# Ecological Assessment of Wanli Coal Mine Using the AHP-Fuzzy Comprehensive Evaluation Method

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**Abstract**: This study evaluates the ecological and environmental impacts of mining at Wanli Coal Mine by constructing an assessment system comprising three criterion levels (natural endowment status, ecological status, and human management index) and 14 indicators. Using the Analytic Hierarchy Process (AHP) and fuzzy comprehensive evaluation, key factors such as annual extraction volume, vegetation coverage, and surface fracture development were identified and weighted. Results show that while human management is rated "Excellent" natural endowment is "very poor"ecological status is "poor"and overall environmental quality is "poor".This indicates that intensive mining has caused significant ecological degradation despite management efforts. The framework provides a basis for targeted restoration and sustainable mining strategies, with applicability to similar mining regions.

## 1 Introduction

As a fundamental energy resource in China, coal mining induces various ecological and environmental issues—including geological hazards, water depletion, land degradation, vegetation loss, and air pollution—which threaten regional ecological security and human habitat health[1-2]. Using Wanli Coal Mine as a case study, this paper develops a tailored evaluation index system and applies the Analytic Hierarchy Process and Fuzzy Comprehensive Evaluation Method to quantitatively assess its ecological quality, providing a scientific basis for ecological protection and restoration in this and similar mining areas[3].

## 2 Current Ecological and Environmental Status of Wanli Coal Mine

Wanli Coal Mine is situated in the northern Ordos Plateau, north of the Dongsheng Coalfield. The area features deeply incised valleys with exposed bedrock and scattered Quaternary deposits, forming eroded hills. The terrain slopes from northwest to southeast, with the highest elevation located at the mine site. Annual precipitation averages 400.2 mm, while evaporation reaches 2256.0 mm, resulting in severe water scarcity. As a typical ecologically fragile zone in western China, mining activities here have led to multifaceted damage to the local ecosystem(Table 1).

**Table 1** Current Ecological Environment Status of Wanli Coal Mine

| enegative effects | On-site photos | Existing problems |
|---|---|---|
| Geological hazard |  | Mining has caused dense surface cracks (10-20 per 100m) and deformation in this hilly area, significantly increasing the risk of landslides and debris flows when rainfall softens the ground. |
| Water Resource Degradation |  | Mining has disrupted groundwater pathways, causing regional water table decline and pollution. Combined with the area's limited and concentrated rainfall, these operations have intensified water scarcity and environmental degradation. |

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| | | |
|---|---|---|
| Land Resource Degradation |  | Surface cracks hasten soil degradation and desertification by drying the soil and stripping nutrients. Mining waste occupies land, generates dust, and leaches pollutants via rainfall, impeding revegetation despite restoration efforts. |
| Vegetation destruction |  | The mining area's native low-coverage dry grassland faces severe habitat damage from altered soil and hydrology. Full-scale mining is projected to reduce vegetation productivity by 45.46%, severely affecting ecosystem productivity |
| Air pollution |  | Coal mining and transportation generate substantial coal dust that settles on roads and surrounding areas. Flue gas emitted from heating boilers in mining areas contains pollutants such as particulate matter, $SO_2$, and NOx, posing threats to local air quality and public health. |

## 3 Evaluation Methodology Introduction

### 3.1 Development of Evaluation Indicator System and Evaluation

Based on principles of representativeness, scientific rigor, systematicity, feasibility, and regional applicability, an ecological environment evaluation system for Wanli Coal Mine was constructed. It comprises 14 specific indicators across three dimensions: Natural Endowment (IN), Ecological Status (IE), and Human Management (IH)[4].The AHP method was used to determine indicator weights. This involved constructing a judgment matrix, calculating eigenvectors and the maximum eigenvalue, and conducting a consistency check (CR < 0.1) to ensure rational weight allocation. The resulting weights for each level are presented in Table 2.

**Table 2** Index system weight table

| Target Layer | Guideline Layer | Guideline Level Weight | Indicator Layer | Indicator Layer Weight |
|---|---|---|---|---|
| Ecological Environment Quality IEQ | Natural Endowment Status Index IN | 0.240 | Topography and land forms C1 | 0.157 |
| | | | Annual precipitation C2 | 0.088 |
| | | | Annual production volume C3 | 0.483 |
| | | | Coal yield C4 | 0.272 |
| | Ecological Environment Status Index IE | 0.550 | Vegetation coverage C5 | 0.249 |
| | | | Development of Surface Cracks C6 | 0.238 |
| | | | Land Disturbance Ratio C7 | 0.223 |
| | | | Degree of aquifer damage C8 | 0.132 |
| | | | Nitrogen Oxide Concentration C9 | 0.065 |
| | | | Land Restoration Rate C10 | 0.093 |
| | Humanistic Management Index IH | 0.210 | Proportion of Environmental Governance Investment C11 | 0.363 |
| | | | Percentage of Environmental Technology Personnel C12 | 0.326 |
| | | | Population density C13 | 0.163 |
| | | | Economic Contribution Rate of Mining Areas C14 | 0.148 |

### 3.2 Indicator Grading System

Based on national and industry standards, relevant research findings, and regional conditions, each indicator is categorized into four grades: Grade I (Excellent), Grade II (Good), Grade III (Poor), and Grade IV (Very Poor). Specific threshold ranges have been established for each grade(Table 3).

### 3.3 Fuzzy Comprehensive Evaluation Method

1. Determine the factor set and evaluation set: Factor set A = {B1, B2, B3}, evaluation set V = {I, II, III, IV}[5].

2. Establish membership functions: Employ trigonometric functions to construct membership functions for each indicator across the four evaluation grades, distinguishing between increasing and decreasing indicator value patterns.

3. Construct fuzzy relationship matrix: Substitute actual values of Wanli Mine indicators into membership functions, calculate their membership degrees for each grade, and form fuzzy evaluation matrix R.

4. Fuzzy synthesis operation: Employ the weighted average operator M(·, ⊕) to synthesize the weight vector W with the fuzzy matrix R. Calculate layer by layer upward to ultimately obtain the membership degree vector of the target layer A for the evaluation set V.

5. Evaluation result determination: Determine the comprehensive evaluation grade based on the maximum membership degree principle.

**Table 3** Wanli coal mine ecological environment classification standard

| Indicator Layer | Actual situation | Mining Site Ecological Environment Grade | | | |
|---|---|---|---|---|---|
| | | Grade I | Grade II | Grade III | Grade IV |
| C1 | The area features rugged, deeply incised terrain with significant relief, where elevation changes can reach up to 110 meters. | The area is characterized by gently sloping hills, with most slopes having gradients of less than 15° | Geomorphology is relatively simple with a single landform type, featuring relative elevations ranging from 100~ 200m and slopes generally between 15~25°. | The terrain is rugged and diverse, characterized by medium-low mountains (200~500m) with slopes generally at 25~45°. | This is a rugged, high-relief mountainous area (＞500 m), featuring complex topography with slopes typically ranging from 45-90°. |
| C2 | Annual average400ml | 1500 | 1200 | 800 | 400 |
| C3 | 10mt | 1mt | 4mt | 8mt | 12mt |
| C4 | 87% | 85% | 80% | 75% | 65% |
| C5 | 48% | 70% | 60% | 50% | 30% |
| C6 | Based on actual measurements, the development density ranges from 10~20m/fissure, meeting Grade III standards. | ground fissures meeting criteria >1 km and <3 m wide, ≤1 km long and <10 m wide, or with density of >50 m/fissure. | Ground fissures >1 km, with surface impact widths ranging 3~10m, or ground fissure development densities between 20~50 m/section. | The ground fissure extends 1 km in length, with a surface impact width of 10~20m. ground fissure density 10~20 m/fissure. | Ground fissure length > 1 km, surface impact width ≥ 20 m, ground fissure density < 10 m/fissure. |
| C7 | 19% | 10% | 20% | 30% | 40% |
| C8 | The Quaternary aquifer was drained. | Aquifers are not connected. | The number of interconnected aquifers is less than half. | Connecting more than half of the aquifers | All aquifers are interconnected. |
| C9 | 155 | 50 | 100 | 200 | 300 |
| C10 | 74.8% | 75% | 60% | 45% | 30% |
| C11 | 0.65/45=1.4% | 1.5% | 1% | 0.6% | 0.5% |
| C12 | 7/1111=0.63% | 2% | 1.5% | 1% | 0.6% |
| C13 | 580800/2160=269 | 200 | 300 | 450 | 600 |
| C14 | 28% | 50% | 35% | 25% | 15% |

The grading standards in Table 3 were set by combining national and industry benchmarks with key local adaptations for the Ordos Plateau's fragile environment. For example:

(1) Standards for topography (C1) and surface cracks (C6) were calibrated using local geomorphology and subsidence data. (2) Thresholds for vegetation cover (C5) and restoration rate (C10) were lowered to reflect the realistic potential of the dry grassland ecosystem.

This ensures the evaluation is relevant to local conditions and realistic restoration goals.

## 4 Results and Discussion

### 4 .1 Structural Analysis of Weight Distribution

The AHP weighting system highlights the core issues within the ecological environment system of Wanli Mine (Figure 1). At the criterion level, the Current Ecological Status (IE) holds dominant importance with a weight of 0.550. This indicates that in fragile ecosystems, the direct “pressure-state” impact from mining is the primary concern within the evaluation framework.The weights of specific indicators further pinpoint the focus of this impact: Surface Crack Development (C6, 0.238) and Land Disturbance Area Ratio (C7, 0.223) have a combined weight of 0.461. This quantifiably confirms that, for topographically fragmented mining areas like Wanli, the physical destruction of surface structure is the main driver of ecosystem degradation. This elevates field observations to a quantifiable priority for decision-making.

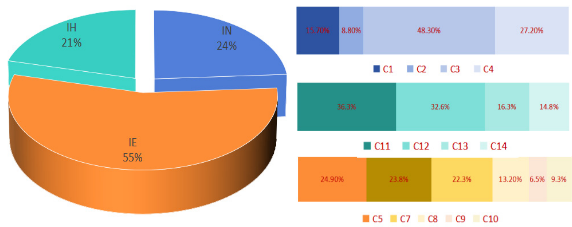


**Figure 1.** Weighting Distribution of Each Indicator

the weight assigned to Natural Endowment (IN, 0.240) reflects the rigid constraints of regional baseline conditions. Among its sub-indicators, Annual Mining Volume (C3, 0.483) is the most significant factor at this level. This reveals a critical conflict: against a backdrop of inherently weak natural carrying capacity (low precipitation, high terrain complexity), the current high-intensity mining scale (10 Mt/a) itself constitutes a massive, persistent stressor. The weighting structure clarifies that the mine's ecological issues stem from the nonlinear interaction between intense human disturbance and a low-threshold ecological baseline.

The AHP weights involve some expert subjectivity. We tested how changes in these weights affected the results. Minor adjustments did not alter the final "Poor" (Grade III) overall rating. This is because key indicators like surface cracks (C6) and high production volume (C3), which have poor scores, consistently carried high weight. Therefore, the main conclusion—that the ecology is under severe stress—is robust. However, weights for management indicators (IH) were more sensitive, showing that views on management effectiveness can vary, though this does not change the overall diagnosis.

### 4.2 Analysis of Fuzzy Comprehensive Evaluation Results

The evaluation results (IN–Grade IV, IE–Grade III, IH–Grade I, Comprehensive–Grade III) reflect complex interactions among ecological, economic, and management subsystems.First, the sharp contrast between very poor natural endowment (Grade IV) and excellent human management (Grade I) presents a core dilemma for Wanli Mine(Figure 2). Despite proactive management efforts (e.g., allocating 1.4% of resources to remediation), these incremental improvements struggle to offset the structural deficits and pressures determined by natural conditions and mining scale. The "good"management performance is mainly seen in process indicators like institutional investment. However, its effectiveness in reversing ecosystem degradation caused by physical damage (e.g., aquifer depletion, soil disintegration) shows clear diminishing marginal returns.

Secondly, the "poor" rating for the current ecological condition is a direct outcome of the aforementioned pressures. Its membership degree of 0.4979 for Grade III indicates a critical and unstable state within that grade, with a significant risk of slipping into Grade IV (0.3295 membership). This reflects substantially reduced ecosystem resilience.

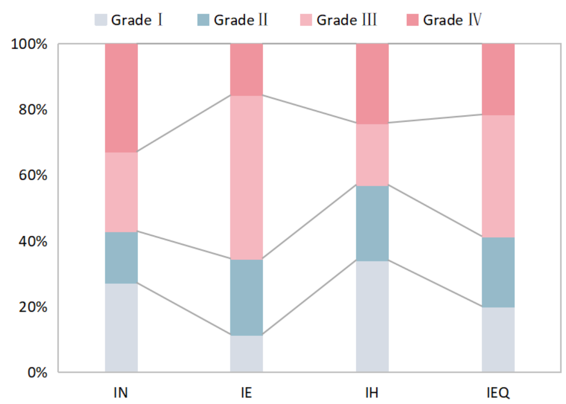


**Figure 2.** Evaluation Results of Membership Degrees Across Dimensions

Specifically, the measured values for key indicators—surface cracks (C6) and aquifer damage (C8)—fall within the "poor" or "very poor" ranges, creating a shortboard effect that lowers the overall rating. Notably, while the land restoration coverage rate (C10) reached 74.8%, nearing the Grade I threshold, a significant disconnect exists between this engineered area and actual ecological outcomes (e.g., vegetation survival, community stability). This reveals a potential tendency in current restoration projects to "prioritize area over function" emphasizing spatial coverage over the substantive recovery of ecosystem structure. From an outcome perspective, this explains why strong performance in management input (C11) fails to translate into a satisfactory overall ecological status.

### 4.3 Systematic Implications of the Synthesis and Reflections on Governance Approaches

The comprehensive evaluation grade for the Wanli Mine is "Poor" (Grade III), primarily dictated by the critical weighting of the Ecological Environment Status (IE). This demonstrates that merely enhancing end-of-pipe management (IH) offers limited improvement. The core strategy must shift upstream to directly mitigate the physical impacts of mining (improving IE), reconciling mining intensity with the ecological baseline (IN).This necessitates a dual paradigm shift in environmental governance: from "end-of-pipe remediation" to "source reduction" via green mining technologies to minimize deformation and land occupation (C6, C7, C8) at the source; and from "engineering measures" to "ecological processes", aiming to restore ecosystem services—like hydrology (C2, C8) and soil fertility—rather than merely achieving morphological targets like vegetation cover (C10).In summary, by deconstructing the weighting logic, this study reveals the nonlinear interaction among "ecological baseline constraints, mining stress, and management response". It provides a scientific basis for strategies targeting ecosystem integrity restoration, offering valuable insights for sustainable mineral exploitation in ecologically fragile regions worldwide.

## 5 Conclusions

(1) This study addresses ecological and environmental issues triggered by mining at Wanli Coal Mine by constructing an evaluation framework comprising three criterion levels—natural endowment state, current ecological environment status, and human management index—and 14 indicators. This framework demonstrates strong regional specificity and systematic coherence.

(2) The Analytic Hierarchy Process (AHP) was employed to determine indicator weights, revealing that annual extraction volume, vegetation coverage, and surface fracture development are key factors influencing ecological quality in the mining area. Fuzzy comprehensive evaluation effectively addressed ambiguities and uncertainties in the assessment.

(3) Evaluation results indicate: Wanli Mine's natural endowment status is "very poor" ecological environment status is "poor" human management index is "Excellent" and overall ecological environment quality is "poor". This clearly demonstrates that despite enhanced management measures, intense mining activities have caused significant ecological degradation on a fragile natural foundation.

(4) The research findings provide a decision-making basis for formulating precise ecological restoration plans and damage-reduction mining measures at Wanli Mine. Its methodological framework also holds reference value for ecological and environmental assessment and governance in mining areas with similar conditions.

This study has limitations. First, data availability was a constraint; for example, aquifer damage (C8) was assessed qualitatively due to limited groundwater monitoring data. Second, the indicators focus more on ecological state (e.g., coverage) than function (e.g., carbon storage). Finally, while the fuzzy evaluation method handles ambiguity well, it can oversimplify borderline cases. These points highlight areas for future improvement through better monitoring and more dynamic metrics.

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## References

1. TORRES A, et al. Mining threats in high-level biodiversity conservation policies[J]. Conservation Biology, 2024.
2. ETTLER V, et al. Contaminant bioaccessibility in abandoned mine tailings in Namibia changes along a climatic gradient[J]. Environmental Science: Processes & Impacts, 2025.
3. SAATY T L. How to make a decision: The Analytic Hierarchy Process[J]. European Journal of Operational Research, 1990, 48(1): 9-26.
4. EVERARD M, et al. Methodological innovations within the RAWES framework for use in development scenarios[J]. Integrated Environmental Assessment and Management, 2024.
5. KUBLER S, et al. A fuzzy comprehensive evaluation method for environmental quality assessment[J]. Ecological Indicators, 2016, 69: 100-112.