



Mortality Analysis and Model Prediction of Children Under 5 years Old in a City of Northwest China

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Keywords: Children under 5 years old; Mortality; Cause of death; Simple seasonal model; Prediction.

Abstract

Background: The mortality rate of children under 5 years old is an important index to measure the quality of maternal and child health work of a region. We aimed to analyze the death status of children under 5 years old in a city of northwest China (Lanzhou) from 2012 to 2018 and establish a time series model to predict the death of children under 5 years old in 2019.

Methods: Collecting death detection data of children under 5 years old in Lanzhou from 2012 to 2018, descriptive epidemiological method was used to analyze the mortality of children under 5 years old.

Results: The total number of deaths of children under 5 years old was 1213 from 2012 to 2018, of which 770 were neonatal deaths, 1026 were infant deaths and 187 were children aged 1 to 4. The average annual mortality rate was 5.89‰, the mortality rate of neonates, infants and children aged 1 to 4 were 3.74‰, 4.98‰ and 0.91‰ respectively. The mortality rate of neonates, infants and children under 5 years old all showed a downward trend, and APC was -10.0%, -9.4% and -8.1% respectively ($P < 0.001$). Congenital heart disease, premature/low birth weight and birth asphyxia were the main causes of death in children under 5 years old, and their mortality rate showed a downward trend, with APC of -13.8%, -13.7% and -13.5% respectively ($P < 0.05$). It is predicted that the total number of deaths of children under 5 years old will be 142 in 2019.

Conclusion: Reducing infant mortality, especially neonatal mortality, is the key to reducing the mortality of children under 5 years old. Simple seasonal model can better reflect the mortality trend of children under 5 years old in the area and make short-term prediction.



Introduction

The mortality rate of children under 5 years old is an important index to measure the economic, cultural, health status and the quality and service level of maternal and child health work of a country or region [10]. In recent years, with the increasing awareness of the death hazards of children under 5 years and the continuous development of global health care, the mortality rate of children under 5 years has been significantly reduced. Nevertheless, it was reported that about 5.6 million children who are under five years still die every year worldwide. These deaths are largely concentrated in developing regions which have the highest rates (45 deaths per 1000 live births respectively) compared to developed regions (6 deaths per 1000 live births respectively) [6]. As the largest developing country and with the largest number of children groups, with the implementation of laws and policies such as *the Law of the People's Republic of China on Maternal and Child Health Care and the Outline for the Development of Children in China (2001-2010)*, great progress has been made in child health care, but the level of child mortality is comparable to that in developed countries. According to WHO data, the mortality rate of children under 5 years old in China was 9.3‰ in 2017, which was significantly higher than that in the United States (6.6‰), Japan (2.6‰) and Australia (3.5‰) [1]. At the same time, due to the imbalance of China's economic development, especially in the eastern and western regions, this gap is more pronounced. In 2017, the mortality rate of children under 5 years old was 4.3‰ in eastern China, 14.8‰ in western China, and that of western China was 3.4 times than that of eastern China [2]. Lanzhou as a central city in the western China is particularly important to understand the deaths of children under 5 years of age.

Therefore, in order to understand the current situation and trend of death of children under 5 years old in northwest China, the study comprehensively analyzed the death data of children under 5 years old, using the exponential smoothing model and ARIMA model to fit the incidence trend of the death of children under 5 years old in Lanzhou from 2012 to 2017, screening the best model to predict the number of children under 5 years of age in 2019, providing a theoretical basis for the development of prevention and control measures for children under 5 years old in northwest China.

Materials and Methods

Study areas

The present study was carried out in Lanzhou city of Gansu Province, China. Lanzhou is an important industrial base and comprehensive transportation hub in northwest China and an important central city in northwest China.

Data sources

The Children's Death Report Cards from January 2012 to December 2018, which was reported by the three-level administration network of Lanzhou. It is included in the floating population of Lanzhou local households and non-local households but living for more than one year.

Research methods

Descriptive epidemiological method was used to analyze the mortality of children under 5 years old in Lanzhou from 2012 to 2018. The Joinpoint software was used to analyze the mortality trends. The exponential smoothing model and ARIMA model were established by SPSS 21.0 software, screening the

best model to predict the number of deaths of children under 5 years old in Lanzhou in 2019.

Exponential smoothing model: The exponential smoothing model refers to predicting future values with a weighted average of previous values of the time series, and assigning a larger weight to recent data in the time series, giving the future data a smaller weight [24,30]. According to whether the sequence is seasonal, the model can be divided into non-seasonal models (Simple model, Holt linear trend model, Brown linear trend model and Damping trend model) and seasonal models (Simple seasonal model, Winters addition model and Winters multiplication model). The key of using exponential smoothing model to predict is to determine the smoothing coefficient. When the original sequence presents a relatively stable horizontal trend, the value is generally between 0.1 to 0.3, and the new sequence contains more information about the original sequence, which is conducive to improving the credibility of the prediction results. When the original sequence fluctuates greatly, the value is generally between 0.3 to 0.5. When the sequence fluctuation is large and the trend is obvious, the value is usually between 0.6 to 0.8 [11]. Various exponential smoothing models have different scopes of application [24,31].

ARIMA model: The basic idea of the ARIMA model is to treat the sequence formed by the predicted object over time as a random sequence, that is, to remove the observed value changes caused by individual accidental causes, the time series is a set of random variables that depend on time t [26]. For time series data with seasonal, periodic and long-term trends, it is more suitable to describe and analyze the ARIMA product seasonal model, namely SARIMA(p, d, q) \times (P, D, Q) s [13].

Model evaluation indices Box-Ljung Q statistic is often used to evaluate whether residual sequence is white noise sequence. When $P > 0.05$, the residual sequence is white noise sequence. It can be concluded that the model achieves better fitting effect [12]. In the process of parameter selection, the optimal model is established according to the principle of maximum stationary R^2 , minimum RMSE, MAPE and normalized BIC [20].

Statistical Analysis

The data was processed and analyzed by Excel 2007, Graph-Pad Prism 7.0, Joinpoint 4.7.0.0 and SPSS 21.0 software. $P < 0.05$ was considered statistically significant.

Results

Mortality of children under 5 years old in Lanzhou from 2012 to 2018

The total number of live births in Lanzhou from 2012 to 2018 was 206063, and the number of deaths of children under 5 years old was 1213, of which 770 were neonatal deaths, 1026 were infant deaths and 187 were children aged 1 to 4 deaths, the number of deaths reported by boys and girls was 652 and 559 respectively. The average annual mortality rate was 5.89‰, the mortality rate of neonates, infants and children aged 1 to 4 were 3.74‰, 4.98‰ and 0.91‰ respectively. Infant mortality accounted for 84.58% of all deaths, and neonatal mortality accounted for 75.05% of infant mortality.

Mortality rate of children under 5 years old and its changing trend in Lanzhou from 2012 to 2018

The mortality rate of neonates, infants and children under 5 years old all showed a downward trend from 2012 to 2018, APC

was -10.0%, -9.4% and -8.1% respectively ($P < 0.001$), while the mortality rate of children aged 1 to 4 showed fluctuating changes, and APC was -1.7% ($P > 0.05$). The mortality rate of children under 5 years old increased slightly in 2017 (Table 1).

Major causes of death in children under 5 years of age

Congenital heart disease, premature/low birth weight and birth asphyxia were the main causes of death among children under 5 years old from 2012 to 2018, accounting for 44.76% of all deaths. The top five causes of neonatal death were premature/low birth weight, birth asphyxia, congenital heart disease, other respiratory diseases and other congenital anomalies. The top five causes of infants death were premature/low birth weight, birth asphyxia, congenital heart disease, pneumonia and other congenital anomalies. Congenital heart disease, traffic accident, accidental fall, pneumonia and other tumors were the top five causes of children aged 1 to 4 (Table 2).

In order to more clearly reflect the changes in the cause of death of children under 5 years old during the past 7 years, the study analyzed the top five causes of death. The mortality rate of congenital heart disease, premature/low birth weight, birth asphyxia and pneumonia all showed a downward trend, especially premature/low birth weight, birth asphyxia and pneumonia, with APC of -13.8%, -13.7% and -13.5% respectively ($P < 0.05$). The mortality rate of other congenital abnormalities showed fluctuating changes ($P > 0.05$, Table 3).

Utilization of health care services for children under 5 years of age

Hospital was the main place of death for children under 5 years old in Lanzhou. 83.18% of children under the age of five received treatment before they died. The diagnostic institutions for death of children under 5 years old were mainly provincial and municipal medical and health institutions (Table 4).

Table 1: Deaths of children under 5 years old in Lanzhou from 2012 to 2018 [N, %].

Year	Live births	Neonates		Infant		Children aged 1-4		Children under 5 years	
		N	MR	N	MR	N	MR	N	MR
2012	29834	159	5.33	201	6.74	22	0.74	223	7.47
2013	28468	134	4.71	184	6.46	34	1.19	218	7.66
2014	30994	114	3.68	150	4.84	30	0.97	180	5.81
2015	25600	85	3.32	121	4.73	26	1.02	147	5.74
2016	29840	93	3.12	116	3.89	20	0.67	136	4.56
2017	32110	99	3.08	143	4.45	27	0.84	170	5.29
2018	29217	86	2.94	111	3.80	28	0.96	139	4.76
APC (%)			-10.0		-9.4		-1.7		-8.1
t			-6.7		-5.4		-0.4		-4.6
P			0.0		0.0		0.7		0.0

Notes: MR: Mortality Rate.

Table 2: Rank of death causes in children under 5 years old in Lanzhou from 2012 to 2018 [N,%].

Death causes	Neonates		Infants		Children aged 1-4		Children under 5 years	
	Causes	N (CR)	Causes	N (CR)	Causes	N(CR)	Causes	N (CR)
1	B	171 (22.21)	B	179 (17.45)	B	27 (14.44)	B	194 (15.99)
2	C	165 (21.43)	C	170 (16.57)	C	25 (13.37)	C	179 (14.76)
3	A	86 (11.17)	A	167 (16.28)	A	15 (8.02)	A	170 (14.01)
4	F	44 (5.71)	F	69 (6.73)	F	11 (5.88)	F	80 (6.60)
5	E	42 (5.45)	E	53 (5.17)	E	10 (5.35)	E	58 (4.78)

Notes: A: Congenital Heart Disease; B: Premature/Low Birth Weight; C: Birth Asphyxia; D: Pneumonia; E: Other Congenital Anomalies; F: Other Respiratory Diseases; G: Traffic Accident; H: Accidental Fall; I: Other Tumors; CR: Constituent Ratio.

Table 3: Mortality causes of the top five diseases among children under 5 years old in Lanzhou from 2012 to 2018 (N, 1/100000).

Year	A		B		C		D		E	
	cases	MR	cases	MR	cases	MR	cases	MR	cases	MR
2012	33	110.61	38	127.37	44	147.48	19	63.69	9	30.17

2013	33	115.92	35	122.95	33	115.92	16	56.2	18	63.23
2014	38	122.6	33	106.47	17	54.85	7	22.59	2	6.45
2015	19	74.22	17	66.41	16	62.5	11	42.97	5	19.53
2016	26	87.13	18	60.32	19	63.67	9	30.16	8	26.81
2017	28	87.2	19	59.17	23	71.63	12	37.37	8	24.91
2018	17	58.19	19	65.03	18	61.61	6	20.54	8	27.38
APC (%)		-8.9		-13.8		-13.7		-13.5		-10.3
T		-3.0		-5.3		-3.1		-2.7		-1.1
P		0.0		0.0		0.0		0.0		0.3

Notes: A: Congenital Heart Disease; B: Premature/Low Birth Weight; C: Birth Asphyxia; D: Pneumonia; E: Other Congenital Anomalies; MR: Mortality Rate.

Table 4: Utilization of pre-death health care services for children under 5 years old in Lanzhou from 2012 to 2018 [N, %].

Categories	Neonates		Infants		Children aged 1-4		Children under 5 years	
	N	CR	N	CR	N	CR	N	CR
Place of death								
Hospital	433	56.23	574	55.95	112	59.89	686	56.55
on passage	156	20.26	197	19.20	28	14.97	225	18.55
at home	181	23.51	255	24.85	47	25.13	302	24.90
Pre-death treatment								
Treated	657	85.32	864	84.21	145	77.54	1009	83.18
Untreated	113	14.68	162	15.79	42	22.46	204	16.82
Diagnostic level								
Provinces (cities)	491	63.77	686	66.86	128	68.45	814	67.11
District and county	225	29.22	266	25.93	27	14.44	293	24.15
Street (township)	24	3.12	32	3.12	11	5.88	43	3.54
Village (clinic)	5	0.65	9	0.88	6	3.21	15	1.24
No medical treatment	25	3.25	33	3.22	15	8.02	48	3.96

Notes: CR: Constituent Ratio.

The main reason for 204 untreated children was lack of time for medical treatment (38.24%), followed by parents who didn't consider their illness serious (11.27%) and financial difficulties (5.88%).

Seasonal distribution of death among children under 5 years old in Lanzhou from 2012 to 2018

In the seasonal distribution of death, the main seasons of death for children under 5 years were the first quarter and the fourth quarter, accounting for 29.18% and 28.03% respectively.

Time series analysis model prediction

Sequence diagram analysis: The result showed that there were two seasonal peaks in the mortality of children under 5 years old, which were January to March and October, respectively. It suggested that there may be seasonal fluctuation trend in the data (Figure 1).

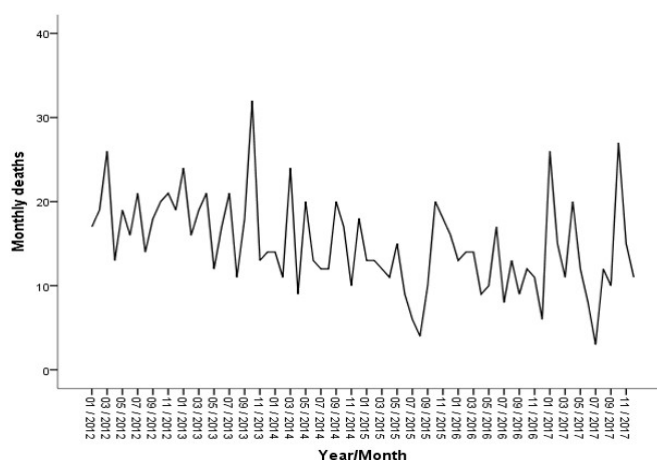


Figure 1: The series diagram of monthly mortality amount of children under 5 years old in Lanzhou from 2012 to 2017

Establishment of model: The monthly mortality data of children under 5 years old were fitted with Simple seasonal, Winters addition, Winters multiplication, SARIMA(0,0,0)(0,1,1)₁₂ and SARIMA(1,0,1)(1,1,1)₁₂ models according to the characteristics of time series maps. The results showed that the fitting effect of exponential smoothing model was better than that of SARIMA model (Table 5).

Combining the parameter settings of the exponential smoothing models, it was found that the Simple seasonal model $\text{Alpha}=0.100$, $P < 0.05$, with statistical significance. Therefore, Simple seasonal model was the best model. White noise test Box-Ljung Q statistic $P > 0.05$ indicated that the residual sequence was white noise sequence, which can be predicted by this model.

Table 5: Estimation of fitting parameters for each model.

Model types	Stationary R ²	RMSE	MAPE	Normalized BIC	Box-Ljung Q statistics	P
Simple seasonal	0.766	4.513	31.576	3.133	21.173	0.172
Winters addition	0.787	4.358	28.713	3.122	20.553	0.152
Winters multiplication	0.746	4.650	30.622	3.252	19.204	0.205
SARIMA(0,0,0)(0,1,1) ₁₂	0.305	5.659	38.405	3.603	16.626	0.480
SARIMA(1,0,1)(1,1,1) ₁₂	0.311	5.784	37.211	3.851	18.435	0.188

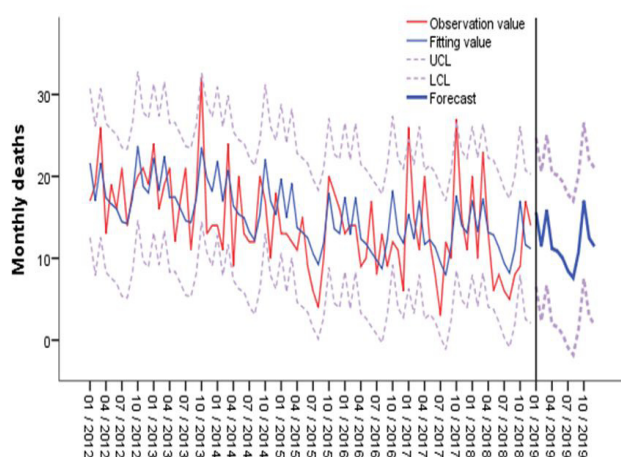


Figure 2: Prediction of mortality trend of children under 5 years old from January to December in 2019

Discussion

Childhood is the key period of life development. Children's development is an important part of economic development and social civilization progress [3]. Deaths among children under the age of 5 is an actionable clinical and public health issue globally [7] and a global goal of the millennium development goals [17]. In order to reduce the mortality rate of children under 5 years old, China and even the world have put forward many feasible strategic guidelines, such as *the United Nations Millennium Development Goals, the outline of China's children's development plan, healthy China 2030* and so on. The implementation of these projects has effectively improved the health of Chinese children and helped the Chinese government to gather information and accumulate experience in reducing the mortality rate in children [28].

The mortality rate of children under 5 years old in Lanzhou

Model fitting effect verification: Simple seasonal model was used to fit the monthly mortality of children under 5 years old in 2018. Compared with the predicted values, the average relative error was 38.85%. The actual value of all months was within the upper and lower limits of the predicted value.

Model prediction: The Simple seasonal model based on the monthly mortality data of children under 5 years old from 2012 to 2018 was used to predict the number of children under 5 years old in 2019. The results showed that the total number of children under 5 years old in Lanzhou in 2019 is 142, which is similar to the level in 2018 (Figure 2).

from 2012 to 2018 showed a trend of slow decline. The highest mortality rate of children under 5 years old in 2014 was 7.66%, which was lower than that specified *Children Development Plan (2011-2020) in Lanzhou*. "Let the infant and the under-five mortality rate be controlled below 10‰ and 13‰ respectively" [3], indicating that under the unremitting efforts of the State, Lanzhou Municipal Government, medical units and the whole people, the child development and protection work has achieved certain results.

According to the *Healthy China 2030 planning outline*, the mortality rate of children under 5 years old in 2015, 2020 and 2030 are lower than 10.7‰, 9.5‰ and 6.0‰ respectively [4]. The mortality rate of children under 5 years old in Lanzhou in 2015 was 5.74%, which was obviously lower than the requirement of *Healthy China 2030*. The mortality rate of children under 5 years old in Lanzhou in 2018 was 4.78%, which also reached the development goal of 2020 in advance. However, it is still the focus of the whole society to continue to reduce the mortality rate of children under 5 years old.

The study found that infant mortality was the main cause of death among children under 5 years old in Lanzhou from 2012 to 2018. Infant mortality accounted for 84.58% of all deaths, and neonatal mortality accounted for 75.05% of infant mortality. This showed that the deaths of children under 5 years old in Lanzhou mainly occurred in neonatal and infant period. The results were consistent with those of Luo Boyan [19]. This suggested that reducing neonatal and infancy mortality is the key to reducing the death of children under five years of age. Therefore, it is necessary to strengthen the prenatal care and perinatal health management work, strengthen the postnatal neonatal visit rate, improve the medical security service level of early neonates, neonatal resuscitation and comprehensive emergency obstetric care can reduce deaths due to intrapartum-related events [14,18].

Overall, the mortality rate of children under 5 years old in Lanzhou from 2012 to 2016 was declining and slightly increased

in 2017, considering that it may be related to the liberalization of the comprehensive two-child policy on January 1, 2016 in China. With the liberalization of the comprehensive two-child policy and the urgent need of most families to have two children, the number of older pregnancies increases. With the increase of women's age, their reproductive system functions begin to decline, the quality of eggs decreases, and they are vulnerable to the interference of various toxic and harmful substances [22,25]. The risk of adverse pregnancy outcomes increases, and the incidence of premature birth and neonatal asphyxia increases accordingly [21,29], which increases the mortality rate of children under 5 years old.

Congenital heart disease, premature/low birth weight and birth asphyxia were the main causes of death among children under 5 years old from 2012 to 2018. It was suggested that pregnant women should have regular maternity check-ups, improve the detection rate of congenital diseases, strengthen the intake of nutrients during pregnancy, strengthen the monitoring during delivery. Hospitals should strengthen the standardized training of midwives, and improve the early diagnostic skills of intrauterine distress [9]. At the same time, we should pay more attention to the prevention and treatment of birth defects, strengthen the premarital examination and pre pregnancy eugenics examination [16]. In addition to congenital heart disease, traffic accidents and accidental falls were also major causes of death in children aged 1 to 4. Children aged 1 to 4 are full of curiosity about the outside world and like to run around [27]. Once the family is not in control, it is easy to cause accidents. In order to reduce the incidence of accidental injuries, parents should strengthen their education on children's traffic regulations and self-protection awareness, change bad habits and behaviors. Effective interventions is also necessary, such as: car seats to prevent road traffic injury [5].

From the utilization of health resources before death, it can be seen that 83.18% of the children received treatment before death, which indicated that the awareness of children's health care in residents is gradually increasing, but some children still die in the way and at home without seeking medical treatment. The main reason for not seeking medical treatment was that they were too late to see a doctor or parents thought that their children's condition is not serious and economic difficulties. Considering that it may be due to the low educational level of parents in rural areas of northwest China, lack of medical knowledge, inadequate understanding of the disease, missed the best treatment time [23]. Secondly, because of financial difficulties, many parents can only give up treatment. Therefore, we should strengthen the establishment of a green channel for children with critical illness to reduce the financial burden of poor families [8].

In the seasonal distribution of death, it was found that the death peak was in the first and fourth quarter, that is, the death peak was in winter and spring. It may be because the cold weather in winter and spring, especially in spring, the temperature difference between morning and evening is relatively large, and the immune system of infants and young children is weak, which increases the risk of children suffering from respiratory diseases [15].

As an important method of time series analysis, exponential smoothing model has strong practicability and high prediction accuracy [14]. In the study, the monthly death data of children under 5 years old in Lanzhou was used to establish a Simple seasonal exponential smoothing model to fit and predict. The total

number of deaths among children under 5 years old in Lanzhou was predicted to be 142 in 2019, which is close to 2018. The exponential smoothing model considers fewer factors and can only make short-term predictions in the process of disease prediction, while the death of children under 5 years old is the result of multiple factors, so in order to predict the death trend of children under 5 years old more accurately, it is necessary to constantly add new actual data and fit them with a variety of influencing factors in the future research.

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