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Scientific Interpretation and Advancement of New Development of Soil and Water Conservation from the Perspective of the Soil and Water Ecological View

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Abstract Traditional soil and water conservation represents valuable practical experience accumulated over thousands of years in human efforts to combat soil erosion. It has made indelible contributions to securing grain production and people's livelihoods as well as safeguarding river safety, laid the disciplinary foundation for soil and water conservation, and fostered practical origins for the soil and water ecological view. With social progress, the shifts from mere soil and water retention to soil and water ecology, and from soil and water conservation 1.0 to soil and water conservation 2.0 (also referred to as "broad-sense soil and water conservation", namely soil and water ecological conservation) constitute an inevitable developmental trend for soil and water conservation. On this basis, this paper discussed the technical system of traditional soil and water conservation and its inherent limitations, and proposed promoting the transformation and upgrading of traditional soil and water conservation guided by the soil and water ecological view, including corresponding directions, pathways, and the transformation and upgrading of three major measures: engineering, vegetative, and tillage measures. Besides, the theoretical connotations, applicable conditions, technical pathways, and measures for ecological, natural, productive, and constructive types under the soil and water ecological view, as well as their synergistic integration, were elaborated. Soil and water conservation 2.0 accordingly covers the protection, governance, and regulation of soil and water ecology across the full territorial space. Scientifically interpreting and advancing the new development of soil and water conservation from the perspective of the soil and water ecological view is an important component of soil and water ecological theory.

Keywords Soil and water ecological view, Scientific interpretation, Advancement, Traditional soil and water conservation, Soil and water ecological conservation, New development

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Traditional soil and water conservation embodies precious practical heritage gained from human struggles against soil erosion over thousands of years. It has secured grain supply and people's livelihoods, maintained riverine stability, laid the disciplinary foundation for soil and water conservation, and nurtured practical origins for the soil and water ecological view. Nevertheless, its limitations have become increasingly prominent amid contemporary development[1]. In practice, traditional approaches primarily target soil and water retention while insufficiently prioritizing the overall functions of ecosystems; engineering techniques are frequently prioritized, with inadequate exploitation of nature's self-organizing and self-restoration capacities; governance focuses on localscale interventions, and there is a lack of macro-systematic thinking at landscape and watershed scales. The transformation and upgrading of traditional soil and water conservation, namely shifting from engineering-dominated to ecology-prioritized modes and from soil and water retention to soil and water ecology, is an inevitable developmental necessity.

1 Inevitable developmental trend: from soil and water retention to soil and water ecology

1.1 Technical system of traditional soil and water conservation

Traditional techniques of soil and water conservation fall broadly into three categories: engineering measures, vegetative measures, and tillage measures[2]. Engineering measures include terraces, check-dams, gully check structures, intercepting and drainage ditches, whose core function is to intercept runoff and stabilize soil by modifying terrain and flow paths. Vegetative measures encompass afforestation, grass planting, and enclosure management, mainly mitigating surface erosion and consolidating soil via vegetation cover. Tillage measures comprise contour tillage, strip cropping, and residue mulching, designed to reduce soil loss on sloping farmlands through optimized farming practices.

This technical system has played an irreplaceable role in China's soil and water conservation work. On the Loess Plateau, terraces and check-dams constructed over decades have rehabilitated millions of hectares of sloping farmlands. Large-scale afforestation and grass planting have greatly boosted vegetation coverage and markedly reduced sediment discharge into the Yellow River. In the red-soil hilly regions of southern China, comprehensive watershed-based management has substantially shrunk soil-erosion area. For instance, Ninghua County in Fujian Province once suffered severe soil erosion. Through the combination of traditional techniques such as "segmented ditches+soil and water conservation forests", and "fish-scale pits+hillside ditches", its soil-erosion area dropped from 455 km² in 1995 to 207.75 km² in 2024, and the rate of soil and water conservation rose to 91.37%[3]. These achievements fully validate the effectiveness of the conventional technical system.

1.2 Limitations of traditional soil and water conservation

1.2.1 Singular governance objective. Traditional practices prioritize soil and water retention over ecosystem integrity. Reducing soil erosion serves as the primary objective, and vegetation is often treated merely as an erosion-control tool rather than an integral component of natural ecosystems. Under such logic, once soil erosion modulus declines, plant-species selection

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and planting patterns are sometimes deemed secondary. To achieve rapid greening, fast-growing alien species may be widely deployed, squeezing habitats for native plants. Excessively high planting density for maximum soil-fixing effects can lead to simplified plant communities and low species diversity. Even where vegetation coverage meets standards, plant communities may degrade over time, failing to restore water retention, biodiversity conservation and carbon sequestration functions. For example, *Leucaena leucocephala* was extensively used for slope stabilization in early production-construction projects in Shenzhen. It performed well initially, yet mature plants later undermined slope stability and produced bleak winter landscapes.

1.2.2 Engineering-dominated governance. Engineering measures have long occupied a dominant position in the conventional technical system. Engineering measures are indispensable on severely eroded sites for slope stabilization and soil and water retention. Nevertheless, overly relying on engineering solutions brings three drawbacks: high construction and maintenance costs, secondary disturbances to natural ecosystems, and impairment of natural landscapes. Early construction of the Yantian–Bagang Expressway in Shenzhen featured extensive masonry revetments. The massive masonry slope at the Xiaomeisha scenic section still impairs urban ecological landscapes[4].

1.2.3 Fragmented governance. Conventional governance targets individual land parcels, lacking holistic consideration of ecosystems at landscape and watershed scales and holistic understanding of coupled interactions among water, soil, and vegetation. It is easy to fall into the situation of treating only the symptoms rather than the root causes. The fragmented governance cannot fundamentally resolve regional soil and water ecological challenges.

1.2.4 Delayed monitoring and supervision. Traditional soil and water conservation suffers from limited monitoring tools, lagging data updates, insufficient refined supervision, and inadequate governance precision. These constraints hinder adaptive comprehensive erosion control and intelligent soil and water ecological management in the new era.

2 Advancing transformation and upgrading of traditional soil and water conservation based on the soil and water ecological view

The underlying cause for the limitations of traditional soil and water conservation lies in people's insufficient awareness of "following nature". People tend to control and transform nature via engineering works instead of complying with and utilizing natural soil and water ecological laws. The soil and water ecological view provides theoretical guidance for reflecting on such mindsets[5]. It holds that stable zonal vegetation constitutes optimal measures for soil and water conservation, and natural self-restoration represents the most sustainable governance force; coordinated development of water, soil, and vegetation forms the fundamental goal of ecological management. This paradigm shift requires soil and water conservation to evolve from soil and water control to soil and water ecology, from engineering dominance to ecological priority, and from single-objective regulation to systematic governance and management.

2.1 Directions and pathways for the transformation and upgrading of traditional soil and water conservation

The transformation and upgrading of traditional soil and water conservation do not negate traditional soil and water conservation but advance it. The core framework can be summarized as follows.

2.1.1 Shifting from one-way remediation to systematic regulation. One-way remediation follows a reactive logic: identifying problems→implementing measures→solving problems. Systematic regulation adopts a proactive preventive logic: complying with natural laws→optimizing structures→maintaining equilibrium.

Such transformation is well exemplified by practices of the Loess Plateau. Traditional governance centred on soil retention and greening. After large-scale revegetation, the region confronted intertwined challenges including soil desiccation, sharp reduction of runoff and sediment, and vegetation degradation. Single-objective regulation focused on soil retention and greening can no longer satisfy multi-objective collaborative demands. A multi-target systematic transition integrating soil and water conditions, ecology, economy and society becomes necessary. Accordingly, the fundamental direction of the transformation and upgrading of traditional soil and water conservation lies in expanding governance from isolated soil and water targets to holistic system management.

2.1.2 Strengthening the core role of vegetation and natural restoration capacity. Vegetation should be elevated from a soil-fixing tool to the dominant element of ecosystems. As primary producers in soil and water ecosystems, plants mediate energy flow, material cycling and information transfer. Vegetative measures should therefore be prioritized. For purple-soil eroded areas, assemblages of grasses, shrubs and trees using nitrogen-fixing shrubs such as *Indigofera amblyantha* improve soil fertility and create habitats for arbor growth, fostering positive-feedback loops where vegetation ameliorates soil and water conditions and soil and water resources sustain plant communities.

To maximize the inherent regenerative capacity of nature, it is needed to rely on self-organizing and self-restoration capacities of ecosystems and adopt appropriate artificial assistance. Assisting rather than replacing nature constitutes a core tenet of the soil and water ecological view.

2.1.3 Integration of engineering practice with ecology, wisdom and development. The integration of engineering and ecology aims at resolving ecological deficits of rigid engineering works. For instance, bio-brick drainage slope protection means building drainage ditches on disturbed slopes with bio-bricks; grass seeds within brick pores germinate to form vegetated ditches blending seamlessly with surrounding landscapes, fulfilling drainage requirements while retaining ecological integrity[6].

The integration of technologies with traditional wisdom means combining indigenous experience with modern science and technology for iterative technical upgrading, and achieving the creative transformation and innovative development of traditional wisdom for its modern standardized application. For example, traditional approaches such as segmented ditches for runoff interception, fish-scale pits for soil and water trapping, and hillside ditches for water-fertility conservation can be scientifically validated and standardized as vital components of modern soil and water ecological technical systems.

The integration of governance and development means coupling soil and water conservation with regional development and livelihood improvement to realize ecological prosperity alongside public wellbeing. Traditional soil and water conservation largely depends on government investment as a purely public-welfare undertaking. It is difficult to form a sustainable driving mechanism. New models such as "soil and water conservation+industry", "soil and water conservation+ecotourism" and "soil and water conservation+carbon sinks" translate

ecological assets into economic benefits, transforming pure investment into rewarding returns and enhancing long-term sustainability.

2.1.4 Promoting digitalization and intellectualization of traditional soil and water conservation. Intelligent soil and water conservation improves the monitoring accuracy, supervision efficiency, and scientific governance level of soil erosion, supporting its modernized administration, ecological protection, and high-quality development. A complete intelligent technical system of soil and water conservation covers five dimensions: space-air-ground integrated perception system, standardized data baselines, professional model engines, intelligent business application, and security assurance systems.

It is necessary to improve digital-twin platforms and perception networks, deepen data governance, optimize intelligent models, strengthen grassroots application, and perfect institutional standards. Meanwhile, it is necessary to shift from traditional manual monitoring and post-governance to real-time perception, prewarning, and targeted decision-making to support the supervision of soil and water conservation, ecological restoration, and the regulation of production construction projects.

2.2 Transformation and upgrading of the three major measures of traditional soil and water conservation

2.2.1 Necessity for transformation and upgrading. In the practice of traditional soil and water conservation, engineering, vegetative, and tillage measures are often implemented separately by water conservancy, forestry, and agricultural authorities, respectively. Although they can function well in their respective areas, the lack of systematic coordination prevents synergistic effects and hinders the coordinated development of water, soil, and vegetation.

The soil and water ecological view provides theoretical guidance for the transformation and upgrading of the three main measures: engineering measures shall create prerequisites for vegetation measures; vegetative measures shall serve as core ecological restoration agents; tillage measures shall maximize the function of soil and water conservation while safeguarding agricultural production. Under unified institutional frameworks (such as establishing a national committee for soil and water ecological conservation[7]), these measures shall cooperate based on comparative advantages to sustain the overall health of soil and water ecosystems.

2.2.2 Ecological optimization of three major measures. Engineering measures shift from dominant to auxiliary roles. Vegetative solutions shall be preferred wherever feasible; ecological engineering alternatives shall replace conventional concrete works whenever possible. Interventions with minimal environmental disturbance take priority under equivalent performance. Engineering measures should activate the regulatory and restorative capacities of nature instead of substituting nature.

Vegetative measures are optimized. Site-specific native species are prioritized to avoid alien-species invasion. In densely populated hilly zones, pure vegetative restoration may compete with farmers for farmland, it is difficult to sustain the outcomes of ecological governance. Agroforestry systems such as intercropping between trees and crops effectively mitigate such conflicts.

Tillage measures bridging engineering and vegetative measures. It is needed to replace down-slope tillage with contour tillage, adopt intercropping instead of monocropping, and implement conservation tillage such as no-tillage and straw mulching.

2.2.3 Organic unification of three major measures. The soil and water ecological view treats water, soil and vegetation as an integrated whole, and all interventions shall facilitate their coordinated development. In severely eroded zones, engineering measures should be first adopted to stabilize terrain and intercept runoff to enable vegetation establishment. Engineering measures are instrumental mainly for generating suitable habitats for vegetation.

Vegetative measures constitute the core means for ecological restoration. Well-adapted native vegetation[8] acts not merely as erosion-control tools but as pivotal hubs within soil and water ecosystems, and maintains virtuous cycles among water, soil and vegetation through root reinforcement, canopy interception and litter-layer water retention.

Tillage measures embed soil and water conservation into agricultural activities. On sloping farmlands, optimized farming practices turn agricultural production itself into a force of soil and water conservation.

The organic integration of the three major measures guided by the soil and water ecological view means realizing their rational spatial layout, sequential implementation, and functional complementarity, prioritizing natural restoration and generating a positive cycle and systematic effects.

3 Four categories of soil and water ecological conservation from the perspective of soil and water ecological view

The transition from soil and water retention to soil and water ecology corresponds to the evolution from soil and water conservation 1.0 to soil and water conservation 2.0 ("broad-sense soil and water conservation", namely soil and water ecological conservation). Its connotation and denotation expand fundamentally compared with traditional frameworks. While conventional soil and water conservation centers on soil and water retention dominated by engineering works, soil and water ecological conservation stresses systematic maintenance and coordination of water, soil and vegetation with diversified site-adapted interventions. Soil and water ecological conservation is classified into ecological, natural, productive, and constructive types[9].

3.1 Ecological type

3.1.1 Theoretical connotation and applicable conditions. This mode targets natural-ecosystem maintenance prioritizing ecological protection, with ecosystem integrity and authenticity as core objectives. For structurally intact, functionally sound regions with slight soil erosion, anthropogenic disturbances are restrained to sustain natural succession and maintain the balance of soil and water ecology. River-source zones, key water-source areas, nature reserves, ecological protection red-line zones, and regions with vital soil and water conservation functions and high potential erosion risks require strict preventive protection, as vegetation recovery becomes extremely difficult once degraded.

3.1.2 Technical pathways and measures. It is necessary to restrain human disturbances, enhance natural restoration capacity, and control the invasion of alien species. Hillside enclosure for forest and grass regeneration constitutes the fundamental measure. Ecological resettlement ("human withdrawal for forest expansion") mitigates human-land contradictions fundamentally. The construction of ecological corridors reconnects fragmented habitats in functionally important yet moderately disturbed areas, facilitating species migration and gene exchange.

3.2 Natural type

3.2.1 Theoretical connotation and applicable conditions. This represents low-intervention governance centred on natural restoration. It applies to moderately degraded ecosystems

retaining self-recovery capacity, where maximum ecological benefits are achieved via minimal artificial interventions. Applicable sites include areas suffering mild-to-moderate soil erosion, non-rocky degraded grasslands, degraded woodlands with residual vegetation cover, and sites with adequate water availability and impaired vegetation. In key erosion-prevention zones, restoration prioritizes natural processes supplemented by moderate artificial assistance. Enclosure protection is implemented for alpine freeze-thaw erosion zones and contiguous desertified wind-erosion lands unsuitable for development. Windy sand regions with arid climates, scarce precipitation, and frequent sandstorms require enhanced forecasting, prevention, and monitoring.

3.2.2 Technical pathways and measures. It is necessary to adopt minimal auxiliary interventions and enclosure protection to promote natural regeneration. Fencing enclosure serves as the foundational measure, while supplementary seeding and planting are applied moderately. To follow near-natural principles, native species are selected, and planting densities mimic natural communities to avoid oversimplified artificial stands. Ecological processes are regulated to boost natural renewal. For forest communities, selective thinning is conducted to improve undercanopy light conditions and trigger seed germination. For grasslands, rotational or prohibited grazing facilitates natural reproduction of grass seeds. For hazard-prone zones threatened by sandstorms, landslides or debris flows, prediction and warning systems and hazard avoidance are emphasized. Where conditions permit, comprehensive governance integrates engineering, vegetative, and tillage measures.

3.3 Productive type

3.3.1 Theoretical connotation and applicable conditions. This integrated mode balances ecological protection and agricultural production. By linking ecological restoration with industrial development, it establishes self-sustaining mechanisms featuring ecological improvement, increased output value, and capital feedback. Hills serve both as erosion sources and agricultural production spaces. Embedding soil and water conservation into agricultural activities and coupling ecological governance with industries guarantees long-term sustainability. Applicable areas include concentrated sloping farmlands, agricultural development zones, economic forest plantations, and densely-populated hilly regions with intensive land use.

3.3.2 Technical pathways and measures. Slope-to-terrace transformation means converting sloping farmlands into horizontal terraces to intercept runoff, mitigate soil loss and improve farming conditions and crop yields. Agroforestry intercropping means interplanting dwarf crops such as peanuts, soybeans and medicinal herbs among young oiltea camellia, walnut and fruit trees. This optimizes land utilization and reduces bare surface erosion. Plant-livestock circular systems mean fermenting livestock manure for organic fertilizer and returning it to farmland to reduce the application of chemical fertilizer and improve soil structure; crop residues serve as forage to lower breeding cost.

3.4 Constructive type

3.4.1 Theoretical connotation and applicable conditions. This mode addresses soil and water ecological maintenance for urbanization and engineering-construction zones. Large-scale surface disturbances from excavation, spoil stacking and site grading disrupt original equilibrium of water, soil, and vegetation, and trigger soil erosion and ecological degradation. Prevention and protection are prioritized. Requirements of soil and water conservation are embedded throughout full project lifecycle spanning planning, construction, operation, and maintenance[10]. Applicable scenarios cover urban development zones, industrial parks, transportation corridors, hydraulic engineering sites, mining areas, and other production construction project areas.

3.4.2 Technical pathways and measures. It is needed to protect topsoil resources, constrain construction disturbances, and implement systematic vegetation restoration. Nature-based solutions respect natural terrain and avoid massive earthworks. Topsoil stripping and preservation constitute primary procedures. Rich in organic matter, microorganisms and seed banks, topsoil is stripped and stockpiled prior to construction, and then backfilled for vegetation restoration after construction.

Construction-phase management is critical, including the construction of temporary drainage-sedimentation facilities, spoil disposal following the principle of "interception before dumping", bare-ground mulching, and temporary greening, which can confine soil erosion during construction within site boundaries. "Space-air-ground-human" integrated digital monitoring network is constructed to enable real-time disturbance surveillance and rapid responses[11]. For steep high slopes, ecological slope-protection technologies, and native plant species are preferred for vegetation restoration.

3.5 Synergistic integration of the four categories

The ecological, natural, productive and constructive types constitute a complete practical spectrum of soil and water ecological conservation with interrelated distinctions and connections, and they are often deployed in combined patterns according to regional characteristics[12]. The ecological type targets pristine ecosystems with core missions of prevention and protection. The natural type addresses moderately impaired ecosystems relying on minimally intervened natural restoration. The productive type resolves human-land conflicts through multifunctional coordination. The constructive type governs anthropogenically disturbed sites via regulation and remediation. Collectively they cover full territorial space scenarios ranging from nature reserves to urbanized zones, from uninhabited wilderness to densely-populated regions. It embodies the core idea of soil and water ecology: adapting measures to local conditions and implementing targeted policies by category. In real-world implementation, the four categories are not mutually exclusive but interconnected and jointly advanced.

4 Conclusions

Soil and water conservation is a fundamental national policy that China must adhere to over the long term. Soil and water conservation safeguards soil and water resources, ecological security, and socio-economic sustainable development, directly supporting flood control, food, and drinking water security. The shifts from soil and water retention to soil and water ecology, from soil and water conservation 1.0 to soil and water conservation 2.0, from fragmented remediation to full-territory management, and from lucid waters and lush mountains to invaluable assets represent an inevitable developmental trend and a new challenge for soil and water conservation. The soil and water ecological view scientifically interprets contemporary innovations in soil and water conservation and offers vital theoretical guidance for China's soil and water conservation, ecological restoration, and integrated governance of mountains, rivers, forests, farmlands, lakes, grasslands and deserts. Meanwhile, it also delivers Chinese wisdom and solutions and provides renewed theoretical momentum for global ecological governance.

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respectively. This suggests that applying a uniform spatial radius of influence to all stations may obscure differences in their functional spatial characteristics. Thirdly, an increase in the number of POIs does not necessarily correspond to an increase in the degree of land-use mix. There are certain differences in functional scale and balance, and the number and structure of functions should be comprehensively considered. Fourthly, spatial planning around rail transit stations should move beyond a uniform buffer-radius approach. Instead, differentiated functional layouts and spatial optimization strategies should be developed based on the functional structure and characteristic spatial scales of individual stations.

This study has several limitations. First, POI data primarily reflect the distribution of facilities and service functions and cannot be directly equated with land-use area. Second, although cumulative buffer zones capture changes in land-use mix across different spatial scales, they do not adequately reveal functional variations within individual distance bands. Future research could therefore adopt ring-based spatial analysis and incorporate multi-source data, including land-use data, building function data, and population activity data, to validate the findings. In addition, expanding the sample of rail transit stations could improve the robustness of characteristic spatial scale identification and enhance the generalizability of the research findings.

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