

A farmland immersion evaluation method based on grey clustering

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Abstract. As we all know, the degree of farmland immersion is affected by many factors such as soil moisture content, natural pore ratio, saturation, soil lithology and so on. However, the conventional submergence assessment method only uses the relative relationship between the depth of phreatic water and the rising height of capillary water to judge the degree of submergence, which is obviously unreasonable. Therefore, in this paper, a method of farmland immersion evaluation based on trigonometric whiteness weight function grey clustering is proposed. The physical properties of soil, surface soil lithology of vadose zone and groundwater level elevation are included in the evaluation index system, and the degree of submergence is classified, and then the weight function is constructed to determine the degree of submergence hazard of each observation point in the immersion area. Case study shows that the method is reasonable and feasible for farmland immersion evaluation.

1 Introduction

Immersion is a common environmental geological problem in plain reservoirs. The influencing factors for reservoir immersion mainly consist of crops and buildings in the submerged area. Therefore, the criteria for immersion evaluation are classified into evaluation criteria for crops and evaluation criteria for buildings. In determining the immersion evaluation criteria, one of the key points is to determine the critical depth of immersion, which is the minimum distance from the groundwater level to the surface under the conditions of normal crop growth and building safety. The distance is expressed by the sum of the soil capillary water and freeboard value, where the freeboard value refers to the root depth or building foundation depth. When ground water depth is greater than the minimum distance, the crops can grow normally, and the foundation below the building foundation still meets the requirements of bearing capacity and deformation. When the groundwater depth is less than the minimum distance, the soil is prone to swamping and salinization, affecting crop growth and causing buildings to tilt, sink, or even collapse. According to the *Code for engineering geological investigation of water resources and hydro-power (GB50487-2008)* [1], two criteria for the occurrence of secondary salinization are proposed to solve the problem of immersion in farmland. For areas where secondary

salinization is unlikely to occur, the minimum ground water depth that is suitable for crop growth is regarded as the critical depth for farmland immersion, which is mainly determined by the type of crops. For areas where secondary salinization is possible, the minimum ground water depth that prevents secondary soil salinization is regarded as the critical depth for farmland immersion, which is mainly determined by groundwater salinity and surface soil properties. Therefore, the evaluation standard for farmland immersion is relatively clear. The influence of reservoir immersion on buildings is mainly classified into direct effect (or influence of groundwater) and indirect effect (or influence of intensity) (Zhang et al., 2014) [2]. The submerged area can exert a complex impact on buildings because of the increase in groundwater level. The increase in water level can soften the foundation, thereby reducing the bearing capacity and increasing the compressibility (Zhou et al., 2006) [3]. Currently, the sum of the height of capillary rise and the foundation depth is often used as the critical depth of buildings (Liang, 2006) [4]. Chen (2018) determined the critical depth of groundwater according to the height of capillary rise and land elevation, and evaluated the impact of Jiangxiang reservoir immersion on crops and residential areas [5], which provides a scientific basis for the relocation of people in reservoir areas and planting of crops. Huang (2011) constructed a structural model in accordance with the bearing capacity of the soil layer at

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the groundwater level [6], which is equal to the sum of additional stress and self-weight stress. The model was aimed at determining the critical depth of building immersion. Wu et al. (2011) proposed that the critical buried depth of a building could be determined according to the bearing capacity of the foundation, influence coefficient of the groundwater level, and three-dimensional surface of the ratio of buried depth to base width [7]. According to the relationship between bearing capacity and foundation stress, Sheng et al. (2020) calculated the critical buried depth under the influence of bearing capacity, determined the critical buried depth affected by additional stress according to the method of layered summation of stress, and then calculated the weight by using analytic hierarchy process (AHP), and determined the critical buried depth of buildings by comprehensively considering various factors [8].

The degree of reservoir immersion is evaluated mainly by comparing the backwater elevation after reservoir water storage and the local critical groundwater depth. If the backwater level of the reservoir is higher than the local critical groundwater depth, immersion will occur. Zheng et al. (2011) used as basis the characteristics of the immersion area to evaluate and re-evaluate [9]. The prediction principles of backed-up groundwater level were then determined according to different stratum structures, and the degree of immersion was classified. Yuan et al. (2012) and Ma et al. (2016) obtained a model of the relationship between the influence of the reservoir immersion length and the ground surface slope according to the results of the groundwater numerical simulation for typical plots [10-11]. Accordingly, the immersion of the reservoir area was analogously evaluated under different conditions. In recent years, mathematical models have been used to analyze and simulate the groundwater variation rule. With the influence of rainfall and evaporation considered, an index system for submergence evaluation has been established. Using fuzzy mathematical theory, Li et al. (2013) comprehensively analyzed the emerging conditions of reservoir immersion, established an evaluation index system, and determined the standard value of the degree of immersion [12]. Wang et al. (2014) used the groundwater dynamics method to predict the immersion disaster degree in the reservoir area [13].

To sum up, although the effects of rainfall and evaporation on groundwater level have been considered in evaluating the degree of damage caused by immersion, it is still evaluated by comparing the backwater level after reservoir impoundment and the critical groundwater depth. This evaluation method cannot fully reflect the crop damage caused by immersion in the study area, given that it considers only one evaluation criterion and lacks overall objectivity. In fact, the soil conditions of the seedbed are crucial for crop production, growth, and eventual yield. High crop yield requires not only adequate soil nutrient but also proper soil physical environmental conditions as well for the coordination of water, gas, and heat in the soil (Atkinson et al., 2007; Zheng, 2012) [14-15]. Therefore, to establish an

immersion evaluation index system, soil physical properties (such as moisture content, natural porosity ratio, saturation, etc.) and soil lithology should also be considered to render the evaluation results more reasonable.

Thus, in the current study, we considered and indexed various factors related to crop growth, formulated quantitative criteria for each factor, and established an immersion evaluation index system. The degree of immersion hazard was evaluated using the grey evaluation method based on the triangular whitening weight function to obtain more comprehensive and objective results.

2 Material and methods

2.1 Establishment of the immersion evaluation index system

The establishment of the immersion evaluation index system should adhere to the following two principles: On the one hand, each evaluation index must remain independent to avoid duplicate indicators; on the other hand, the evaluation system should fully reflect the degree of immersion in the submerged area. The Code for Engineering Geological Investigation of Water Resources and Hydropower (GB50487-2008) and reference [12] indicate that combined with the actual reservoir immersion area, the evaluation index system of the degree of immersion in the submerged area was constructed based on 3 aspects: soil physical properties, groundwater level elevation, and surface soil lithology of the vadose zone. The overall framework of the evaluation system is shown in Fig.1.

Based on the principle of the analytic hierarchy process (AHP) and grey theory, the evaluation system was categorized into three levels: the target layer, the criterion layer, and the sub-criterion layer. The target layer was the overall indicator of the degree of immersion, the criterion layer was the overall framework and angle of the evaluation index system, and the sub-criterion layer was the further development of the criterion layer. The criterion layer consisted of basic indicator factors $X_i=[X_1, \text{Soil physical properties}; X_2 \text{Soil lithology of the vadose surface}; X_3, \text{Elevation of groundwater level}]$. The sub-criterion layer consisted of factor indicators with each indicator set factor $X_{ij}=[X_{11}, \text{Moisture content}; X_{12}, \text{Natural porosity ratio}; X_{13}, \text{Saturation}]$ and $X_{3j}=[X_{31}, \text{Ground water depth}, X_{32}, \text{Capillary water rising height}]$.

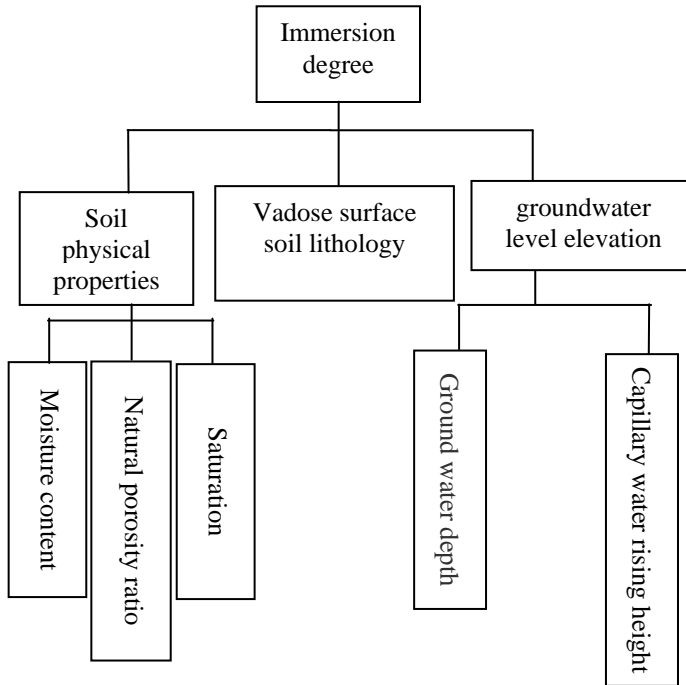


Fig. 1 Evaluation index system of the degree of immersion

2.2 Construction of the triangular whitening weight function

To objectively and fully reflect the degrees of reservoir

immersion in accordance with the index grading method, the maximum and minimum values of the same index for all evaluation units should be regarded as the terminal limits of the bad grey class and the excellent grey class, and whether the smaller or greater indicator is superior one should be considered. In this study, the degree of immersion was categorized into four: “no”, “mild,” “moderate,” and “serious.” The interval of each grey indicator value is shown in Table 1. The soil lithology of the vadose surface, x_2 , cannot be directly expressed using a numerical value; thus, it is classified under the “no” class when it is clay and so on. By the principle of the grey evaluation method, the central points of the four grey categories are recorded as $\lambda_1, \lambda_2, \lambda_3,$ and λ_4 . On the basis of the characteristics of the study area, referred to as the actual observation values, all indexes are extended to the direction of the best grey class and the worst grey class. To facilitate the construction of the triangular whitening weight function, two immersion degree grey classes—“impossible” and “extremely serious”—can be added. The central points of the two grey classes are recorded as λ_0 and λ_5 . In particular, these two grey classes are only used to construct the weight functions and are not included in the grey classes of evaluation in the actual evaluation. The grey center points of each factor index can be calculated using the formula $\lambda_{ij}^k = \frac{1}{2}(x_{ij}^k + x_{ij}^{k+1})$ (Shi, 2015) [16]. The results are shown in Table 2.

Table 1 Classification of the degrees of immersion

Indicators		No	Mild	Moderate	Serious
Soil physical properties, x_1	Moisture content x_{11}	$x_{11}^1 \leq 0.2$	$0.2 < x_{11}^2 \leq 0.25$	$0.25 < x_{11}^3 \leq 0.35$	$0.35 < x_{11}^4 \leq 0.4$
	Natural porosity ratio, x_{12}	$0.8 < x_{12}^1 \leq 0.9$	$0.6 < x_{12}^2 \leq 0.8$	$0.5 < x_{12}^3 \leq 0.6$	$x_{12}^4 \leq 0.5$
	Saturation, x_{13}	$0.5 \leq x_{13}^1 < 0.55$	$0.55 \leq x_{13}^2 < 0.75$	$0.75 \leq x_{13}^3 < 0.8$	$0.8 \leq x_{13}^4$
Soil lithology of the vadose surface, x_2	Clay	Silty clay	Silty sand	Sand	
Increase in groundwater level, x_3	Ground water depth, x_{31}	$3.5 \leq x_{31}^1$	$1.5 \leq x_{31}^2 < 3.5$	$0.5 \leq x_{31}^3 < 1.5$	$x_{31}^4 < 0.5$
	Height of increase of capillary water level, x_{32}	$1.8 < x_{32}^1 \leq 2.5$	$1.2 < x_{32}^2 \leq 1.8$	$0.8 < x_{32}^3 \leq 1.2$	$0.5 < x_{32}^4 \leq 0.8$

Table 2 Grey center points of indicators

Criteria	Indicators	λ_0	λ_1	λ_2	λ_3	λ_4	λ_5
Soil physical properties, x_1	Moisture content, x_{11}	0.125	0.175	0.225	0.3	0.375	0.425
	Natural porosity ratio, x_{12}	1	0.85	0.7	0.55	0.4	0.25
	Saturation, x_{13}	0.4	0.525	0.65	0.775	0.9	1
Groundwater level elevation, x_3	Ground water depth, x_{31}	5.5	4	2.5	1	0.25	-0.5
	Capillary water level rise height, x_{32}	3.5	2.15	1.5	1	0.65	0.15

The grey center is used to construct the triangular whitening weight function for each index about k levels (k=1, 2, 3, 4) in accordance with Formula (1). Among them, the degrees of membership of an observational value x of indicator j to the four grey classes are expressed as $f_j^1(x)$, $f_j^2(x)$, $f_j^3(x)$, $f_j^4(x)$.

$$f_j^1(x) = \begin{cases} 0 & x \in [\lambda_0, \lambda_1] \\ \frac{x - \lambda_0}{\lambda_1 - \lambda_0} & x \in (\lambda_0, \lambda_1] \\ \frac{\lambda_2 - x}{\lambda_2 - \lambda_1} & x \in (\lambda_1, \lambda_2) \end{cases}, \quad f_j^2(x) = \begin{cases} 0 & x \in [\lambda_1, \lambda_2] \\ \frac{x - \lambda_1}{\lambda_2 - \lambda_1} & x \in (\lambda_1, \lambda_2] \\ \frac{\lambda_3 - x}{\lambda_3 - \lambda_2} & x \in (\lambda_2, \lambda_3) \end{cases} \quad (1)$$

$$f_j^3(x) = \begin{cases} 0 & x \in [\lambda_2, \lambda_3] \\ \frac{x - \lambda_2}{\lambda_3 - \lambda_2} & x \in (\lambda_2, \lambda_3] \\ \frac{\lambda_4 - x}{\lambda_4 - \lambda_3} & x \in (\lambda_3, \lambda_4) \end{cases}, \quad f_j^4(x) = \begin{cases} 0 & x \in [\lambda_3, \lambda_4] \\ \frac{x - \lambda_3}{\lambda_4 - \lambda_3} & x \in (\lambda_3, \lambda_4] \\ \frac{\lambda_5 - x}{\lambda_5 - \lambda_4} & x \in (\lambda_4, \lambda_5) \end{cases}$$

2.3 Determination of the evaluation index weight

To understand the relative importance of various factors (or indicators) in reservoir immersion and to determine the weight of each index in the comprehensive evaluation index system, the 1–9 scale of AHP was used. Experts in relevant fields scored each factor according to its relative importance to immersion and obtained the score judgment matrix, as presented in Table 3.

The largest eigenvalue of the evaluation matrix and its corresponding normalized feature vector W are solved using Formulas (2)–(4):

$$\bar{W}_i = \sqrt[n]{M_i}; \quad (2)$$

$$W_i = \bar{W}_i / \sum_{i=1}^n \bar{W}_i; \quad (3)$$

$$\lambda_{\max} = \sum_{i=1}^n \frac{(\lambda W)_i}{n W_i} \quad (4)$$

In the formula $M_i = a_{i1} \cdot a_{i2} \cdots a_{in}$;

i , matrix line;

j , matrix column;

n , rows; and

λ_{\max} , matrix eigenvalues.

Table 3 Judgment matrix of the score

Degree of damage by immersion	Soil physical properties	Soil lithology of vadose surface	Elevation of groundwater level
Soil physical properties	1	3	1/4
Soil lithology of vadose surface	1/3	1	1/5
Elevation of groundwater level	4	5	1

(a) Judgment matrix 1

Soil physical properties	Moisture content	Natural porosity ratio	Saturation
Moisture content	1	1/2	2
Natural porosity ratio	2	1	3
Saturation	1/2	1/3	1

(b) Judgment matrix 2

Elevation of groundwater level	Ground water depth	Capillary water level rise height
Ground water depth	1	3
Capillary water level rise height	1/3	1

(c) Judgment matrix 3

The feature vector of the judgment matrix in Table 3 was calculated, and the results were $W_a=(0.23, 0.10, 0.67)$, $W_b=(0.30, 0.54, 0.16)$, and $W_c=(0.75, 0.25)$. The guideline layer and sub-guideline layer weight of the immersion evaluation index system are presented in Table 4.

Table 4 Weights of the criterion and sub-criterion layers

Soil physical properties, x_1	Soil lithology of the vadose surface, x_2	Elevation of groundwater level, x_3
0.23	0.10	0.67
Moisture content, x_{11}	Natural porosity ratio, x_{12}	Saturation, x_{13}
0.30	0.54	0.16
Ground water depth, x_{31}	Capillary water level rise height, x_{32}	
0.75	0.25	

To prove the rationality of the judgment matrix, verification of its consistency is necessary. Given that the matrix is a second-level matrix, the judgment matrix is always completely consistent. Therefore, verification of the consistency of the eigenvalues in Table 3(c) is not necessary; only the judgment matrix in Tables 3(a) and 3(b) need to be checked. When the consistency ratio C.R.

<0.1, the consistency of the judgment matrix is acceptable. C.R. can be calculated using Formulas (5) and (6):

$$C.I. = \frac{\lambda_{\max} - n}{n - 1} \quad (5)$$

$$C.R. = C.I./R.I. \quad (6)$$

where λ_{\max} , eigenvalues of the judgment matrix;
 n , order of the judgment matrix;
 C.I., consistency index;
 R.I., average random consistency index

By calculation, the eigenvalues of the judgment matrix in Tables 3(a) and 3(b) are $\lambda_{\max} = 3.085$, $\lambda_{\max} = 3$; thus, the judgment matrix C.I. = 0.042 in Table 3(a) and the judgment matrix C.I. = 0.004 in Table 3(b). As shown in Table 5, the average random R.L. can be obtained. As shown in Tables (a) and (b) R.L.=0.52. By calculation, C.R.= 0.082468 < 0.1 in Table 3 (a), and (b) C.R.= 0.008849 < 0.1 in Table 3, which show that the consistencies of the judgment matrix in Tables 3 (a) and 3(b) are acceptable. Thus, the weight value in Table 4 can be used as the index weight.

Table 5 Average random consistency index calculated for 1000 times (1–15 dimensional matrix)

Dimension	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
R.I.	0	0	0.52	0.89	1.12	1.26	1.36	1.41	1.46	1.49	1.52	1.54	1.56	1.58	1.59

Table 4 shows that the weight coefficients of the soil physical properties, soil lithology of the vadose surface, and groundwater level elevation are 0.23, 0.10, 0.67. These results prove that the primary factor affecting the degree of immersion was the elevation in groundwater level, followed by soil physical properties and soil lithology of the vadose surface. For the soil physical properties, the three sub-guideline layer indexes were water content, natural porosity ratio, and saturation. The natural porosity ratio, which accounted for more than the other two indicators of weight, was identified as the main factor affecting the soil physical properties.

3 Case study

Shifosi Reservoir is the only control project on Liaohe River, which is a plain reservoir. After the completion of the first-period project in 2006, varying degrees of immersion were observed in the downstream areas of the Chenpingpu Auxiliary Dam on the right bank, multiple wetlands, and swamps; normal agricultural activities were no longer possible. The non-wetland and non-swampy areas could be planted with crops; however, their crop yields were severely impaired by immersion. To reasonably evaluate the degree of damage caused by

immersion in the submerged area and to provide a scientific basis for demarcating the crop planting areas, the indexes of soil physical properties, which were closely related to crop yields, were included in the evaluation system. Grey clustering evaluation based on triangular whitening weight function was used to evaluate the degree of damage caused by immersion on the downstream immersion areas of the Chenpingpu auxiliary dam.

3.1 Evaluation index data

To obtain the numerical values of moisture content, natural porosity ratio, saturation, diving immersion depth, soil lithology of the vadose surface, and capillary water level rise height in the immersion evaluation index system, two typical sections were selected (shown in Fig. 2) within the immersion area under study. Soil sampling was conducted monthly from April to July in 2015. Affected by farmland cultivation and rainfall, the observation points were adjusted according to the actual situation. The locations of the observation points are shown in Fig. 2. The observation point number marked with the default serial number of the GPS device and the

monthly observation point numbers for each month are listed in Table 6.

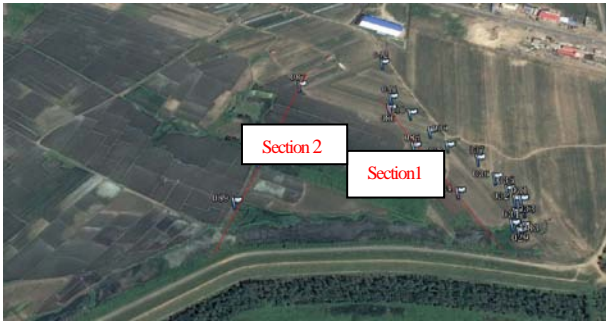


Fig. 2 Location of observation points

After the collected soil samples were analyzed, the evaluation data on the observation points were obtained, as shown in Table 6.

The data on the height of capillary rise were obtained from the Shifosi Reservoir observation data. According to the Shifosi Reservoir monitoring records, the water level of the reservoir from April to July in 2015 basically remained at 46 m. Therefore, the groundwater level of the immersion areas was simulated at 46 m (Yan et al., 2017) [17]. The results are shown in Fig. 3. Combined with the hypsographic map of the study areas to calculate the diving immersion depths of the observation points, the results are presented in Table 6.

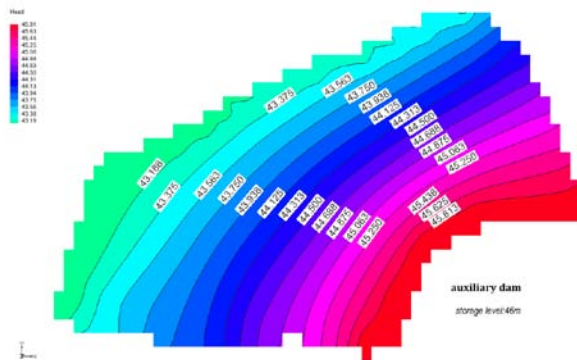


Fig. 3 Contour of the groundwater level below the reservoir water level at 46 m

Table 6 Evaluation index data on observation points

Month	Number	Moisture content (%)	Porosity ratio	Saturation (%)	Soil lithology	Depth of groundwater (m)
April	29	0.19	0.49	0.91	Sand	0.09
	32	0.25	0.70	0.96	Silty clay	-0.20
	34	0.24	0.57	0.93	Sand	-0.10
	36	0.19	0.69	0.71	Sand	-0.03
	37	0.17	0.58	0.78	Sand	0.35
	39	0.17	0.78	0.59	Sand	0.50
	40	0.19	0.56	0.89	Sand	1.10
May	83	0.13	0.48	0.74	Sand	0.09
	84	0.12	0.69	0.48	Sand	-0.05
	85	0.20	0.54	0.91	Sand	0.20
	86	0.24	0.75	0.84	Sand	0.55
	87	0.23	0.58	0.92	Sand	1.22
	88	0.33	0.72	0.93	Sand	0.10
	89	0.24	0.65	0.97	Sand	-0.05
June	33	0.25	0.72	0.94	Sand	-0.10
	36	0.23	0.67	0.90	Sand	-0.03
	38	0.16	0.69	0.62	Sand	0.50
	41	0.20	0.71	0.76	Sand	0.60
	42	0.19	0.64	0.79	Silty clay	1.45
	87	0.23	0.60	1.00	Sand	1.22
	84	0.21	0.61	0.89	Sand	-0.05
July	38	0.18	0.70	0.65	Sand	0.50
	42	0.21	0.64	0.84	Silty clay	1.45

3.2 Calculation results and analysis

For each piece of evaluation index data entered into the triangle whitening weight function (1), whitening weight clustering coefficients of different grey levels for the indexes were obtained. Table 7 shows the whitening weight clustering coefficients of the observation points in April. The comprehensive clustering coefficient

formula $\sigma_i^k = \sum_{j=1}^m f_j^k(x_{ij}) \cdot \eta_j$, combined with the corresponding index and level weights, was used to obtain a comprehensive clustering coefficient of the degree of immersion of each observation point in April in Table 8.

Table 7 Whitening weight clustering coefficient of observation points in April

Point number		Whitening weight clustering coefficient					
	Code	x_{11}	x_{12}	x_{13}	x_{31}	x_{32}	x_2
29	x_{ij}^1	0.731	0	0	0	0	0.000
	x_{ij}^2	0.269	0	0	0	1.000	0.000
	x_{ij}^3	0	0.587	0	0	0	0.000
	x_{ij}^4	0	0.413	0.900	0.787	0	1.000
32	Code	x_{11}	x_{12}	x_{13}	x_{31}	x_{32}	x_2
	x_{ij}^1	0	0	0	0	0.185	0.000
	x_{ij}^2	0.616	0.985	0	0	0	1.000
	x_{ij}^3	0.384	0.015	0	0	0	0.000
34	Code	x_{11}	x_{12}	x_{13}	x_{31}	x_{32}	x_2
	x_{ij}^1	0	0	0	0	0	0.000
	x_{ij}^2	0.796	0.132	0	0	1.000	0.000
	x_{ij}^3	0.204	0.868	0	0	0	0.000
36	Code	x_{11}	x_{12}	x_{13}	x_{31}	x_{32}	x_2
	x_{ij}^1	0.782	0	0	0	0	0.000
	x_{ij}^2	0.218	0.966	0.529	0	1.000	0.000
	x_{ij}^3	0	0.034	0.471	0	0	0.000
37	Code	x_{11}	x_{12}	x_{13}	x_{31}	x_{32}	x_2
	x_{ij}^1	0.901	0	0	0	0	0.000
	x_{ij}^2	0	0.182	0	0	1.000	0.000
	x_{ij}^3	0	0.818	0.956	0.133	0	0.000
39	Code	x_{11}	x_{12}	x_{13}	x_{31}	x_{32}	x_2
	x_{ij}^1	0.959	0.529	0.496	0	0	0.000
	x_{ij}^2	0	0.471	0.504	0	1.000	0.000
	x_{ij}^3	0	0	0	0.333	0	0.000
40	Code	x_{11}	x_{12}	x_{13}	x_{31}	x_{32}	x_2
	x_{ij}^1	0.739	0	0	0	0	0.000
	x_{ij}^2	0.261	0.083	0	0.067	1.000	0.000
	x_{ij}^3	0	0.917	0.113	0.933	0	0.000
	x_{ij}^4	0	0	0.887	0	0	1.000

Table 8 Comprehensive clustering coefficient of observation points in April

Point number		Comprehensive clustering coefficient			
		σ_1	σ_2	σ_3	σ_4
29	x_1	0.217	0.080	0.317	0.370
	x_3	0.000	0.250	0.000	0.590
	x_2	0.000	0.000	0.000	1.000
	x	0.050	0.186	0.073	0.580
32	x_1	0.000	0.715	0.122	0.059
	x_3	0.046	0.000	0.000	0.300
	x_2	0.000	1.000	0.000	0.000
	x	0.031	0.265	0.028	0.214
34	x_1	0.000	0.308	0.529	0.114
	x_3	0.000	0.250	0.000	0.400
	x_2	0.000	0.000	0.000	1.000
	x	0.000	0.239	0.122	0.394
36	x_1	0.232	0.672	0.095	0.000
	x_3	0.000	0.250	0.000	0.470
	x_2	0.000	0.000	0.000	1.000
	x	0.054	0.322	0.022	0.415
37	x_1	0.267	0.098	0.598	0.007
	x_3	0.000	0.250	0.100	0.650
	x_2	0.000	0.000	0.000	1.000
	x	0.062	0.190	0.204	0.537
39	x_1	0.651	0.337	0.000	0.000
	x_3	0.000	0.250	0.250	0.500
	x_2	0.000	0.000	0.000	1.000
	x	0.150	0.245	0.168	0.435
40	x_1	0.219	0.122	0.513	0.145
	x_3	0.000	0.300	0.700	0.000
	x_2	0.000	0.000	0.000	1.000
	x	0.051	0.229	0.587	0.133

In comprehensive clustering, the comprehensive clustering coefficients of the degree of damage caused by immersion in the target layer are listed in Table 9. The formula $\max_{1 \leq x \leq 4} \{\sigma_i^k\} = \sigma_i^{k^*}$ can be used to determine the grey levels of the observation points. For example, if $\max_{1 \leq x \leq 4} \{\sigma_{29}^k\} = \sigma_{29}^4 = 0.58$, then that point is classified under the “serious” grey category.

Table 9 Comprehensive clustering coefficient of the degree of damage caused by immersion

Grey level	April							May						
	29	32	34	36	37	39	40	83	84	85	86	87	88	89
1	0.050	0.031	0.000	0.054	0.062	0.150	0.051	0.011	0.024	0.029	0.040	0.000	0.013	0.000
2	0.186	0.265	0.239	0.322	0.190	0.245	0.229	0.178	0.280	0.208	0.309	0.333	0.279	0.308
3	0.073	0.028	0.122	0.022	0.204	0.168	0.587	0.090	0.011	0.113	0.230	0.530	0.044	0.053
4	0.580	0.214	0.394	0.415	0.537	0.435	0.133	0.556	0.401	0.614	0.421	0.129	0.552	0.413

Grey level	June						July		
	33	36	38	41	42	87	84	38	42
1	0.013	0.000	0.059	0.038	0.079	0.000	0.016	0.066	0.053
2	0.321	0.331	0.312	0.327	0.343	0.351	0.270	0.331	0.372
3	0.027	0.029	0.176	0.266	0.436	0.513	0.076	0.168	0.420
4	0.389	0.452	0.435	0.368	0.005	0.101	0.437	0.435	0.018

Table 10 Results of grey clustering evaluation of the degree of damage caused by immersion

Point	April							May						
	29	32	34	36	37	39	40	83	84	85	86	87	88	89
Degree of immersion	serious	mild	serious	serious	serious	serious	moderate	serious	serious	serious	serious	moderate	serious	serious

Point	June						July		
	33	36	38	41	42	87	84	38	42
Degree of immersion	serious	serious	serious	serious	moderate	moderate	serious	serious	moderate

On the basis of the evaluation results, ubiquitous damage can be observed in the study area (see Table 10), with 17 observation points under the serious immersion category, 5 under the moderate immersion category, and 1 under the mild immersion category. Therefore, the more immersion areas are categorized as serious immersion and are not suitable for crop cultivation.

4 Conclusions

In this study, the soil physical properties and other factors affecting crop growth were incorporated into the immersion damage evaluation index, and an evaluation system of the immersion damage was established. Simultaneously, the degree of damage caused by immersion was classified according to grey clustering evaluation based on the triangular whitening weight function. The weight function was constructed to calculate the degree of damage caused by the immersion of the observation point location. The conclusions drawn are as follows:

(1) Crop yields are closely related to soil physical properties, and incorporating it into the immersion evaluation system can render the evaluation results more scientific;

(2) The results indicate that the study area is seriously damaged by immersion; as such, the area is not conducive to crop growth;

(3) This study only observed the typical section and not the entire immersion area because of the agricultural period during the experiment. In the latter part of the study, this evaluation method could be applied in the entire immersion area, providing a basis for reasonable cultivation in the immersion area.

Acknowledgements

This research was financially supported by Liaoning Provincial Water Resources Department.

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