the Holt-Winters addition model were not statistically significant. The model was used to fit the number of cases from 2006 to 2020, as shown in Fig. 8.

GM(1,1) model

The GM(1,1) model was established with the number of pesticide poisoning from 2006 to 2020 as the time series. The development coefficient $a=0.0456$ and gray action $b=12612.8669$ were obtained. The fitting degree test of the model shows that $C=0.0707$ and $P=1$, so the accuracy of the model is excellent and can be used for extrapolation prediction, as shown in Table 4.

Effect evaluation of the model

We choose the average relative error as an indicator of the model's predictive effect, because it is not affected by the time unit and plays a very important role in the comparison

Table 1 Comparison of various ARIMA(p,d,q)×(P,D,Q)_S models

Model parameter	BIC	MAPE	R^2	Ljung-Box Q	P value
ARIMA(1,1,1)×(0,1,1) ₁₂	9.528	22.822	0.387	24.911	0.051
ARIMA(0,1,1)×(0,1,1) ₁₂	9.486	27.664	0.391	24.720	0.075
ARIMA(1,1,1)×(1,1,0) ₁₂	9.533	22.928	0.384	25.114	0.048
ARIMA(0,1,1)×(0,1,0) ₁₂	9.466	27.888	0.381	21.750	0.195

Fig. 6 Residual ACF and residual PACF diagram **Fig. 7** Fitting diagram of ARIMA(0,1,1)(0,1,0)₁₂ model from 2006 to 2020 **Table 2** Analysis of fitting results of each seasonal exponential smoothing model

Model type	Smooth R^2	RMSE	MAPE	MAE	BIC	Ljung-Box Q	P value
Simple seasonal model	0.539	97.465	15.891	38.095	9.217	28.754	0.026
Holt-Winters additive model	0.557	97.730	15.324	37.999	9.251	29.723	0.013
Holt-Winters multiplicative model	0.586	90.656	14.123	35.365	9.101	24.670	0.055

Table 3 Statistical analysis of each seasonal exponential smoothing model

Model type	Data conversion	Parameter	Predicted value	SE	T value	P value
Simple seasonal model	Natural logarithm	α	0.600	0.068	8.810	0.000
		δ	4.067E–5	0.049	0.001	0.999
Holt-Winters additive model	Natural logarithm	α	0.602	0.069	8.688	0.000
		γ	3.354E–6	0.011	0.000	1.000
		δ	0.000	0.063	0.003	0.997
Holt-Winters multiplicative model	Natural logarithm	α	0.432	0.057	7.634	0.000
		γ	0.000	0.009	0.027	0.979
		δ	0.167	0.054	3.090	0.002

Fig. 8 Fitting diagram of Holt-Winters multiplicative model from 2006 to 2020 **Table 4** Judgment of predicting model's goodness of fit with GM(1,1)

The grade of the model's goodness of fit	P value	C value
Good	>0.95	<0.35
Eligibility	>0.80	<0.50
Reluctance	>0.70	<0.65
Disqualification	≤0.70	≥0.65

of prediction results of different time series. According to Table 5, the average relative error of Holt-Winters multiplicative exponential smoothing model is the smallest (0.058), followed by ARIMA(0,1,1)(0,1,0)₁₂ model (0.096), and GM(1,1) model has the worst fitting effect (0.274). By comparing the fitting effects of these three models, we determine that the optimal model is Holt-Winters multiplicative exponential smoothing model.

Optimal model prediction

After comparison in Table 5, the Holt-Winters multiplicative exponential smoothing model was used to model the

time series to predict the number of pesticide poisoning in Jiangsu Province from 2021 to 2023. The results are shown in Fig. 9 and Table 6. From 2021 to 2023, the number of cases in the future will be 454, 410 and 368 respectively, and the overall trend is still declining. It is expected that the total number of cases in the next 3 years will reach 1232.

Discussion

As a major agricultural province, Jiangsu province has a large production and consumption of pesticides, which is easy to cause pesticide poisoning due to improper use (Chen et al. 2008). Studies have shown that pesticide poisoning occurs frequently in people's production and life, continuously harming people's health, and has become an occupational health issue worthy of attention (Zhang et al. 2011). Although the number of pesticide poisoning has decreased year by year, the increase of pesticide types and the decline of the resistance level of the population have brought new challenges to the prevention (Wang 2005). The number of pesticide cases in Jiangsu Province has shown an obvious downward trend since 2006, and the seasonal trend is significant, reaching the peak in July and August every year.

Table 5 The number of pesticide poisonings predicted by the three models from 2008 to 2020

Date	Actual value	ARIMA(0,1,1)(0,1,0) ₁₂		Holt-Winters multiplication model		GM(1,1)	
		Predicted value	Relative error	Predicted value	Relative error	Predicted value	Relative error
2008	4941	6028	0.220	5157	0.044	4825.603	0.023
2009	3917	3819	0.025	4395	0.122	4323.504	0.104
2010	3755	3138	0.142	3675	0.004	3843.767	0.050
2011	3148	3357	0.066	3318	0.054	3385.397	0.075
2012	2556	2483	0.029	2646	0.035	2947.441	0.153
2013	2083	1994	0.043	2137	0.026	2528.991	0.214
2014	1373	1444	0.052	1583	0.153	2129.177	0.551
2015	1306	879	0.327	1271	0.027	1747.171	0.338
2016	1345	1267	0.058	1375	0.022	1382.178	0.028
2017	1360	1324	0.026	1452	0.068	1033.440	0.240
2018	1035	1080	0.043	1045	0.010	700.235	0.323
2019	961	862	0.103	1023	0.065	381.870	0.603
2020	574	643	0.120	644	0.122	77.684	0.865
Average			0.096		0.058		0.274

Fig. 9 Number of pesticide poisonings in Jiangsu Province (2011–2023)

Jiangsu province belongs to the subtropical monsoon climate, which is hot and rainy in summer. The hot and humid environment leads to the breeding of various pests, so in order to improve the survival rate of crops the use of various pesticides increases. In addition, long-standing planting habits in the province require top dressing of many crops in the summer. So people are more likely to be exposed to pesticides in summer than in other seasons, which directly or indirectly increases the likelihood of local pesticide poisoning.

At present, prediction models for various chronic diseases and epidemics include BP artificial neural network model, grey prediction GM(1,1) model, generalized regression neural network (GRNN) model and ARIMA model, etc. (Ding et al. 2002; Ren et al. 2013; Yi et al. 2012; Zhu et al. 2013). Both the ARIMA model and the exponential

smoothing model selected in this paper belong to the time series model, and both predict the future incidence trend by revealing the law of the existing data changing with time (Jing and Yang 2017). The advantage of ARIMA model is that it can reflect the influence of many external factors in variables. The parameters of the model can be adjusted to reflect the periodicity, seasonal trend and random fluctuation of the time series. However, ARIMA model has high requirements on time series, and the modeling process is complex, so it is difficult to determine the value of parameters quickly and accurately. In this paper, the average relative error of ARIMA model is 0.096, which basically meets the prediction requirements. Compared with ARIMA model, exponential smoothing model attaches more importance to the influence of recent data and gives higher weight, so it is suitable for analyzing data with little influence of time factor

Table 6 Number of pesticide poisoning cases in Jiangsu Province from 2021 to 2023

Date	Number of pesticide poisoning	Date	Number of pesticide poisoning	Date	Number of pesticide poisoning
2021.01	26	2022.01	23	2023.01	21
2021.02	29	2022.02	26	2023.02	24
2021.03	31	2022.03	28	2023.03	25
2021.04	35	2022.04	32	2023.04	29
2021.05	41	2022.05	37	2023.05	33
2021.06	44	2022.06	40	2023.06	35
2021.07	52	2022.07	47	2023.07	42
2021.08	68	2022.08	61	2023.08	54
2021.09	43	2022.09	39	2023.09	35
2021.10	34	2022.10	31	2023.10	28
2021.11	28	2022.11	25	2023.11	23
2021.12	23	2022.12	21	2023.12	19
Total	454	Total	410	Total	368

(Liu et al. 2020). To improve the data stability, logarithmic transformation was firstly carried out, and Holt-Winters exponential smoothing model was introduced. Finally, the average relative error was 0.058, which shows that the model has good fitting effect. GM(1,1) grey model is a dynamic prediction model with a wide range of applications. It can achieve the purpose of modeling and predicting the incidence trend by processing the data under the background of less sample size and information. In this study, the average relative error of GM(1,1) model is 0.274. The prediction effect is not ideal, and the accuracy is poor.

Among the three models selected in this paper, the fitting effect of GM (1,1) model is the worst, and its relative average error is much higher than the other two models, which is mainly related to the sharp decrease of the number of cases after 2013. The relative error of GM(1,1) model from 2008 to 2013 is still at a low level, but the prediction ability of the whole GM(1,1) model decreases with the large deviation of prediction value after 2013. The results indicate that the GM(1,1) model, although requiring a smaller sample size, is only applicable to monotonically varying time series without significant stochastic fluctuations, which is consistent with the results of previous studies (Lan 2008). The fitting results of ARIMA (0,1,1) (0,1,0)₁₂ model and Holt-Winters exponential smoothing model are great, and the predicted values were not much different from the actual values. Therefore, It is considered that the two models can basically be used to predict the trend of pesticide poisoning in the future. However, the average relative error of ARIMA(0,1,1)(0,1,0)₁₂ model is slightly higher than that of Holt-Winters exponential smoothing model when comparing the fitting effect between the two models. Our analysis is that

the fitting effect of ARIMA model is affected by the stationarity of data. When analyzing time series with obvious trend and seasonality, Holt-Winters exponential smoothing model has higher prediction accuracy, and previous study has also reached the same conclusion (Bian et al. 2021).

Finally, the Holt-Winters exponential smoothing model with the best fitting effect was used to predict the number of pesticide poisoning in Jiangsu province in the next 3 years. On the whole, there will still be a decreasing trend year by year in the future, and the number of pesticide poisoning is 454, 410 and 368 respectively, reaching 1232 in total. Although there has been a significant decrease compared to before, but the number of cases of pesticides in Jiangsu province is still at a high level. This reminds us that we should still pay attention to the local residents' exposure and use of pesticides and do well in prevention and treatment.

As shown in Fig. 10, the Ministry of Health issued the *Pesticide Poisoning and Health Management Measures (Trial)* in 1988, but pesticide poisoning incidents are still common. In 2006, to effectively detect pesticide poisoning cases, the Chinese Center for Disease Control and Prevention (CDC) adopted the Occupational Disease Surveillance and Reporting System (ODSRS). With the *Ministry of Agriculture of the People's Republic of China No. 322 announcement*, since January 1, 2007, the use of methamidophos and other five highly toxic organophosphorus pesticides in agriculture has been completely prohibited. This paper found that the number of pesticide poisoning has been decreasing since 2007, and the two are directly related. Compared with last year, the number of cases fell precipitantly in 2008, indicating that the policy has achieved great results. The number of cases in September 2013 was in a trough, which may be related to the issuance of the

Fig. 10 Change trend of pesticide poisoning and agricultural related policy factors in Jiangsu Province from 2006 to 2020. 1: Occupational Disease Surveillance and Reporting System (ODSRS), 2: Ministry of Agriculture of the People's Republic of China No. 322 announcement, 3: the Implementation Measures of Jiangsu Province for Technical Identification of Crop Production Accident, 4: Articles of Association of National Pesticide Registration and Review Committee

Implementation Measures of Jiangsu Province for Technical Identification of Crop Production Accidents in the same year. Since then, *the implementation measures of the Regulations on Pesticide Management* have been updated every year, and the number of pesticide poisoning has decreased year by year.

The advantage of this study lies in the wide range of the study population, including the pesticide poisoning situation of the whole Jiangsu province in the past 15 years. The sample size is large and representative. Moreover, the age of the population in this study is not limited, which is more convincing compared with many studies that only focus on the elderly population. The disadvantage of this study is that some pesticide poisoning cases may be omitted.

To reduce the number of pesticide poisoning, we should strengthen technical training and mental health education for practitioners. Rural areas are high infection regions of suicide by taking pesticides, which is the focus of prevention. The formulation of relevant pesticide policies is of great significance to the prevention and control of pesticide poisoning. Therefore, it is necessary to pay close attention to the development of policies in real time.

Although the number of pesticide poisoning has decreased year by year, pesticide poisoning cannot be ignored. We still need to take more measures to protect people from pesticide poisoning. At the same time, through the prediction of the number of pesticide poisoning in the next 3 years, this paper also provides a basis for the formulation of pesticide-related policies in the future.

Conclusion

Therefore, based on the number of pesticide poisoning from 2006 to 2020, this paper uses the Holt winters exponential smoothing model to predict that the number of patients in the next 3 years will be 454, 410 and 368 respectively. The results show that pesticide poisoning is still an important health problem in China. The government should strengthen pesticide supervision and publicity of relevant knowledge.

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Data availability No data are available. Internal data used in this protocol are highly sensitive and confidential and only accessible to approved personnel. Linked data are kept securely by Jiangsu CDC. Researchers interested in collaborations or further information are invited to contact the corresponding author.

Declarations

Ethics approval and consent to participate In abiding with the ethical requirements, the study conformed to the Declaration of Helsinki and was nominated to be exempted from institutional ethical review by the Research Ethics Board of Jiangsu Provincial CDC. Official permission was taken from each respondent for this study, and informed consent was obtained from all participants.

Consent for publication Consent given by all contributing authors.

Competing interests The authors declare no competing interests.

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