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ORIGINAL ARTICLE

Water resource vulnerability assessment in Rawalpindi and Islamabad, Pakistan using Analytic Hierarchy Process (AHP)

Rabia Shabbir, Sheikh Saeed Ahmad *

Department of Environmental Sciences, Fatima Jinnah Women University, Rawalpindi, Pakistan

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Abstract The vulnerability evaluation is always an initial step toward sustainable development. Therefore, the regionalization of the assessment to rationally utilize and develop water resources and planning for the amelioration of the vulnerability status is very important and has practical significance. The present study was aimed to analyze the vulnerability status of the water resource system in Rawalpindi and Islamabad with the help of Analytic Hierarchy Process (AHP) keeping in view the complex, integrated, comprehensive and hierarchical nature of vulnerability evaluation of water resources. The vulnerability index developed as a combination of climatic and socio-economic factors selected on the basis of their significance, relevance and scientific credibility. The water resources in both areas were found relatively vulnerable with the socio-economic factors enhancing the effect of climatic factors. The vulnerability of water resources is of special significance and needs a lot of attention of researchers and policy makers.

1. Introduction

Vulnerability is defined in many different and contradictory ways in the literature (Füssel and Klein, 2006). A major role is played by Intergovernmental Panel for Climate change (IPCC) (Hutton et al., 2011). Accordingly, vulnerability is defined as the degree to which the socio-ecosystems (SESs) of the case study region may be unable to cope with or susceptible to the adverse effects of climatic change.

The potential impact assessment for the identification of key vulnerabilities, their mitigation and adaptation has become more important in recent decades (Parry et al., 2007). Gay (2000) analyzed and introduced basic elements for the vulnerability studies on different physical aspects such as meteorological drought, water resources, forest ecosystems and coastal zones; vulnerability studies on some productive sectors such as agriculture, energy and industry, human settlements and population. Other relevant studies to the above issues have been undertaken by different authors (Hall and Murphy, 2010; Sener and Davraz, 2013; Siddayao et al., 2014; Yuan et al., 2015).

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* Corresponding author. Tel.: +92 3215167726; fax: +92 519271168.
E-mail address: drsaeed@fjwu.edu.pk (S.S. Ahmad).

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Nowadays, renewable water resources are put under great stress with the increasing demand of water. The quality and availability of freshwater resources are impacted by both climatic change and the non-climate changes. Roughly about one-quarter of the world population lives in countries experiencing water stress which accounts for 1.7 billion people (IPCC, 2001). Therefore, different research initiatives on vulnerability of water resources are important to understand the nature of resources as well for the protection, effective management and sustainable development of water resource system.

Globally different water resource vulnerability evaluation indices have been defined which involve a wide range and variety of contents, for ease of analysis and evaluation, relevant to the actual conditions like water availability, requirement and the impact of different factors. The Analytic Hierarchy Process (AHP) is one such multi-criteria decision making method used

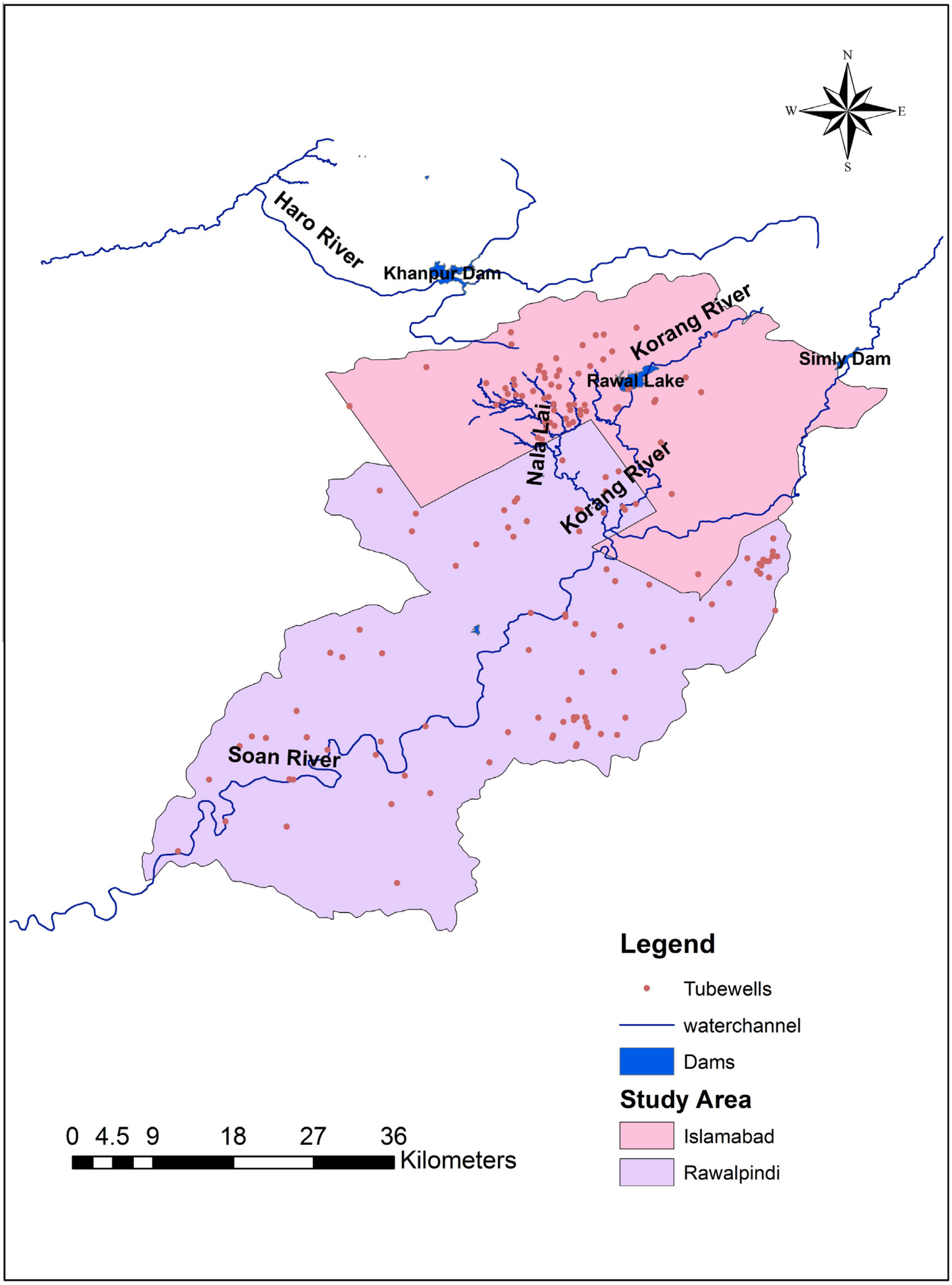

Figure 1 Map of the study area with water resources.

to evaluate and support decisions having even competing and multiple objectives (Cay and Uyan, 2013; Cheng and Tao, 2010; Guiqin et al., 2009). The basic principle of AHP for a complicated problem involves finding out relative factors first and to ensure their hierarchies, then comparing these factors with each other to ensure their comparative significance and finally give their weights (Fan et al., 2000; Ouma and Tateishi, 2014; Wen et al., 2000).

The present study therefore aimed to evaluate the vulnerability of water resource in Rawalpindi and Islamabad using AHP keeping in view the complex, integrated and comprehensive and hierarchal nature of vulnerability evaluation of water resources.

2. Materials and methods

2.1. Study area

Islamabad Federal Capital lies between 72° 48′ and 73° 22′ east longitudes and 33° 28′ and 33° 48′ north latitudes. The city is situated on the northern edge of Pothwar Plateau. Rawalpindi lies between 72° 38′ and 73° 37′ east longitudes and 33° 04′ and 34° 01′ north latitudes. On the north it is covered by the Federal Capital, Islamabad (GoP, 2005). Islamabad-Rawalpindi terrain contains mountains and plains exceeding 1175 m and is mainly uneven (Sheikh et al., 2007).

Seasonal conditions and rainfall of the twin cities are very much similar. Both cities have a lot of variation in temperature, defined by distinct seasons, with a minimum and maximum of −2 °C and 45 °C respectively. Average annual precipitation is 95.2 mm with monthly averages of 267 and 309 mm in July and August respectively, caused mainly by the Monsoon (GoP, 2005).

Due to a vast migration activity from rural to urban areas, the population in Rawalpindi and Islamabad area has greatly increased. The total population of the Rawalpindi–Islamabad area is over 4.5 million, with 3 million inhabitants in Rawalpindi and 1.5 million in Islamabad, making the region the third largest metropolitan area of Pakistan. The pressure on the demand of natural resources has increased due to this rapid population growth and has also adversely effected the environment (Sheikh et al., 2007). The study area is shown in Fig. 1.

2.2. Water resources in study area

The main water resources in the two cities are surface water and ground water. Simli Dam and Khanpur Dam are major water resources for the capital city Islamabad. Khanpur Dam also supplies water to Rawalpindi city along with Rawal Dam (Fig. 1). Along with the surface water, Capital Development Authority (CDA) is supplying the ground water of 180 tube wells to Islamabad while Rawalpindi Development Authority (RDA) is supplying by 260 tube wells to Rawalpindi. Private and municipal wells are also used to fulfill the water requirements.

2.3. Establishment of vulnerability evaluation index system

The main purpose of this research was to develop a relatively simple and practical method for the water resource vulnerability assessment. Water resource vulnerability evaluation could be done by different methods but they vary depending upon the scale of study, conditions of the index system and scope of application. The AHP is a kind of assessment method that combines qualitative and quantitative analysis by matrix calculation based on structured model. The method of assessment of water resource vulnerability with AHP involved establishment of the index system, construction of judgment matrix and single permutation of layer. The judgment matrix was created by comparing indices of same level one by one.

The vulnerability evaluation index system of the study area was comprised of 12 indices subdivided into 3 categories on the basis of vulnerability forming factors i.e. (i) Natural Vulnerability (ii) Artificial Vulnerability and (iii) Bearing Vulnerability, which were used for relative importance grading of pairwise elements (Fig. 2). The natural vulnerability reflects

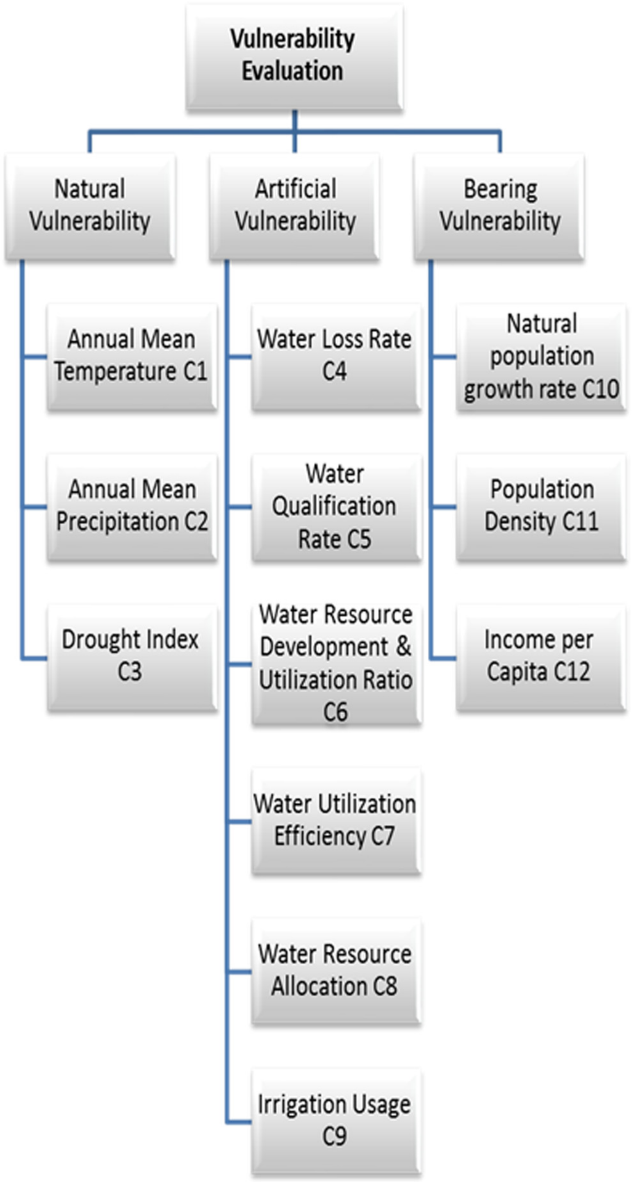

Figure 2 Water resource vulnerability evaluation index system of Rawalpindi and Islamabad.

the static characteristics of water resource vulnerability and its influencing factors. The artificial vulnerability reflects the dynamic characteristics of water resource vulnerability and its influencing factors. The bearing vulnerability is formed by system external load and its influencing factors (Yanhui et al., 2012).

These indices were selected keeping in view the actual conditions of study area, complexity of problem, the environmental quality, its stability, easy data acquisition and relatively easy quantization of quantitative indexes. In accordance with the water resource characteristics of the study area two indices including irrigation usage and water qualification rate were added to the system while rest were taken from related previous work (Lin et al., 2012; Siddayao et al., 2014; Xue-lei et al., 2003; Yanhui et al., 2012). Brief description of each index is given in Table 1.

2.4. Evaluation process

Original data about the situation of each index were derived from available statistical data for years 2006–2010, which in turn were considered as the bases for assessing the vulnerability of the water resource in the study area. The data were collected mainly from PCRWR (Pakistan Council for Research in Water Resources), WASA (Water and Sanitation Authority), CDA (Capital Development Authority), RDA (Rawalpindi Development Authority) and PBS (Pakistan Bureau of Statistics). After the data collection, Synthetic Index Method/Maximum value method was selected for the standardization of collected data for the elimination of impact on calculation caused by difference in dimensions of original data. The formula of index is shown as follows (Eq. (1)) (Yanhui et al., 2012).

$$C_i = 1 - x_i / x_i(max) \tag{1}$$

In the formula C_i was the standardized value of each index while x_i and x_i (max) were original value and maximum value of the ith index respectively.

The effect of each index component/factor on vulnerability of water resource system is reflected by weight, mainly highlighting these factors impact on evaluation results. Each index weight (W_i) is calculated by Analytic Hierarchy Process (AHP). It is a type of method for evaluation which pools the structure model based qualitative and the quantitative analysis by the calculation of matrix. The basic principle of AHP is about the finding of relative factors of complex environmental problems first, hierarchy formation and finally assigning weights to each factor after their comparison (Fan et al., 2000; Wen et al., 2000). The weights of specific criteria are determined by ranking their importance and suitability (Sener et al., 2010).

The first step of evaluation by AHP involved analyzing the significance of elements in the same layer of judgment matrix, which was to figure out the eigenvector (W_i). There are various methods for the calculation of eigenvector. The values in each row of matrix were multiplied together and then the nth root of that product gave a good estimation of correct answer. The nth roots were summed and that sum was used to normalize the eigenvector elements to add to 1.00. The biggest eigenvalue (λ_{max}) was calculated as Eq. (2).

$$\lambda_{\max} = \sum_{i=1}^{n} (AW_i)/nW_i \tag{2}$$

The next step was to make a statistical step about uniformity. The value of CI (Consistency Index) was an index used for assessment of judgment matrix's departure from uniformity (Eq. (3)).

$$CI = (\lambda_{\max} - n)/(n - 1) \tag{3}$$

Table 1 Brief description of vulnerability evaluation index system.

Criterion Layers	Indices	Description
Natural vulnerability	Annual mean temperature C1	It referred to the average temperature for the entire year at the study area
	Annual mean precipitation C2	It referred to the average rate of rainfall for a period of one year in the study area
	Drought index C3	It referred to the total gap between water supply and demand in the study region during the study time period
Artificial vulnerability	Water loss rate C4	It referred to the rate of water loss from transmission lines during water supply to the study region during the specified time period
	Water qualification rate C5	It referred to rate of successful supply of water to study area during the specified time period
	Water resource development & utilization ratio C6	It referred to the percentage of increase in planned water supply over the water consumption in the study region during the specified time period
	Water utilization efficiency C7	It calculated the efficiency of water consumption system or amount of water wasted after successful supply of water to the study area during the specified time period
	Water resource allocation C8	It referred to the planned water supply out of the available water to the study area during the specified time period
	Irrigation Usage C9	It referred to the rate of planned water consumption for agricultural purposes in the study area during the specified time period
Bearing vulnerability	Natural population growth rate C10	It referred to the rate of increase in population of study area in specified time period as a fraction of initial population
	Population density C11	It referred to the ratio of population over the study area during study period
	Income per capita C12	It referred to average income of people in study area during the specified time period

Table 2 RI table values (Source: Saaty, 1980).

n	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

In order to make certain the consistency of pairwise comparison matrix, the consistency judgment was checked for the suitable value of n by CR (Zou and Li, 2008), given in Eq. (4).

$$CR = CI/RI \tag{4}$$

where RI was the random consistency index. The RI values for different numbers of n are shown in Table 2. If value of CR is < 0.1, then it shows the uniformity of judgment matrix, otherwise adjustment is required for judgment matrix (Chakraborty and Banik, 2006).

The sequencing and sorting of value of relative importance was the next step. The final step was the comprehensive evaluation of vulnerability. The comprehensive evaluation of vulnerability (V_i) was done by Eq. (5).

$$V_i = \sum_{j=1}^{n} C_{ij} \times W_{ij} \tag{5}$$

where, V_i indicated vulnerability of water resource, n was number of aim layers, C_{ij} and W_{ij} indicated the standardized value and aim layer j weight coefficient respectively.

3. Results and discussion

On the basis of water resource vulnerability evaluation index system of Rawalpindi and Islamabad, three evaluation layers and 12 indices were defined according to AHP, the relations among factors and layers were figured out and judgment matrices compared, which were comprised of ratios of comparative importance of every pair of factors established by layers (Tables 3–5) and finally relative weight of all indices was computed layer by layer which was further summed up criteria wise.

Finally the vulnerability was calculated with the relative weight and standardized data of each index. The Table 6 shows the standardized data of each indicator.

From these C_i and W_i, the total vulnerability was found to be 1.403 for Rawalpindi and 1.314 for Islamabad (Table 7).

Table 3 Natural vulnerability and its relative judgment matrix for Rawalpindi and Islamabad.

	C1	C2	C3	W_i
Rawalpindi				
C1	1	1/7	2	0.15
C2	7	1	8	0.77
C3	1/2	1/8	1	0.07
$\lambda_{max} = 3.014$ $CI = 0.005$ $CR = 0.0086$				
Islamabad				
C1	1	1/5	3	0.22
C2	5	1	7	0.64
C3	1/3	1/7	1	0.08
$\lambda_{max} = 3.129$ $CI = 0.0645$ $CR = 0.111$				

The water resource vulnerability evaluation index developed proved that the water resources in Rawalpindi and Islamabad both were found to be relatively vulnerable according to the vulnerability standards given in Table 8. But the climate was not the single contributing factor in vulnerability; non-climatic factors like socio-economic variables were also involved in the total vulnerability of water resources, enhancing the effect of climate change as predicted and supported by the results of past studies (Lvliu, 2002; Lin et al., 2012; Sener and Davraz, 2013; Yanhui et al., 2012).

According to IPCC (2001), the adverse effect of climate change on the system, its sensitivity, adaptability and change rate within the system defines the vulnerability. Therefore, water resource vulnerability here meant change in water resource system including the natural and artificial structures i.e. water resources, water transportation, loss, drainage, water supply, demand and management, utilization, water shortage

Table 4 Artificial vulnerability and its relative judgment matrix for Rawalpindi and Islamabad.

	C4	C5	C6	C7	C8	C9	W_i
Rawalpindi							
C4	1	1	1/5	1	1/2	1/7	0.05
C5	1	1	1/5	1	1/2	1/7	0.05
C6	5	5	1	5	4	1/3	0.29
C7	1	1	1/5	1	1	1/7	0.06
C8	2	2	¼	1	1	1/7	0.09
C9	7	7	3	7	7	1	0.45
$\lambda_{max} = 6.176$ $CI = 0.0353$ $CR = 0.0285$							
Islamabad							
C4	1	3	1/3	1	3	1/2	0.16
C5	1/3	1	1/5	1/3	1	1/4	0.06
C6	3	5	1	3	5	2	0.33
C7	1	3	1/3	1	3	1/2	0.16
C8	1/3	1	1/5	1/3	1	1/4	0.06
C9	2	4	1/2	2	4	1	0.24
$\lambda_{max} = 6.441$ $CI = 0.088$ $CR = 0.071$							

Table 5 Bearing vulnerability and its relative judgment matrix for Rawalpindi and Islamabad.

	C10	C11	C12	W_i
Rawalpindi				
C10	1	1	1/6	0.125
C11	1	1	1/6	0.125
C12	6	6	1	0.125
$\lambda_{max} = 3.005$ $CI = 0.0025$ $CR = 0.0043$				
Islamabad				
C10	1	1	1/5	0.143
C11	1	1	1/5	0.143
C12	5	5	1	0.723
$\lambda_{max} = 3.01$ $CI = 0.005$ $CR = 0.008$				

Table 6 Standardized data of each indicator in Rawalpindi and Islamabad.

Criterion layers	Indicators	Rawalpindi (C_i)	Islamabad (C_i)
Natural vulnerability	Annual mean temperature C1	0.21	0.27
	Annual mean precipitation C2	0.79	0.7
	Drought index C3	0.1	0.07
Artificial vulnerability	Water loss rate C4	0.14	0.3
	Water qualification rate C5	0.11	0.1
	Water resource development & utilization ratio C6	0.50	0.48
	Water utilization efficiency C7	0.13	0.30
	Water resource allocation C8	0.17	0.1
	Irrigation usage C9	0.67	0.39
Bearing vulnerability	Natural population growth rate C10	0.0	0.0
	Population density C11	0.0	0.0
	Income per capita C12	0.45	0.39

Table 7 Total water resource vulnerability with each criterion layer in Rawalpindi and Islamabad.

Criteria Layer	Calculated V_i for Rawalpindi	Calculated V_i for Islamabad
Natural vulnerability	0.607	0.53
Artificial vulnerability	0.453	0.504
Bearing vulnerability	0.34	0.28
Total	1.403	1.314

and degree of occurrence of natural disasters under climate change. Among several problems, rapid increase in population growth (Sheikh et al., 2007), shortage of available water (SCEA, 2006), reduction in water table due to excessive withdrawal especially in Rawalpindi, change in rainfall pattern (Abbas, 2008; Khan, 2012) and poor socioeconomic conditions (GoP, 2011) have greatly contributed to the relative vulnerability of water resources in these two cities. Other problems like insufficient distribution of resources, lack of maintenance of infrastructure and policy measures for their operation, lack of awareness and citizens' involvement in different water projects, confusion of technical, social, political and environmental aims and lack of legal framework have been worsening the effect of above mentioned major factors.

In short the application of AHP for the development of vulnerability evaluation index system is mainly the comprehensive evaluation of natural and socio-economic attributes. This evaluation index system was set up according to the index characteristics of productivity, stability and the capacity of the system, which made the evaluation process comparatively comprehensive. The evaluation results of the water resource vulnerability accorded comparatively with the actual conditions of the two cities. The combination of natural and man-made factors acts as a barrier to the development. The vulnerability of water resources is of special significance and needs a lot of attention of researchers and policy makers.

4. Conclusion

The results of the study showed that both non climatic and climatic factors have an impact on water system making it relatively vulnerable. When any water resource is already pressurized by a number of factors, then any small change like water withdrawal, waste discharge or the climate change can affect the resource system. Vulnerability acts as a barrier to sustainable development. Therefore, the regionalization of the assessment to rationally utilize and develop water resources and planning for the amelioration of the vulnerability status is of practical significance.

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Table 8 Water vulnerability grading standards (Source: Yanhui et al., 2012).

Degree of vulnerability	Invulnerable	Invulnerable relatively	Vulnerable moderately	Vulnerable relatively	Very vulnerable
Range of vulnerability	$v \leqslant 0.2$	$0.2 < v \leqslant 0.7$	$0.7 < v \leqslant 1.3$	$1.3 < v \leqslant 1.8$	$v > 1.8$

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