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Article

Assessing Anthropogenic Ecological Impacts on the Natural Environment

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Abstract: The optimization of natural resource use plays a significant role in transitioning ecological management issues into economic calculations. Based on this foundation, a methodology was developed to quantify the damage pollution inflicts on various recipients. Major recipients include the population; residential and communal infrastructure (urban areas, housing, urban transportation, green spaces, and other structures); agricultural lands, animals, and vegetation; forest resources; elements of industrial and transport infrastructure; fish resources; and recreational and therapeutic resources. Given the waste generated by industrial enterprises and environmental changes, society is increasingly aware of the need to preserve an unchanged natural environment, including clean air, greenery, and drinking water. The document presents both scientific and practical findings related to environmental preservation and ecological management.

Keywords: ecology, environmental protection, natural resources, management methods, management mechanisms, ecological management, natural resource utilization, air quality, social factors.

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1. Introduction

Throughout human history, society has progressively altered the planet's natural landscape, with impacts comparable to those of geological forces. Today, the intensity and scale of human-induced changes in certain natural components and landscapes are continually increasing.

Currently, a crucial condition for effective environmental protection is ensuring that the economic entities responsible for anthropogenic impacts compensate for the environmental damage they cause, assessed in monetary terms. Each year, hundreds of billions of tons of minerals are extracted from the earth, mixed, and relocated; 16 billion tons of oxygen are drawn from the atmosphere; 3.5 to 4 thousand cubic kilometers of water are consumed for household and industrial needs; and over 9 billion tons of biomass are produced globally. Annual wood production exceeds 2 billion tons. Presently, about one-third of the world's arable land has suffered erosion, disrupting the ecological balance and landscape due to human activities. Soil deflation causes the loss of tons of soil particles per hectare annually, while water erosion not only reduces arable land but also fragments the landscape, complicating agricultural mechanization. Consequently, it is essential to economically assess the extent of environmental degradation and pollution to measure the costs of mitigation. Estimating the value of lost recreational sites, therapeutic facilities, and biological resources, such as flora and fauna, is a challenging but necessary endeavor.

Environmental disruptions in natural landscapes can be classified into three main types: fundamental, single-component, and multi-component. Fundamental disruptions involve geological and geomorphological shifts in landscapes, biotic components, and microclimates. Examples of such disruptions include the construction of urban areas, residential settlements, large reservoirs, open-pit mining, and deforestation, all of which introduce localized, significant alterations to natural landscapes. Single-component and multi-component changes are usually associated with agricultural production. For instance, soil characteristics, river flow, and microrelief properties vary depending on farming practices and cultivation techniques. The structural changes these economic activities induce in landscapes give rise to various categories of anthropogenic landscapes.

Conservation and management of natural and ecological resources generally require regulated use or preventive measures to avoid contamination from waste and industrial emissions.

While protecting biological resources, it is essential to balance their use for raw materials, environmental conservation, and natural disaster protection. Sustainable management of mineral resources, along with reducing waste from production and consumption, helps reduce environmental pollution, thereby preserving both ecological and biological resources.

The cumulative impact of human activities on environmental pollution and resource depletion affects three major areas: the health of ecological systems, economic assets, and human well-being. Consequently, environmental damage can be classified into three types: ecological, economic, and social damage.

2. Materials and Methods

Ecological damage reflects the disruptions occurring within natural systems, where adverse consequences may arise even from slight deviations from optimal conditions. Typically, economic damage denotes the actual or potential financial losses in the economy that result from environmental degradation due to anthropogenic activities. For instance, a single automobile consumes an average of 4 tons of oxygen per year, releasing approximately 200 components in its exhaust emissions, including 800 kilograms of carbon monoxide, 40 kilograms of nitrogen oxides, and nearly 200 kilograms of hydrocarbons.[1]

Beyond direct losses (natural damage), economic damage includes the costs incurred to address the consequences of pollution or environmental degradation. These costs vary depending on the economic activities impacting the environment. For instance, in sugar factories, fully purifying water costs 100 times more than the expense of a 30% purification process, illustrating the steep rise in costs with increased levels of purification. [2]

Alongside economic damage, it is crucial to consider the social damage caused by environmental pollution. Social losses can be categorized as either recoverable or non-recoverable. Recoverable losses, such as lost productivity or health-related costs, can often be quantified in monetary terms. French studies indicate that environmental factors, like urban noise pollution, can decrease physical labor productivity by 30% and mental productivity by 60%. In general, enhancing the ecological environment can increase labor productivity by at least 3%.[3]

In addition, non-recoverable social losses, which cannot be readily quantified, include aspects such as health deterioration, diminished creativity, premature retirement due to health issues, reduced life expectancy, and psychological distress. Economic, material (e.g., decreased industrial and agricultural productivity), and social damages (e.g., higher healthcare costs, increased disability rates, and reduced work productivity) due to environmental pollution contribute significantly to the gross regional damage estimates.

Aggregate damage represents the total losses for society and the economy in the absence of environmental protection measures. The types of local damages that contribute to aggregate losses include: industrial damage (this includes shortened lifespan of infrastructure due to aggressive environmental conditions, additional repair costs; loss of raw materials in industrial waste; and costs of water and air purification in industrial processes); damage to agriculture and forestry (additional costs arising from reduced crop yields and livestock productivity); public health damage (includes expenses related to health services, sick leave payments, and lost productivity due to increased illness; damage to residential and communal services (includes additional costs related to maintaining housing, green spaces, and other communal facilities in deteriorated conditions); direct economic damage to the public (additional expenditures for longer travel distances to recreational areas and increased costs in personal service sectors due to environmental degradation); damage due to increased workforce instability (expenses associated with high turnover rates due to environmental issues). [4]

The economic mechanism of environmental management involves optimizing the relationship between nature users and the natural environment, achieved by aligning material incentives with resource preservation goals.

The environment serves three main functions: Resource provisioning; Absorbing and neutralizing waste and pollutants; Providing recreational, aesthetic, and ecological services to society.

These functions collectively support life and are essential for sustainable development. If there is no mechanism for damage compensation (e.g., the "polluter pays" principle), the resulting losses become a real burden for other economic agents and the population. In Uzbekistan, for example, annual agricultural losses due to land degradation amount to approximately 31 million USD.

This research employs comparative analysis, statistical evaluation, economic comparison, and logical reasoning to examine the management of ecological factors within the economy. Key methods include scientific abstraction, analysis and synthesis, as well as induction and deduction.

3. Results and Discussions

Human economic activity significantly impacts biocenoses, leading to various landscape-ecological consequences. All human-altered landscapes can be divided into two main categories based on their economic value: cultural and non-cultural landscapes. Cultural landscapes are actively maintained by humans to fulfill economic, aesthetic, and other functions optimally. Conversely, non-cultural anthropogenic landscapes are typically the result of irrational economic practices.

Social and economic processes in landscapes can be grouped into seven primary categories, as summarized in Table 1.

Table 1. Types of Social and Economic Processes and Their Corresponding Anthropogenic Landscapes

№	Socio-economic processes in the landscape	Type of Anthropogenic Landscape
1.	Construction and extraction of minerals (technogenic processes)	Urbanized and industrial landscapes; rural areas and farms; surface infrastructure; artificial reservoirs; mining landscapes
2.	Slope terracing (terrace farming)	Mountain agricultural landscapes
3.	Land reclamation	Irrigated lands; drained lands
4.	Agriculture	Agricultural landscapes; orchards and vineyards; primitive farming landscapes
5.	Livestock farming (pastoralism)	Artificially improved pastures; natural meadows; low-productivity pastures
6.	Forestry	Exploited forests; natural forests; secondary shrublands; 6.4. monoculture plantations (planted forests)
7.	Recreation	Recreational landscapes; forest parks; nature reserves and national parks

Recognizing nature as a comprehensive process, the condition of natural resources can be analyzed as the outcome of interactions between society and nature. This perspective allows for optimal environmental management strategies for resource usage, improvement, and conservation. Consequently, natural resource conditions and their application within various economic sectors can be categorized into three groups: natural-ecological labor resources, biological resources, and mineral raw materials. Each resource type plays a unique economic role, characterized by distinct material cycles, resource states, and outcomes of ecological-economic regulation, as presented in Table 2.

In addressing environmental management challenges, these indicators collectively provide a basis for implementing conservation measures, improving environmental quality, and promoting efficient resource utilization. As a result, these regulation activities yield multiple benefits, including reducing pollution, increasing resource valuations, and optimizing resource use.

Table 2. Framework for Regulating Natural-Ecological Resources [8]

Resource Group	Type of Material Cycle	Key Resource State Indicators	Economic Role	Main Regulation Activity	Regulation Outcomes
Natural-Ecological Labor Resources	Natural	Pollution Level	Living Conditions	Preservation	Conserved resources
Biological Resources	Biotic	Productivity	Work Tool	Improvement	Enhanced resources
Mineral Raw Material Resources	Economic	Reserves	Resource for Production	Utilization	Utilized resources

Assessing economic damage involves synthesizing several approaches into a comprehensive framework, which can be conceptualized as the combined value of natural losses and the expenses required to mitigate adverse effects or restore degraded resources. The economic damage (v) is determined by the volume of natural losses (Ri) and the costs of offsetting their impact on economic activities (Z), as shown in Equation 1:

$$V = f(Pi, Z) \tag{1}$$

Natural losses primarily include the direct damage to resources and the subsequent economic consequences, such as soil destruction during mineral extraction or the repurposing of agricultural lands for industrial or reservoir construction.

Direct losses to natural resources encompass impacts like deforestation, soil erosion, and air pollution, which contribute to forest degradation. For instance, the construction of dams adversely affects aquatic ecosystems by obstructing fish migration routes necessary for reproduction. Furthermore, pollution of water bodies with hazardous substances, thermal contamination, reduced oxygen levels, and excessive growth of aquatic plants severely impact water quality and biodiversity.

Calculating economic damage poses complex methodological challenges, as it requires detailed, case-specific approaches for each environmental component and recipient. Current methodologies for economic damage assessment include three primary approaches:

1. Direct Calculation Method. This approach compares costs in polluted and controlled areas by examining healthcare expenses, agricultural yields, livestock productivity, and asset lifespan. It provides a straightforward economic assessment of pollution-related losses.
2. Analytical Method. The analytical method utilizes predefined mathematical correlations between pollution levels and recipient conditions to quantify damages. This model is particularly useful for forecasting the impact of specific pollutants on economic resources.
3. Empirical Method. The empirical method estimates damage by extrapolating general environmental impact trends onto specific contexts, allowing for a simplified damage assessment where detailed data is unavailable.

These methods each serve distinct functional purposes. Direct and analytical methods demand extensive data collection and processing, making them less practical for broad application. Consequently, they are primarily employed as foundational tools for developing empirical damage estimation frameworks. The empirical method is less precise but provides a simpler means of calculating overall environmental damages due to widespread pollution.

The empirical model aggregates environmental damage as the sum of damage to the atmosphere, water bodies, soil, and underground resources. This simplified approach enables easier evaluation of overall environmental harm. For instance, atmospheric damage is assessed based on the total volume of pollutants (in standardized toxic tons) released within a specific area.

Total pollution figures are converted into standardized toxic units per ton to represent their cumulative impact. In Uzbekistan, for example, the volume of both recyclable and non-recyclable toxic waste in 2020 reached 51,240,460.736 tons and 29,114,034.984 tons, respectively.

Additional calculations account for pollutant dispersal factors and the relative toxicity levels across various population densities. These factors help estimate the localized environmental threat posed by pollutant concentrations.

$$y = y_a+y_b+y_n+y_n \quad (2)$$

Here, total environmental damage (y) is calculated as the sum of atmospheric (ya), water (yb), soil (yn), and underground (yn) damages.

For atmospheric pollution, damage costs are adjusted based on pollutant dispersal conditions, land density, and the relative danger posed by the concentration of harmful substances.

$$y_u=\gamma \times f \times \sigma \times \mu \quad (3)$$

The approach used to calculate atmospheric pollution damages is similarly applied to assess the economic costs associated with water and soil pollution. These frameworks form the basis of the "Temporary Methodology for the Economic Evaluation of Environmental Protection Efficiency and the Economic Damage from Pollution," which facilitates the economic modeling of resource conservation. Through this methodology, sector-specific frameworks were developed to calculate damages caused by pollution across various recipient categories: 1) population; 2) residential and communal services (e.g., urban areas, housing infrastructure, urban transportation, green spaces); 3) agricultural lands, animals, and plants; 4) forest resources; 5) industrial and transport infrastructure elements; 6) fish resources; 7) recreational and therapeutic resort resources.

This approach allows for a comprehensive evaluation of both aggregate economic damages and the costs associated with specific environmental damage elements. For any given region, the breakdown of environmental damage costs typically includes 40% for increased public health expenses, 25% for damage to residential and communal services, 20% for losses in agriculture and fisheries, 5% for forestry losses, and 10% for industrial damages.

Studies indicate that atmospheric pollution incurs the highest economic costs, accounting for approximately 60% of total environmental damage, followed by water pollution at 30%, and solid waste pollution at around 10%. The complexity of evaluating environmental damage poses significant methodological challenges, and as a result, these assessments are seldom integrated into the general performance metrics of industrial enterprises. However, accounting for such damages is crucial during project planning, environmental impact assessments, and evaluations of environmental protection effectiveness. Proper damage estimation supports governmental ecological policies and informs financial allocations for environmental conservation efforts.

Pollution from industrial activities primarily stems from waste, including unused portions of resources. Therefore, economic damage indicators are essential for evaluating the efficiency of resource-and energy-saving technologies. By summarizing the applications of gross economic damage indicators, we can outline their functions within the national economy as shown in Table3.

Table 3. Functional Roles of Gross Economic Damage Indicators from Environmental Pollution [10]

Accounting Function	Measures the negative impacts of economic activities on the environment.
Strategic Function	Guides environmental protection strategies, informs technology development, and supports ecologically sound decisions on production location and expansion.
Restrictive Function	Limits the establishment of new facilities in ecologically vulnerable areas and restricts polluting industrial activities.
Investment Function	Helps determine the scope and structure of investments in environmental protection.
Incentive Function	Encourages improvement in environmental performance through fines, penalties, and pollution fees.

As shown in Table 3, gross economic damage indicators from environmental pollution play a critical role in various regulatory and administrative functions. These indicators address both immediate concerns (such as fines for environmental violations) and long-term strategic considerations (such as selecting technologies and optimizing production locations). Together, these indicators support the overarching goal of addressing environmental protection as a multifaceted challenge requiring coordinated action.

4. Conclusion

Integrating economic damage indicators into decision-making is essential for choosing optimal scenarios in industrial and urban planning, infrastructure placement, and the layout of recreational facilities. For instance, research shows that locating a chemical plant near an urban area increases pollution-related damages by 8-10 times compared to siting the facility 5 kilometers outside city limits.

Assessing economic damage is, therefore, an indispensable component of ecological management, uniting critical social, economic, and technical objectives under a coherent environmental protection strategy. Factoring in these economic assessments is crucial for guiding the allocation of investments in environmental protection, identifying pollution-intensive industries and regions, and devising strategies to reduce ecological impacts. Technological development plans should account for the direct and indirect economic costs associated with raw material extraction, production, and disposal. For instance, when evaluating the economic viability of switching internal combustion engines to hydrogen fuel, it is essential to consider not only the operational damage caused by gasoline engines but also the full environmental impact of gasoline extraction and refining. Additionally, the economic costs of producing the electricity required for hydrogen generation should also be incorporated. Evaluating environmental damage serves as a critical factor in shaping sustainable environmental policies. By incorporating damage assessments, policymakers can determine the necessary funding for conservation initiatives and prioritize areas requiring urgent ecological intervention. Moreover, effective economic damage assessment underscores the need for environmentally sound planning in industrial and urban development. Environmental pollution resulting from industrial processes predominantly comprises unused resource fractions, making economic damage indicators vital for assessing the effectiveness of resource-conserving technologies. Gross economic damage indicators thus provide a functional foundation for national environmental policy, supporting various domains such as pollution control, strategic resource management, and investment optimization.

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