

Article

Ecological Restoration and Regeneration Strategies for the Gumi Mountain Mining Area in Wuhan Guided by Nature-Based Solution (NbS) Concepts

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Abstract: To remedy ecological damage and soil contamination in mining brownfields, this research focuses on the Gumi Mountain mining area in Wuhan. It proposes restoration strategies based on Nature-based Solutions (NbSs). Besides terrain restoration and soil enhancement, it also involves the redesigning of water systems, hydrological management, and the stratified planting of native species to restore plant communities. As China's inaugural quartz optical fiber was born here, we need to consider its history when making reclamation strategy for the Optics Valley City. This research took the Pulsed High Magnetic Field Facility (PHMFF) as the prototype to build a model that integrates “mountain, river, forest, farmland and flower” ecosystems. Based on NbS, we divided the brownfield by functions and redesigned the tourist routes. This research offers new methodologies for similar efforts in mine rehabilitation.

Keywords: brownfield; NbS concepts; ecological restoration; magnetic field; regeneration



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1. Introduction

The Gumi Mountain mining brownfield is located at the intersection of Jiangxia district and Hongshan district in Wuhan. It is in the core area of Wuhan Future City in the East Lake High-tech Development Zone, Wuhan. The surrounding region used to be rich in mineral resources and had boosted the mining economy of Wuhan. However, by 2013, mines in the Optics Valley were abandoned and closed gradually, leaving numerous brownfields, including those in the Gumi Mountain. These brownfields may have environmental contamination, but the idle land in urban areas still has potential for redevelopment. Mining brownfields have problems of ecological damage and idle land. Mining alters the topography and landscape, increasing the risk of landslides and mudslides; the waste water from slag contains lead, mercury, and other heavy metals, which pollute the surrounding environment through surface run-off and soil leaching, destroying the physical and chemical properties of the soil and the aquatic ecosystem and affecting the survival of plants and aquatic organisms; and land idling also hinders ecological self-healing and restricts sustainable regional development.

China is rich in mineral resources, and the sustainable development of the mining sector plays an important role in the country's overall sustainable development. In recent years, Nature-based Solutions harness the power of nature to boost natural ecosystems, biodiversity, and human well-being to address major societal issues. As a core strategy for sustainable development, NbSs have been applied in various sectors. Ecological restoration

technologies for NbS application to mine-site rehabilitation are evolving, and the combined use of various technologies and innovative research has provided strong support for the restoration and sustainable development of mine-site ecosystems (see Table 1). For the restoration of damaged mine ecosystems to achieve the goal of sustainable management [1,2], NbSs have been widely recognized and applied in the construction of ecological civilization in China, and the use of NbSs for mine ecological restoration has been employed for the optimization of traditional restoration concepts and methods, which has a greater potential for future development in China's mine ecological restoration [3–5]. NbS, as a core tool for sustainable development, is also used in practical research in many disciplines abroad. For example, a study in San Francisco indicates that brownfield redevelopment could offset 14% of the city's annual greenhouse gas emissions [6]. The advanced slope greening technique from Japan and the U.S.'s wetland treatment both incorporate NbS concepts. As a leading nation in NbS initiatives, China has made top-down efforts for years, advancing top-level planning for land ecological protection and rehabilitation and promoting the integration of NbSs with policy and technology. Examples include research on NbS applications in mining regeneration focusing on ecological restoration technologies [7,8] and the use of self-assessment tools for evaluating mining restoration projects. The concept of "brownfield engineering", introduced by Zheng [9], explores brownfield habitat systems.

The scientific questions addressed by the core elements of NbSs on which the study is based on and about are as follows: (1) Ecological basis and function: taking ecosystem protection and restoration as the basis, focusing on the maintenance of the biodiversity and restoration of ecosystem functions while emphasizing the sustainable use and adaptive management of natural resources in order to respond to the complex socio-ecological challenges of climate change and the enhancement of human well-being. (2) Landscape-level linkages: thinking dynamically at the landscape level, focusing on the intrinsic linkages between brownfield environmental remediation and urban ecological development. (3) Multi-disciplinary integration and practice: based on the overall understanding of NbSs, we integrate multi-disciplinary perspectives and conduct in-depth investigations on brownfield remediation using the actual site of Gumi Hill as an example. The significance of this research lies in the fact that through a series of ecological restoration measures, the stability and self-regulation ability of the mining ecosystem are enhanced, the restoration of ecological balance is promoted, and a model can be provided for the ecological restoration of similar urban mining areas, which is conducive to the improvement and protection of the overall ecological environment. Therefore, the author tries to introduce the NbS perspective to explore whether the NbS concept in mine remediation can effectively solve the ecological problems in mining areas [10,11] and to explore the inspiration of NbSs to the brownfield regeneration strategy in China.

Table 1. Progress on the application of NbSs for mine-site remediation (compiled by the author).

	Time	2020	2021	2022	2023	2024
Status of NbS application for ecological restoration of mining areas	Internal	In the foundation stage, there is research on pollution control methods in mining watersheds based on NbSs [12]	Systematic thinking develops, fewer individual studies of mines [13]	Exploring new engineering techniques for mine rehabilitation	Increased relevant research to drive mainstreaming of NbSs in relevant policies [14,15]	NbS research and localization integration [16], key technology research and application, and other representative research results
	External	Research on the potential and application strategy of major concentration of NbSs in ecological restoration of mining areas [17]	Nature combined with appropriate human intervention to improve sustainability	Heavy-metal-tolerant plant breeding to improve soil fertility	Establishment of artificial wetlands and aquatic plant communities in mining areas to improve water quality [18]	Successfully restored the ecosystem function of the mine site and explored how to achieve sustainable development of the mine site
Application of ecological restoration techniques	Internal	Joint restoration technology for integrating ecology and landscape [19]	Precision allocation technology, organic waste improvement technology in soil improvement, etc. [20]	Mulch greening, slope construction greening, and eco-bag greening	Focus on soil and water environment pollution remediation and integrated soil and vegetation remediation [21]	Soil remodeling works—soil texture improvement—biological restoration [22,23]
	External	Modeling local ecosystems and identifying multi-factor interactions [24]	Absorbed NbS repair path: reduce interference and eliminate threats [25]	Ecological restoration, efficient reuse technology for mineral processing wastewater, etc.	Water remediation techniques using the neutralizer method and the establishment of “swamp forest systems” to reduce metal levels	Ecological restoration of mining pit lakes [26]

2. Resource Analysis of the Mining Area

2.1. Analysis of the Mining Area's Condition

In 2013, the National Pulsed Magnetic Field Facility was established in Wuhan Optics Valley. With the goal of transforming brownfields into assets, the city began its mine reclamation efforts [27]. The mine site was originally used for mining, but years of mining activities caused extensive water and soil pollution. Scars left by previous mining activities can still be seen today. Gumi Mountain has been severely damaged. The inclination of its slopes is nearly vertical, with angles from 80–90 degrees, offering substantial challenges to reforestation. Below the mountain, there is a large weed-infested pit of which the soil is heavily polluted, posing safety hazards. One of the places the original forests can be found is on the northwestern side of the mountain. They help preserve some ecological function. However, in the northeast, there are abandoned mining buildings left to decay. Due to the exposure of iron-sulfide minerals, there are many acid mine tailings scattered across the site. Acid mine drainage that drains from abandoned mine sites also pollutes the environment (see Figure 1).

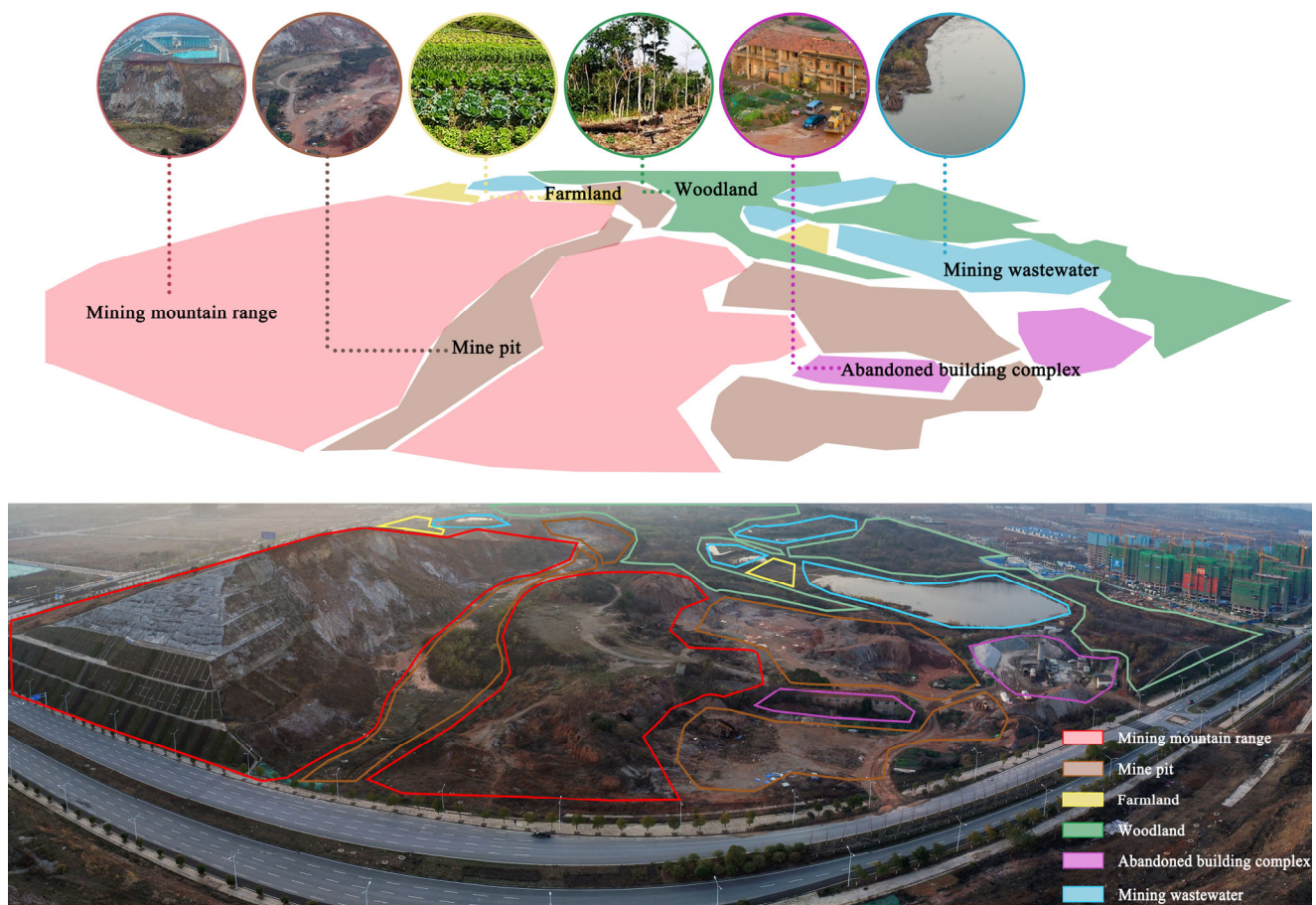


Figure 1. Site condition analysis (illustrated by author).

2.2. Landscape Resource Analysis

Looking from the relationship among mountains, waters, and urban brownfields, we find that the waters in the northeast are surrounded by some forests, forming an open space. The damaged mountain stands out in the southeast, far away from the scattered water bodies. There is a lack of harmonious mountain–water landscape. Looking from the perspective of a mining landscape, there is gorgeous forest scenery opposite to the chain of mountains in the site. One can stand on top of the mountain overlooking the forest valley below him. The existing pit, adjacent to current water bodies, forms a unique landscape that serves as a historical relic of mining activities. The folds of the mountains are formed under varied conditions of water-rich stratum and stratum with strong ground pressure. As a result, steep, sloping sides and sharp ridges could be found against the undulating terrain, forming a magnificent a mining landscape (Figure 2).

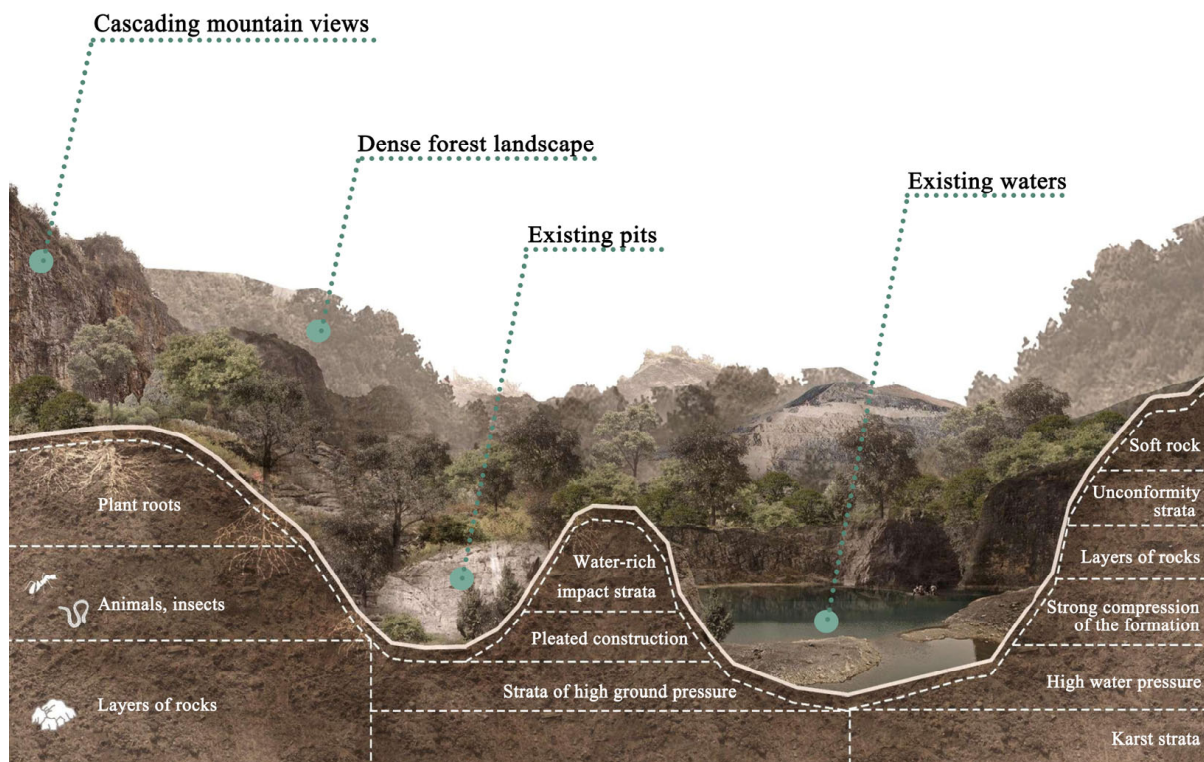


Figure 2. Analysis of mining landscape resources (illustrated by author).

3. Ecological Restoration of Mining Areas Guided by NbS Concepts

This study focuses on exploring the ecological remediation strategy of brownfield sites in urban mining industry using the concept of NbSs as a guide, and the scientific connotation of NbSs is particularly important as the World Conservation Union (IUCN) has proposed eight basic guidelines and 28 indicators for the implementation of NbSs [28]. The eight basic criteria include the following: identifying one or more societal challenges addressed by NbSs; proposing ecological restoration based on the scale of the challenge; emphasizing that NbSs should result in a net increase in biodiversity and ensure ecosystem integrity; emphasizing economic viability; focusing on both economic viability and social equity; highlighting the need for NbSs to be fairly weighed in order to achieve their main objectives and continue to provide multiple benefits; highlighting the need for an evidence-based adaptive management of natural solutions and evidence for the adaptive management of natural solutions; and providing an emphasis on NbSs to achieve sustainability and mainstreaming [29].

Among the eight NbS indicators, in the spatial scale perspective, NbSs emphasize design based on a more macro-scale landscape, which is a holistic process of integrated natural resource management from a more macro-perspective [30], which is a larger scale than previous mine restoration concepts, and make mine restoration more systematic. Gumi Mountain ecological restoration will be carried out around eight principles: remodeling the terrain and cleaning up the soil as a priority; the hydrological treatment, the filtering of large pollutants, and then the reconstruction of the water system so that it has directionality; the water and soil both need to be considered in the ecological restoration of vegetation; the selection of native anti-pollution plants; the preparation of the ecological site communities; and finally the solid waste through physical or chemical means to form a renewable resource. The main implementation steps to the site are as follows: terrain restoration—soil improvement—hydrological treatment—water system reconstruction—vegetation restoration—solid waste disposal.

3.1. Terrain Restoration and Soil Improvement

Under the guidance of NbSs, the primary mountain body and major mining pit are retained, while the land is leveled and smaller pits are joined to create a cohesive pit group. Bioremediation is a cost-effective, environment-friendly soil restoration technique that has minimal adverse effects on the ecosystem than conventional ways of directly filling abandoned pits [31]. Utilizing original landforms to create complete ecological communities that encompass water and mountains, terrain restoration follows natural contours and connects with existing water bodies to increase water areas (see Figure 3a). The pH value of the soil in Wuhan urban green space is between 5.05 and 10.89 [32]; the original acidity and alkalinity of the site is also in this range, but the site is polluted by heavy metals from the mining industry, the slag contains iron oxides that lead to the acidification of the soil, the pH value reaches between 4.10 and 4.51, and, for the soil with a very high content of acidity, the soil is improved by applying lime, which is rich in calcium and magnesium and can rapidly increase the content of exchangeable Ca and Mg in the soil after application. Lime is rich in calcium and magnesium, and, after application, it can rapidly increase the content of exchangeable Ca and Mg in the soil. Due to the strong flocculation of calcium ions and the formation of hydroxides by some amorphous forms of aluminum and iron in the soil, it can very well reduce the force between soil particles, improve the structure of the soil, neutralize the concentration of hydrogen ions in the soil, and reduce the harmful substances in the soil, as shown in the results of the study conducted by Wang Jinghua et al. Experiments on red soil in Jiangxi showed that the application of 200 kg/667 m² limestone powder can effectively reduce the acidity value of the soil surface by 2–3 units [33,34]. Mineral and industrial wastes: in addition to the traditional method of applying lime, some mineral and industrial wastes such as dolomite, fly ash, phosphogypsum, phosphorite powder, alkali slag, and industrial wastes can play a role in improving acidic soil.

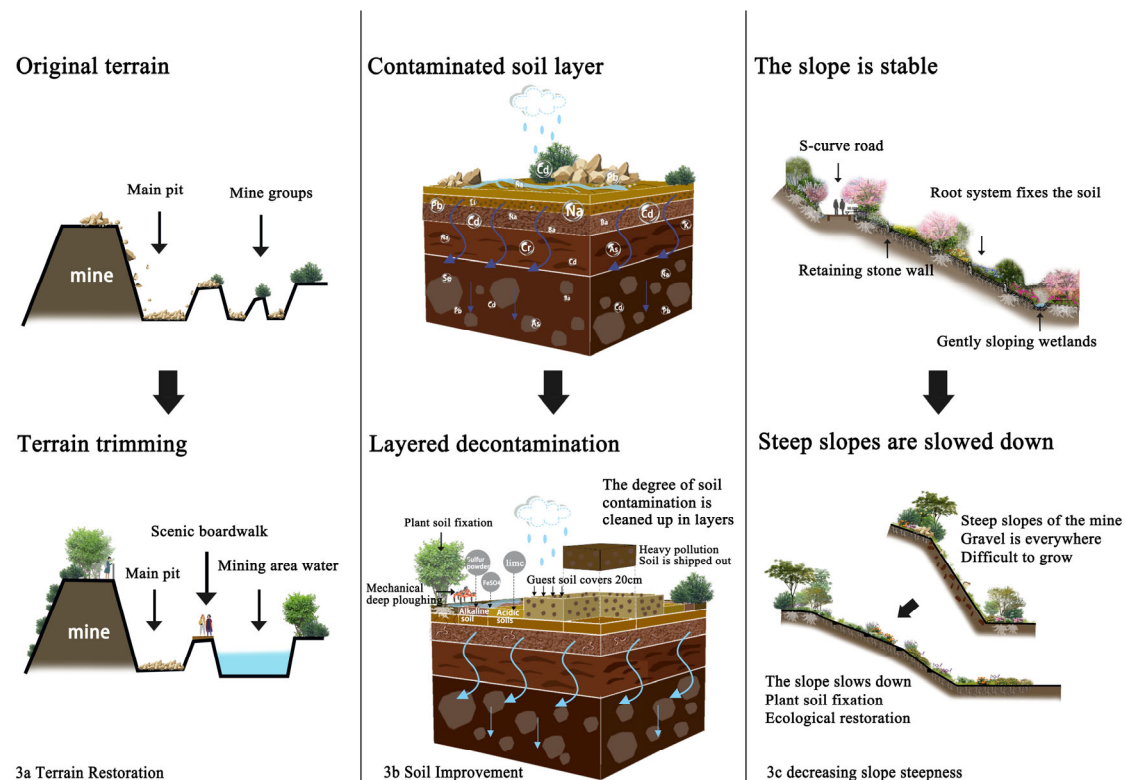


Figure 3. Terrain restoration and soil reshaping of the mining area (illustration by author).

In addition to the acidic soil, there is a very-high contamination by slag of calcium hydroxide and other alkaline substances affecting the alkaline content of the soil; in the Gumi Mountain mining brownfield in the northeast corner of the region, the alkaline content of the soil is very high, and the pH value of the highest content is up to 10.5, which can be used in the whole-soil replacement method to improve the quality [35]; for the local soil improvement measures, the need for planting acid-loving plants, digging out an appropriately large tree hole, and then filling the tree hole with acidic nutrient soil, rotted organic fertilizer, mountain mud, etc., can have the effect of improving soil fertility, permeability, and pH in the planting area. Soil with a low alkaline content can have organic acid, sulfur powder or ferrous sulfate (FeSO_4), sulfuric acid, and other acidic substances added to it in a way that reduces the pH of the soil, making the soil acidic or neutral, thus reducing the solubility and solubility of heavy metals. The above two methods are used to reduce the soil pH to between 6.0 and 7.5 so that it meets the plant-growth and planting requirements.

In addition to regulating the soil pH, attention should also be paid to the enhancement of soil fertility, which is the ability of the soil to supply and coordinate the growth and development of crops from both the environment and nutrient conditions [36], usually used to enhance the traditional three major elements of fertilizer; but, in terms of use, the absorption rate of the three major elements is also different. Among them, phosphorus fertilizer is basically at 10–15%, potash fertilizer is at 40–45%, and nitrogen fertilizer is at 30–35%. However, when the three fertilizers are actually used, there is a mutual resistance between them, which affects the absorption rate of the fertilizer. One of the biggest points is that the use of too much phosphorus fertilizer will affect the absorption of nitrogen fertilizer. Then, according to the soil nutrient status, add nitrogen, phosphorus, potassium, and other chemical fertilizers or organic fertilizers to supplement the soil fertility. Therefore, the main method used in this study is the soil fertility enhancement technology of biochar. Biochar is a carbon-rich material produced by the pyrolysis of organic materials, such as crop residues, woody material, animal manure, etc., at high temperatures in a low-oxygen environment [37]. According to Yuan Shuai et al. [38], the studies on the main types of biochar and their physicochemical properties concluded that, affected by the differences in biochar source material, the cracking process, and cracking equipment, the carbon content of biochar ranged from 30% to 90%, with an average of 64%; the ash content mainly varied between 0 and ~40%, an average of 16%, and the ash mainly includes sodium, magnesium, potassium, calcium, and other mineral elements; as a way of indirectly returning organic fertilizer materials to the field, the advantage of using biochar lies in the physical and chemical properties such as high stability, strong adsorption, porous, low density, etc.; the ash contains a certain amount of mineral nutrients and salt ions, giving it the potential for greater application in soil improvement, fertility improvement, carbon sequestration, emission reduction, the remediation of pollution, and greater application potential [Progress in Research on Soil Fertility Enhancement Principles and Technology].

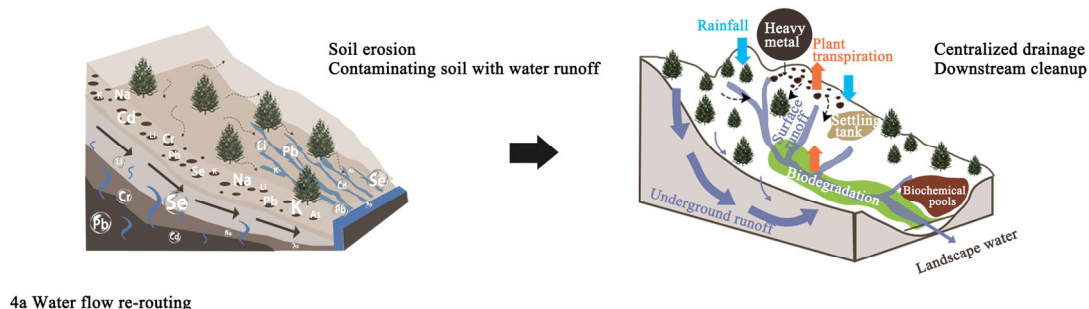
For soil restoration, mechanical deep ploughing technology is the essence of mechanical soil mixing, loosening, and turning. The deep ploughing process of burying fertilizer, straw, and surface grass can promote soil maturation; is conducive to a reduction in pests and diseases and the elimination of weeds; and is conducive to the enhancement of the soil's water retention and water storage function, to adjusting the proportion of three-phase (gas, liquid, and solid) relations, and to restoring the soil granular structure [39]. The spade plough, for deep-ploughing machinery, is the most widely used deep-ploughing spade type in the production process: it has a back to stand up; after the ploughing of the vegetation, it does not show its head; it is good at turning over the district as regards cover performance, etc.; for other implements, it is not as good. For the use of spade

ploughs to break the compacted soil layer in the mining area and improve soil aeration and water permeability, a deep ploughing depth of 30–50 cm, so that the soil is loose, is conducive to the growth of plant roots and soil microbial activities [40] (Figure 3b). After the extremely contaminated areas have been transported off site, a 20 cm thick layer of uncontaminated soil is re-laid to create conditions for subsequent revegetation. Post-soil remediation efforts focus on preserving the pit environment while increasing plantable areas by decreasing slope steepness because the original mountain terrain had near-vertical slopes covered in rubble, making it difficult to plant vegetation. Native species, which use their root systems to maintain the soil, can be planted in tiers thanks to retaining wall terracing, which stabilizes the slopes (see Figure 3c).

3.2. Hydrological Treatment and Reconstruction of Water Systems

In the Gumi Mountain region, heavy metals in the soil reach deeper layers under the influence of rain where the average annual rainfall is approximately 1300 mm. This has a substantial impact on vegetation restoration. Thus, hydrological treatment is critical for addressing ecological concerns in mining areas. Due to extensive mining history, the Gumi Mountain brownfield has significantly altered the original topography and distribution of the water system, resulting in serious soil erosion and widespread pollution from heavy metals carried by water. To prevent further deterioration, a strategic water flow route will be devised, focusing on collection, treatment, and purification to prevent uncontrolled run-off during rains from worsening pollution (see Figure 4a).

Hydrological treatment — dredging



Water system reconstruction — water integration

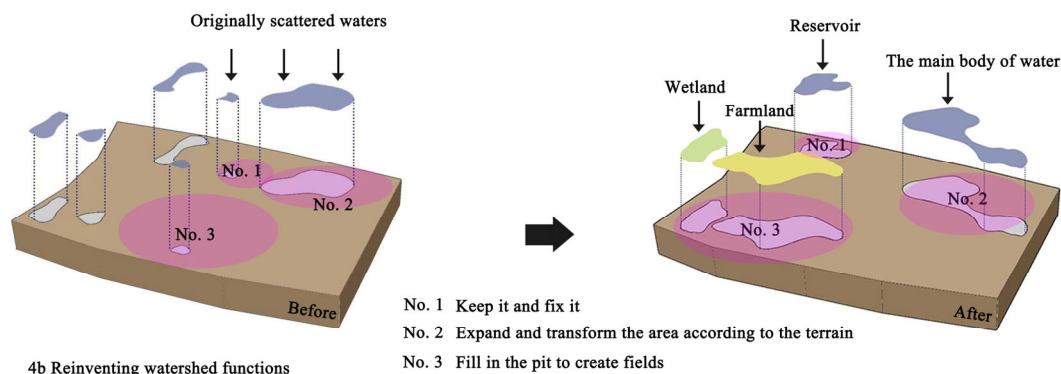


Figure 4. Hydrological treatment and water system reconstruction (illustration by author).

The waters of the site are scattered and have different levels of pollution so the hydrological treatment approach starts with naming the scattered waters of the site as Water Body No. 1, No. 2, and No. 3. According to the degree of pollution, to implement water purification and restoration measures so that the entire site has new life, firstly, a centralized

treatment and sedimentation process is carried out, and then water purification is carried out according to the steps of the mining wastewater treatment process in accordance with the specificity of each water body (Figure 5). For example, regarding Water Body 1, a small reservoir contaminated during mining operations, ozone will be used to oxidize organic pollutants and iron filings to convert hexavalent chromium to trivalent chromium, followed by precipitation removal. The biofilm approach will be adopted [41,42] in which microorganisms develop a biofilm on reactor fillers, degrading pollutants as wastewater flows through while taking advantage of the reservoir's elevation. Water Body 2, located near the mines, suffers from pollution by both heavy metals and solid waste. Polluted water is filtered by sedimentation to remove big pollutants and metal ions and then treated with chemical agents to precipitate and remove contaminants. This area is mostly affected by cadmium wastewater, which is treated by adding sodium sulfide to generate cadmium sulfide precipitate, and hazardous substances are neutralized through redox reactions. Water Body 3 consists of dispersed ponds that were once utilized for irrigation but are now too contaminated for agricultural purposes. Treatment includes physical and chemical methods, followed by refilling to support agricultural and wetland construction, minimizing habitat damage to local residents (see Figure 4b). The above methods were used in the treatment of mining wastewater and domestic sewage, such as at Shanghai Chenshan Botanical Garden Pit Garden, Nanning Garden Expo Park, Romania Salt Mining Theme Park, etc. Because of the geographic environment, the mining distribution, resource differences, and other internal and external factors interfere, resulting in different degrees of water pollution in the mining area and harmful substances contained in the treatment methods, which were also different; so, for the Gumi Mountain, the original water resource characteristics of the zoning block were considered. Therefore, our proposed study method is a more suitable treatment method to deal with the characteristics of the original water resources in Gumi Mountain.

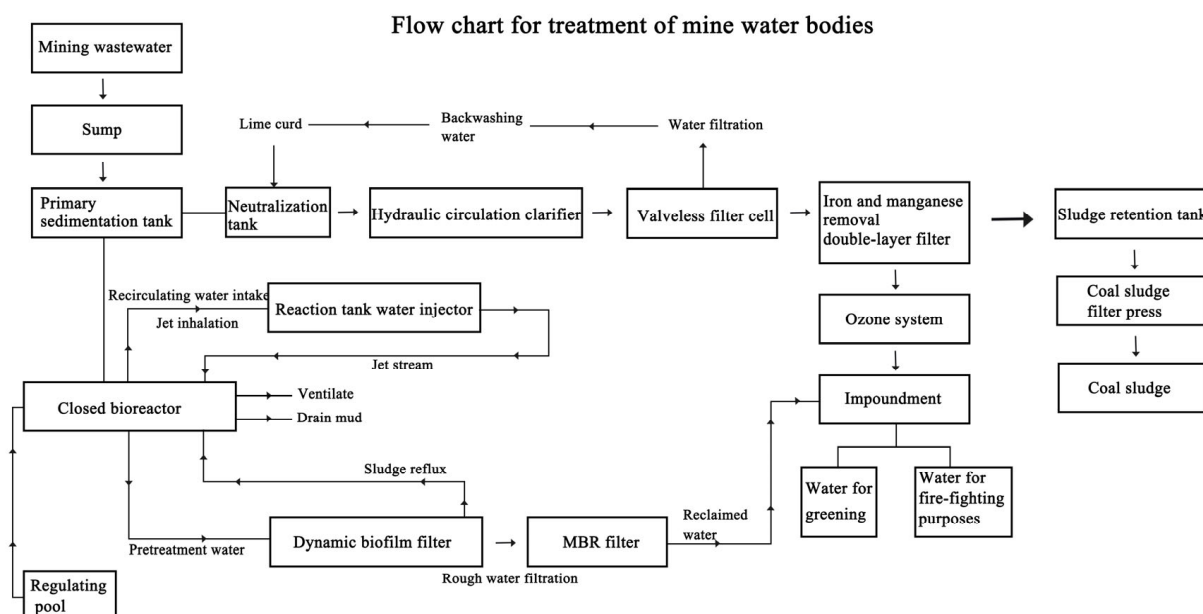


Figure 5. Flow chart for treatment of water bodies in the mining area (image source: drawn and redrawn by Huapu Environmental Protection).

3.3. Vegetation Restoration of the Mining Area

Vegetation restoration is divided into two parts: mine mountain and mine woodland, and layered planting is carried out to build a complete ecological community. When constructing the plant ecological community in the mining mountain, it is necessary to

master the characteristics of various plants such as anti-pollution, enrichment ability, etc., to play the special role of woody plants in the repair of soil heavy-metal pollution; the checking of the preferred species of the repair of heavy metals in urban soils, comprehensively considered, and reasonably configured according to the ecological nature is imperative [43]. The stratified design is the “Herbaceous Restoration Layer—Soil-Stabilizing Shrub Layer—Ecological Tree Layer” structure. The herbaceous restoration layer uses salt and drought-tolerant plants like *Setaria viridis* (L.) P. Beauv. and *Suaeda glauca* (Bunge) Bunge to effectively repair the soil. The plants that aid in soil reinforcement, slope protection, and water conservation such as *Lonicera japonica* Thunb., *Amorpha fruticosa* L., and *Vitex negundo* var. *heterophylla* (Franch.) Rehd. are part of the soil-stabilizing shrub layer. The forest community’s appearance is determined by the tree layer located at the top, which includes trees like *Cinnamomum camphora* (L.) Presl and *Celtis julianae* Schneid. that help stabilize the soil, purify the air, and conserve water (Table 2).

Table 2. Detailed list of vegetation for mountain restoration in mining areas.

Vegetation Layer	Plants	Ecological Role
Herbaceous Restoration	<i>Setaria viridis</i> (L.) P. Beauv.	Soil stabilization, prevention of erosion, and water source protection.
	<i>Suaeda glauca</i> (Bunge) Bunge	Enhancing soil nutrients and fertility and reducing cadmium levels.
Soil-Stabilizing Shrubs	<i>Lonicera japonica</i> Thunb.	Water and soil retention and water source conservation.
	<i>Amorpha fruticosa</i> L.	Soil reinforcement, slope protection, and water conservation.
	<i>Vitex negundo</i> var. <i>heterophylla</i> (Franch.) Rehd.	Rainfall interception and soil improvement.
	<i>Ziziphus jujuba</i> var. <i>spinosa</i> (Bunge) Hu ex H.F.Chow.	Soil stabilization and structural enhancement.
Ecological Tree Layer	<i>Cinnamomum camphora</i> (L.) Presl	Air purification, water conservation, and erosion prevention.
	<i>Celtis julianae</i> Schneid.	Humidity and temperature control, carbon fixation, and oxygen release.
	<i>Ginkgo biloba</i> L.	Air purification, soil and water conservation, and humidity regulation.
	<i>Pistacia chinensis</i> Bunge	Resistance to sulfur dioxide, hydrochloric acid, and coal smoke
	<i>Leucaena leucocephala</i> (Lam.) de Wit	Soil improvement, rain interception, and wind and sand control.

Pioneer plants and sustainable species are necessary for mine land restoration (Table 3) to stabilize the soil, and resistant plants like *Myriophyllum verticillatum* L. and *Imperata cylindrica* (L.) P. Beauv. are first introduced as the pioneer species. The deep penetration of these plants’ root systems loosens the soil and improves its aeration and permeability, which supports the succeeding plants’ growth and their water and nutrient absorption. These roots release organic acids as they grow, which helps decompose soil minerals and raise soil fertility. In order to create a stable plant community, sustainable plants like *Fatsia japonica* (Thunb.) Decne. & Planch. and *Serissa japonica* (Thunb.) Thunb. are then introduced as soil conditions improve. By providing a reliable habitat and food supply for wildlife, their longevity contributes to ecosystem stability and increases the plant

community's resilience. Since the reservoir and adjacent water bodies are polluted by heavy metals (Cr, Cu, Zn, Cd, and Pb), NbSs are incorporated into water restoration to create gentle-sloped wetlands. Metal-accumulating plants like *Sonchus wightianus* and *Descurainia sophia* (L.) Webb ex Prantl are planted here. Through a systematic ecological vegetation restoration method, a stable vegetation community is gradually established in the mining area. In the mining region, the combination of wetlands and wooded areas promotes self-sustaining ecological recovery, while the planting of evergreen and deciduous species offers year-round visual appeal.

Table 3. Detailed list of vegetation for forest land restoration in mining areas (edited by the author).

Vegetation Layer	Plants	Ecological Restoration Role
Pioneer Plants	<i>Myriophyllum verticillatum</i> L.	Heavy-metal adsorption, stabilizes sediment, and oxygen provision.
	<i>Imperata cylindrica</i> (L.) P. Beauv.	Soil and water conservation, water purification, and organic matter increase.
	<i>Dichondra micrantha</i> Urb.	Soil retention, air purification, and weed suppression.
	<i>Erigeron annuus</i> (L.) Pers.	Organic matter increase, microbial proliferation, and ecosystem link.
	<i>Parthenocissus tricuspidata</i> (Siebold & Zucc.) Planch.	SO ₂ , NO _x absorption, and soil and water conservation.
	<i>Canna indica</i> L.	Soil stabilization and SO ₂ and HCl absorption.
	<i>Crinum asiaticum</i> var. <i>sinicum</i> (Roxb.ex Herb.) Baker	Dust particle absorption.
	<i>Lycoris radiata</i> (L'Hér.) Herb.	Strong root anchorage, soil improvement, temperature, and humidity regulation.
	<i>Nephrolepis cordifolia</i> (L.) C. Presl	Accumulating As, Hg, Pb, and Cd.
Sustainable Plants	<i>Fatsia japonica</i> (Thunb.) Decne. & Planch.	Temperature and humidity regulation, enhancement of soil fertility, dust filtration.
	<i>Serissa japonica</i> (Thunb.) Thunb.	Temperature and humidity regulation and enhancement of soil fertility.
	<i>Aucuba chinensis</i> Benth.	
	<i>Gardenia jasminoides</i> J.Ellis	Temperature and humidity regulation, enhancement of soil fertility, and absorption of harmful gases such as sulfur dioxide and hydrogen chloride.
	<i>Elaeocarpus decipiens</i> Hemsl.	
	<i>Platanus orientalis</i> L.	
	<i>Buxus megistophylla</i> H. Lévl.	SO ₂ and HCl absorption and temperature and humidity regulation.
	<i>Mahonia fortunei</i> (Lindl.) Fedde	Soil and water conservation and air purification.
	<i>Cinnamomum camphora</i> (L.) Presl	Smoke and dust filtration, water conservation, and erosion prevention.
	<i>Celtis julianae</i> Schneid.	Humidity control, carbon fixation, and oxygen release.
	<i>Magnolia grandiflora</i> L.	Dust filtration, disinfection, temperature, and humidity regulation.
	<i>Zelkova serrata</i> (Thunb.) Makino	Absorbs pollutants, conserves water, and impacts erosion control.
	<i>Ginkgo biloba</i> L.	Air purification, soil and water conservation, and humidity control.

Table 3. Cont.

Vegetation Layer	Plants	Ecological Restoration Role
Wetland Plants	<i>Sonchus wightianus</i>	Soil improvement, nitrogen fixation, and rainfall retention.
	<i>Descurainia sophia</i> (L.) Webb ex Prantl	Soil loosening, nutrient cycling, and erosion prevention.
	<i>Phragmites australis</i> (Cav.) Trin. ex Steud.	Water purification, soil improvement, and climate moderation.
	<i>Typha orientalis</i> C. Presl	Heavy-metal ion adsorption and pollutant particle capture.

3.4. Solid Waste Management

The Gumi Mountain mining brownfield produced a significant amount of solid waste like mining slag and debris during extraction after adopting four ecological restoration measures. Managing these materials is essential. Some are backfilled into the excavated areas using layered compaction to prevent subsidence to solve the problem of waste storage and avoid surface collapse. Sections that cannot be internally backfilled are used to manufacture building materials. For construction use, materials like bricks and tiles are burned at high temperatures, which effectively immobilizes harmful substances and allows for the creative use of solid waste.

4. Strategies for Regenerating the Gumi Mountain Mining Brownfield

4.1. Functional Positioning and Model Development

Guided by the NbS concept, ecological corridors with the surrounding environment are established in the project so as to expedite the restoration of ecological balance within the mining brownfield. This entails incorporating the nature into the Optics Valley High-tech Zone's development plans. To accelerate the brownfield ecosystem's succession towards a stable natural state, the biological and energetic components from adjacent ecosystems, such as insects and birds, that aid in seed dispersal, as well as organic matter like fallen leaves that enrich the soil, are introduced [44]. In the study, the site's existing resources are used to integrate the five natural elements of "mountain, water, forest, field, and flower" to create a geographically significant magnetic point. A multifaceted area for science teaching, cultural entertainment, and stress alleviation is created using a prototype pulsed magnetic field experimental device. This gives the area the appeal of a creative hub in the Optics Valley technology industry center, which is envisioned as the Optics Valley Future City (see Figure 6).

4.2. Functional Zoning

Guided by the NbS concept, the Gumi Mountain mining brownfield is converted into a magnetic point model and divided into distinct experiential zones. This approach improves the site use while minimizing the impact on the existing resources. The area is divided into five sections based on its original functions: Mountain—Magnetic Valley, Water—Vortex Swirl, Forest—BT Seed Forest, Field—Magnetic Source, and Flowers—Floral Magnetic Tiles. The BT Seed Forest and Floral Magnetic Tiles primary attractions serve as secondary attractions, while Vortex Swirl, Magnetic Valley, and Magnetic Source house the main attractions. These zones interact and connect in an ecological cycle (see Figure 7).

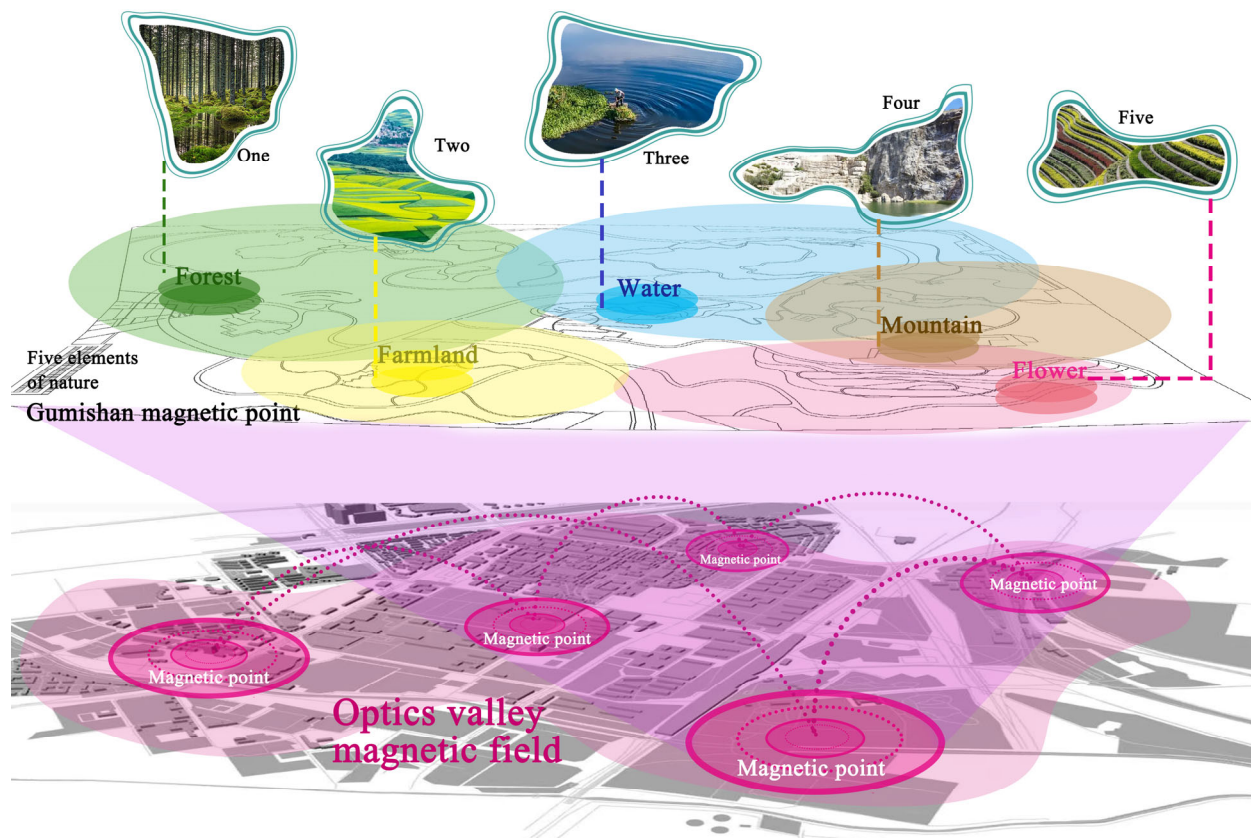


Figure 6. Model construction of the Gumi Mountain mining brownfield magnetic field (illustration by author).

From the expected ecological point of view, the five functional zones are divided into protected and non-protected participatory landscapes, with the protected landscapes being the Seed Forest and the whirlpool vortex. The Seed Forest retains the original forest area and becomes the Seed Forest of the magnetic field, which constantly provides vitality and power for the site, and a small number of trestles and waterfront platforms are available for people to experience the natural forest area, which reduces the activities of the crowd in the area; the vortex is like the pulse of the site, which is unceasingly growing; without water, the wind will be scattered, and, if there is water, the gas will be stopped, and there will be no wind; the protection of the water is especially valued, and the whole area of the water is open for 30% of people to have fun and enjoyment so as to protect the ecology of the site. The non-protected landscapes are Magnetic Valley, Magnetic Source, and Flower Magnetic Sticker. Magnetic Valley is located in the central area of the site, the mine and the pit depression, to form a magnetic center point. Magnetic Valley is divided into two major blocks: one is the northwest of the smaller mine pits, due to the small difference in elevation, away from the water body, used for children's activities; the second is the northeast of the mine pits. Here, the geography is more complex, northeast of the body of water; in the water season, the water flows from the lakes to the pits, resulting in the formation of wetland landscapes; in the dry season, the formation of the natural landscape and the upper set of corridors and other corridors are set up, and the site is open for recreational viewing. The corridor is connected to the children's activity area, and there is a height difference between the children's activity area and the mountain. The slide and other devices are built, and the corridor can be passed in any period of time. The corridor of the tidal wetland is connected to the corridor of the mine mountain, which is closer to the mountain, and the features of the place are observed from different perspectives. The

corridor forms the Magnetic Valley of the convergence of energies, and it is a great urban scar that you can stop by to feel it. The basis of the formation of the Magnetic Source is to keep some of the original farmland of the original site and to plant crops and play the role of scientific research and science and technology. The Magnetic Source is formed on the basis of retaining part of the original farmland of the original site, planting crops and, at the same time, playing a role in scientific research and the popularization of science. Additionally, it serves to enhance people's sensory experience, the close experience of the growth of rice paddies, opening up science and technology experience projects to achieve the purpose of teaching and enjoying. For the flower magnet area in the south of the mine-planted sea of flowers, the gently sloping part of the trapezoidal flower field, the flower field in the restoration of mines, at the same time, has a great ornamental role in attracting crowds of people to stop to enjoy and thus produce certain economic benefits. This zoning not only meets the expectations of ecological protection but also promotes the economic development of the site and its surroundings.

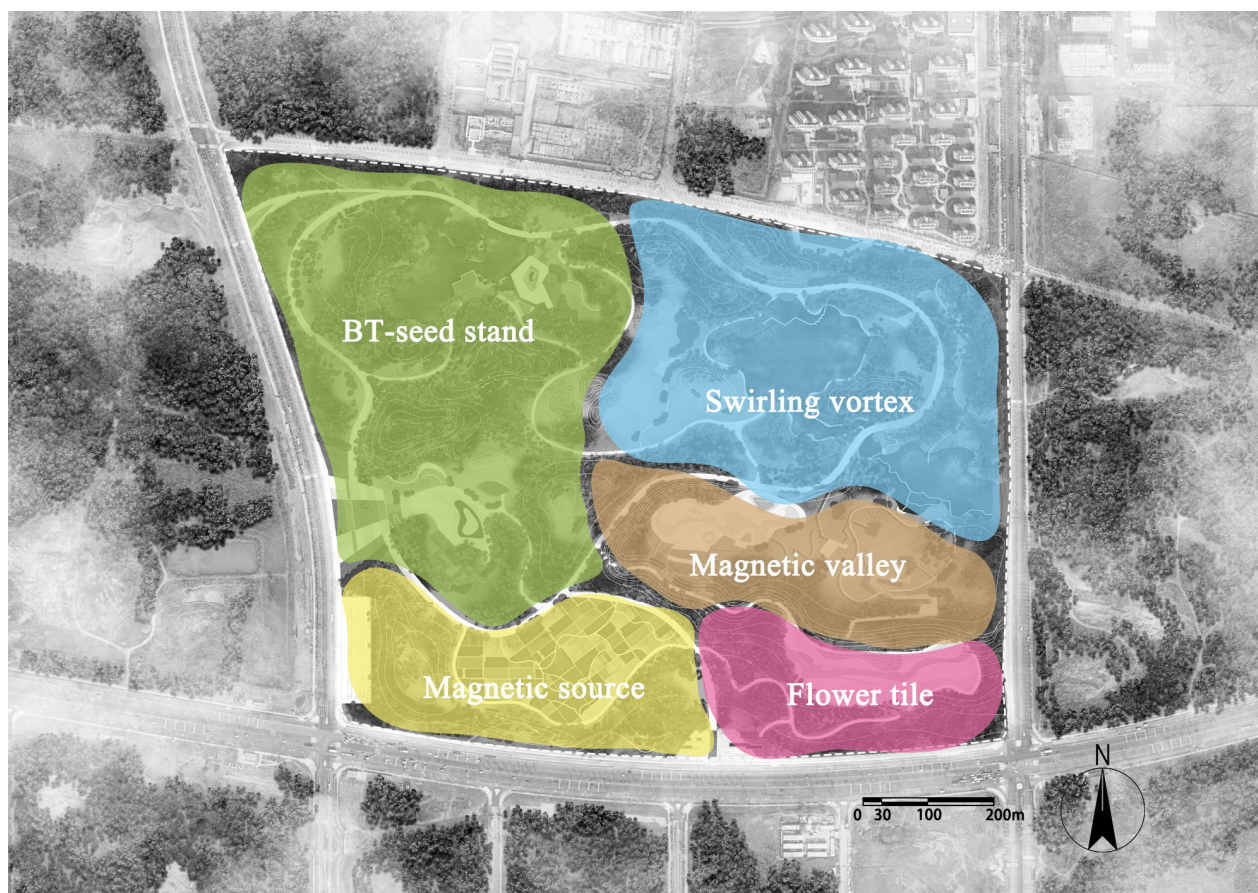


Figure 7. Zoning map of Gumi Mountain mining brownfield (illustration by author).

4.3. Reconstruction of Tour Paths

In order to restore the natural ecology, the site's interior roads, which were originally asymmetrical routes used for mining, farming, and reservoir management, have been redesigned using hydrological and topographical analysis. The site is naturally divided into functional areas in accordance with NbS concepts. With quick-access viewing trails, waterfront promenades, and educational walks about magnetic fields, the major water feature, Swirl Vortex, is made for viewing enjoyment. It provides broad vistas of the mountains and encourages reflection on the natural world (Figure 8a). With a main encircling road and internal trails, the former big mining pit has been converted into the Magnetic

Valley. The Magnetic Bridge, a mountain corridor bridge, is connected by a wetland corridor that permits intimate engagement with the mountainous terrain (Figure 8b). The Magnetic Source, with its numerous field trails and observation platforms, is an agricultural observation place that allows visitors to take a close look at farming landscapes and engage in practical cultivation activities while also incorporating educational elements (Figure 8c). The BT-Seed Forest serves as a repository for ecological resources with little human involvement, fostering a natural ecological community with only a peripheral eco-path and a few forest trails. In keeping with the development of Optics Valley Future City, the Main Entrance is situated at the Magnetic Plaza in the south of the Seed Forest where an ecological conference center has been constructed to increase site reputation and draw in visitors (Figure 8d). Terraced flower fields can be seen at the Floral Magnetic Tiles that are located on the mining area's southern slope. To prevent overdevelopment and additional harm, this area features a peripheral mountain path and a solitary flower-viewing walk (Figure 8e).

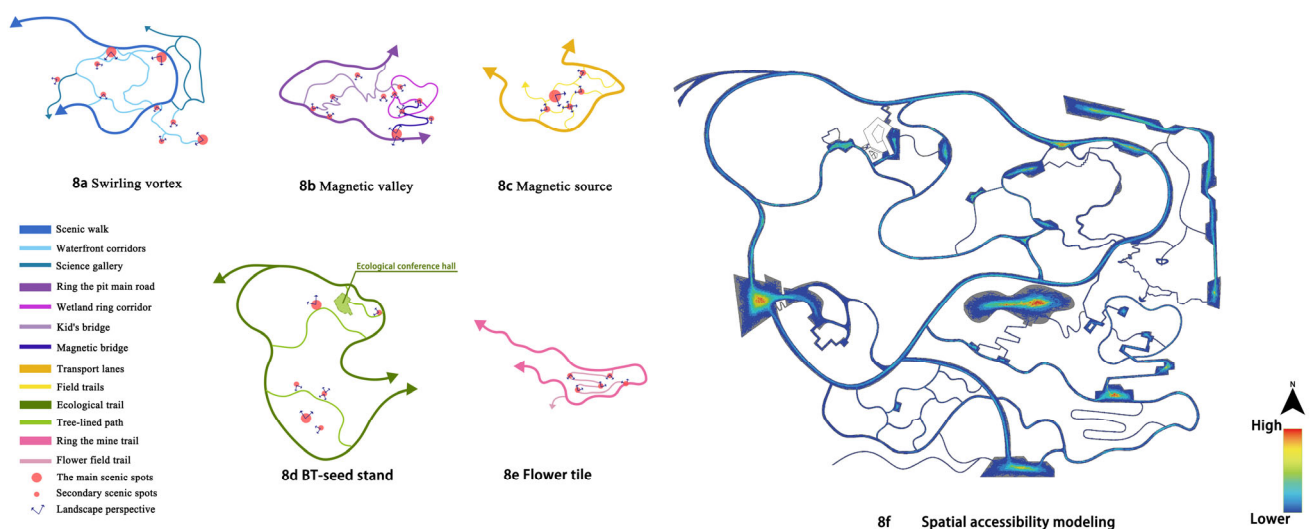


Figure 8. Reconstruction of tour routes in primary and secondary viewing areas under spatial syntax analysis (illustration by author).

The tour paths were analyzed under spatial syntactic analysis (Figure 8f). Through the precise quantification of space, such as the calculation of connectivity, depth value, integration, and other key indicators, we are able to gain a clear insight into the intrinsic connections between different spatial areas. This allows us to plan tour paths that are no longer based on subjective assumptions but with solid data support. For example, the Main Entrance, Cyclone Vortex, and Magnetic Valley are highly integrated areas that are naturally more attractive to tourists, and paths with low depth values also imply higher accessibility, while the Magnetic Source and Seed Grove have high depth values, and low accessibility, and fewer tourists choose to enter them. The tour paths analyzed through spatial syntax take into account various spatial characteristics and are highly compatible with the behavioral patterns of tourists, thus being more reliable. This strongly supports the feasibility of the designed paths and ensures that, in the actual scenario of the Gumi Mountain Mining Brownfield, tourists can naturally and smoothly follow the planned routes, maximizing the touring experience while guaranteeing the efficient use of space.

4.4. Design of Scenic Viewpoints for the Mining Landscape

The mountain's northern slope offers a variety of spectacular views from the summit, including cliffs and a view of the mining pit below. Geological features of the mountain's

rocky surfaces have been maintained throughout the brownfield restoration, guaranteeing ecological safety and highlighting the site's distinct character. Visitors can get a far-reaching perspective of the entire mountain and appreciate its full shape from the northernmost viewing platform. A tranquil view of the water can be found on one side of the Swirl Vortex viewing platform, while a 45-degree upward view of the mountain on the other side evokes a subtle sense of awe. A deep sense of human insignificance in the face of nature is fostered by the requirement for a 90-degree upward look in order to glimpse the mountain peak from the circular pathway surrounding the pit. Visitors can physically interact with the mountain's rugged terrain from the Magnetic Bridge, getting up close to the scarred ground and "listening" to the mountain's silent story (Figure 9). A primary goal of this restoration project is to regenerate the bare earth and mining slopes, highlighting the rugged, steep rock walls and providing an opportunity for environmental education. These diverse points of view provide distinct perspectives on the scarred landscape. This approach integrates self-healing ecology with the regeneration of historical remnants while honoring the natural process of ecological succession, which is consistent with the NbS philosophy.

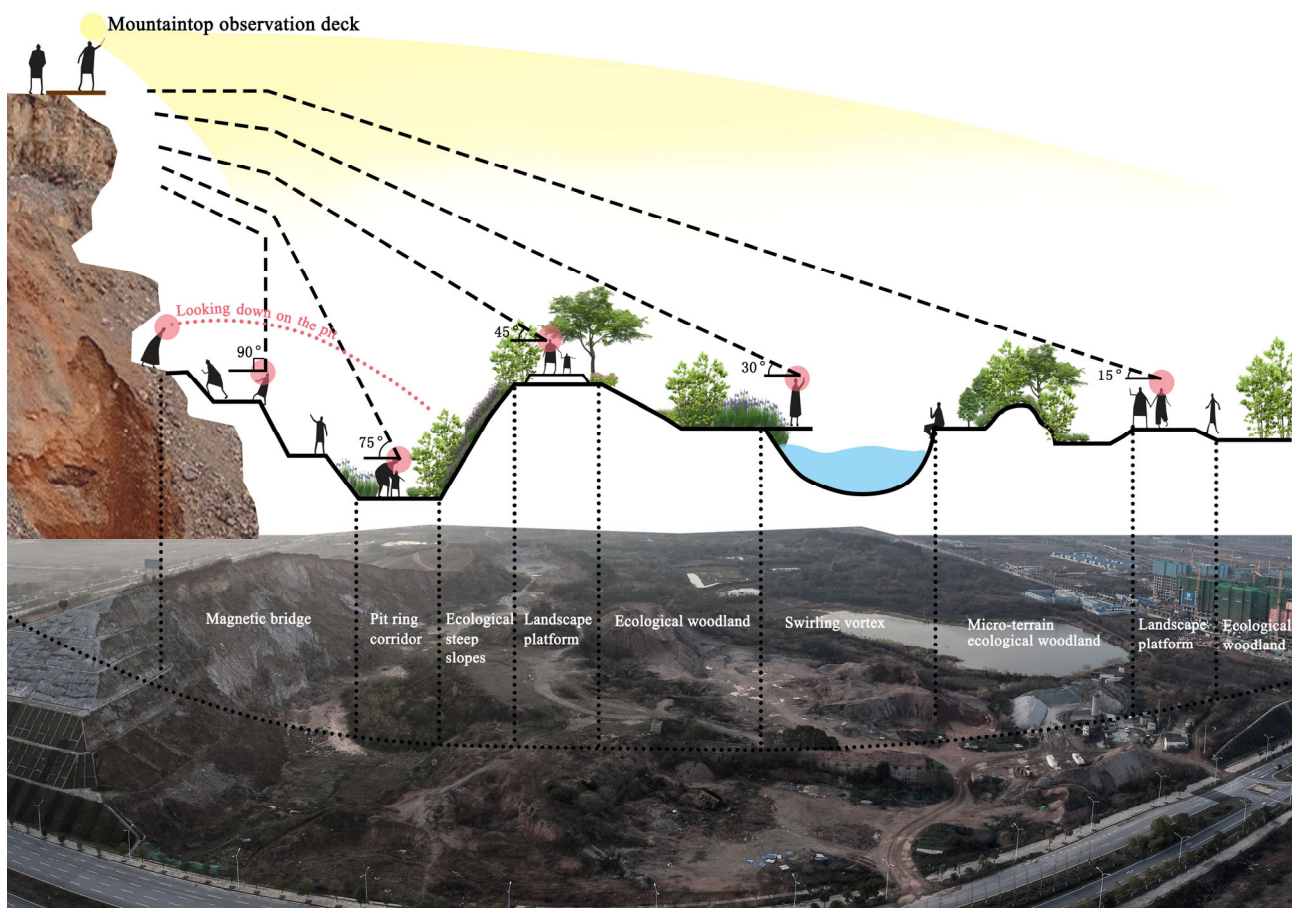


Figure 9. Analysis of scenic viewpoints for the mining landscape (illustration by author).

The brownfield regeneration strategy for Gumi Hill Mining presents a multidimensional mix of successes and complex challenges. On the positive side, the ecological area has been highly effective. In terms of vegetation restoration, the extensive planting of native plants has greatly increased the vegetation cover and promoted the restoration of biodiversity. The restoration of the hydrological system through rational planning of the water system and the construction of wetlands can improve water quality but also enhance the capacity of water resources, effectively reducing soil erosion. At the economic level, the Gumi Mountain mining brownfield strongly promotes industrial vitality. Additionally,

the creation of magnetic points can radiate the surrounding area, and the convergence of multiple magnetic points can create a Guanggu magnetic field, which can also create considerable economic benefits for the Guanggu Industrial Park. However, the implementation of the strategy will also face many challenges. It is necessary to continue to optimize the strategy in order to achieve the sustainable regeneration and development of mining brownfield sites.

5. Conclusions

This study focuses on exploring the ecological remediation of brownfield sites and exploring the historical and cultural values of the mining area driven by the NbS concept, which is cleverly integrated into the landscape design. Based on ecological remediation and sustainable development, it makes use of the natural landscape resources, preserves the historical relics, and creates a regeneration strategy suitable for the brownfield site of Gumisan Mining by analyzing and processing the elements of topography, soil, hydrology, and so on. This strategy takes the surrounding industries (the fiber-optic industry and electronic information industry), as well as the pulsed strong magnetic field experimental device, as a blueprint, discovers the value of the site, and creates a suitable ecological remediation model. The model helps to find the commonality of brownfield regeneration, in which Gumi Mountain highlights its individuality, take it as a pilot to create more “magnetic points” according to the characteristics of the surrounding sites, and finally create a magnetic field in the Optics Valley. The ecological remediation of brownfield sites in the Gumishan Mining Industry drives green industries such as eco-tourism and agriculture, promotes local economic development, and generates a regional radiation effect, which fully reflects the importance and feasibility of NbSs in the ecological remediation of mining areas.

Mining brownfield remediation needs to evolve over time, and the NbS concept provides scientific foresight to guide its regeneration. With the implementation of a series of targeted strategies, NbSs are expected to promote the coordinated development of ecology, economy, and society and transform ecologically impaired mining areas into sustainable development zones. NbS-driven mine regeneration is not only an input but also carries huge economic potentials, and the rational reuse of land resources, the development of specialty agriculture, eco-forestry, or the introduction of suitable industrial industries can create new economic growth points. The follow-up study plans to introduce social capital, adopt the PPP model, and explore the ecological compensation mechanism. Based on the economic benefits brought about by the enhancement of ecosystem services in the mining area, such as the value-added impact of neighboring ancillary facilities and the increase in income from eco-tourism, we are exploring new technologies for the remediation of heavy-metal contamination in soil, such as cultivating ultra-enriched plants with gene-editing technology and combining them with microbial remediation to improve the efficiency. We aim to optimize the design of green corridors in the magnetic field of Gumi Mountain by applying GIS and landscape ecology principles. Although this study focuses on brownfield remediation, it explores more possibilities for the sustainable development of brownfield sites in the process, which will provide lessons for the remediation and regeneration of brownfield sites in other mining industries.

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