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Risk Assessment for Ecological Planning of Arid Inland River Basins Under Hydrological and Management Uncertainties

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Abstract The Shiyanghe river basin, an arid inland basin of northwest China, is taken as an example to analyze the risk for achieving the ecological planning objective in arid inland river basins under uncertainty conditions. Hydrology and management uncertainties that affect the accomplishment of ecological planning objective are analyzed quantitatively with the methods of Bayesian theory based Probabilistic model, scenario analysis and interval analysis. Bayesian probabilistic analysis method was used to analyze the hydrological uncertainties in the form of probability and interval distributions in planning period, while the scenario analysis method and interval method were used to analyze the managing uncertainties in the form of interval numbers. Instead of the ecological risk analysis, which for arid inland river basin, of studying the impact of environmental and human factor on ecological system, water resources and environment, we focused on analysing the possible impact of hydrological and management uncertainty factor on the ecological planning, and forecasting the degree of the completion under the uncertainty. Our study provided the probabilities of achieving ecological planning objective and the possible deviation of different scenarios. The more local water resources and higher level of local water resource utilization and management appeared to lead higher probability to achieve the ecological objective. This study can help environment and water resource managers and planner to formulate a rational planning for arid inland river basins under hydrological and management uncertainty.

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1 Introduction

1.1 Risk Assessment of Ecological Planning of River Basin Under Uncertainty

Ecological planning of river basin plays a vital role in a regional ecological and social development, however, the ecological planning are often failed due to uncertainties exist in nature and project management (Korteling et al. 2013; Hope 2006a). To determine the impact of uncertainty on achieving the planning objective, managers and decision makers always pay attention to two aspects: (1) Whether the planning objective could be achieved in the planning period or not, and what is the probability of the achievement (2) What is the possible deviation if the result could not achieve the planning objective (Gu et al. 2015). Therefore, risk assessment of the achievement of the ecological planning objective under uncertainty is essential for decision maker to measure the feasibility of the planning objective under uncertainty in advance, and it can help to make the more rational planning to tackle the uncertainty factor.

The researches for ecological risk assessment of river basin mainly include water environment assessment (Liu et al. 2013; Hsin-Ting and Tung 2014), river basin disaster assessment (Marianne et al. 2012), as well as integrative ecological risk assessment for river basin (Zwart et al. 2008), these studies mostly focus on the impacts of environmental disasters and human factors on ecological systems and natural receptor (Hope 2006a, b; Gottardo et al. 2011; Zhang et al. 2012; Martin-Carrasco et al. 2013).

Traditional studies of the uncertainty influence on ecological planning mainly focus on evaluating the “unexpected event” and proposing measures to decrease the risk (Suter and Glenn 2001). “Evaluating the unexpected event” means studying the likelihood that adverse ecological effects may occur or are occurring for exposure to stressor (Hope 2006a; Norton et al. 1992). The researches of the “unexpected event” always include identifying uncertainty and analyzing the probability of occurrence of adverse effects, besides, it include uncertainty management and risk prevention. However, there are few researches on the “expected event” which is about the achievement of the planning objective, whereas it is the main concern of the decision makers and the managers, therefore it is necessary to carry out the relevant study.

The key of the study is to find the restriction factor of achieving the ecological objective, the relationship between the restriction factor and the accomplishment degree of the planning objective is the relationship that between the independent variable and dependent variable. The variation range of planning results could be estimated through analyzing the variation of the restriction factor under uncertainty, and the risk of achieving the planning objective could be estimated correspondingly.

1.2 Risk Assessment of Ecological Planning of Arid Inland River Basin Under Uncertainty

Arid inland river basin (AIRB) is located in arid climate zones and its water cycle system is unique with separate and closed lands (Zhu et al. 2004), therefore the local area has low vegetation rate and extreme fragile ecosystem (Buytaert et al. 2012). With socioeconomic development, the resource system and the ecosystem in some arid river basins is subjected to increasing risk of water shortage which leads to highly contradiction between mankind and land (Ji et al. 2006; Zhang et al. 2015). Many authority of AIRB formulate ecological planning to ensure sustainable development of ecology and social economy, however the ecological planning objective are often failed due to uncertainties existed in nature and project management, such as lingering drought, schedule delay, etc (Gu et al. 2015).

For the risk assessment of ecological planning in AIRB, according to the local characteristics, the natural restriction factor is usually the local limited water resources and the management restriction factor is the implementation of the planning, while the uncertainties of the restriction factors are the possible variation of the local water resources volumes and the implementation in the planning period separately.

As for the hydrological uncertainty, the risk assessment of ecological planning for AIRB refer to the hydrological uncertainties in planning period, there are many studies about the hydrological prediction under uncertainty, it include the variation range of runoff volumes (Wu et al. 2008) or rainfall volumes (Fraedrich et al. 2015) and the relevant frequency distribution (Samuel and Sivapalan 2008), the methods include Bayesian method (Zhang and Zhao 2012), monte carlo method (Taguas et al. 2015) and fuzzy set method (Tayfur and Brocca 2015) and so on.

The Bayesian analysis method has been studied and used widely, e.g., in 1985, Krzysztofowicz developed Bayesian theory based on Probabilistic forecast model (BPF) by integrating the Bayesian method and traditional hydrological forecast to describe the uncertainty of hydrological forecast in the form of probability distribution (Krzysztofowicz 1985). The BPF is new in hydrological forecast uncertainty research. BPF overcomes the limitation of information utilization in deterministic hydrology model and can estimate the decision making risk quantitatively with greater accuracy. By analyzing the risk and generating a series of decisions quantitatively, BPF provides decisions and technical supports for flood hazard mitigation and water dispatch (Krzysztofowicz 1999, 2002; Krzysztofowicz and Kelly 2000; Ma et al. 2013).

As to the aforementioned traditional hydrological forecast method, BP neural network has the characteristics of self-learning, self-organizing, self-adapting and fault tolerance, it has been widely used in hydrological forecasting models (Campolo et al. 2003; Loukachine and Loeb 2003), such as runoff forecast (Chua and Wong 2011), rainfall forecast (Ren et al. 2010), rainfall- runoff forecast (Ren et al. 2010), flood forecast (Chen et al. 2010), etc.

Therefore the combination of BP and BPF can predict the sliding interval distribution and probability distribution of runoff in the forecast year, however, there are few studies integrating the BPF with risk assessment of achievement of ecological planning and the studies about the AIRB are even less.

As for the management uncertainty, scenario analysis and interval analysis have been widely used. Scenario analysis method is a description of a set of reasonable and uncertainty events that might occur in future (Jarke et al. 1998; Schwartz 1996; Cornish 2004). The method includes identification of event development situation, description of the event occurrence probability, and influence analysis. Scenario analysis method has been applied in water resources planning, environmental planning, ecological risk analysis and so on (Zhu et al. 2011; Karvetski et al. 2011a, b; Varum and Melo 2010; Hunt et al. 2010). Due to subjectivity and fuzziness of the artificial factors, it is difficult to analyze the probability distribution or membership grade. Instead, interval method is used to analyze the uncertainty quantitatively, and the system responding range can be calculated based on the interval analysis. The foundation of interval analysis was put forward by Moore (1962), and the interval analysis can be used to solve the calculation error. It is an important branch of statistical analysis. Interval analysis can get an interval number which contains the precise number. It is more meaningful compared to point value analysis (Moore 1962; Moore and Lodwick 2003; Hansen 1965; Xiao et al. 2013).

Therefore, the risk assessment for ecological planning for AIRB under uncertainty could be effectively carried out by analyzing the natural and management uncertainty constraint factors.

The researches of ecological risk assessment of AIRB mainly focus on the impact of climate variation on water resources as well as the impact of land use structure variation and human factor on local ecological system, water resource and water environment (Zhang et al. 2015; Liu et al. 2013; Bao et al. 2006; Ji et al. 2006). Whereas there are few studies on the risk assessment for achieving the objective of ecological planning and fewer still studies on the risk assessment of ecological restoration planning for AIRB under uncertainty. Therefore, this study should be a beneficial supplement to the current studies on ecological risk assessment.

The objective of this paper is to assess the risk in achieving the ecological planning objective for AIRB under the hydrology and management uncertainties. The study entailed several elements: (1) analyzing the probability of achieving the planning objective, (2) analyzing the possible deviation if the objective could not be achieved. Some analysis methods, e.g., BPF, BP neural network, scenario analysis, interval analysis, etc. are introduced to analyze the uncertainties in the ecological risk assessment. Shiyanghe river basin in China is taken as the study area.

2 Methodology

The ecological planning of arid inland area is generally formulated based on predicting the volumes of local water resources in the planning period, hence determining the water resource quantity is the dominant factor. The probability of accomplishment and the possible deviation could be estimated through analyzing both the water quantity which is essential to achieve the objective and the possible frequency distribution as well as the possible distribution interval of the water quantity in different water utilization and management scenario.

The hydrology uncertainties mainly refer to hydrology prediction. Because BP neural network has the characteristics of self-learning, self-organizing, self-adapting and fault tolerance, it has been widely used in hydrological forecasting models (Campolo et al. 2003; Loukachine and Loeb 2003; Üreyen and Gürkan 2008), such as runoff forecasting (Chua and Wong 2011), rainfall forecasting (Ren et al. 2010), rainfall- runoff forecasting (Ren et al. 2010), flood forecasting (Chen et al. 2010), etc. This paper will adopt Bayesian forecasting system based on BP neural network to analyze the uncertainties of runoff prediction in the form of interval numbers and probability.

As for management uncertainties, the study will adopt interval analysis method and scenario analysis method to analyze water resources consumption in the form of interval numbers in planning period. Commonly, there are two management scenarios for planning: the scenario of meeting the planning requirement and the scenario of maintaining the status quo.

Figure 1 shows the framework of the study.

2.1 Analysis of Hydrological Uncertainties

Two types of variables which are the runoff model prediction results and the discrete time observation flow are defined in BPF (Davies et al. 1992), $X = \{x_1, x_2,\ldots,x_t\}$ is defined as the measured process in prediction time t, while $S = \{s_1,s_2,\ldots,s_k\}$ is defined as the actual flow

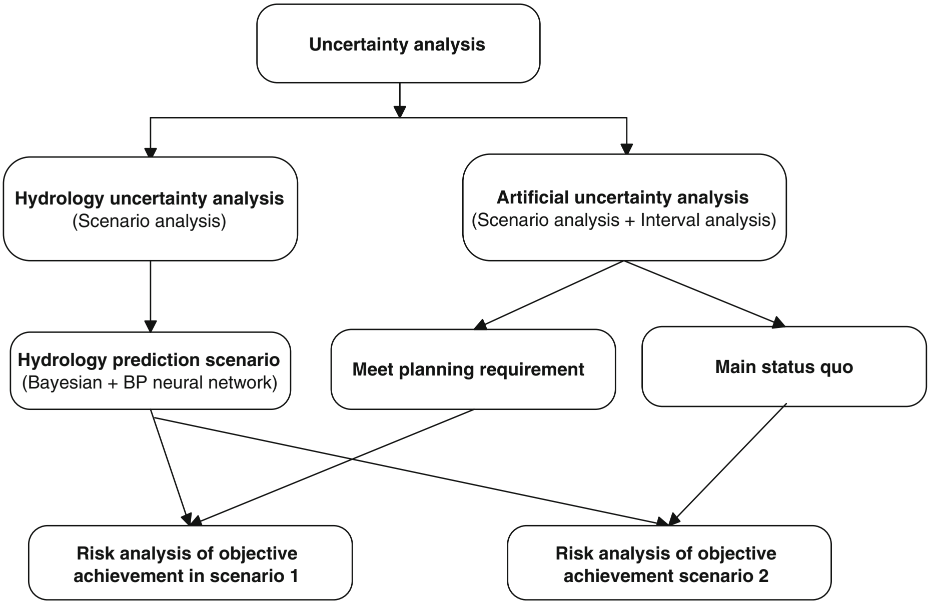

Fig. 1 Framwork of the study

process in prediction time t (k is the period in prediction time). X = $\{x_{1d},x_{2d},\ldots,x_{td}\}$ denotes the deterministic prediction value of X_d, Y = $\{(x_{1d}\text{-}x_1),(x_{2d}\text{-}x_2),\ldots,(x_{td}\text{-}x_t)\}$ denotes the residual sequence of prediction value X_d, $S_d = \{s_{1d},s_{2d},\ldots,s_{kd}\}$ is neural network prediction value of S corresponding to measure process variable X, X_d and S_d are calculated by medium and long term hydrological forecasting model. The basic concept of BPF is to predict the probability of S in accordance with known information of X, X_d and S_d in the predictive period t.

Bayesian posterior density function of S_k can be obtained using of prior distribution to show the natural uncertainty in known measure process, and likelihood function to describe the uncertainty of hydrological model and parameters, as well as Bayesian formulation to couple the prior distribution and prior distribution

$$\pi_k\left(s_k\middle|s_{kd},X,\ Y\right)=\frac{l_k\left(s_{kd}\middle|s_k,Y\right)h_k\left(s_k\middle|X\right)}{\int_{-\infty}^{\infty}l_k\left(s_{kd}\middle|s_k,Y\right)h_k\left(s_k\middle|X\right)d_{s_k}}$$

Where

π_k The posterior density of S_k
h_k Prior density
l_k Likelihood function

2.2 Analysis of Management Uncertainties

With the scenario method and the interval method, the artificial uncertainty in the planning period could be classified in two groups: the scenarios of meeting the planning requirement and of maintaining the status quo by the water resource utilization and management. The water consumption volume in first scenario is set as lower bound and the latter is set as the upper bound.

3 Case Study

Shiyanghe river basin, an inland river basin in the northwest of China, is a typical ecological deterioration basin caused by the excessive use of water. The river originates from the southern foots of Qilianshan mountain and disappears in Minqin basin in the northern Shiyanghe river basin. The basin belongs to warm temperate continental arid climate, with less precipitation, much evaporation, fragile ecological environment, and the arid index is over 52. The northern region of Minqin basin downstream is surrounded by Tenggeli desert, the western is surrounded by Badanjilin desert, and the middle has the typical desert alluvial oasis which is narrow and flat (Fig. 2).

The total area of basin is 41600 km^2, where the total area of farmland is 416 km^2, the total population is 227,000, and the population density is 55 per square mile. The basin involves Wuwei city, Jinchang city, Zhangye city and Baiyin city, among them, Wuwei city is the center of economy, politics and social development. The population of Wuwei occupies 78.4 % of the whole basin's population, while the area irrigated occupies 70 %, GDP occupies 61 %, and the total grain output occupies 80 %. Wuwei city has the largest population and the highest water resources utilization degree. The contradiction between water supply and demand of Wuwei city is the most serious of the whole Hexi area.

The main problem of the basin is water resources shortage. With the rapid growth of the basin social economy and population, the production water squeezes ecological water

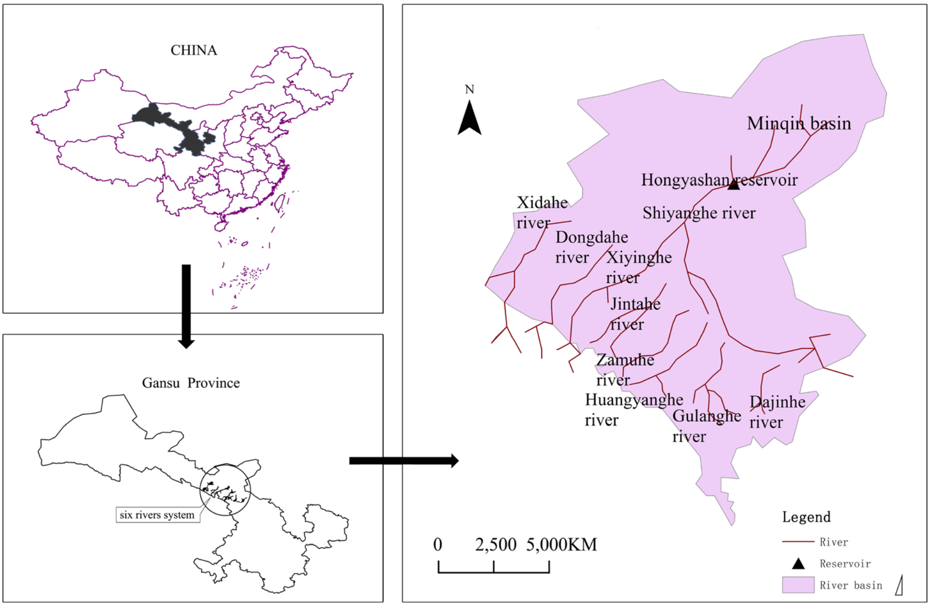

Fig. 2 The study area

seriously and it leads to the deterioration of ecological environment. In the recent 20 years, the population, irrigated area, total grain output of the basin has increased by 33 %, 30 %, 45 % separately, while the water resources supply diminished 1 %, the conflict between the supply and demand of water resources becomes increasingly serious.

The excessive use of water resources in Shiyanghe river basin not only leads to the largely decrease of the surface water, but also leads to the regional groundwater lowering and water quality deterioration. Overall, the ecological environment of the whole basin has been deteriorated greatly. In 1950s Minqin basin covers 1702 square kilometers, whereas the basin covers 1313 square kilometer right now. Since 1990s, the windbreak and sand fixation in desert fringe occurred degeneration due to water scarcity. Furthermore, the fixed dunes had moved again, and the Tenggeli deserts in the north of Minqin and the Badanjilin deserts in the west of Minqin had crept gradually, and the Minqin oasis faced the danger of disappearance. Owing to the water lack, 33,000 square kilometers natural bush had withered and 20,000 square kilometers farmland had been abandoned, part of the bush and the farmland had become deserts.

To deal with the ecological crisis of the basin, the Shiyanghe basin general improvement planning was formulated by related department in 2007. The objective of the ecological planning is that “With the precondition of normal flow year in 2020, the underwater level keeps a sustainable growth in Minqin basin, hence shallow groundwater areas with the groundwater level less than 3 miles in the area of about 70 square kilometres are expected, and there would be a wetland in certain areas in the arid area”.

The Shiyanghe river basin can be divided into three different hydrological segments according to the natural water system and water resources management and utilization. The three segments are six river systems in the midstream, six river systems downstream and Xidahe river system, six river systems in the midstream lies in Wuwei south basin including Dongdahe, Xiyinhe, Jintahe, Zamuhe, Huangyanghe and Gulanghe rivers, the six river systems downstream lies in Minqin basin (Fig. 3).

Minqin wetland is located in the Minqin basin. Some water from Wuwei south basin flow into Minqin basin, the others flow into Xihe river system artificially (transferred from Dongdahe river to Xidahe river system).

According to Shiyanghe water consumption balance table in 2020 of Shiyanghe basin general improvement planning, the ecological objective will be achieved if the basin water resources allocation meets the standard of the balance table, that is, there will be local wetland when the storage of groundwater in Minqin achieves 29.56 km^3 in planning year.

The basin water consumption balance table in planning year (2020) is as follow (Table 1):

Note: the parameters meaning of the table are as appendix.

WC_{agr}	Agricultural water consumption
WC_{eco}	Basic ecological water consumption
$WC_{ind\text{-}dom}$	Industrial and domestic water consumption
WC_{tot}	Total water consumption
WE_{in}	Basin water exchange (input)
WE_{out}	Basin water exchange (output)
$WL_{irr\text{-}eva}$	Water loss including irrigation conveyance and other evaporation
WR_{loc}	Local total water resources amount behind mountain-pass
WT	Water resources transferred from outer basin
WE_{tot}	Total groundwater amount

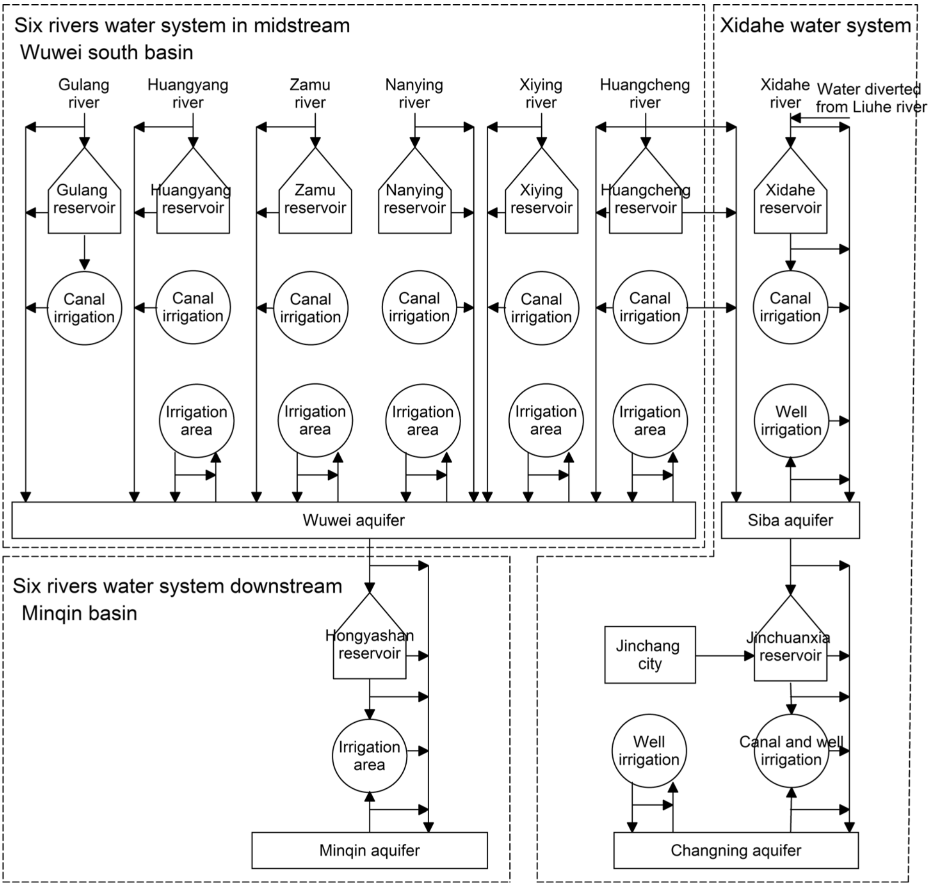

Fig. 3 Utilization and transformation of Shiyanghe river water resource system

At present, Shiyanghe basin has reached the ecological planning objective of the first planning stage in 2010, i.e., the basin has reached the water consumption balance of planning in 2010. The basin water consumption balance table in 2010 is as follow (Table 2):

One characteristic of water resources system is that there exist uncertainties and the uncertainties would influence the whole water system. The uncertainties would cause great

Table 1 Shiyanghe river basin water consumption balance table in 2020 unit: (10^8 m^3)

Subarea	WR_{local}	WT	Aggregate	WC_{agr}	$WC_{ind\text{-}dom}$	WC_{eco}	$WL_{irr\text{-}eva}$	WC_{tot}	WE_{out}	WE_{in}	UW_{tot}
Wuwei south basin	12.9369	0.1525	13.0894	6.0034	1.4025	0.5346	1.6255	9.5660	3.4875		0.0359
Minqin basin	0.3122	0.4575	0.7697	1.5803	0.1486	0.1924	0.7346	2.6559		2.1458	0.2596
Xidahe water system	2.0612	0.4000	2.4612	1.1673	1.3054	0.1163	0.5684	3.1574		1.3417	0.6455

Table 2 Shiyanghe basin water consumption balance table in 2010 unit: (10^8 m^3)

Subarea	WR_{local}	WT	aggregate	WC_{agr}	$WC_{ind\text{-}dom}$	WC_{eco}	$WL_{irr\text{-}eva}$	WC_{tot}	WE_{out}	WE_{in}	UW_{tot}
Wuwei south basin	12.9369	0.1830	13.1199	6.2704	1.2413	0.4947	1.8493	9.8557	3.2077		0.0564
Minqin basin	0.3122	0.4270	0.7392	1.6091	0.1678	0.1976	0.6179	2.5924		1.8660	0.0128
Xihe water system	2.0612	0.4000	2.4612	1.8827	1.1034	0.0876	0.7718	2.8455		1.3417	0.0426

risk in water resources system and ecological environmental system and the uncertainties would influence the feasibility and reliability of ecological planning.

3.1 Identifying Risk Source and Analyzing Uncertainty Factors

3.1.1 Identifying Risk Source

The main factors that influence water resource planning are presented in Tables 1 and 2.

$$\begin{aligned} UW_{minqin} &= W_{minqin} + WT_{minqin} + WE_{out} - WC_{minqin} \\ WE_{out-wuwei} &= WE_{inp-minqin} + WE_{inp-xihe} \\ WE_{out-wuwei} &= W_{wuwei} + WT - WC_{wuwei} - UW_{wuwei} \end{aligned}$$

Note: the parameters meaning of the table are as follows.

W_{minqin}	The local total water resources behind mountain-pass in Minqin area
W_{wuwei}	The local total water resources behind mountain-pass in Wuwei south basin
WC_{minqin}	Total water consumption in Minqin
WC_{wuwei}	Total water consumption in Wuwei basin
$WE_{inp\text{-}minqin}$	Basin water exchange (input) in Minqin basin
$WE_{inp\text{-}xihe}$	Basin water exchange (input) in Xihe water system
$WE_{out\text{-}wuwei}$	Basin water exchange (output) in Wuwei south basin
WT_{minqin}	Water resources transferred from outer basin in Minqin
UW_{minqin}	The storage of groundwater in Minqin area
UW_{wuwei}	The storage of groundwater in Wuwei south basin

The factors that influence groundwater storage can be divided into two groups: the hydrological factor (the local total water resources behind mountain pass in Wuwei south basin and Minqin basin) and managment factor (water resources transferred from outer basin total water, total water consumption, basin water exchange (output) in Wuwei south basin, basin water exchange (input) in Minqin basin and the storage of groundwater in Wuwei south basin (influenced by management factors)).

In hydrological uncertainty factors analysis, the $WE_{inp\text{-}xihe}$, $WE_{out\text{-}wuwei}$ and W_{minqin} are stable. The mostly influence factor of UW_{minqin} are W_{minqin}, i.e., the six river system including Gulang river, Huangyang river, Zamu river, Jinta river, Xiying river, and Dongda river.

Table 3 Runoff statistics data of six the rivers behind mountain-pass of Shiyanghe river basin

River	Hydrological observation station	East longitude	North latitude	Data period (year)
Dongdahe river	Shagousi station	101°56′	38°00′	1959–2013
Xiyinghe river	Sigouzui station	102°14′	37°56′	1959–2013
Jintahe river	Nanying reservoir station	102°31′	37°48′	1959–2013
Zamuhe river	Zamuhe station	102°34′	37°42′	1959–2013
Huangyanghe river	Huangyanghe reservoir station	102°44′	37°35′	1959–2013
Gulanghe river	Gulang station	103°52′	37°27′	1959–2013

Both meeting the planning objective and maintain current status scenarios were evaluated for artificial managing uncertainties, while the upper interval of the water storage level in planning year was set as the status quo level (the water consumption level in Wuwei south basin and Minqin basin maintain status quo), while the corresponding lower interval was set that the water storage level meet the planning standards (the water consumption level in Wuwei south basin and Minqin basin meet the planning level).

3.1.2 Uncertainty Quantitative Analysis

Hydrological Uncertainty Analysis (1) Empirical data collecting and sorting

The empirical data are annual runoff of six rivers behind mountain-pass of Shiyanghe river basin in Gansu province from 1959 to 2013 (55 years). All the hydrological observation stations of the six rivers are listed in Table 3.

With the methods of probability theory and mathematical statistics, the six rivers' runoff volumes in the upstream of Shiyanghe river basin were analyzed statistically to determinate the input of BP neural network forecasting. According to variation period of high flow

Table 4 Input and output of neural network

Classification	Number	Input (year)	Output (year)
Training set	1	1959–1966	1977
	2	1960–1967	1978
	…	…	…
	30	1988–1995	2006
Testing set	31	1989–1996	2007
	…	…	…
	37	1995–2002	2013
Forecasting set	38	1996–2003	2014
	…	…	…
	44	2006–2013	2020

Table 5 The forecast result of six rivers runoff

Time (year)	2014	2015	2016	2017	2018	2019	2020
Total runoff volume of the six rivers ($10^8 m^3$)	13.27	12.86	13.68	13.33	11.19	13.14	13.18

years, normal flow years and low flow years of annual six rivers runoff in Shiyanghe basin, 8 years runoff volume were set to each group as an input unit of BP neural network as Table 4 shows.

This study adopts three-layer neural network, the number of input-layers is 8, the number of hidden units is 32, and the number of output layer is 1. The runoff volume of years from 2010 to 2020 is forecasted with the trained model, and the results are shown in Table 5.

(2) Bayesian probabilistic forecast

The posteriori probabilistic density function of six rivers total runoff volumes in 2020 are forecasted with the Bayesian probabilistic forecast model, the results show that the total runoff volumes follow the normal distribution with mean 13.2290×10^8 (m^3) and variance 2.0395×10^8 m^3 (m^3) (Figs. 4 and 5). Figure 4 showed the posterior denstiy distribution, wherethe 50 % runnoff quantile corresponded to a probability of 0.20. Figure 5 showed the distribution function of the runoff volume in 2020.

Artificial Uncertainty Analysis of Artificial Factor The water consumption in the scenario of meeting the planning requirement was set as the lower bound, whereas the water consumption in the scenario of maintaining the status quo was set as the upper bound.

According to Shiyanghe basin general improvement planning, 1.3417×10^8 m^3 volumes water will be flowed into Xihe river system in planning year (2020). The water resources supply and water consumption in Xihe river system were not considered in this study because

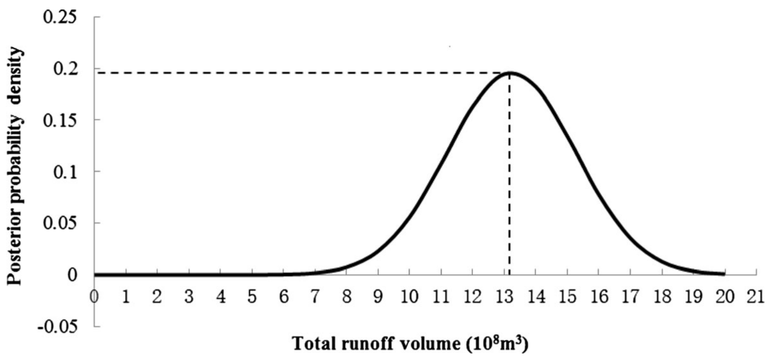

Fig. 4 The posterior probability density of total runoff volume of six rivers

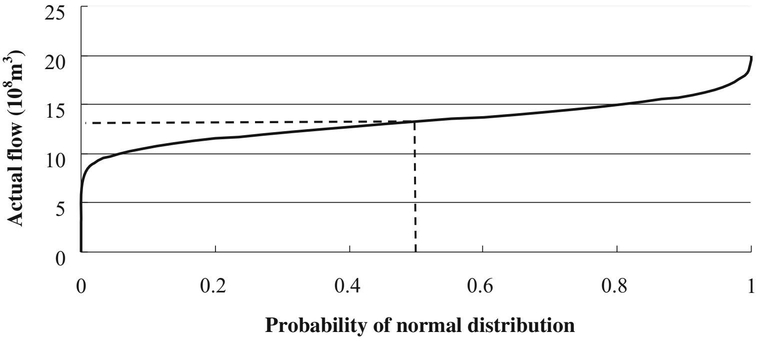

Fig. 5 The distribution of total runoff volume of six rivers

we mainly focused on the ecological objective. Therefore, the water exchange between the two basins was set as 1.3417×10^8 m^3 in planning year.

Table 6 lists the total water consumption in Wuwei south basin and Minqin basin in planning year when the water saving level maintains the status quo.

3.2 Reliability and Deviation Analysis of Ecological Objective

3.2.1 The Reliability of Ecological Objective Accomplishment

The reliability probabilities of ecological objective achievement were 22.624 and 55.6944 %, corresponding to the water saving level maintaining the status quo and meeting the planning requirement, respectively.

3.2.2 Deviation Analysis

The Scenario of Meeting the Planning Objective On the premise of $WE_{inp\text{-}xihe}$ is 1.3417×10^8 m^3, the ecological objective of Minqin basin wetland downstream can be achieved only when the W_{wuwei} is more than 12.9369×10^8 m^3, and only this volume can the balance of water consumption in Wuwei south basin and Minqin basin be satisfied, and vice versa.

The 95 % confidence interval of predictive runoff behind mountain pass was $[9.2315, 17.2265] \times 10^8$ m^3. The runoff behind mountain-pass that satisfies the balance of water consumption in planning year (2020) is 12.9369×10^8 m^3. The lower bound of predictive values (9.2315×10^8 m^3) is less than runoff behind mountain pass that can satisfy the balance of water consumption in planning year, while the upper bound (17.2265×10^8 m^3) is bigger than the runoff.

Table 6 Shiyanghe basin water consumption balance table in 2020 unit: (10^4 m^3)

	Water saving objective achieved in planning year	Water saving level maintain the status quo	Water consumption interval
W_{wuwei}	95660	112611.02	[95660, 112611.02]
WC_{minqin}	26559	27852.48	[26559, 27852.48]

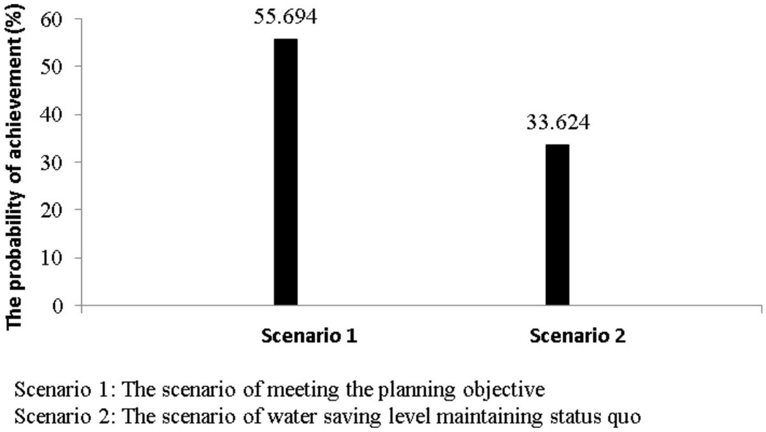

Fig 6 The probability of the achievement in two management scenarios

Because the ecological objective can be achieved when the runoff behind mountain-pass is more than the runoff satisfying water consumption balance, the deviation is 0.

We can also get that when the water saving objective is achieved, the loss deviation interval in Wuwei south basin and Minqin basin is $[0, 3.7054] \times 10^8$ m^3.

There may be a deviation interval of $[0, 0.2596] \times 10^8$ m^3 between the status quo and the ecological objective when the groundwater storage of Minqin wetland downstream is 0.2596×10^8 m^3.

The Scenario of Water Saving Level Maintaining Status Quo Set the water consumption in planning year maintains the status quo, the $WE_{inp\text{-}xihe}$ is 1.3417×10^8 m^3, and the water volumes transferred from outer basin maintains the 2020 planning objective. Based on the above setting, the six rivers runoff behind mountain-pass that meets the ecological objective is 14.7613×10^8 m^3. As 14.7613×10^8 m^3 is greater than the lower bound of the predictive runoff behind mountain pass in 2020 (9.2315×10^8 m^3) and less than the upper bound (17.2265×10^8 m^3), the loss deviation in Wuwei south basin and Minqin basin is [0,

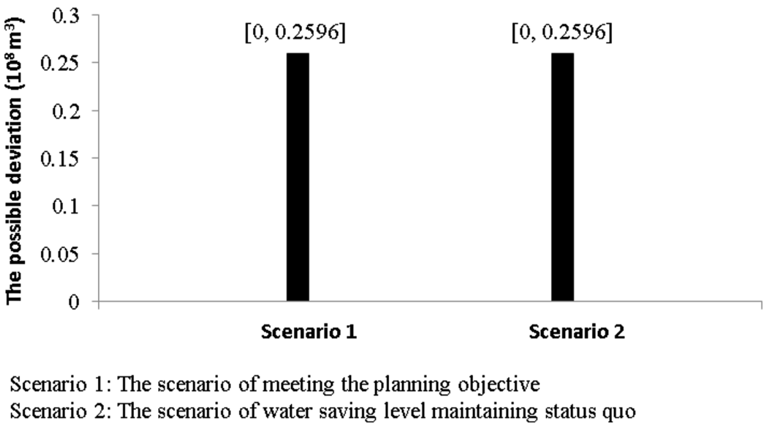

Fig. 7 The possible deviation of the planning objective in two management objective

5.5289] × 10^8 m^3, and there may be [0, 0. 2596] × 10^8 m^3 water between the status quo and the ecological objective.

4 Conclusion

The results showed that in the scenario meeting the planning requirement, the probability and the possible deviation are 55.6944 % and [0, 0.2596] × 10^8 m^3, while in the scenario maintaining the status quo are 22.624 % and [0, 0.2596] × 10^8 m^3, respectively (Figs. 6 and 7).

The results also showed that the ecological objective achievement depends on the hydrology and the water resources utilization and management in planning year. It shows that the greater volume of local water resources and the higher level of local water resources utilization and management lead to the higher probability of achieving ecological objective.

5 Discussion

It is essential for the environment and water resource managers and planner to makes risk assessment for achieving the ecological objective under uncertainty when the ecological planning is confronted with the influence of hydrological uncertainties and management uncertainties, it can help the planner to make more rational and practical ecological planning to tackle the uncertainties.

In the study, the hydrological uncertainty prediction method is applied in the risk assessment for achieving the ecological planning objective of arid inland river basin, while has been seldom applied in ecological risk assessment. The key of the application is that the local water resources volume being the natural constraint factor of the ecological objective, and the application is only fit for the region with water supply and water cycle are relatively independent, and it may refer to the joint probability distribution of the runoff volumes once the water system including the rivers from other watersheds, Therefore the application has some limitation.

The hydrological uncertainty and the management uncertainty are considered in the study, the BP, BPF, scenario analysis and interval analysis have been used to analyze the probabilities of the achievement and the possible offset under uncertainties. The BPF can effectively tackle uncertainties of hydrology prediction in the forms of probability distribution and interval distribution, whereas the scenario based analysis can help the decision maker to consider eventualities. The combination of these methods can help the decision maker to estimate the decision risk and the consequence quantitatively, and what is more, it can help the managers of arid inland river basins to identify desired planning under various environmental conditions and management factors.

The researches about arid inland river basin mostly focus on the impact of natural factor or human factor on ecological system, water resources and environment. Instead of it, the study not only analysis the possible impact of hydrological and management uncertainty factor on the ecological planning, but also forecast the level of the implementation under uncertainty. This study would be a beneficial supplement to the current studies on ecological risk assessment of arid inland river basin.

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Appendix

Table 7 Nomenclatures for variables and parameters

W_{minqin}	The local total water resources behind mountain-pass in Minqin area
W_{wuwei}	The local total water resources behind mountain-pass in Wuwei south basin
WC_{agr}	Agricultural water consumption
WC_{eco}	Basic ecological water consumption
$WC_{ind\text{-}dom}$	Industrial and domestic water consumption
WC_{minqin}	Total water consumption in Minqin
WC_{wuwei}	Total water consumption in Wuwei basin
$WC_{ind\text{-}dom}$	Industrial and domestic water consumption
WC_{tot}	Total water consumption
WE_{in}	Basin water exchange (input)
$WE_{inp\text{-}minqin}$	Basin water exchange (input) in Minqin basin
$WE_{inp\text{-}xihe}$	Basin water exchange (input) in Xihe water system
WE_{out}	Basin water exchange (output)
$WE_{out\text{-}wuwei}$	Basin water exchange (output) in Wuwei south basin
WE_{tot}	Total groundwater amount
$WL_{irr\text{-}eva}$	Water loss including irrigation conveyance and other evaporation
WR_{loc}	Local total water resources amount behind mountain-pass
WT	Water resources transferred from outer basin
WT_{minqin}	Water resources transferred from outer basin in Minqin
UW_{minqin}	The storage of groundwater in Minqin area
UW_{wuwei}	The storage of groundwater in Wuwei south basin

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