Suitability evaluation of remediation technology for polluted farmland

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Abstract: The suitability evaluation model of the remediation technology of polluted farmland has been constructed by analytic hierarchy process. The evaluation index of remediation technology has been constructed based on the physical and chemical index of farmland, farming system and the characteristic of remediation technology. In addition, the potential risk factors such as the distance of the industrial and mining enterprises, and the economy factors such as repair cost and local economy level have all been considered to construct the suitability evaluation system of the remediation technology of polluted farmland. Shilou town in Beijing was selected for the testing site, with the pollution of cadmium, arsenic and organic matter pollution. Chemical passivation, phytoremediation and biological compost technology were used for restoring the polluted farmland. According to the suitability evaluation model, the phytoremediation technology is suitable for general pollution. And chemical passivation and biological compost technology are more suitable to restore the polluted farmland. The combined remediation technologies of chemical passivation and phytoremediation are more suitable. It can avoid the limit of the one technology, complement the defect for each other and receive more remediation effects.

Keywords: polluted farmland, remediation technology, suitability evaluation, analytic hierarchy process (AHP)
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1 Introduction

Due to the wide use of chemical fertilizers, pesticides, agricultural film, sewage irrigation, solid waste pollution, as well as industrial pollution, the poisonous and harmful material in farmland soil turns to overload, which affects the soil fertility, the physical and chemical properties, and seriously causes crop pollution and human health risk indirectly[1]. At present, 12 Mt of food is polluted by heavy metals each year, and the directly economic loss caused is over 20 billion Yuan (RMB). Because of the concealment, hysteresis, accumulation, and longer government cycle, the harm of the soil pollution can be very serious[2,3]. So the remediation of polluted farmland soil is extremely urgent.

In recent years, the polluted soil remediation technology has become an international hot issue, and it is developing rapidly. At present, there are a lot of soil remediation technologies such as replacing soil, chemical leaching[4], microbial remediation[5], phytoremediation method[6,7], etc. According to the principle of remediation, it can be divided into physical remediation, chemical remediation, bioremediation, and combined remediation technologies. According to the remediation

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method, remediation technology can be divided into pollution treatment technology and packaging technology of pollution sources. The remediation technology can be divided into the in situ repair technology and ectopic repair technology according to the fixed position[8].

It is important to choose a remediation technology under the conditions of short time, low cost, and high efficiency. Li[9] and Gu et al.[10] have evaluated the remediation technology from six aspects, remediation time, remediation efficiency, maturity, remediation cost, soil type and pollutant type, respectively. Li et al.[11] has assessed the sustainability of two typical remediation techniques, in situ stabilization /solidification and off site landfill, with the method of multi-criteria assessment. All the mentioned evaluate methods are mainly focused on the characteristics of remediation technologies and types of pollutants without considering the potential factors such as the sources of space pollution and farmland soil fertility. Therefore, this article aims to comprehensively evaluate the suitability of remediation technology, which involves the potential factors and economic factors.

2 Analysis of evaluation objects and impact factors

2.1 Determination of evaluation objects

Evaluation objects refer to the farmland remediation technology, such as soil flushing, electroremediation, phytoremediation (Table 1)[12-18]. The main pollutants of the farmland pollution are heavy metals, inorganic contaminants and organic contaminants. There are different remediation technologies for different pollutants. For example, volatile heavy metals can be removed by using the thermal desorption, while this method is not suitable for the remediation of polluted farmland by involatile heavy metals. In addition to a single farmland remediation technology, combined remediation technologies can avoid the shortcoming of single farmland remediation technology and complement each other, thus to improve the effect of remediation, and with more invest, such as microorganism phytoremediation and chemical passivation phytoremediation.

Table 1 Evaluation of the remediation technology of polluted farmland

Technologies	Remediation time/month	Remediation efficiency/%	Cost/$·m⁻³	Maturity	Pollutant type	Soil type
Replacing soil	1-3	>95	Moderate	application	A-L	a-i
Physical separation	1-3	50-90	Low	application	A –D, J-L	a-i
In situ/ectopic fixed	6-12	>90	Moderate	application	A-D, G, J-K	a-i
Electric heating	1-12	>90	Moderate	pilot scale	A-D，J，L	a-i
Vitrification	6-24	>90	High	application	A-D, F-H, J-L	a-i
Soil-Vapor-Extraction	6-24	75-90	Low	application	A-C, E	f-i
Electrokinetic remediation	1-6	50-90	High	application	A-D, H, J	f ,j
Soil washing	1-12	>90	Moderate	application	A-E，J-L	f-i
In situ chemical oxidation	1-12	>50	Moderate	application	A-D, F, J-L	none
In situ chemical reduction	1-12	>50	Moderate	application	A-G, J-L	none
Phytoremediation	>24	<75	Low	pilot scale	A-E, G, J	a-i
Microbial remediation	6-24	70-90	Low	application	A-G	c-i
Biological compost	6-24	>75	Low	application	B-I	c-i
Bioventing	1-6	>90	Low	application	D, I, K-L	d-i
Bioreactor	1-6	>90	Low to moderate	application	B-F, K-L	d-i

Note: Pollutant type: A-heavy metal, B- Non halogenated volatile organic compounds, C- Halogenated volatile organic compounds, D- Non halogenated semi volatile organic compounds, E-fuel, F-explosives, G-POPs, H- radionuclide, I- pesticide, J-inorganic, K- Heavy carbs, L-insecticide. Soil type: a-fine clay, b-in clay, c-silt clay, d-clay loam, e-silt loam soil, f-sludge; g-sandy clay, h-sandy loam, i-sand, j-clay. Remediation time is the actual running time of every technology, but not including the time of investigation, feasibility study, remediation technology screening, and the design engineering.

2.2 Selection of impact factors

The general evaluation of polluted farmland remediation technology is mainly according to the remediation efficiency, remediation time, and target pollutants, to evaluate the suitability of the remediation technology for soil remediation. However, the polluted farmland would be further polluted by the industrial pollution, life pollution or automobile exhaust pollution, if it is near the industrial, mining areas, residents or too close to roads[19]. If the fields are irrigated by wastewater, it could further aggravate heavy metals pollution of farmland[20]. At the same time, the poor fertility and sticky soil of the polluted farmland can also increase the difficulty of remediation. Therefore, these factors should be considered in remediation of evaluation. In addition, for the remediation costs, remediation farmers hope to get good results with the minimum economic cost. So the suitability evaluation of remediation technology should add the economic indicators. The specific impact factors of remediation technology are shown in Figure 1.

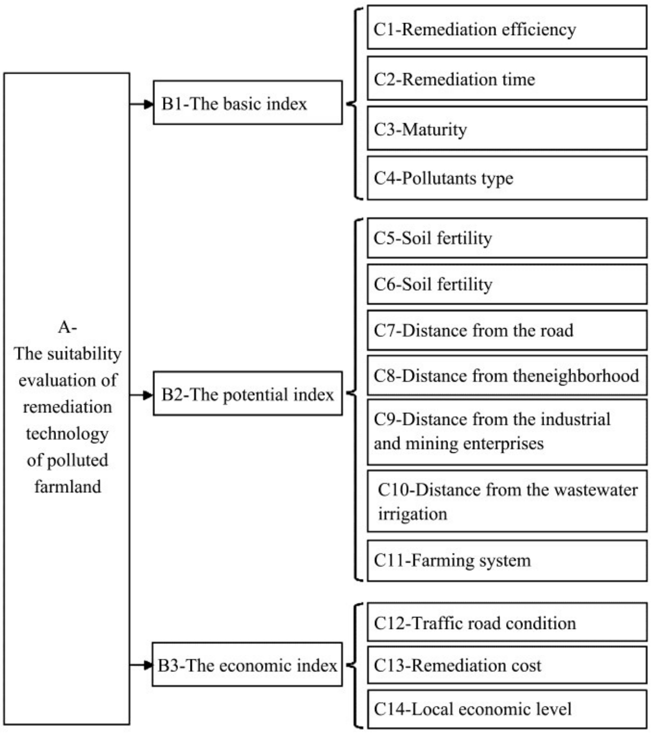

Figure 1 Impact factors of farmland pollution remediation technology

3 Evaluation method based on analytic hierarchy process

Analytic hierarchy process (AHP) is associated with the evaluation (decision) elements into the target, criterion and index level, based on the qualitative and quantitative analysis methods of evaluation (decision). Based on the deep analysis of the essence of the complex problems, influencing factors, their internal relations and so on, and with less quantitative information to make decision of mathematical thinking process, thus to provide easy evaluation methods for multiple objectives, guidelines, or no structural characteristics of a complex decision problem (decision). This method is especially suitable for the evaluation of (decision) structure which is difficult to directly correct measurement occasions[21,22]. This article uses the analytic hierarchy process to determine the weights of evaluation factors in order to avoid the influence of subjective factors.

3.1 Determination score of impact factor

At first, the standardized scores of impact factors should be graded before the suitability evaluation of farmland pollution remediation technology. Delphi technology[23] is chosen to ensure the precision of evaluation. Impact factors are graded using a 10-point scale score for Figure 1 (Table 2).

Table 2 Standard of suitability evaluation factor remediation technology

Evaluation factors	Evaluation factors				
Soil texture	Chiltern	Sand	Sandy loam	Loam	Clay
Cropping system	Crop rotation	Newground	Reclamation	Cultivated	Lie waste
Vegetation	Vegetable	Field crops	Hergabe	Garden	Other
Soil fertility	Much more	More	General	Poor	Very poor
Remediation time/months	1-3	1-6	6-12	12-24	>24
Maturity	Application	Pilot scale			
Remediation efficiency/%	>90	75-90	50-75	25-50	<25
Distance from the road/m	<400	400-1000	1000-2000	2000-4000	>4000
Distance from the industrial and mining enterprises/m	<500	500-2000	2000-4000	4000-6000	>6000
Distance from the neighborhood/m	<400	400-1000	1000-2000	2000-4000	>4000
The traffic road/m	<600	600-1000	1000-3000	3000-5000	>5000
Distance from the wastewater irrigation/m	<50	50-150	150-300	300-500	>500
Remediation cost/$\$\cdot m^{-3}$	Low	Low to moderate	Moderate cost	Moderate to high	High
Score	10	8	6	4	2

3.2 Construction of suitability evaluation method

Some impact factors of suitability evaluation have a limit value. For example, if the farmland pollution is less than the standard value, there is no need to repair the polluted farmland. Based on the self-purification ability of farmland, the farmland can refine the pollution itself. And for different pollution levels, different repair technologies can be chosen. Therefore, some appropriate class can be firstly determined with limit value. The remediation technology is more suitable for restoration of the pollution farmland with the higher scores of appropriate class and grade.

3.2.1 Determination of appropriate class

According to the farmland soil environment quality standard, the suitable evaluation is determined by single pollution index and synthetic pollution index.

First, single pollution index model has been used to test the situation of farmland pollution. The single pollution index means a certain pollution level of pollutants in the soil. The formula is as follows:

$$P_i = C_i / S_i$$

where, P_i is the single pollution index; C_i is the measured values of soil pollutants; S_i is the evaluation standard of pollutants in soil.

If the single pollution index is less than 1, then it is identified as inappropriate class. On the other hand, it is necessary to do further inspection of comprehensive pollution index. The comprehensive pollution index means the combined effect of environmental quality of soil polluted by a variety of pollutants. The formula is as follows:

$$P = [(\overline{P} + P_{\max}^2)^2]^{1/2}$$

where, P is the comprehensive pollution index; $\overline{P}$ is the mean of the single pollution index; $P_{\max}$ is the max value of the single pollution index.

If the comprehensive pollution index is less than 1, then it is not suitable for class either. For those that the comprehensive pollution index and single pollution index are both more than 1, then it is suitable for the class.

There are no limit values of the potential factors such as the distance from the industrial, mining enterprises, residential areas and the economic factors. So there is no limit to the potential factors and economic factors. The index comparison method was used to determine the suitability of each evaluation objects.

3.2.2 Division of fitness level

After the suitable class of polluted farmland confirmed, the fitness level would be classified by the comprehensive pollution index of the degree of polluted soil. At the same time, the comprehensive evaluation index would be calculated by the index weighting method, with the weight of each factor value and standardized evaluation value. Formula is as follows:

$$S = \sum_{i=1}^{n} (S_i \times Q_i)$$

Where, S is the total score of suitability evaluation of polluted farmland remediation technology; Q_i is the weight of each impact factors; S_i is the scores of each impact factors; n is the number of each impact factors.

The fitness level is divided into four levels, “highly suitable”, “more suitable”, “suitable” and “poorly suitable”, respectively, by clustering model. If the total score of polluted farmland remediation technology is 8-10, it means the remediation technology is high suitable to the polluted farmland. If the score is between 6-8 or 4-6, it means the remediation technology is more suitable or suitable to the polluted farmland respectively. The score less than 4 means poorly suitable, and other remediation technology is recommended to remedy the polluted farmland. The unsuitable class means that the farmland can remove the pollution itself, and there is no need to take any remediation technology.

4 Examples of application

The suitability evaluation method was used to evaluate the suitability of remediation technology for the pollution of farmland irrigation area, as a case of Shilou town of Fangshan district in Beijing.

4.1 Situation analysis in the study area

Shilou town is located in the southwest of Beijing suburbs and the downstream of Zhoukoudian river and Mapaoquan river. It is suitable for the growth of the crops with flat topography, as well as deep and fertile soil. And it was the leading producer of Jingxi Gongmi rice in history. However, it cannot meet the requirements of the growth of crops because of the lack of rainfall and surface water in this area. In order to ensure the agricultural production, domestic sewage and production waste water has been quoted for decades from upstream of Yanshan petrochemical chemical industry base for irrigation, and the wastewater irrigated farmland area are up to 2 000 hectares. And the history of wastewater irrigation has been up to 50 years. After the 1990s, the sewage treatment plant has been set up to purify the sewage of Yanshan petrochemical industry. There were 496 motor-pumped wells that have been shafted for reducing sewage irrigation, and the contradictions of wastewater irrigation have gotten some relief. On the one hand, sewage irrigation can increase the N, P and other nutrients and organic matter content in soil. But on the other hand, it can also accumulate the heavy metals, such as As, Cd, Cu, Fe, Mn, Pb, Cr, and Hg. With the accumulation of heavy metals, it can cause the soil pollution in different degrees and affect the quality of soil environment. It can further threat the quality and safety of agricultural products.

4.2 Data acquisition and processing

Two hectares farmland near to the highway at Shilou town (116°2'55.75"E, 39°39'26.88"N) has been selected. The fertile soil mainly grows corn and wheat. The basic soil physical and chemical properties are shown in Table 3.

Table 3 Physical and chemical properties of polluted farmland

Item	Alkali-hydrolyzale nitrogen/mg·kg^{-1}	Available phosphorus /mg·kg^{-1}	pH	CEC /cmol(+)·kg^{-1}	Organic matter/%
Content	119	16.3	7.8	8.62	3.07

The contents of heavy metals and organic pollutants in the soil are shown in Table 4. It shows that heavy metal contents in the region are more than the background value in Beijing area, but lower than those of the national secondary standard of soil quality. Comparing with the soil background values of Beijing, this area has been moderate cadmium pollution and low arsenic pollution, according to the single pollution index and synthetic pollution index.

Table 4 Heavy metals of polluted farmland

Item	Mean /(mg·kg^{-1})	Maximum /(mg·kg^{-1})	95% confidence interval/(mg·kg^{-1})	Background value of Beijing/(mg·kg^{-1})	Secondary standard[a]/ (mg·kg^{-1}) (pH>7.5)	> secondary standards /average ratio[b]/%
As	9.70	12.42	9.47-9.93	7.81	25	0
Cd	0.229	0.450	0.217-0.241	0.119	0.6	0
Cr	63.28	94.10	62.1-64.5	29.80	250	0
Hg	0.111	0.416	0.102-0.121	0.080	1	0
Cu	25.00	37.60	24.4-25.6	18.70	100	0
Pb	28.16	40.90	27.1-29.2	24.60	350	0
Zn	88.59	274.00	83.6-93.6	57.50	300	0
Organic pollutant	388.01	2610.50				60

Note: a- Secondary standard is derived from the GB15618-1995; b- The ratio of content is greater than the secondary standards or average.

Meanwhile, the organic pollutants in the region should also be taken in account with the content beyond the average 60%.

According to the pollution of cadmium, arsenic and organic pollutants, chemical passivation, phytoremediation and biological compost are used respectively to remedy the pollution.

4.3 Construction of evaluation index model

The evaluation index system has been determined by the method above, and the analytic hierarchy process has been used to calculate the weight factor. The weight of each influence factor has been calculated by the hierarchy analysis software for the judgment matrix of criterion layer B (the impact factors of A) to target layer A (the object), and index layer C (the impact factors of B) to criterion layer B (see Table 5). At the same time, the consistency of judgment matrix should be calculated, and the consistency proportion of the judgment matrix is less than 0.1 which having satisfactory consistency[24]. Then it is reasonable to construct the suitability evaluation model of remediation technology with hierarchical analysis method.

At the same time, the evaluation factor should be standardization, and the suitability evaluation model is set up by the weighted addition.

Table 5 Weights of every impact factor

Impact factors	Weight	Impact factors	Weight	Impact factors	Weight
Efficiency	0.2880	Soil fertility	0.0598	Farming system	0.0301
Time	0.1503	a	0.0126	Road condition	0.0327
Maturity	0.0554	b	0.0126	cost	0.1079
Pollutants type	0.1063	c	0.0301	Economic level	0.0594
Soil texture	0.0395	d	0.0180		

Notes: a- Distance from the road, b- Distance from the neighborhood, C- Distance from the industrial and mining enterprises, d- Distance from the wastewater irrigation.

4.4 Evaluation results and analysis

Chemical passivation, phytoremediation and biological compost were used to remedy the pollution of cadmium, arsenic and organic pollutants. The scores of three remediation technologies were 7.28, 5.85 and 7.11, respectively, according to the suitability evaluation model. The phytoremediation technology is general suitable for the remediation technology of farmland pollution. The chemical passivation technology and biological compost technology are more suitable for the remediation technology of farmland pollution.

With the combined pollution, the biological compost is only applicable to organic pollution of farmland, chemical passivation technology is also more suitable for the heavy metal pollution of farmland. So combined remediation technology of chemical passivation and phytoremediation has been used for remediation. The score of combined technology was 8.01, which is higher suitable for combined pollution. The combined technology can avoid their limiting factors, and complement the defects for each other, and receive better remediation effect.

4.5 Discussion

The soil fertility has a great influence on the effect of soil restoration, but this article generally discussed the soil fertility, no specific analysis of organic matter, alkali-hydro nitrogen, nitrate nitrogen, etc. The air pollution of farmland can also affect the remediation effect. The direction of the wind was not considered because of its instability and variation. In addition, the scores of the evaluation system are marked by expert with subjectivity in some extent. So the method of the score should be further discussed for objectivity.

5 Conclusions

The suitability evaluation model of the remediation technology of polluted farmland has been constructed by analytic hierarchy process. The evaluation index of remediation technology has been constructed based on the physical and chemical indexes of farmland, farming system and the characteristic of remediation technology. In addition, the potential risk factors such as the distance of the industrial and mining enterprises, and the economy factors such as repair cost and local economy level have all been considered to construct the suitability evaluation system of the remediation technology of polluted farmland. This remediation technology is more comprehensive, accurate and effective.

Shilou town in Beijing has been selected for the testing site, with the pollution of cadmium, arsenic and organic matter pollution. Chemical passivation, phytoremediation and biological compost technology have been used for remedying the polluted farmland. According to the suitability evaluation model, the phytoremediation technology is suitable for general repair of contaminated farmland. And chemical passivation and biological compost technology are suitable to repair polluted farmland. The combined remediation technologies of chemical passivation and phytoremediation is higher suitable. The combined remediation technologies can avoid the limit of the one technology, complement the defect for each other and receive more remediation effects.

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