Original Article

Forecasting Nitrate Concentration in Babol Groundwater Resources Using the Grey Model (1,1)

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Abstract

Aims: Nitrate can enter water bodies through using chemical fertilizers and discharging the effluents from municipal and industrial sewage treatment plants. As a superiority to the conventional statistical models, Grey models (GMs) require only a limited amount of representative data to estimate the behavior of unknown systems. In the current study, the nitrate concentration of the year 2023 in Babol groundwater resources was forecasted by using GM, namely GM (1, 1). **Materials and Methods:** This descriptive-cross-sectional study was performed in the city of Babol. The data of 63 wells in urban and rural areas during the warm and cold seasons between 2007 and 2017 were supplied from the Health Center and Babol Rural Water and Sewage Company. In data set, the observed values between 2007 and 2015 were used to fit models, and the observed values between 2016 and 2017 were used to evaluate the accuracy of the model's predictions. To assess the efficiency of the model fitted and precision of the predicted values, we used indexes of forecast absolute error, small error probability, and the proportion of variance statistical metrics. **Results:** Simulated results showed that the accuracy of the model GM (1, 1) to predict and forecast both data sets is entirely appropriate and reliable. The forecasting values of nitrate concentration of the year 2023 and 8 years later, for urban and rural areas in warm and cold seasons, are 21.30 and 7.30 and 15.63 and 5.34 mg/L, respectively. **Conclusion:** Although the predicted concentration of nitrate in the studied area is lower than that the standard concentration suggested by the World Health Organization, all water resources should be protected effectively.

Keywords: Babol, Grey model (1.1), groundwater resources, nitrate

Introduction

Groundwater is one of the most important sources for preparing drinking water required for many people around the world.[1] Groundwater quality may be affected by effluents from urban, commercial, industrial, and agricultural activities[2] Population growth, on the one hand, and the reduction of available water resources, on the other hand, have further enhanced the importance of the protection of water resources.[3] The main sources of groundwater contamination by nitrate include nitrogen in fertilizers, rain water, irrigation return flow, septic system leakage, and wastewater wells.[4] Pollution of groundwater with nitrate through chemical fertilizers is a matter of environmental concern across the world.[5] Groundwater pollution occurs when untreated agricultural wastewaters containing nitrogen fertilizers are released into the environment.[6,7] High concentrations of nitrate in drinking water can cause problems such as methemoglobinemia in infants.[8] Organic form of nitrogen comprises compounds such as protein, urea, and other organic nitrogenous substances, and the inorganic form of it includes compounds such as ammonia, nitrite, and nitrate.[9] The presence of nitrite in drinking water can be problematic, especially for children. In the gastrointestinal tract and in the stomach of infants aged under 6 months, there are alkaline conditions, converting

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nitrate to nitrite; then, nitrite oxidizes iron in the red blood cell hemoglobin and ultimately prevents the transport and transfer of oxygen to the tissues and cells of the body. This phenomenon is called methemoglobinemia.[10] In newborns, the onset of this condition causes bruising and, if not treated promptly, leads to death.[11] The maximum concentration for nitrate recommended by the World Health Organization (WHO) and Iranian Standards for drinking water quality is recommend to be 45 mg/L.[12] The Grey system theory is an interdisciplinary scientific area that was first introduced during the 1980s by Deng Julong[13] as a method for making quantitative predictions. Since then, the theory has become quite popular with its ability to deal with the systems that have partially unknown parameters. The Grey method has numerous applications for economics, physics, social sciences, and recently in public health. As a superiority to the conventional statistical models, Grey models (GMs) require only a limited amount of representative data to estimate the behavior of unknown systems.[13,14] The suggested method is capable of generating an exact prediction even though only a few observations are provided. Hence, it is very valuable in the case of a small size data sets because traditional methods, for example, least-squares extrapolation, require longer data span to produce a good forecast. In addition, these results can be obtained without making any assumption about an original dataset, and thus is of high reliability. Another advantage is that the developed method is easy to use.[15] As far as the author's knowledge and literatures reported yet, no study has been found to investigate forecasting nitrate concentration in water resources by GM. The aim of the study was to forecast nitrate concentration in Babol groundwater resources in urban and rural areas using GM to the year 2023.

Materials and Methods

This descriptive-cross-sectional study was performed in the city of Babol. The information of 63 wells in urban and rural areas during the warm and cold seasons between 2007 and 2017 was obtained from the Health Center and Rural Water and Wastewater Company. The location of the water resources of the urban and rural areas of Babol is shown in Figures 1 and 2. The city of Babol (36°33′05″N 52°40′44″E) located in the central part of Mazandaran Province has an area of over 1578 km^2 with six parts and eight cities and more than 510 villages; moreover, its urban and rural areas have 260,000 and over 230,000 inhabitants, respectively. In addition, the city of Amol (36°28′11″N 52°21′03″E) is located in the central part of Mazandaran Province. The drinking water required for the urban and rural inhabitants who live in Babol is supplied by the twenty wells located in the city of Amol and 43 wells near the villages. Table 1 shows the nitrate concentration measured in urban and rural areas in the different studied years. The purpose of this study was to evaluate the GM as a forecasting model for small and imperfect information, for example in some environmental health sciences, especially pollutant concentration in the environment. We chose the GM (1, 1) for forecasting because it has proven its efficiency in different domains with limited information. Moreover, there are limited studies that have explored GM from the viewpoint of critical parameters in environmental health.

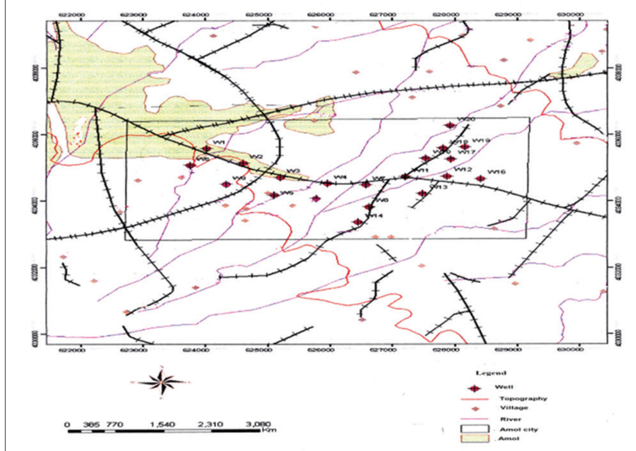

Figure 1: The location of the urban wells

Table 1: Actual nitrate concentration in Babol groundwater resources (mg/L)

Year	Nitrate concentration in urban areas (mg/L)		Nitrate concentration in village areas (mg/L)	
	Warm seasons	Cold seasons	Warm seasons	Cold seasons
2007	8.9	6.60	2.23	2.31
2008	10.0	7.06	2.47	2.40
2009	11.6	9.31	2.53	2.79
2010	12.5	9.91	3.37	3.04
2011	13.0	12.83	3.93	3.36
2012	12.5	13.05	3.85	3.49
2013	13.4	12.03	3.86	3.72
2014	13.9	12.38	4.15	3.56
2015	14.7	12.58	4.40	3.75
2016	15.9	12.64	4.60	3.88
2017	16.1	12.67	4.80	3.91

Grey system theory: Setting up and testing of grey model (1, 1)

Local prediction is forecasting the future based only on a set of the most recent information in a time series. A Grey system theory is an interdisciplinary scientific area that was first introduced in the early 1980s by Deng. In recent years, GMs have been successfully employed in many prediction applications.[16] A Grey system is a system that is not completely known, i.e., the knowledge of the system is partially known and partially unknown.[13,14] Grey forecasting can be utilized in situations with relatively short data ($n \geq 4$).[17] A GM algorithm is described as follows:

$$\left\{x^{(0)}(i)\right\} = \left\{x^{(0)}(1), x^{(0)}(2), \ldots, x^{(0)}(n)\right\} \quad , \quad n^3 4 \tag{1}$$

Where the superscription (0) represents the original series. We assume that the original data are positive. The original series is transformed into a new series $x^{(1)}(k)$ using the first-order accumulated generating operations (AGO). By defining $AGO.x^{(0)}(k) = x^{(1)}(k) = \sum_{i=1}^{k} x^{(0)}(i)$, we get a new series:

$$x^{(1)}(k): \{x^{(1)}(k)\} = \{x^{(1)}(1), x^{(1)}(2), ..., x^{(1)}(n)\},\ k = 1,2,...,n \quad (2)$$

For some processes, $x^{(1)}(k)$ can be modeled by a first-order differential equation (whitening equation) as follows:

$$\frac{dx^{(1)}}{dt} + ax^{(1)} = b \quad (3)$$

Where a and b are Grey parameters. The Eq. (3) is called GM (1, 1), where the first one denotes the order of the difference equation and the second one is the number of variables. In the below derivative equation:

$$\frac{dx^{(1)}}{dt}(t) = \lim_{\Delta t \to 0} \frac{x^{(1)}(t+\Delta t) - x^{(1)}(t)}{\Delta t} \quad (4)$$

We can assume that $\Delta t = 1$, therefore, derivative approximately is equal to:

$$\frac{dx^{(1)}}{dt}(k) = x^{(1)}(k+1) - x^{(1)}(k) \quad (5)$$

For the GM, if Δ is small enough, then $\left|x^{(1)}(k+1) - x^{(1)}(k)\right|$ will be small. Let $Z^{(1)}(k)$ as the mean value of adjacent $x^{(1)}$, i.e.,

$$Z^{(1)}(k) = \frac{1}{2}\left[x^{(1)}(k) - x^{(1)}(k-1)\right] \ or \ Z^{(1)}(k+1) = \frac{1}{2}\left[x^{(1)}(k+1) - x^{(1)}(k)\right] \quad (6)$$

By inserting Eqs. (5, 6) into Eq. (4), GM (1, 1) can be written as $x^{(1)}(k+1) - x^{(1)}(k) + az(k+1) = b$. When $k = 1$, $x^{(1)}(2) - x^{(1)}(1) = -az(2) + b$. In addition, we know that $x^{(1)}(1) = x^{(0)}(1), x^{(1)}(2) = x^{(0)}(1) + x^{(0)}(2)$, thus with: $x^{(0)}(2) = -az(2) + b$. We will give that:

$$x^{(0)}(t) = -az(t) + b \ , \quad t = 2,3,...,n \quad (7)$$

We can write Eq. (7) in matrix form, $\begin{vmatrix} x^{(0)}(2) \\ x^{(0)}(3) \\ \vdots \\ x^{(0)}(n) \end{vmatrix} = \begin{vmatrix} -z(2) & 1 \\ -z(3) & 1 \\ \vdots & \vdots \\ -z(n) & 1 \end{vmatrix} \begin{bmatrix} a \\ b \end{bmatrix}$.

Assume that $x_N = \begin{vmatrix} x^{(0)}(2) \\ x^{(0)}(3) \\ \vdots \\ x^{(0)}(n) \end{vmatrix}$, $Z = \begin{vmatrix} -z(2) & 1 \\ -z(3) & 1 \\ \vdots & \vdots \\ -z(n) & 1 \end{vmatrix}$, and $\hat{a} = \begin{bmatrix} a \\ b \end{bmatrix}$, therefore, formula in matrix form is:

$$x_N = Z\hat{a} \quad (8)$$

By produce z^T in the right and left of the above, $\hat{a} = \left(z^T z\right)^{-1} z^T x_N$ we get the parameter a and b and the solution of (3): $x^{(1)}(t) = \left|x^{(1)}(0) - \frac{b}{a}\right| e^{-at} + \frac{a}{b}$. We accept through common practice that $x^{(1)}(0) = x^{(0)}(1)$, substituting this for the above formula, and we have

$$x^{(1)}(k+1) = \left[x^{(0)}(1) - \frac{b}{a}\right] e^{-ak} + \frac{b}{a} \quad (9)$$

Eq. (9) above calls time response function. If we apply the inverse accumulated generation operation (IAGO), the predicted equation at k will be as follows:

$$\hat{x}^{(0)}(k) = \hat{x}^{(1)}(k+1) - \hat{x}^{(1)}(k) \ , \quad k \geq 2 \quad (10)$$

That is called predicting formula.[18]

Testing the efficiency and accuracy of the Grey model (1, 1)

To evaluate the forecasting model, we have calculated the accuracy of the prediction values. Furthermore, different standard metrics can be used to test the model, as follows: forecast absolute error in percent, mean forecast absolute error, variance ratio, and small error probability between $x^{(0)}(k)$ and $x^{(0)}(k)$ based on the formula:

$$\Delta(k) = x^{(0)}(k) - \hat{x}^{(0)}(k), \left|\Delta(k)\right| = \left|x^{(0)}(k) - \hat{x}^{(0)}(k)\right|.$$ [19]

I. Forecast absolute error in percent:

$$FAE = \frac{\left|x^{(0)}(k) - \hat{x}^{(0)}(k)\right|}{x^{(0)}(k)} \times 100$$

II. Mean forecast absolute error in percent:

$$\%MFAE = \sum_{i=1}^{n} \frac{\left|x^{(0)}(k) - \hat{x}^{(0)}(k)\right|}{x^{(0)}(k)}$$

III. Variance ratio: $c = \frac{S_2}{S_1}$

Standard deviation of original series:

$$S_1 = \sqrt{\frac{\sum\left[x^{(0)}(i) - \overline{x}^{(0)}(i)^2\right]}{n-1}}$$

, Standard deviation of absolute error:

$$S_2 = \sqrt{\frac{\sum\left[\Delta^{(0)}(i) - \Delta^{(0)}(i)^2\right]}{n-1}}$$

IV. Small error probability (P):

$$P = p\left\{\left|\Delta^{(0)}(i) - \Delta^{(0)}(i)^2\right| < (0.6745)\, S_1\right\}.$$

The less the value for C is, the better the prediction of GM model. The more the value P indicates, the more the probability of little error and the higher precision. The criterion of judgment under different precision levels is expressed in Table 2.[20] On the other hand, the developing coefficient "a" of the GM is also used as a criterion to judge the forecasting capability of the GM. For $-\alpha \leq 0.3$, the model can be used for medium- and long-term forecasting, $0.3 < -\alpha \leq 0.5$, the model is suitable for short-term forecasting, $0.5 -\alpha \leq 0.8$, the model is carefully employed in short-term forecasting, $0.8 < -\alpha \leq 1$, the model should be modified with residual, and for $-\alpha > 1$, the model is not suitable for forecasting.[21]

Date sources

Information related to nitrate concentration in groundwater of study site was provided by measuring nitrate of water in 46 wells rural and 20 urban wells for the period from 2007 until 2017. In this study, we adopted the data provided by rural and urban water and wastewater organization of Babol. Table 1 shows the data for nitrate concentration from 2007 to 2017 in the urban areas and rural areas of Babol in warm and cold seasons.

Results

Empirical analysis

The data analyzed in this article were obtained from nitrate concentration in Babol groundwater. Training data from 2007 to 2015 were used for model fitting and data from 2016 to 2017 were reserved for validation. The following procedure was used to construct a GM (1, 1) to estimate nitrate concentration between 2007 and 2023. Eq. (1) obtains the primitive sequence $X^{(0)}$ as follows:

$X^{(0)}$ for the urban area in warm seasons = (8.86, 10.0, 11. 6, 12.5, 13, 12.5, 13. 4, 13.9, 14.7)

$X^{(0)}$ for the urban area in cold seasons = (NA, 7.06, 9.31، 9.91, 12.83, 13.05, 12.03, 12.38, 12.58)

$X^{(0)}$ for the rural area in warm seasons = (2.23, 2.47, 2.53, 3.37, 3.93, 3.85, 3.86, 4.15, 4.40)

$X^{(0)}$ for the rural area in cold seasons = (2.31, 2.40, 2.79, 3.04, 3.36, 3.49, 3.72, 3.56, 3.75)

Eq. (2) obtains the one-order sequence $X^{(1)}$ as follows:

$X^{(1)}$ for the urban area in warm seasons = (8.86, 18.9, 30.5, 43, 56, 68.5, 81.9, 95.8, 110.5)

$X^{(1)}$ for the urban area in cold seasons = (7.06, 16.37, 26.28, 39.11, 52.16, 64.19, 76.57, 89.15)

Table 2: The criterion of judgment

Precision grade	Excellence (%)	Pass (%)	Reluctance pass (%)	No pass (%)
MFAE	<5	5<<10	5<<10	>10
Variance ratio (C)	<0.35	<0.60	<0.65	≥0.65
Small error probability (*P*)	>0.95	>0.80	>0.70	≤0.70

MFAE: Mean forecast absolute error

$X^{(1)}$ for the rural area in warm seasons = (2.23, 4.70, 7.23, 10.60, 14.53, 18.38, 22.24, 26.39, 30.79)

$X^{(1)}$ for the rural area in cold seasons = (2.31, 4.71, 7.5, 10.54, 13.9, 17.39, 21.11, 24.67, 28.42)

Based on the actual data and Eq. (8), time response function, the GM (1, 1) model for nitrate concentration in urban and village areas in warm and cold seasons was set up. Grey parameters (*a, b*), for each of the corresponding data sets, (−0.0435, 10.2412), (−0.0403, 9.8703), (−0.0734, 2.4638), and (−0.0542, 2.4833) are estimated, respectively.

Accumulate matrix Z and constant vector X_N for nitrate concentration of urban areas in warm were as follows:

$$Z=\begin{bmatrix} -13.880 & 1 \\ -24.680 & 1 \\ -36.700 & 1 \\ -49.430 & 1 \\ -62.190 & 1 \\ -75.180 & 1 \\ -88.855 & 1 \\ -103.180 & 1 \end{bmatrix}, X_N=\begin{bmatrix} 10.04 \\ 11.56 \\ 12.48 \\ 12.98 \\ 12.54 \\ 13.44 \\ 13.91 \\ 14.74 \end{bmatrix}, \text{Eq. (7) obtains } \hat{a} : \hat{a} = \begin{bmatrix} a \\ b \end{bmatrix}$$

$$= \begin{vmatrix} -0.0435 \\ 10.2412 \end{vmatrix}$$

The forecasting model obtained by Eq. (9) is:

$$x^{(1)}(k+1) = \left[x^{(0)}(1) - \frac{10.2412}{(-0.0435)} \right] e^{-(-0.00435)k} + \frac{10.2412}{(-0.0435)} \quad (11)$$

The forecasted values for nitrate concentration of urban areas in warm seasons for the years from 2008 to 2015 were 8.86, 10.86137, 11.34444, 11.849, 12.37601, 12.92645, 13.50137, 14.10187, and 14.72907 tons in year, respectively. These values were obtained by Eqs. (9) and (11), providing the reduction sequence of:

$\hat{X}^{(0)}$ = (10.86137, 11.34444, 11.849, 12.37601, 12.92645, 13.50137, 14.10187, 14.72907).

Accumulate matrix Z and constant vector X_N for nitrate concentration of urban areas in cold seasons were as follows:

$$Z=\begin{bmatrix} -11.715 & 1 \\ -21.325 & 1 \\ -32.695 & 1 \\ -45.635 & 1 \\ -58.175 & 1 \\ -70.380 & 1 \\ -82.860 & 1 \end{bmatrix}, Xn=\begin{bmatrix} 9.31 \\ 9.91 \\ 12.83 \\ 13.05 \\ 12.03 \\ 12.38 \\ 12.58 \end{bmatrix}, \text{Eq.(7) obtains } \hat{a} : \hat{a} = \frac{a}{b} =$$

$$\begin{vmatrix} -0.0403 \\ 9.8703 \end{vmatrix}$$

The forecasting model obtained by Eq. (9) is:

$$x^{(1)}(k+1)=\left[x^{(0)}(1)-\frac{9.8703}{(-0.0403)}\right]e^{-(-0.0403)k}+\frac{9.8703}{(-0.0412)} \quad (12)$$

The forecasted values for nitrate concentration of urban areas in cold seasons for the years from 2008 to 2015 were 7.06, 10.36183, 10.78759, 11.23084, 11.69231, 12.17274, 12.67291 and 13.19363 tons in year, respectively. These values were obtained by Eqs. (9) and (12), providing the reduction sequence of:

$\hat{X}^{(0)}$ = (10.36183, 10.78759, 11.23084, 11.69231, 12.17274, 12.67291, 13.19363).

Accumulate matrix Z and constant vector X_N for nitrate concentration of village areas in warm seasons were as follows:

$$Z=\begin{bmatrix} -3.465 & 1 \\ -5.965 & 1 \\ -8.915 & 1 \\ -12.565 & 1 \\ -16.455 & 1 \\ -20.310 & 1 \\ -24.315 & 1 \\ -28.590 \end{bmatrix}, X_N=\begin{bmatrix} 2.47 \\ 2.53 \\ 3.37 \\ 3.93 \\ 3.85 \\ 3.86 \\ 4.15 \\ 4.40 \end{bmatrix}, \text{Eq.(7) obtains } \hat{a} : \hat{a} = \frac{a}{b} = \begin{vmatrix} -0.0734 \\ 2.4638 \end{vmatrix}$$

The forecasting model obtained by Eq. (9) is:

$$x^{(1)}(k+1)=\left[x^{(0)}(1)-\frac{2.4637}{(-0.0734)}\right]e^{-(-0.0734)k}+\frac{2.4637}{(-0.0734)} \quad (13)$$

The forecasted values for nitrate concentration of urban areas were 2.23, 2.72625, 2.933869, 3.157298, 3.397743, 3.656499, 3.934961, 4.234629, and 4.557118 tons in year, respectively, in cold seasons for the years from 2008 to 2015. These values were obtained by Eqs. (9) and (13), providing the reduction sequence of:

$\hat{X}^{(0)}$ = (2.933869, 3.157298, 3.397743, 3.656499, 3.934961, 4.234629, 4.557118).

Accumulate matrix Z and constant vector X_N for nitrate concentration of village areas in cold seasons were as follows:

$$Z=\begin{bmatrix} -3.510 & 1 \\ -6.105 & 1 \\ -9.020 & 1 \\ -12.220 & 1 \\ -15.645 & 1 \\ -19.250 & 1 \\ -22.890 & 1 \\ -26.545 \end{bmatrix}, X_N=\begin{bmatrix} 2.40 \\ 2.79 \\ 3.04 \\ 3.36 \\ 3.49 \\ 3.72 \\ 3.56 \\ 3.75 \end{bmatrix}, \text{Eq.(7) obtains } \hat{a} : \hat{a} = \frac{a}{b} = \begin{vmatrix} -0.0542 \\ 2.4833 \end{vmatrix}$$

The forecasting model obtained by Eq. (9) is

$$x^{(1)}(k+1)=\left[x^{(0)}(1)-\frac{2.4833}{(-0.0542)}\right]e^{-(-0.0542)k}+\frac{2.4833}{(-0.0542)} \quad (14)$$

The forecasted values for concentration of village areas in cold seasons for the years from 2008 to 2015 were 2.31, 2.680525, 2.829828, 2.987447, 3.153845, 3.329511, 3.514962, 3.710742 and 3.917427 tons in year, respectively. These values were obtained by Eqs. (9) and (14), providing the reduction sequence of: $\hat{X}^{(0)}$ = (2.680525, 2.829828, 2.987447, 3.153845, 3.329511, 3.514962, 3.710742, 3.917427).

Tables 3 and 4 show the actual concentration data, prediction of nitrate concentration, average absolute error, and average forecast absolute error (%). The nitrate concentration was calculated and compared using absolute values, absolute error, and forecast absolute error (%) for the GM (1, 1). Tables 3 and 4 represent that training data from 2007 to 2015 for the average, maximal, and minimal residual errors for the urban area of Babol in warm seasons were 3.0933, 5.0560, and 0.0741 (%) and for cold seasons were 7.3502, 12.4642, and 1.1866 (%), respectively. For the village area of Babol in warm seasons, the corresponding values were 7.3464, 13.5434, and 1.9420 (%) and for cold seasons were found to be 4.9737, 11.6886, and 1.4275 (%), respectively. The MFAE% of GM (1, 1) for 2016–2017 was 1.7202% for the urban area of Babol in warm seasons and 10.7676% for cold seasons and 8.2816% for the village area of Babol in warm seasons and 9.1250% for cold seasons, for validation data. Furthermore, according to the highly prediction accuracy of the criteria [Table 1], the GM (1, 1) in this study was adequate to forecast nitrate concentration in Babol. The forecasted nitrate concentration during the period of 2017–2023 for the urban area of Babol ranged between 16.7831 and 20.8624 mg/L in warm seasons and between 14.8877 and 18.2083 mg/L for cold seasons. The corresponding value for the village area of Babol was observed between 5.6796 and 8.1977 mg/L in warm seasons and between 4.6092 and 6.0440 mg/L in cold seasons. In 2023, the forecasted nitrate concentration for the urban area of Babol in warm seasons was obtained to be 20.8624 and for cold seasons 18.2083. The corresponding value for the village area of Babol was found to be 8.1977 mg/L and 6.0440 mg/L in warm and cold seasons, respectively.

The precision of Grey forecasting model (1, 1)

As was explained, to investigate the precision of the Grey forecasting model GM (1, 1), we can calculate measures of mean forecast absolute error, variance ratio, and small error probability (*P*). To test the precision of models, absolute error and forecast absolute error of both data sets were calculated. The results are shown in Tables 3 and 4. The variance ratio for nitrate concentration in urban and village areas (warm and

Table 3: Actual concentration data from 2007 to 2017 and prediction of nitrate concentration and absolute error and forecast absolute error (%) from 2007 to 2023 in the urban area of Babol in warm and cold seasons with GM (1, 1)

Years	Warm seasons				Cold seasons			
	Actual values	Estimated values	Absolute error	Forecast absolute error (%)	Actual values	Estimated values	Absolute error	Forecast absolute error (%)
2007	8.86	NA	NA	NA	NA	NA	NA	NA
2008	10.04	10.8614	0.8214	8.1809	7.06	NA	NA	NA
2009	11.56	11.3444	0.2156	1.8647	9.31	10.3618	1.0518	11.2978
2010	12.48	11.8490	0.6310	5.0561	9.91	10.7876	0.8776	8.8556
2011	12.98	12.3760	0.6040	4.6533	12.83	11.2308	1.5992	12.4642
2012	12.54	12.9264	0.3864	3.0817	13.05	11.6923	1.3577	10.4037
2013	13.44	13.5014	0.0614	0.4566	12.03	12.1727	0.1427	1.1865
2014	13.91	14.1019	0.1919	1.3793	12.38	12.6729	0.2929	2.3660
2015	14.74	14.7291	0.0109	0.0741	12.58	13.1936	0.6136	4.8778
Average error (%)			0.3653	3.0933			0.8479	7.3502
Variance ratio (C)				0.2450				0.4567
Small error probability (*P*)				0.9691				0.9265
2016	15.90	15.3842	0.5158	3.2442	12.64	13.7357	1.0957	8.6689
2017	16.10	16.0684	0.0316	0.1963	12.67	14.3001	1.6301	12.8662
Average error (%)			0.2737	1.7202			1.3630	10.7676
2018		16.7831				14.8877		
2019		17.5295				15.4995		
2020		18.3092				16.1363		
2021		19.1235				16.7993		
2022		19.9740				17.4896		
2023		20.8624				18.2083		

NA: Not available

Table 4: Actual concentration data from 2007 to 2017 and prediction of nitrate concentration and absolute error and forecast absolute error (%) from 2007 to 2023 in the village area of Babol in warm and cold seasons with GM (1, 1)

Years	Warm season				Cold season			
	Actual values	Estimated values	Absolute error	Forecast absolute error (%)	Actual values	Estimated values	Absolute error	Forecast absolute error (%)
2007	2.23	NA	NA	NA	2.31	NA	NA	NA
2008	2.47	2.7263	0.2562	10.3745	2.40	2.6805	0.2805	11.6886
2009	2.53	2.9339	0.4039	15.9632	2.79	2.8298	0.0398	1.4275
2010	3.37	3.1573	0.2127	6.3116	3.04	2.9874	0.0525	1.7287
2011	3.93	3.3977	0.5323	13.5434	3.36	3.1538	0.2061	6.1356
2012	3.85	3.6565	0.1935	5.0256	3.49	3.3295	0.1605	4.5985
2013	3.86	3.9350	0.0750	1.9420	3.72	3.5150	0.2050	5.5118
2014	4.15	4.2346	0.0846	2.0392	3.56	3.7107	0.1507	4.2343
2015	4.40	4.5571	0.1571	3.5709	3.75	3.9174	0.1674	4.4647
Average error (%)			0.2394	7.3464			0.1578	4.9737
Variance ratio (C)				0.30394				0.3211
Small error probability (*P*)				0.9367				0.9541
2016	4.60	4.9042	0.3042	6.6123	3.88	4.1356	0.2556	6.5882
2017	4.80	5.2776	0.4777	9.9509	3.91	4.3660	0.4560	11.6618
Average error (%)			0.3909	8.2816			0.3558	9.1250
2018		5.6796				4.6091		
2019		6.1121				4.8659		
2020		6.5776				5.1369		
2021		7.0785				5.4230		
2022		7.6175				5.7251		
2023		8.1977				6.0440		

NA: Not available

cold seasons) is 0.2450 and 0.4567 and 0.3471 and 0.3174, respectively. The small error probability of both data set is 0.9691 and 0.9265 and 0.9265 and 0.9503, respectively. According to this result and the criterion of judgment, the efficiency of the model fitted and the precision of predicted values in urban in warm seasons and for village areas in warm and cold seasons were in excellence and for urban areas in cold seasons were in pass range. Therefore, we can conclude that GM (1, 1) in both of data sets has forecasting precision and is useful for medium- and long-term forecasting. Tables 3 and 4 show the estimations, and Figures 3-6 show the trend in the data separately. Figure 3 shows the actual concentration data from 2007 to 2015 and prediction of nitrate concentration and absolute error and forecast absolute error (%) from 2007 to 2023 in the urban area of Babol in warm seasons with GM (1, 1). Figure 4 depicts the actual concentration data from 2007 to 2015 and the prediction of nitrate concentration and absolute error and forecast absolute error (%) from 2007 to 2023 in the urban area of Babol in cold seasons with GM (1, 1). Figure 5 represents the actual concentration data from 2007 to 2017 and the prediction of nitrate concentration and absolute error and forecast absolute error (%) from 2007 to 2023 in the rural area of Babol in warm seasons with GM (1, 1). Figure 6 displays the actual concentration data from 2007 to 2017 and the prediction of nitrate concentration and absolute error and forecast absolute error (%) from 2007 to 2023 in the rural area of Babol in cold seasons with GM (1, 1).

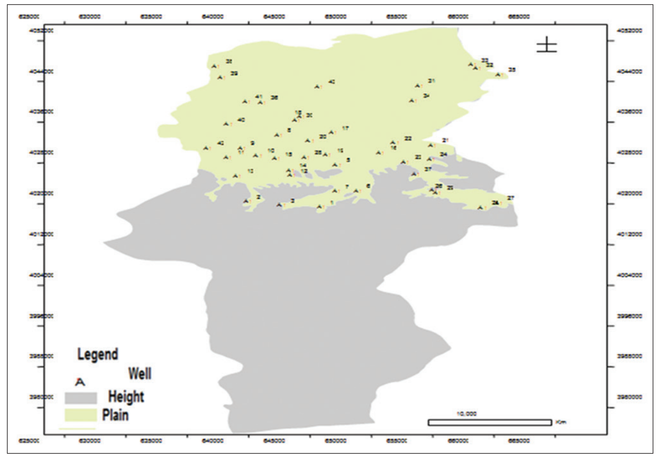

Figure 2: The location of the rural wells

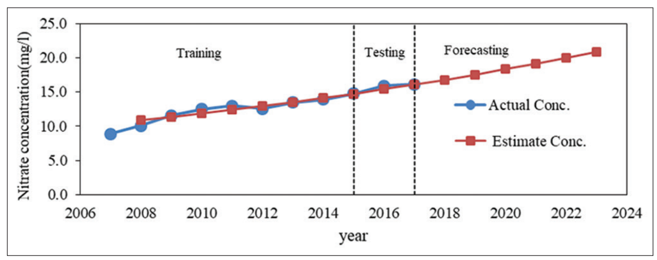

Figure 3: Forecasting of urban nitrate concentration collected in warm seasons using Grey model (1, 1) during 2007–2023

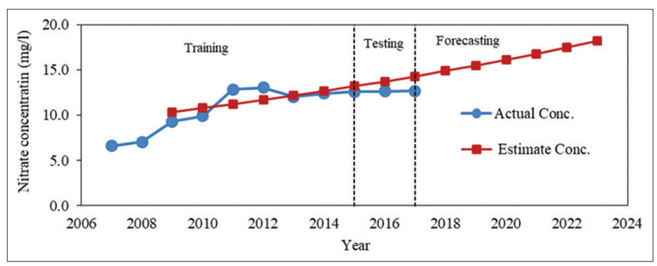

Figure 4: Forecasting of urban nitrate concentration collected in cold seasons using Grey model (1, 1) during 2007–2023

Discussion

The GM (1,1) is capable of effectively dealing with incomplete and uncertain information using only a few data points. The results showed that the average residual error of the GM (1, 1) was below 10% for all wells. Table 3 shows that the forecasted nitrate concentrations for the years 2018–2023 were 16.99, 17.78, 18.60, 19.46, 20.36, and 21.30 mg/L for the urban areas in warm seasons and 13.64, 14.02, 14.41, 14.80, 15.21, and 15.63 mg/L in cold seasons, respectively. In addition, Table 4 shows that the forecasted nitrate concentrations for the years 2018–2023 were 5.3, 5.6, 6.0, 6.4, 6.8, and 7.3 mg/L for the urban areas in warm seasons and 4.29, 4.48, 4.68, 4.89, 5.11, and 5.34 mg/L in cold seasons, respectively. The GM (1,1) used in the present study estimated that the forecasted nitrate concentrations of the urban and rural areas in warm and cold seasons will reach 21.30, 15.63, 7.3, and 5.34 mg/L in 2023. As mentioned above, the WHO standard for the nitrate concentration is 45 mg/L, but it is the most important factor in esophageal cancer. According to the survey, the forecasted nitrate concentrations showed that the values will increase over the period between 2018 and 2023. The forecasted concentrations in warm and cold seasons in urban areas for the years 2018 and 2023 are 16.7831, 20.8624, 14.8877, and 18.2083 mg/L, respectively.

The results of Gardner and Vogel revealed that the nitrate concentrations in the descending scale from the agricultural land are notably greater than the nitrate concentration in other parts.[22] Besides, Rajaee *et al*. used the multivariate linear regression analysis, artificial neural network, and wavelet neural network models to predict the concentration of nitrate in the Karaj River.[23] In a systematic study on nitrate concentration by Akhavan *et al*., it was reported that the nitrate concentration was higher than the allowable levels in 31% of the drinking water resources of Qazvin city.[6] In the prediction of the future water quality status of the Babol aquifer, the entry of effluents and agricultural return waters should be considered because they can affect the qualitative status of the aquifer considering the water intake. The results of this study are consistent with those of Tweed *et al*. and Foster *et al*.[24,25] Furthermore, the findings of the study conducted by Jalali in the city of Hamadan revealed that the main factor for increasing the nitrate concentration in water resources is attributed to the excessive use of chemical fertilizers for

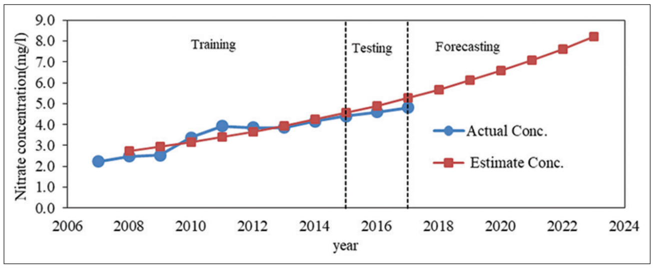

Figure 5: Forecasting of rural nitrate concentration collected in warm seasons using Grey model (1, 1) during 2007–2023

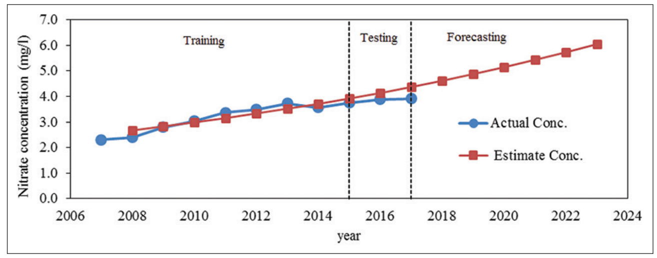

Figure 6: Forecasting of rural nitrate concentration collected in cold seasons using Grey model (1, 1) during 2007–2023

agricultural purposes, which accords with the results obtained in the present study.[26] Moreover, in other studies carried out in the cities of Babol and Hamadan, similar results have been reported.[27,28] Joekar-Niasar and Ataie-Ashtiani, based on a lumped-parameter model, reported that the main source of nitrate pollution in groundwater resources is the release of household wastewater.[29] However, the main reasons for the increase of nitrate concentration in groundwater are as follows: the abundance of agricultural land in the villages of Babol, the lack of wastewater collection and treatment systems, continuous use of nitrogen fertilizers in soil, and the entry of urban and industrial wastewaters into water and soil resources, and so on. Therefore, it is suggested that the wastewater collection and treatment systems should be started as soon as possible and the use of wells for sewage disposal should be minimized. In the case of wells where the concentration of nitrate and nitrite is more than the global standard, they can be taken out of the circuit and used only for agriculture and industrial applications. This model reveals a high degree of forecasting validity, presenting a clearly viable means of forecasted nitrate concentration in the urban and rural areas in Babol in warm and cold seasons.

The results of this study showed that the wells' nitrate concentration in the studied areas of the city of Babol was less than the WHO standard. However, it is difficult to predict the concentration of nitrate due to the effect of various factors. However, the determination of its limits can be very useful for future decisions. The model GM (1, 1), with a precision of 93% for predicting the concentration of nitrate in the wells of the rural and urban areas of Babol for 2023, showed to be a suitable model.

Conclusion

In this research, the use of the GM (1, 1) model for modeling the nitrogen-ion-time series, which is unstable and has oscillatory nature, was studied. The advantage of the GM (1, 1) model is that it is possible to quickly and accurately predict the nitrate content using qualitative data and qualitative conditions such as hot and cold seasons. As a result, the management of the highest quality water resources is considered. The government should formulate policies promoting the water resource management. Finally, it is recommended that more studies are needed to survey closely which polluters may contaminate the water resources of the city of Babol and increase the content of nitrate.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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