Desalination and Water Treatment
www.deswater.com

doi: 10.5004/dwt.2018.22055

119 (2018) 235–242
July

Application of ARIMAX model in predication of basin water resources under climate change

Xiu-yu Zhang[a,*], Qi-ting Zuo[b], Xue-fang Du[a], Jing Tian[b]

[a]*School of Water Conservancy, North China University of Water Resources and Electric Power, Zhengzhou 450046, China, Tel.+86 371 69313568; emails: zhangxiuyu@ncwu.edu.cn (X.-y. Zhang), 928101510@qq.com (X.-f. Du)*
[b]*College of Water Conservancy and Environment, Zhengzhou University, Zhengzhou 450001, China, emails: zuoqt@zzu.edu.cn (Q.-t. Zuo), 280890239@qq.com (J. Tian)*

Received 7 August 2017; Accepted 20 December 2017

ABSTRACT

Currently, climate change is regarded as one of the most important global environmental problems at home and abroad, and its impacts on hydrology and water resources mainly concentrated on the process response to hydrological cycle and the change of water volume. Taking Tarim River Basin, which is the largest continental river in China, as a typical example, this paper identifies the main factors driving the evolution of its water resources system based on the scientific cognition of basin water resources system features, obtains key meteorological factors data as the input of basin water resources system changes by adopting some existing climate scenarios and climate models, analyses and calculates its water resources volume in future different level years under the three kinds of climate scenarios: RCP8.5, RCP4.5 and RCP2.6 by constructing the autoregressive integrated moving average model (ARIMAX) dynamic regression forecasting model of the meteorological factors (such as temperature and precipitation) and runoff. The calculation results can clearly reflect the overall situation of basin water resources under different climate scenarios and provide basis for development, utilization and optimal allocation of basin water resources.

Keywords: Climate change; Water resources forecasting; ARIMAX model; Climate model

1. Introduction

Water is one of the most important basic resources for mankind's survival and development. With the population growth and socioeconomic development, human has an increasing demand for water resources. China is the largest developing country tortured by shortage of water resources. Droughts, floods and water pollution are three major bottlenecks restricting China's economic and social development. Currently, climate change is regarded as one of the most important global environmental problems at home and abroad, and it will have a significant impact on ecological environment, water resources and economic society in the world. Therefore, research on water resources under the climate change is of great practical significance.

Experts and scholars at home and abroad have made a lot of researches on the impact of climate change on hydrology and water resources at different basins or regions and achieved fruitful results [1–12]. Climate change has changed the watershed hydrological processes and the distribution of water resources in time and space. Together with the profound influence of human activities on the hydrology and water resources system, climate change has caused the regional imbalance of supply and demand of water resources, frequent occurrence of flood and drought and the serious damage to the natural ecological system. Future climate variation will further change the distribution of water resources in time and space, increase or reduce water consumption, thus probably affecting the change of the watershed or regional water resources carrying capacity. Previous researches can give a clue what methods and approaches are generally used

---

* Corresponding author.

Presented at 2017 Qingdao International Water Congress, June 27–30, 2017, Qingdao, China.

1944-3994/1944-3986 © 2018 Desalination Publications. All rights reserved.

to research such problems; that is, during the evaluation of water resources response to future climate change, the selection of climate change scenario, the construction of hydrological model and the coupling of atmospheric system and land-surface water resources system are key to such research.

Based on the scientific cognition of basin water resources system features, this paper identifies the main factors driving the evolution of basin water resources and employs some existing climate scenarios and climate models to obtain key meteorological factors data as the input of basin water resources system changes; adopting the system identification method based on historical data, this paper also establishes the input–output relationship submodel between meteorological factors and land-surface water resources systems, and calculates the output results of water resources system factors by input of different meteorological factors in real time; predicated on the above data, the adaptive system identification unit model is applied to calculate the characteristic value of water resources at each key node and at different partitions.

2. Theoretical basis for predication of basin water resources under climate change

The water cycle links together the atmosphere, hydrosphere, lithosphere and biosphere on the earth, and is an important tie between the atmospheric system and the land-surface water resources system. Hydrological model is an important method to simulate and quantize the relationship between water resources formation and conversion, and water cycle theory is an important basis for studying the complex relationship between meteorological factors and land-surface water resources systems.

2.1. Water cycle theory

The water cycle is the most active in natural environment, and is also the basis of water resources formation. It is no exaggeration to say that all hydrological phenomena will disappear if without the water cycle. It is also the water cycle that makes water a renewable resource in a never-ending cycle. The global water cycle takes place at any time, between ocean and land, land and land, ocean and ocean.

Water cycle is more likely to be affected by global climate change, especially the atmospheric circulation; in turn, change in water cycle will also affect the global climate change. Here is a simple analysis of their relationship. First, water cycle is the main means of transmission, storage and conversion of energies in atmospheric system. Therefore, the change of the water cycle will inevitably affect the change of the atmospheric system. In turn, the change of the atmospheric system will also lead to the change of the water cycle mode, thus affecting the water cycle. Second, the energy that contributes to the water cycle is mainly from solar radiation energy, so the change of the solar radiation energy received by the water body will inevitably lead to the change of the water cycle. At the same time, the water cycle can redistribute the solar radiation energy on the earth's surface and relieve the heat imbalance at different latitudes. If the water cycle changes, it will inevitably alters the distribution of solar radiation energy, and thus affect the climate change. Third, the strength of water cycle and its path may also directly affect the weather around the world, such as extreme precipitation events, and can even determine the basic characteristics of the climate, such as rain, snow, hail, storm and other weather phenomena which are all the products of the water cycle.

From the perspective of system science, the natural water cycle can be seen as the driving force for the transformation and development of elements (or links) within the natural water resources system. There are complex interactions between elements (or links): one element (or link) can either promote or restrict the development of other elements (or links). Similarly, the "natural – social" water cycle can be seen as the driving force for the sustainable development of "economic society - water resources - ecological environment" complex system, and the sustainable utilization of water resources can be understood as a function of the sustainable development of "economic society - water resources - ecological environment" complex system.

Therefore, identification of climate change impact on hydrology and water resources system and its mechanism and quantitative research of water resources system response to climate change are prerequisites for the study of predication of basin water resources under climate change; while the water cycle is an essential scientific basis for research on the impact of climate change on hydrology and water resources system.

2.2. Hydrological model

Hydrologists have tried to establish hydrological models to simulate hydrological processes and further to reveal hydrological phenomena and laws of their development and changes. The hydrological model is an approximate description of the complex water cycle (evaporation, precipitation, infiltration, surface runoff and subsurface runoff) in nature, an important method for carrying out hydrological research, and an inevitable result of the study and cognition of water cycle laws.

While in practical applications, considering the change of understanding and requirements for hydrological models, the restriction of technical conditions at different stages and the difference of research purposes, simulation methods and service objects, hydrologists have developed hundreds of hydrological models at each period. The research on hydrological models has evolved from the black box model and conceptual model to today's distributed hydrological model [13].

Simply, the hydrological model can be divided into two categories: physical model and formal model. The physical model refers to an alternative system of prototype system, and the formal model is the simulation of prototype system. After appropriate generalization, the physical or mathematical equations are generally defined as mathematical model.

Mathematical model can be divided into empirical model, conceptual model and theoretical model. To be specific, the empirical model is also called the black box model or input–output model, and it does not involve the internal physical mechanism of the system, so its parameters has little physical significance, such as random time series model, including auto-regressive and moving average model. This kind of models can lead to good simulation results, and they are often used for actual flood forecasting, hydrological design and planning [14,15].

Climate changes are the main factors affecting the total water resources in the river basin, and the changes of temperature and precipitation are easy to cause environmental changes such as snow cover, freezing and thawing, evaporation, runoff and so on, further leading to changes of time–frequency of hydrological events and of water resources volume. As different basin water resources systems have different features, this paper chooses the input–output model instead of the distributed hydrological model which has more requirements for data, to simulate and analyze the correlation between temperature and precipitation changes and hydrological elements, the sensitivity of temperature and precipitation to runoff and the impact on hydrology and water resources system.

2.3. Climate change scenario and climate model

The climate change scenario is based on a series of scientific assumptions and provides a reasonable description of the future world climate. Regional climate change scenarios can be obtained by the following five methods [16]: arbitrary scenario setting method, time analogy method, spatial analogy method, time series analysis method and output method based on global climate models (GCMs). At present, GCMs are the most important and effective tool for climate change prediction, and output methods based on GCMs are often used in the study of the impact of climate change on hydrology and water resources.

GCMs output is generally based on greenhouse gas and aerosol emission scenarios. The Intergovernmental Panel on Climate Change (IPCC) has developed two emission scenarios [17,18]: IS92 (1992) and SRES (2000). In 2011, Climatic Change published a special issue, detailing the new generation of greenhouse gas emission scenario – Representative Concentration Pathways (RCP), which was used in IPCC's fifth Assessment Report for the first time, including RCP8.5, RCP6.0, RCP4.5 and RCP2.6 [19] (as shown in Fig. 1).

So far, many atmospheric science research institutions in the world have developed more than 40 different GCMs. Commonly used GCMs include the American National Center for Atmospheric Research (NCAR) model, German Max Planck Institute for Meteorology (ECHAM4) model, Canadian Meteorological Center (CCC) model, British Hadly Climate Prediction and Research Center (HADL) model and Japanese Climate Science Research Center (CCSR) model. Chinese scientists have also developed and established their own climate models on the basis of foreign climate models, including the CAS Institute of Atmospheric Physics (IAP, EAC, GOALS) model, the State Oceanic Administration (NOA) model and the National Climate Center (NCC) model. It should be noted that, output results of GCMs greatly differ due to the constraints in objective knowledge of global climate systems and reliability of data, which poses a challenge for current climate models.

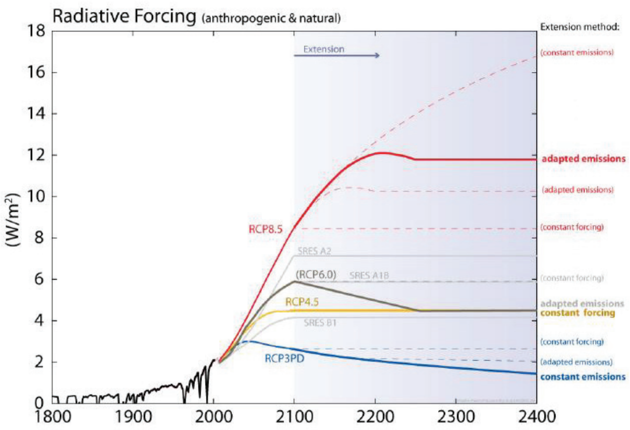

Fig. 1. Time variation of radiative forcing under RCP scenarios [19]

With an view to introducing China's regional climate change estimates in the future under the new generation of greenhouse gas emission scenario RCPs to the public in a more intuitive, visible and simple way, the Climate Change Adaption Laboratory of National Climate Center, with the support of related climate change projects of China Meteorological Bureau, provided simulation and forecast data of CMIP5 (The Fifth Phase of The CMIP) GCMs and new regional climate models in 2012, prepared and published the 3rd version of "China Regional Climate Change Prediction Data Set" (Version 3.0), which was available for researchers working on research of climate change impacts [19].

Climate change scenarios and climate models are designed to provide background data for the prediction of water resources volume, the data that include the analysis of the past and current climate and the forecasting of future scenarios. In the case study, this paper will use the monthly average dataset of model set provided by the China Regional Climate Change Prediction Data Set (version 3.0). The grid resolution of the dataset is 1° × 1°; the emission scenarios include RCP 2.6, RCP4.5 and RCP8.5; the climatic elements are precipitation and temperature; and the simulation period is from 1901 to 2005 (past) and from 2006 to 2100 (future).

2.4. ARIMAX model

The time series model is often used in studies of the change law of economic indicators. ARIMA model is an effective method to study the change law of univariate time series in economic and social systems. Some experts and scholars also use the ARIMAX model to describe the variation of multivariate time series in economic and social systems, but most of the ARIMAX models only contain one input sequence [20–22].

In addition to following its own change rules, basin water resources system is also affected by other time series, such as temperature, precipitation and human activities. In this case, an ARIMA model with a single time series or an ARIMAX model with an input time series cannot better express the change rule of multivariate time series in water resources system; therefore, for the integrity of econometric model, it is necessary to establish an ARIMAX model with multiple input variables.

Assumed that the response sequence y_t and the input variable sequence (i.e., independent variable sequence) $x_t^{(i)}$ are both stationary, a regression model of the response sequence and the input variable sequence can be constructed as follows:

$$y_t = \sum_{j=0}^{\infty} v_j^{(1)} B^j x_t^{(1)} + \sum_{j=0}^{\infty} v_j^{(2)} B^j x_t^{(2)} + \cdots + \sum_{j=0}^{\infty} v_j^{(k)} B^j x_t^{(k)} + \frac{\theta(B)}{\varphi(B)} a_t \qquad (1)$$

where $\theta(B) = 1 - \theta_1 B - \ldots - \theta_q B^q$, $\phi(B) = 1 - \phi_1 B - \ldots - \phi_p B^p$ is transfer function model, $x_t^{(j)}$ is input factor (intervention factor) and y_t is output factor.

For reducing the number of parameters, it can be simplified to:

$$y_t - \mu = \frac{\theta_1(B) B^{b_1}}{\varphi_1(B)} x_t^{(1)} + \cdots + \frac{\theta_k(B) B^{b_k}}{\varphi_k(B)} x_t^{(k)} + \frac{\theta(B)}{\varphi(B)} a_t \qquad (2)$$

where $\theta_i(B) = \theta_0^{(i)} - \theta_1^{(i)} B - \cdots - \theta_{q_i}^{(i)} B^{q_i}, \varphi_i(B) = \varphi_0^{(i)} - \varphi_1^{(i)} B - \cdots - \varphi_{p_i}^{(i)} B^{p_i}$, ($i$ = 1,......, k).

The above model is the ARIMAX model with multivariate time series, also called ARIMA model with intervention sequence or dynamic regression model. This model can be used to express the response sequence as a combination of past values of random fluctuation and past values of other sequences (input sequences). Generally, the response sequence is defined as the dependent sequence or output sequence, and the input sequence is defined as the independent sequence or predictive factor sequence.

3. Prediction of Tarim River Basin water resources volume under climate change

3.1. Overview of study area

Tarim River is the longest inland river in China. Its basin is located in the south of Xinjiang Uygur Autonomous Region and covers an area of 1.02 × 10^6 km^2, 71°39′–93°45′ east longitude and 34°20′–43°39′ north latitude. Tarim River lies in the heartland of Eurasia and flows through the southern part of Xinjiang, covering Akesu Prefecture, Kashgar Prefecture, Hotan Prefecture, Kizilsu Kirghiz Autonomous Prefecture and Bayingol Mongolian Autonomous Prefecture. Affected by human activities in the middle and upper reaches, especially the development of oasis agriculture, the Tarim River Basin has undergone tremendous evolution, and its water systems are gradually separated from the mainstream. Currently, there are only three water systems having natural hydraulic connection, especially surface water connection with the mainstream of Tarim River: namely Akesu River, Yarkant River and Hotian River, known as three origins at the upper reaches of Tarim River. Kaikong River feeds water to the lower reaches of Tarim River via Kuta Main Canal. All these rivers are jointly called “4 origins”, as shown in Fig. 2.

Tarim River Basin is located in the depression area between Tianshan geosyncline and Tarim platform, and shows the same geomorphic features with Tarim Basin, higher in west and north and lower in east and south, like a ring. The Tarim River Basin is surrounded by mountains, and demonstrates complex and diverse geomorphic features, such as mountains and basins. It is divided into three major geomorphic units: plateau mountain area, piedmont plain and desert area. The plateau mountain area is the runoff formation area of the Tarim River origins and mainstreams, the piedmont plain is the main utilization and consumption area of water resources, and the desert area is composed of fixed, semi-fixed and mobile dunes [23,24].

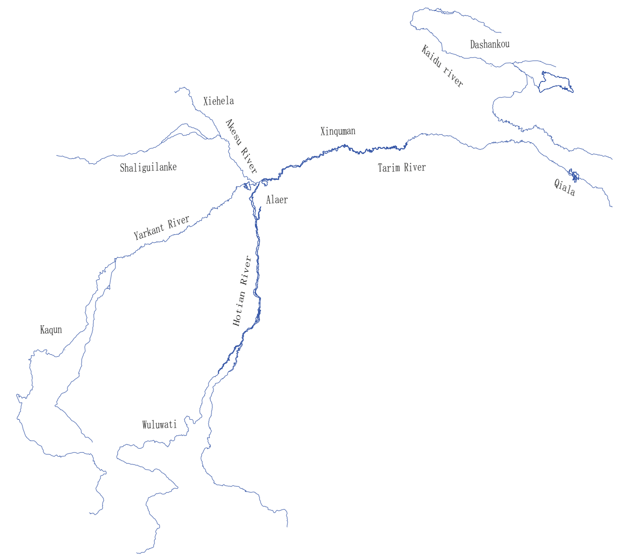

Fig. 2. Distribution of Tarim River Basin water systems.

3.2. Data information

This research selects the representative hydrological stations of “4 origins and 1 mainstream” of Tarim River, including: Dashankou on Kaidu River, Shaliguilanke and Xiehela on Akesu River, Kaqun and Yuzimenleke on Yarkant River, Wuluwati and Tongguziluoke on Hotian River, and Alaer, Xinquman and Qiala on mainstream (Fig. 2). The surface runoff data derive from the surface water resources database of Xinjiang Hydrographic and Water Resources Survey Bureau, in which the observational data from 1961 to 2010 are used; the meteorological data derive from the observational data of nationwide meteorological stations of China Meteorological Administration from 1961 to 2010; the GCM and climate change prediction data used are from the “China Regional Climate Change Prediction Data Set” (Version 3.0) which was prepared and published by National Climate Center of China Meteorological Administration.

3.3. Description of multivariate time series ARIMAX model

As described in previous paragraphs, multivariate time series model (ARIMAX) is established for constructing the quantitative regression relationship between the input series and the output series. It is widely used to describe the variation of multivariate time series in complex systems, and it also demonstrates unique advantages in water resources systems. In addition to following its own change rules, the land-surface water resource system is also affected by other time series, such as temperature, precipitation and evaporation. In such case, the ARIMA model with a single time series or the ARIMAX model with an input time series cannot better express the change rule of multivariate time series in water resources system; therefore, it is necessary to establish an ARIMAX model with multiple input variables. This model can be used to express the hydrological response sequence under climate change as a combination of past values of random fluctuated hydrological sequences and past values of temperature, precipitation and evaporation sequences (called input sequences). The hydrological response sequence represents the dependent sequence or output sequence, and the input sequences such as temperature, precipitation and evaporation sequences represent the independent sequence or predictive factor sequence.

Due to special geographical location and basin structure of Tarim River Basin, the river runoff is mainly supplied by melt water of glacier snow which is affected by temperature, precipitation and other climate factors, and applies to the ARIMAX model which contains multiple input variables. The ARIMAX models of Hotian River, Yarkant River, Akesu River and Kaikong River are established, respectively, and the modeling data include the long-term historical climate simulation and future climate change prediction data under RCP8.5, RCP4.5 and RCP2.6 scenarios, as well as the runoff observational data of the hydrological stations in origin area from 1961 to 2010. The ARIMAX model is constructed as follows.

(1) Draw the sequence diagram of raw data.

First, draw the time series charts of annual precipitation, annual mean temperature and annual runoff. Second, analyze the basic trend of observation data: whether it fluctuates around a horizontal line or a straight line, whether it rises or falls exponentially, and whether it shows the seasonal change. Finally, judge whether the sequence is stationary or non-stationary.

(2) If the sequence is non-stationary, change it to a stationary one.

If the annual precipitation, annual mean temperature and annual runoff sequences are not stationary, transform them into stationary ones with different methods. For example, if the sequence shows linear trend, adopt the difference method; if the sequence shows exponential trend, take the logarithm and then use the difference method; if the sequence shows seasonal trend, adopt the seasonal difference method and establish a seasonal model.

(3) Check whether sequences are stationary after transformation.

After the sequences are transformed, observe the new sequence diagrams and correlation diagrams, test the unit root, and finally judge whether they are stationary. If the transformed sequences are still non-stationary, repeat the steps in (2) until they are stationary.

(4) Establish ARIMAX models for stationary sequences.

Identify the model fitted to each sequence by analyzing correlation diagrams in step (3). In general, the sequence can choose any one of three models; therefore, three models should be established first. These models should be established from low order to high order until the order coefficient of the next model is not significant, and finally, only one model should be selected for each sequence through the residual sum of squares, Akaike information criterion (AIC) function, Durbin Watson statistic and other indicators. Analysis of the fitting results is based on the estimated results of the selected model. Draw the sequence diagrams of true value, fitted value and residual, and determine whether the model is the best.

(5) Predict according to selected model.

Calculate the predicted value according to the selected model. If the model is established using the transformed time series, it is necessary to reverse the prediction results of the model to obtain the predicted value of the original sequence.

3.4. Calculation processes and results analysis

3.4.1. Analysis of basin water resources

In this paper, the four hydrological stations are all selected from the control stations at mountain-pass of four origins. These four rivers are mainly supplied by glaciers and permanent snows, and their runoff mainly changes with the climate and is less likely to be affected by human activities. Alaer, Xinquman and Qiala hydrological stations on mainstream of Tarim River are all located in the desert oasis area, susceptible to human activities. The catchment areas controlled by Shaliguilanke hydrological station and Xiehela hydrological station on Akesu River are 19,166 and 12,816 km^2, respectively, their mean annual runoffs are 28.66×10^8 and 48.58×10^8 m^3, respectively, and their yearly runoff deviation coefficients are 0.24 and 0.22, respectively. The catchment areas controlled by Kaqun hydrological station and Yuzimenleke hydrological station on Yarkant River are 50,248 and 5,389 km^2, their mean annual runoffs are 65.99×10^8 and 8.47×10^8 m^3, respectively, and their yearly runoff deviation coefficients are 0.19 and 0.20, respectively. The catchment areas controlled by Wuluwati hydrological station and Tongguziluoke hydrological station on Hotian River are 19,983 and 14,575 km^2, respectively, their mean annual runoffs are 20.73×10^8 and 22.30×10^8 m^3, respectively, and their yearly runoff deviation coefficients are 0.25 and 0.23, respectively. The catchment area controlled by Dashankou hydrological station on Kaikong River is 19,022 km^2, its mean annual runoff is 35.15×10^8 m^3, and its yearly runoff deviation coefficient is 0.17. The mean annual runoffs of Alaer hydrological station, Xinquman hydrological station and Qiala hydrological station on mainstream of Tarim River are 43.38×10^8, 35.43×10^8 and 5.49×10^8 m^3, respectively, and their yearly runoff deviation coefficients are 0.27, 0.29 and 0.80. Details are shown in Table 1. The overall water resources regime in Tarim River Basin reflects that mountainous runoff of origin area is relatively stable, and the interannual variation is relatively small; in mainstream area, the water intake and use are larger due to the impact of human activities, and the interannual variation of river runoff is larger.

3.4.2. Building of basin water resources prediction model

The Tarim River Basin is a complex system composed of mountains, oases and deserts in arid inland area, where most precipitation is concentrated in mountain area, and little in oases and deserts. Runoff is easy to form in mountain area. As approaching the mountain pass, the water volume becomes larger; when flowing into the plain area, the runoff water becomes less and less and even disappears due to lack of precipitation, thus causing the river drying up. Considering these features of water resources system of Tarim River Basin, this paper uses the runoff of hydrological stations at the mountain pass to represent the total water resources

Table 1
Characteristic values of hydrological stations at “4 origins and 1 mainstream” of Tarim River Basin

Name of rivers		Hydrological station	Catchment area (km^2)	Mean annual runoff		Time order (a)
				C_V	(10^8 m^3)	
Hotian River	Kara kashgar River	Wuluwati	19,983	0.25	20.73	50
	Yurungqash River	Tongguziluoke	14,575	0.23	22.30	50
Yarkant River	Yarkant River	Kaqun	50,248 (47,378)	0.19	65.99	50
	Tizinafu River	Yuzimenleke	5,389	0.20	8.47	50
Akesu River	Toxkan River	Shaliguilanke	19,166 (10,206)	0.24	28.66	50
	Kumarik River	Xiehela	12,816 (2,306)	0.22	48.58	50
Kaikong River	Kaidu river	Dashankou	19,022	0.17	35.15	50
Tarim River	Main stream	Alaer		0.27	43.38	50
		Xinquman		0.29	35.43	50
		Qiala		0.80	5.49	50

Note: The numbers in the brackets are catchment area in China.

volume in the basin, and adopts the ARIMAX model to construct the dynamic regression forecasting model of runoff and meteorological factors such as temperature and precipitation at hydrological stations, depicts the input–output relationship between meteorological factors and land-surface water resources systems, and calculates the water resources volume in the Tarim River Basin under different climate scenarios in the future. Taking the Hotian River as an example.

According to the aforesaid ARIMAX modeling steps, the sequence diagrams of precipitation, temperature and runoff of Hotian River are drawn and shown in following Figs. 3(a)–(c).

From Fig. 3, we can see that three sequences are all kind of stationary, but the stationary test is still required. Results of unit root test show that these three sequences are all stationary, but the average precipitation and runoff both present white noise sequence, and the average temperature presents non-white noise sequence. That is to say, only the temperature sequence needs the relative optimum order determination. The runoff prediction model of Hotian River is obtained as follows by modeling the temperature and precipitation and making pretreatment of white noise, model order and parameter estimates:

$$jl1_t = 0.097434pjjs1_t - 3.76591pjqw1_{t-1} \tag{3}$$

where $jl1_t$ represents the annual runoff of Hotian River at the mountain pass; $pjjs1_t$ represents the annual precipitation; $pjqw1_{t-1}$ represents annual mean temperature and t represents the year.

Finally, the runoff sequence fitting chart (Fig. 4) should be prepared, where “*” represents the observation data of runoff sequence, the middle curve represents the fitted value of prediction model, and the upper and lower curves represent the 95% confidence interval of fitted value of prediction model. Intuitively, the dynamic regression model manifests good fitting results, and the fitting curve is right located in the 95% confidence interval, meeting the accuracy requirement of this model. Since these three sequences are of little self-nature, the output results of ARIMAX model are similar to those of general regression models.

3.4.3. Dynamic prediction results of basin water resources

The ARIMAX models of Hotian River, Yarkant River, Akesu River and Kaikong River are established, respectively, and the modeling data include the long-term historical climate simulation and future climate change prediction data under RCP8.5, RCP4.5 and RCP2.6 scenarios, as well as the runoff observational data of the hydrological stations in origin area from 1961 to 2010. Due to too large differences in air temperature, precipitation and runoff, the sequence diagrams for these three factors are drawn, respectively. From the results of unit root stationary test, the three sequences for these four origins are all stationary, but some factors present non-white noise sequence, so relative optimum order determination should be respectively made. Establish the ARIMAX model of each origin mountainous runoff according to the relative optimum order determination, and finalize the dynamic prediction model formulas of mountainous runoff for Hotian River, Yarkant River, Akesu River and Kaikong River through AIC and Schwartz Bayesian information criterion statistics comparative analysis.Based on such formulas, the water resources dynamic prediction volumes of “4 origins and 1 mainstream” in Tarim River Basin in different level years under RCP8.5, RCP4.5 and RCP2.6 scenarios can be obtained (Table 2). The overall situations of water resources of Tarim River Basin in 2020 and 2030 under RCP8.5, RCP4.5 and RCP2.6 scenarios are relatively stable, of which, the water resources volumes of Akesu River and Kaikong River show an increasing trend, while the water resources volumes of Hotian River and Yarkant River show a decreasing trend.

4. Conclusion

Taking Tarim River Basin, which is the largest continental river in China, as an example, this paper, based on the scientific cognition of Tarim River Basin water resources system features, analyzes its water resources regime, identifies the main factors (including temperature and precipitation) driving the evolution of its water resources system, and reveals that the origin areas are susceptible to climate change and that the mainstream area are affected by both climate change and human activities; by constructing the ARIMAX dynamic

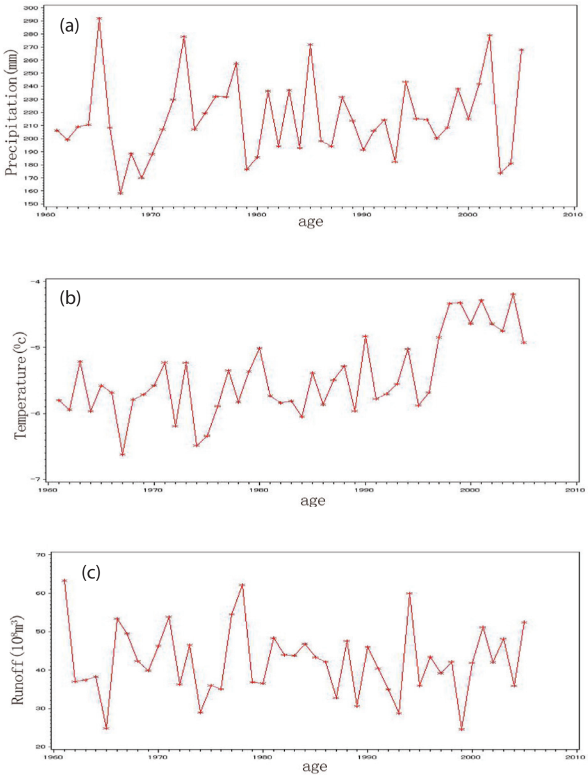

Fig. 3. Sequence diagrams of (a) precipitation, (b) temperature and (c) runoff of Hotian River.

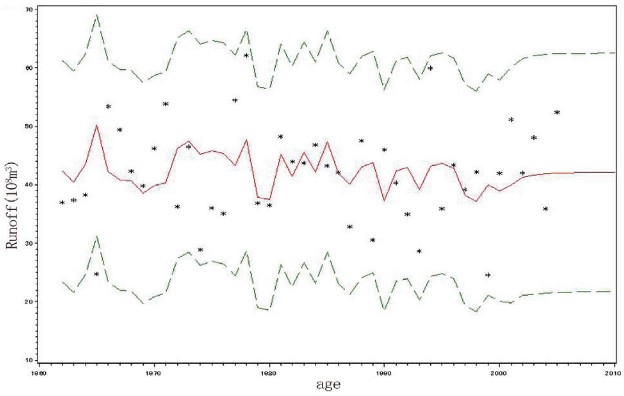

Fig. 4. Prediction of runoff ARIMAX model of Hotian River.

regression model of the meteorological factors (such as temperature and precipitation) and runoff, this paper also forecasts the water resources volume in Tarim River Basin in future different level years under the three kinds of climate scenarios: RCP8.5, RCP4.5 and RCP2.6. The overall situations of water resources of Tarim River Basin in 2020 and 2030 under RCP8.5, RCP4.5 and RCP2.6 scenarios are relatively stable, of which, the water resources volumes of Akesu River and Kaikong River show an increasing trend, while the water resources volumes of Hotian River and Yarkant River show a decreasing trend. Mainly due to the impact of climate change, especially the impact of rising temperatures, mountain glaciers abate and retreat accelerated, there glaciers and snow melting in advance, the amount of ablation increased in flood season.

In this paper, ARIMAX dynamic regression prediction models of meteorological factors such as runoff, temperature, precipitation and so on are established to build an input–output relationship submodel between meteorological factors such as temperature and precipitation and land-surface water resources system (runoff). Quantitative linkages between “climate change” factors and “water system factors”. In consideration that the research contents involve meteorology, hydrology and many other disciplines, and based on the complexity of problems, this paper uses some simplified calculation methods when establishing the model, for example, using a simple regression analysis method to establish the input–output relationship between meteorological factors and land-surface water resources systems. In future, the research in this field can be further expanded to make the calculation results more accurate and more practical.

How to maintain the healthy water cycle of the basin and support the sustainable development of the economy and society are major challenges to the basic and applied research of water science in the new era in response to the problems of water shortages and water disasters caused by climate change. Combining with the characteristics of Tarim River Basin water resources system and according to the water resources in the Tarim River Basin under different climate change scenarios, the next step is to systematically put forward the strategy and adaptability of water resources regulation and control under the climate change from the aspect of allocation, utilization, dispatch and management. Control measures to provide a scientific basis for the positive response to possible negative impacts of climate change and the implementation of strict management of water resources.

Table 2
Dynamic prediction of water resource volume in Tarim River Basin (10,000 m^3)

Partition	Water resource volume in 2020 under different scenarios			Water resource volume in 2030 under different scenarios		
	RCP2.6	RCP4.5	RCP8.5	RCP2.6	RCP4.5	RCP8.5
Hotian River	463,242	462,749	468,906	461,403	462,750	454,587
Yarkant River	722,798	719,962	720,004	705,851	704,811	698,280
Akesu River	796,123	793,728	813,991	846,141	869,591	861,298
Kaikong River	363,181	385,238	388,575	393,206	373,832	384,039
Total	2,345,344	2,361,677	2,391,476	2,406,601	2,410,984	2,398,204

Acknowledgments

This study was supported by the University Key Scientific Research Projects of Henan Province (15A570004), the University Young Backbone Teacher Training Program of Henan Province (2016GGJS-075) and the High Level Talents Scientific Research Project of NCWU.

References

[1] Y. Shi, X. Zhang, Impact of climate change on surface water resources in arid area of Northwest China and its future trend, Sci. China, Ser. B: Chem. Life Sci. Earth Sci., 9 (1995) 968–977.

[2] J. Zhang, G. Wang, Climate change and sustainable utilization of water resources in China, Hydrosci. Eng., 4 (2009) 17–21.

[3] J. Xia, C. Liu, G. Ren, Opportunity and challenge of the climate change impact on the water resource of China, Adv. Earth Sci., 1 (2011) 1–12.

[4] G. Ren, T. Jiang, W. Li, An integrated assessment of climate change impacts on China's water resources, Adv. Water Sci., 6 (2008) 772–779.

[5] Z. Hao, L. Li, J. Wang, Impact of climate change on surface water resources, Earth Sci. (J. China Univ. Geosci.), 3 (2007) 425–432.

[6] F. Li, G. Zhang, L. Dong, Review of climate change impacts on water cycle and water resources, Sci. Geogr. Sin., 4 (2013) 457–464.

[7] Y. Liu, J. Zhang, G. Wang, Evaluation on the influence of natural climate variability in assessing climate change impacts on water resources: I. Models and methods in reference period, Adv. Water Sci., 2 (2012) 147–155.

[8] Y. Chen, Z. Li, Y. Fan, Research progress on the impact of climate change on water resources in the arid region of Northwest China, Acta Geogr. Sin., 9 (2014) 1295–1304.

[9] Y. Chen, Z. Xu, The possible impact of global climate change on water resources in the Tarim River Basin, Sci. China, Ser. D: Earth Sci., 11 (2004) 1047–1053.

[10] G. Wang, J. Zhang, J. Liu, Review of climate change impacts on hydrology and water resources, China Water Resour., 2 (2008) 47–51.

[11] Z. Yang, Y. Yu, J. Wang, Climate change and its impact on water resources in Yixun River Basin, Adv. Water Sci., 2 (2011) 175–181.

[12] D. Huiping, W. Zhengfang, T. Laihua, Review of climate change impacts on hydrology and water resources, Acta Geogr. Sin., S1 (1996) 161–170.

[13] Z. Xu, Hydrological models: past and future, J. Beijing Normal Univ. (Natural Sci.), 3 (2010) 278–289.

[14] Z. Xu, L. Cheng, Progress on studies and applications of the distributed hydrological models, J. Hydraul. Eng., 9 (2010) 1009–1017.

[15] S. Sorooshian, Evolution of hydrologic modeling: meeting the requirements from the flood forecasting to hydroclimate predictions, J. Beijing Normal Univ. (Natural Sci.), 3 (2010) 241–244.

[16] J. Zhang, G. Wang, Climate Change Impacts on Hydrology and Water Resources, Science Press, Beijing, 2007.

[17] IPCC, The Fourth Assessment Report [EB/OL]. Available from: http://www.ipcc-ddc.cru.uea.ac

[18] Compilation Group, The 2nd National Assessment Report on Climate Change, Science Press, Beijing, 2011.

[19] National Climate Center, China Regional Climate Change Prediction Data Set (Version 3) [DB/OL], National Climate Center, Beijing, 2012.

[20] Y. Wang, Y. Xu, Applications of multivariate stationary time series ARIMAX Model, Stat. Decis., 18 (2007) 132–135.

[21] Y. Wang, Applied Time Series Analysis, China Renmin University Press, Beijing, 2005.

[22] G.E.P. Box, G.M. Jenkins, Time Series Analysis: Forecasting and Control, Posts & Telecommunications Press, Beijing, 2005.

[23] X. Zhang, Q. Zuo, Analysis of water resource situation of the Tarim River Basin and the system evolution under the changing environment, J. Coastal Res., 73 (2015) 9–16.

[24] X. Zhang, Q. Zuo, Analysis of series variational characteristics and causes of Tarim River Basin runoff under changing environment, Appl. Ecol. Environ. Res., 15 (2017) 823–836.