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旱区生态环境质量的综合定量评价模型

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摘要：生态环境质量是社会经济可持续发展的基础。因此，建立旱区生态环境质量的定量评价是区域可持续发展的主要依据。现有的评价方法大多是通过根据评价区评价指标量化值与评价等级标准来建立评价模型，评价区不同，评价模型也不相同，计算工作量较大。根据给定的生态环境质量评价等级标准，采用随机技术模拟生成足够数量的评价指标序列，应用人工神经网络模型(artificial neural network, ANN)，以评价指标生成序列与其所属的评价等级值进行网络训练。网络训练后，以评价区的评价指标为网络的输入，通过计算，可获得相应的生态环境质量评价等级值。并以甘肃省石羊河流域生态环境脆弱的民勤县为研究对象，应用 1975～2000 年资料进行了实例研究。结果表明，民勤县 1975～2000 年生态环境质量效应评价值分别为 2.9501，4.0090，4.1342，4.1637，4.9736，5.0128，说明该地区的生态环境质量是持续下降的，与以往采用的模糊综合评价等级值 3，4，4，4，5，5 一致。文中 ANN 模型建立后，对于不同评价区，只要给定相应的评价指标值，通过 ANN 模型计算，可直接得出生态环境质量评价等级值。因此，模型具有实用、可操作性强的特点，大大减少了评价区的计算工作量，可以用于生态环境质量效应评价。

关键词：旱区；生态环境质量；指标体系；评价方法；人工神经网络

Comprehensive quantitative assessment models for ecological environment in arid area

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Abstract: The quantitative assessment of local environmental conditions constitutes one of the most important issues for researchers in the area of sustainable development in arid areas. During the past two decades, a number of methods have been used to assess environmental quality. The methods include: comprehensive assessment methods, fuzzy assessment methods, gray system clustering, principle component analysis, factor analysis and projection pursuit algorithms. These models usually establish functions based on assessment indicators and their assessment grade values. Variation in these models is high and the calculations are cumbersome.

Environmental quality, economics, and society constitute a very complicated system. The system is influenced by multiple factors and constraints, such as weather, geography, political systems and world affairs. The factors in this complex system have mutual effects and different forms of uncertainties, therefore the relationship between indictors and their assessment grade value is nonlinear.

An artificial neural network (ANN) is a mathematical model structure that is capable of representing the complex nonlinear processes related to the inputs and outputs of any system. ANNs also have excellent nonlinear approximation capabilities. Due to these factors ANN techniques have drawn a lot of interest from researchers studying environmental

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quality. In this case study, we applied ANN techniques to analyze data from Minqin County, Gansu Province, China. The area, which is in the Shi Yanghe basin, represents one of the most environmentally degraded areas in all of China. Our purpose was to establish a general-purpose model for the quantitative assessment of environmental quality in arid areas.

The ecological environment quality indicator system in the study area had 32 indicator and assessment criteria. The criteria were classified into 5 grade values, i.e. 1, 2, 3, 4 and 5, where 1 = excellent, 2 = good, 3 = average, 4 = bad, and 5 = worst. Our work consisted of three steps. First, according to assessment criteria, we used stochastic simulation methods to generate 21 training samples (#1～#21) containing 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 200, 300, 400, 500, 600, 700, 800, 900, 1000, 1500 and 2000 indicator groups for each grade value respectively. Their sample sizes for training samples #1～#21 were 50, 100, 150, 200, 250, 300, 350, 400, 450, 500, 1000, 1500, 2000, 2500, 3000, 3500, 4000, 4500, 5000, 7500, 10000 respectively. Secondly, a 3-layer Back Propagation (BP) network was built to assess the environmental quality. It had one input layer, one hidden middle layer and one output layer. The stochastic simulation indicators were used as inputs and their corresponding grade values as target outputs to train the network. The input and output data were normalized to fall in the range [0.05,0.90]. The network was trained until the mean squared error (*MSE*) was less than 0.001. After that, weights and biases were obtained for the 21 ANNs. Finally, environmental indicators collected in Minqin County from 1975 to 2000 were input into each network and the results assessed.

According to the assessment results, the assessment values were stable after the sixth sample (training sample size = 600). This indicated that the model can be used to assess environmental conditions in arid areas. The assessment results for 1975, 1980, 1985, 1990, 1995, and 2000 were 2.9501, 4.0090, 4.1342, 4.1637, 4.9736, 5.0128 respectively. The results are in agreement with results derived using fuzzy assessment methods (Shi Y W, 2003), and indicate that environmental quality in the study area is decreasing. This decline can be attributed to an overall shortage of water in the region as well as inefficient use of the water that is available. We suggest that the situation could be improved by constructing water saving systems.

The model in this paper requires iterative calculations, but with the ANN calculation toolbox contained in Matlab, its solution is feasible and convenient. The model could be used to assess environmental quality from any area as long as the indicators and criteria are the same. Stochastic techniques were used to simulate assessment indictor samples and a trial calculation was used to determine the training sample size, however, the results from the present study showed the possibility of assessing environmental quality from a new perspective. Additional research needs to be done to determine the fastest and most effective methods for determining the sample size required to train the ANN.

Key words: arid area; ecological environment; indicators system; assessment method; artificial neural network

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生态环境质量是社会经济可持续发展的基础。因此,建立生态环境质量的定量评价是旱区可持续发展的主要依据。目前,国内外许多学者从各自的研究领域出发,对其进行了研究,评价方法主要有综合评分法、模糊综合评价法、灰色聚类评价法、主成分分析、因子分析法和投影寻踪法等[1~8]。所有这些评价方法大多是根据评价区评价指标量化值与评价等级标准,建立评价模型,评价区不同,评价模型也不相同,计算工作量较大[5]。

本文是在给定生态环境质量效应评价等级标准下,试图寻求一种通用的评价模型,进行不同地区生态环境质量的综合评价。其根据是生态环境质量效应评价,实际上是根据已定的评价等级标准,由指标组成的指标值序列,确定出相应的等级值。如果,根据给定的生态环境质量效应评价等级标准,采用随机技术模拟生成足够数量的评价指标序列,以这些指标生成序列和其所属的评价等级值来建立评价模型,则大大减少了模型建立工作量。人工神经网络(Artificial Neural Network,ANN)是一种大规模具有高度并行处理能力的非线性动力系统,由于其具有自适应性、自学习性、容错性和联想记忆能力等许多常规方法所不具备的特点,因而为一些用常规方法难以达到理想效果的问题解决提供了一条崭新的途径。

基于上述思路,本文应用BP(Back Propagation)网络模型,以评价指标为网络的输入值,生态环境质量效应评价等级为网络的输出值,建立了生态环境质量效应评价的ANN模型,并以甘肃省石羊河流域生态环境脆弱的民勤县2000年指标值进行了实例研究。

1 生态环境质量效应评价的ANN模型

1.1 BP网络

根据生态环境质量效应评价研究问题的特点,本文选用BP 网络作为ANN 建模的基本网络。BP 网络是一种多层前向神经网络[6]。一般地,一个ANN 若有m 个隐含层,且每个隐含层均由p 个单元组成,则可将其表示为ANN(n, m, p, q)。用x_i(i=1, 2,…, n)表示其输入,w_{ij}^h(i=1, 2,…, n;j=1, 2,…, p)表示从输入层到隐含层的连接权,w_{jk}^h(j=1, 2, …,p;k=1, 2, …, q)表示从隐含层到输出层的连接权。y_j^h 表示隐含层的输出,则其算式为:

$$y_j^h = f(s_j) = f(\sum w_{ij}^h x_i + \theta_j) \ (i = 1,2,\cdots,n; j = 1,2,\cdots,p) \tag{1}$$

式中,$f(s_j)$是表示生物神经元特性的Sigmoid;s_j 是j 单元的输入;θ_j 是阈值。对于输出层,式(1)中的$i\rightarrow j$=1,2,…,p;$j\rightarrow k$=1,2,…,q。当隐含层为m 层时,(1)式中的h=1,2,…,m,且当h >1 时,i=1,2,…,p。$f(s_j)$一般采用用logsig(s_j)函数,即:

$$\text{logsig}(s_j) = \frac{1}{1 + e^{-s_j}} \tag{2}$$

当给定一组学习(输入)模式x_t(i=1, 2, …, N),并给定ANN 结构,即可用适当的算法对ANN 进行训练,使其输出$\hat{y}_i$ 与实际输出y_i 之间的误差E 小于等于限定值E_o,即$E\leqslant E_o$,则训练结束,相应的ANN 及其参数便构成所求问题的ANN 模型。

1.2 模型的基本形式

设生态环境质量效应评价指标序列为x_{ij},评价等级序列为y_i,i=1, 2,…, n;j=1, 2,…, m,n,m 分别表示指标序列容量和评价指标数目。则有:

$$y_i = f(x_{ij}) \tag{3}$$

式中,ANN 模型的输入层有m 个单元(x_{ij};j=1, 2,…, m),输出层有一个单元(y_i)。

1.3 模型建立的步骤

(1)根据生态环境质量效应评价等级标准,采用随机技术模拟生成足够数量的评价指标序列,以这些指标生成序列和其所属的评价等级值构成建模序列[5]。设第k 个评价等级中评价指标取值的下限和上限分别b_j^k,a_j^k,y_i^k 为其相应的评价等级值,i=1, 2,…, n_k;j=1, 2,…, m;k=1, 2,…, K,n_k 为按第k 个评价等级生成指标序列容量,m 为评价指标数目,评价等级数目为K。则评价指标随机模拟公式为:

$$x_{ij}^k = RAND(x) \times (b_j^k - a_j^k) + a_j^k。\tag{4}$$

式中,对于第k 个评价等级可生成n_k 组(x_{ij}^k,y_i^k)。对所有(x_{ij}^k,y_i^k) ,k=1, 2,…, K,重新编排下标,可得序列(x_{ij},y_i),i=1, 2, …, N;j=1, 2,…, m。

(2)评价指标和评价等级值序列规格化处理 评价指标按下式进行规格化处理:

$$x'_{ij} = \frac{x_{ij} - x'_{\min}}{x_{\max}^j - x_{\min}^j}\alpha + \beta \tag{5}$$

式中,α 和β 是规格化数据的上下限限定因子,即把数据规格化在[β,α]之间;$x_{\max}^j$和 $x_{\min}^j$分别为第j 个指标的最大、最小值。

评价等级值按下式进行规格化处理:

$$y'_i = \frac{y_i - y_{\min}}{y_{\max} - y_{\min}}\alpha + \beta \tag{6}$$

式中,$y_{\max}$和 $y_{\min}$分别表示y_i 的最大、最小值;α 和β 意义同前。

(3)选取ANN 的隐含层数和各隐含层单元数,给定输出与实际输出之间的误差限定值E_o。根据序列 (x_{ij},y_i),对ANN 进行训练。当$E\leqslant E_o$ 时,则训练结束。相应的ANN 结构参数、权重和阈值便构成生态环境质量效应评价ANN 的模型。

(4)生态环境质量效应评价 设生态环境质量效应评价指标值为(x_{ij});i=1, 2,…, n;j=1, 2,…, m,n 为评价区指标序列容量,m 为评价指标数目。将x_{ij}、y_i 代入式(5)~(6)进行规格化处理,并以规格化处理化后的值x'_{ij}作为ANN 的输入值,y'_i 作为输出值,按上述训练获得的ANN 结构参数及权重和阈值,通过计算得到输出的规格化值y'_i。由式(7)可得评价等级值y_i。即:

$$y_i = \frac{(y'_i - \beta)(y_{\max} - y_{\min})}{\alpha} + y_{\min} \tag{7}$$

2 实例研究

本文选用石羊河生态环境脆弱的民勤县为例[9],进行2000 年生态环境评价。其评价指标体系、评价标准见资料①,评价等级数越大,表明生态环境质量越差,最好级为1,最差级为5。石羊河流域位于甘肃省河西走廊东部,腾格里沙漠和巴丹沙漠之间,属完全封闭的内陆河流域,具有功能完整的生态系统。民勤县位于石羊河流域下游,隶属于甘肃省武威市管辖,其东北、西北分别被腾格里沙漠和巴丹吉林沙漠包围,中部为石羊河冲击湖积成狭长而平坦的绿洲带,是我国典型的荒漠绿洲带之一。2000 年,

① 师彦武.旱区流域水资源开发的水土环境效应分析及综合评价模型.西北农林科技大学硕士论文.2003.

全县总人口 29.83×10^4 人，土地面积 1.6×10^{4}km^2，境内荒漠气候特征明显，多年平均降水量为 113mm，目前年径流只有 1.0×10^{8}m^3，仅占实际需水量的 1/5，用水主要开采地下水，工农业生产和绿洲存在都强烈地依赖于水资源。2000 年生态环境评价指标如表 1 所示。

表 1 民勤县生态环境质量评价指标值

Table 1 Assessment indicators values of ANN model for ecological environment in Minqin County

评价指标 Assessment indicators	年份 Year					
	1975	1980	1985	1990	1995	2000
人均水资源占有量 Renewable water resources produced internally per capita(m^3/人)	829	769	701	657	599	571
单位耕地水资源占有量 Renewable water resources produced internally per arable area(m^3/hm^2)	8100	6150	4800	4350	3150	2700
水资源利用率% of water resources withdrawal to renewable water resources produced internally(%)	65.0	68.0	73.4	75.0	77.4	78.5
平水年缺水率% of water shortage in normal year(%)	17.8	21.3	23.7	28.6	35.1	39.6
水资源负载指数 Supporting value of water resources	21.4	22.6	23.5	23.4	24.5	25.2
耕地灌溉率(%) % of irrigated area to arable area	64.2	85.5	72.9	66.7	66.8	65.1
地表径流模数 Surface water per geographical area($10^4m^3/km^2$)	1.84	1.51	1.34	0.93	0.72	0.68
水域面积缩减率 Decrement rate of water area(%)	11	19	26	39	51	67
上游来水量缩减率 Decrement rate of water area at upper reaches of a river(%)	34.3	46.5	52.2	60.3	66.3	70.0
灌溉用水矿化度 Degree of mineralized irrigation water (mg/L)	630	750	840	1030	1180	1250
地表水质综合指数 Comprehensive index of surface water quality	0.35	0.70	0.40	1.25	0.82	0.75
河流含沙量 Sediment concentration of river(kg/m^3)	0.75	0.92	0.41	0.83	2.30	1.70
地下水超采率% of ground water overexploited(%)	27.8	55.6	77.9	93.7	134.0	149.0
地下水位埋深 Annual average depth of ground water level (m)	3.2	9.4	11.7	15.6	19.8	25.6
地下水位年降幅 Annual descent range of ground water level(m/a)	0.35	0.50	0.61	0.31	0.42	0.57
地下水矿化度 Degree of mineralized groundwater(mg/L)	820	1870	2340	2880	3610	4700
绿洲面积率% of oasis area to geographical area(%)	10.2	8.2	8.7	8.9	9.2	9.8
人工绿洲面积增加率 Increased rate of natural oasis area (%)	1.1	3.6	7.8	5.8	−1.5	−7.7
天然绿洲面积缩减率 Decreased rate of natural oasis area (%)	5.9	14.1	22.5	26.8	29.7	32.0
植被覆盖率 Vagetation covering rate(%)	28.9	23.6	19.7	13.9	11.7	14.8
缺水林地死亡率 woodland vanish rate(%)	3.1	8.5	15.3	22.8	32.3	46.0
天然草场退缩率 Decrement rate of natural grassland(%)	34.5	38.4	41.8	47.5	54.3	62.0
土壤盐渍化面积比例% of salinized arable area to total arable area(%)	33.0	42.7	52.6	65.7	76.7	85.0
土壤盐渍化程度 Salinized arable grade(%)	59.1	54.8	56.5	61.8	63.5	65.0
盐渍化面积扩大率 Expand rate in salinized arable area(%)	29.0	45.3	56.4	65.7	70.8	75.3
盐渍化区土壤含盐量 Soil salt content in salinized arable area(g/kg)	7.90	5.40	6.10	6.80	8.10	7.94
沙漠化面积比率% of desertified area to geographical area (%)	75.4	75.7	74.9	74.7	78.5	75.0
潜在沙漠化面积比率% of latent desertified area to geographical area(%)	21.2	19.3	16.5	17.8	20.3	23.0
沙漠化程度 Desertified area grade(%)	53.8	48.6	45.8	46.5	51.3	56.4
沙漠化面积扩大率 Desertified area expanded rate(%)	−0.9	−1.0	−1.6	−1.8	0.3	−0.1
沙漠化区地下水埋深 Groundwater depth of desertified area (m)	4.8	5.8	6.3	7.4	9.3	11.0
沙漠化区植被覆盖率 Vegetation covering rate of desertified area(%)	11.8	10.9	10.4	10.5	9.8	9.5

2.1 模型结构确定

取指标数 $m=32$，ANN 选用二层隐含层，隐含单元数为 32，规格化数据的上、下限为 $\alpha=0.9$，$\beta=(1-\alpha)/2$，响应函数 $f(s_j)=\mathrm{logsig}(s_j)=\frac{1}{1+e^{-s_j}}$，误差控制 $E_o=0.0001$。

2.2 训练样本序列随机生成

根据表 1 中指标的取值范围和评价等级，利用(4)式随机生成 P 个评价序列，对于每个评价序列，其每个评价等级分别随机生成 l 个评价指标值，则 5 个评价等级组成的训练样本序列容量为 $5l$。本文分别选取 $P=21$ 个样本序列，其中 $l=10\sim2000$，则训练样本序列容量分别为 50～10000，见表 2 所示。

表 2　训练样本随机生成序列

Table 2　Numbers of training sample which stochastically simulation

项目 Item	序号 No. of sample										
	1	2	3	4	5	6	7	8	9	10	11
指标生成数 Stochastic simulation indicators	10	20	30	40	50	60	70	80	90	100	200
样本数量 Numbers of sample	50	100	150	200	250	300	350	400	450	500	1000

项目 Item	序号 No. of sample									
	12	13	14	15	16	17	18	19	20	21
指标生成数 Stochastic simulation indicators	300	400	500	600	700	800	900	1000	1500	2000
样本数量 Numbers of sample	1500	2000	2500	3000	3500	4000	4500	5000	7500	10000

2.3 ANN 模型参数与评价区评价等级值确定

应用(5)～(6)式进行样本数据的规格化处理，根据ANN 模型进行21 个样本序列训练。训练结束后，利用式(7)进行评价区生态环境评价等级值还原计算。当评价区生态环境评价等级值达到稳定时，其模型参数作为 ANN 模型生态环境质量评价的参数。

通过计算，民勤县 2000 年生态环境评价等级值如图 1 所示。前 p 个($p=1,2,\cdots,21$)样本与其评价等级值见图 2 所示。从图 1 和图 2 可以看出，第 6 个样本序列(当样本容量 300 时，每个评价等级中指标随机生成 60 个指标序列)以后，评价等级值基本保持稳定。因此，选用第 6 个样本对应的参数可作为 ANN 模型参数。表 3 列出了第 6 个样本每个指标随机生成的前 20 个样本点和训练结果。民勤县 2000 年生态环境评价等级值如表 4 所示。表 4 说明民勤县 1975～2000 年生态环境质量是持续下降的。评价等级值为 2.9501，4.0090，4.1342，4.1637，4.9736，5.0128，与文献[9]模糊综合评价等级值 3,4,4,4,5,5 相一致。表明，文中模型具有实用、可操作性强的特点，可以用于生态环境质量效应评价。

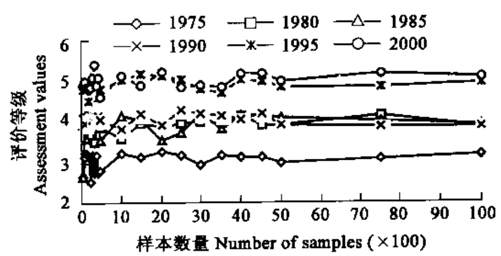

图 1　样本数量与评价结果

Fig. 1　Relationship between number of samples and their assessment values

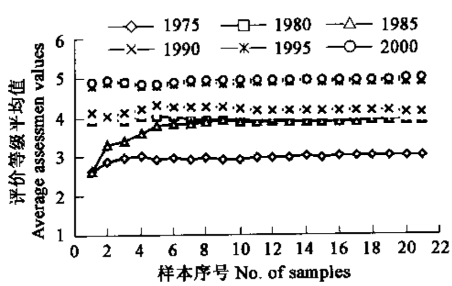

图 2　样本序列评价结果评价值

Fig. 2　Avereage assessment values of samples

3 结论

生态环境质量效应评价指标与评价等级间为非线性关系，属于非函数的模式识别。本文应用人工神经网络模型，根据生态环境效应评价等级标准，采用随机技术生成评价指标序列，建立评价指标与评价等级值的 ANN 模型，试图寻求一种通用的生态环境效应评价模型。并以甘肃省石羊河生态环境脆弱的民勤县为研究对象，应用了 ANN 模型的应用。通过评价指标随机生成序列计算评价区生态环境效应评价等级值，根据随机生成序列与评价区评价等级值以及前 p 个($p=1,2,\cdots,p$)随机生成序列评价等级值的平均值，最后确定出评价指标随机生成序列的容量大小和ANN 模型评价模型的稳定判断。虽然，文中ANN 网络模型训练相对复杂，但是，人工神经网络模型的计算已有现成的计算工具箱和软件包，借助于计算机是完全可以实现求解的。在给定的生态环境质量效应评价指标与评价等级下，ANN 模型建立后，对于不同评价区，只要在 ANN 网络模型的输入层单元输入评价区的生态环境质量效应评价指标，通过模型计算，即可获得相应的评价等级值，大大减少了评价计算工作量。因此，文中

ANN 模型具有实用、可操作性强的特点，可以用于生态环境质量效应的评价，为区域生态环境质量效应的评价提供了一条途径。但是，本文采用试算方法确定ANN 模型中评价指标随机生成序列组成训练样本集的容量大小，因此，其快速有效的方法还有待于进一步研究。

表3 ANN 模型样本训练结果与评价等级标准比较

Table 3 Comparison results between ANN model calculated and assessment grades

样本序号 No. of samples	评价等级 Assessment grades	ANN 模型值 ANN's models value	相对误差(%) Relative error	样本序号 No. of samples	评价等级 Assessment grades	ANN 模型值 ANN's models value	相对误差(%) Relative error	样本序号 No. of samples	评价等级 Assessment grades	ANN 模型值 ANN's models value	相对误差(%) Relative error
1	5	4.9810	0.3793	35	4	3.9947	0.1315	69	2	1.9955	0.2231
2	5	4.9826	0.3486	36	4	3.9953	0.1185	70	2	2.0105	−0.5244
3	5	5.0221	−0.4419	37	4	4.0105	−0.2625	71	2	2.0005	−0.0266
4	5	5.0211	−0.4211	38	4	3.9950	0.1253	72	2	1.9892	0.5375
5	5	4.9930	0.1402	39	4	4.0039	−0.0971	73	2	1.9933	0.3341
6	5	5.0117	−0.2334	40	4	3.9997	0.0079	74	2	2.0098	−0.4914
7	5	5.0194	−0.3883	41	3	2.9985	0.0495	75	2	2.0003	−0.0134
8	5	4.8845	2.3100	42	3	2.9808	0.6385	76	2	2.0023	−0.1137
9	5	5.0043	−0.0859	43	3	2.9929	0.2361	77	2	2.0103	−0.5165
10	5	5.0186	−0.3719	44	3	3.0042	−0.1390	78	2	2.0081	−0.4042
11	5	5.0219	−0.4370	45	3	2.9980	0.0680	79	2	2.0029	−0.1427
12	5	5.0082	−0.1641	46	3	2.9993	0.0239	80	2	2.0075	−0.3772
13	5	4.9871	0.2583	47	3	2.9928	0.2390	81	1	0.9976	0.2410
14	5	5.0141	−0.2820	48	3	3.0025	−0.0849	82	1	1.0078	−0.7842
15	5	4.9648	0.7044	49	3	3.0051	−0.1702	83	1	0.9897	1.0267
16	5	5.0151	−0.3028	50	3	3.0014	−0.0469	84	1	1.0023	−0.2286
17	5	4.9842	0.3152	51	3	3.0016	−0.0549	85	1	0.9979	0.2112
18	5	4.9881	0.2384	52	3	2.9929	0.2364	86	1	1.0098	−0.9779
19	5	5.0156	−0.3121	53	3	3.0051	−0.1700	87	1	0.9919	0.8122
20	5	4.9926	0.1488	54	3	2.9974	0.0851	88	1	0.9927	0.7274
21	4	4.0110	−0.2754	55	3	2.9984	0.0524	89	1	1.0020	−0.2008
22	4	3.9970	0.0760	56	3	2.9928	0.2394	90	1	0.9951	0.4851
23	4	4.0082	−0.2049	57	3	3.0042	−0.1400	91	1	1.0013	−0.1287
24	4	4.0126	−0.3145	58	3	3.0007	−0.0231	92	1	1.0191	−1.9125
25	4	4.0073	−0.1818	59	3	3.0000	−0.0006	93	1	1.0032	−0.3183
26	4	4.0039	−0.0970	60	3	2.9952	0.1600	94	1	0.9959	0.4132
27	4	4.0041	−0.1024	61	2	2.0103	−0.5143	95	1	0.9909	0.9107
28	4	3.9968	0.0793	62	2	1.9907	0.4652	96	1	0.9926	0.7360
29	4	4.0003	−0.0078	63	2	1.9942	0.2876	97	1	0.9914	0.8622
30	4	4.0041	−0.1023	64	2	2.0062	−0.3086	98	1	0.9892	1.0804
31	4	4.0124	−0.3109	65	2	1.9945	0.2770	99	1	1.0103	−1.0259
32	4	4.0039	−0.0963	66	2	2.0052	−0.2599	100	1	1.0105	−1.0540
33	4	3.9949	0.1277	67	2	1.9957	0.2162				
34	4	4.0166	−0.4162	68	2	1.9848	0.7596				

表4 民勤县生态环境质量效应评价值

Table 4 Assessment values of ANN model for ecological environment in Minqin County

	年份 Year					
	1975	1980	1985	1990	1995	2000
ANN 评价等级值 ANN's models value	2.9501	4.0090	4.1342	4.1637	4.9736	5.0128
文献[9]评价等级值 Literature's models value[9]	3	4	4	4	5	5

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