Coupling of water and land resources and its application in regionalization *

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Abstract—This paper focuses on the coupling of water and land resources based on several factors related closely to either water or land resources, which have become a topical subject due to the economic expansion and their sustainable development in recent years. A case of Qihe County in Shangdong Province, China has been used to demonstrate the methodology of the coupling and its application in regionalization with the help of geographical information system (GIS) tool. Field observation and measurement of soil salt and moisture in several profiles are used to verify the results of the coupling, which gives reasonable distribution of different areas regarding to the advantages and disadvantages for sustainable agriculture.

Keywords: coupling, water resource, land resource, regionalization.

1 Introduction

Water shortage and wide distribution of alkaline land are two major factors that have effects on the sustainable development of agriculture in north China. One project area in Qihe County (36°24′—37°00′N, 116°23′—117°37′E, just in the north of the Yellow River) of Shangdong Province has been selected for intensive field observation and measurement of soil salt and moisture from 1989 to 1991 in 9 profiles with 8 layers for each: 0—5, 5—20, 20—40, 40—70, 70—100, 100—150, and more than 200 (cm). The survey for agricultural planning of Qihe County during the period of 1983—1984 yielded many maps related to land and water resources of the county, such as annual average ground water table, mineralization level of ground water, soil texture and structure, land use, land class etc., which are defined as factors of land and water resources coupling and provide considerable base for the study.

The aim of this paper is to explore the relationships among the factors of water and land resources in a profile and an area by coupling, and apply these relationships for a certain purpose, such as to calculate regional evaporation from ground water surface and to carry out hydrologic regionalization.

2 Methodology

The tool of Geographical Information System (GIS), such as ARC/INFO, which is powerful in spatial analysis and convenient in digitizing, editing and plotting, was used to overlay relevant factors of both land and water resources. For each factor, several classes have been defined and delineated in the map of Qihe County, e.g., five classes for ground water depth: less than 1, 1—2, 2—3, 3—4 and more than 4 (m).

The relationships between different class within each factor have to be defined before any coupling and reclassification can be processed. In order to define the above relations, the general

* Supported jointly by the National Natural Science Foundation of China and the Core Projects(1996-200, KZ951-A1-203-04) of CAS

objective of coupling should be decided because the factors of water and land resources have varied effects on different purposes, for example, to build a house or a road may pay less attention to soil texture or ground water quality than the farmers do. Therefore, an inquiry form was designed and distributed to local experts according to the purpose of agricultural production, asking them to evaluate the similarity degree in the scale of 0—1 between different classes within each factor. Then the similarity degree for each factor from the experts was averaged for later use. Thus, 9 factors in total, i. e., geomorphologic type, lithology, surface soil texture, soil type, soil structure, ground water depth, mineralization level of ground water, annual variation of ground water depth and exploitation conditions for ground water were evaluated and weight-averaged similarity degree for each of them were calculated.

After overlaying the related factors by using GIS, many blocks or coupling units may hence be produced with coupling factors and their characteristics included. The addition rule was used to calculate the similarity degree between any two blocks. Supposed six factors were used for coupling, then the maximum possible similarity degree between any two blocks was 6.0, which divided subsequently the accumulated similarity degree, yielding standardized similarity degree. The fuzzy matrix of standardized similarity degree between any two blocks can consequently be created with 1.0 in the diagonal line, and the classification can be carried out based on this matrix by using fuzzy method (Lou, 1983).

Given an original fuzzy relation or matrix R, the second order fuzzy relation is defined as $R_2 = R \copyright R$, the third order relation as $R_3 = R_2 \copyright R$, $\cdots$ $R_n = R_{n-1} \copyright R$. Where © is fuzzy operator for multiplication. $R_{n-1} = R_n = R_{n+1} = R_{n+2} = \cdots$, if R is a matrix of symmetry and with 1.0 in the diagonal line. Given fuzzy matrix A and B, then an element of fuzzy matrix C, $C = A \copyright B$ may be expressed as:

$$C_{ij} = \underset{k}{\mathrm{Max}}^{\mathrm{Min}[a_{ik}, b_{kj}] = \bigvee_k [a_{ik} \wedge b_{kj}]},$$

where $\vee$ is the operation to choose the maximum value, $\wedge$ to choose the minimum value.

The matrix of R_{n-1} can be obtained through the operation according to Equation (1) and then be used for classification if one threshold λ from 0 to 1 is given. The larger the λ value, the more classes will be created. When 1 is assigned to λ, the number of yielded class will be exactly the same as the original one, and when a certain small value is assigned to λ, only one class will be obtained.

3 Results

The measurement of soil salt has showed that soil salt of the profile from 0 to 200 cm follows a periodic cycle: stable (Dec. to Feb.) →intensive salt accumulation (Mar. to Apr.) →stable (May to June) →salt dilution (Jul. to Aug.) →salt accumulation (Sept. to Nov.). This cycle is closely related to the fluctuation of ground water depth, but not to soil moisture due to irrigation practice. Combined the soil salt movement with the ground water depth, the critical water depth can be proposed to prevent upward movement of salt to root zone and thus land degradation.

Table 1 gives more or less the same depth as that in the practice, in which the following depth has been adopted: 3.0 m for Mar.—Jun., 1.7 m for Jul. —Sept., 2.1 m for Oct. —Dec. By using the policy of controlling ground water depth, the alkaline land in the project area has decreased substantially.

Table 1 The critical groundwater depth (CGD) for the project area

Period	Dec. to Feb.	Mar. to Apr.	May to Jun.	Jul. to Aug.	Sept. to Nov.
CGD, m	2.0	2.5	1.75	1.65	2.25

The field observed data in the sites of 9 profiles for ground water depth and mineralization level (*ML*) has given the following results: (1) *ML* is rather stable, and slightly increases when ground water table is going down; (2) *ML* in the period of salt accumulation is normally greater than that in the period of dilution. The average *ML* for Sept. —Nov. of 1989 was 0.76 g/L, while 0.62 g/L for Jul. —Aug. of 1990; (3) *ML* changes yearly due mainly to the variation of rainfall.

Two or more coupling factors in regional base can be overlaid by using ARC/INFO to analyze the internal relations among factors. Table 2 gives the coupling results of ground water depth and mineralization level for the whole county.

Table 2 The averaged mineralization level for varied ground water depth

Ground water depth, m	Averaged mineralization level, g/L
<1	0.50—1.50
1—2	0.51—1.51
2—3	0.45—1.45
3—4	0.15—1.15
>4	0.28—1.28

Table 2 shows that three different layers can be identified in the vertical profile: upper layer (ground water depth less than 2m), middle layer (2—3 m) and lower layer (>3m). In the upper layer, *ML* may increase slightly with the lowering of water depth. This is similar to the result mentioned above in the profile base. *ML* of lower layer is generally low, and increases with the lowering of water depth. The middle layer is a transitional one with *ML* locating between the upper and lower layers.

The evaporation E from ground water surface for the whole county has been calculated according to Аверьянов formula (Lei, 1988): $E = Eo \times (1 - h/ho)^n$, where Eo is evaporation from free water surface measured by E-601 (annual average Eo for Qihe County is 1135.8 mm; Hong, 1988), h is ground water depth in m, ho is the maximum water depth in which E is close to zero, and n is a dimensionless parameter. ho and n can be chosen empirically based mainly on soil texture. 3.7, 2.5 and 2.0 have been assigned to n, and 3.5 m, 2.5 m and 2.5 m to ho for the soil with the texture of fine-sand, loam and clay, respectively. Thus, regional distribution of E (Fig. 1) can be easily obtained from the coupling of ground water depth and soil texture together with the above formula.

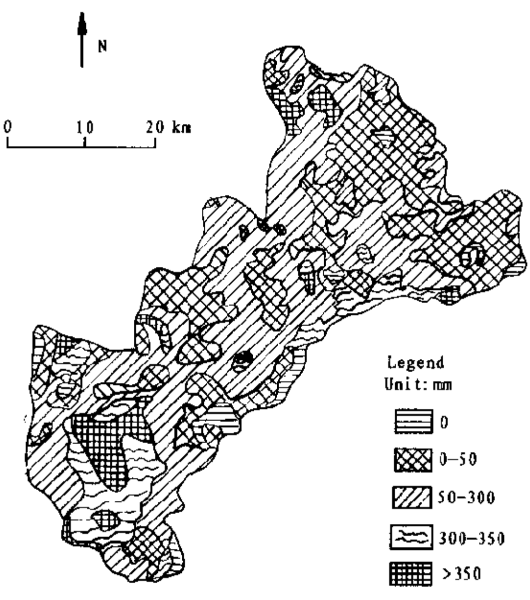

Fig. 1 The regional distribution of evaporation from ground water for Qihe County

Four factors have finally been selected for classification based on trial-and-error:

soil texture, mineralization level, ground water depth and geomorphologic type. Varied values have been assigned to λ, yielding divergent classification schemes. If $\lambda = 3.67$, then there are total 8 classes derived with two main coupling classes that account for about 90% area of Qihe County; If $\lambda = 3.68$, then there are 12 classes with three main coupling classes, which is roughly closed to the real situation. Thereafter, regionalization can be carried out based on these 12 classes. Three main classes have been defined as separate regions (Region I, II, III, in Fig. 2), the others, which account for only 8% area of the county, been defined as one region (Region IV), in which the combination of all coupling factors disfavors the agricultural productivity. These regions can be described easily by using average value and/or main characteristics of coupling factors. The average ground water depth and mineralization level for Region I, II and III are given in Table 3.

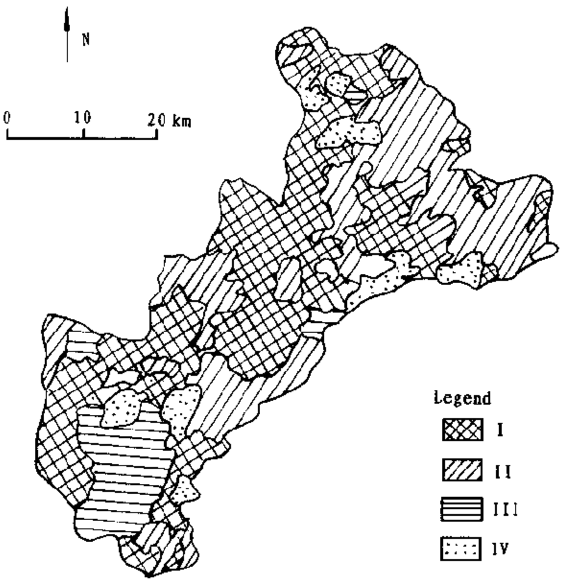

Fig. 2 Four regions derived from 12 classes of the coupling

Table 3 The average ground water depth (GWD) and mineralization level for Region I, II and III

Region	I	II	III
Ground water depth, m	1—2	2.1—3.1	0—1
Mineralization level, g/L	0.42—1.42	0.35—1.35	0.31—1.31

Compared to traditional regionalization method, the advantages of the proposed scheme based on the coupling are given as following:

- All the planning and relevant work in the past may well be included in the coupling.
- The region's boundary can be delineated clearly and rather objectively.
- The regionalization scenario can be easily adjusted to adapt for varied purpose, and classification scheme can be modified readily by simply changing λ value.
- And, both quantitative and qualitative characteristics of each region may well be described such as that shown in Table 3, let alone routine measurement for area and boundary length.

4 Conclusions

The coupling of land and water resource factors on a regional base may lead to interesting discoveries of internal relations among these factors, and some of them can be verified by field observation and measurement. The concept of similarity degree for different classes within each factor has been adopted and the classification and thus regionalization can be carried out by using fuzzy method. The regionalization of one case study based on the coupling is rather realistic and can possibly be used in policy-making as regard to the sustainable development for agriculture in China.

Acknowledgment—The author appreciates greatly the Water Conservation Bureau of Qihe County, which provided main data sources.

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(Received for review November 6, 1997. Accepted February 18, 1998)