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A proposed framework for estimating the environmental damage cost of mining activities in line with the goals of sustainable mining: a case study of Sungun-Ahar copper mine, Iran

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ABSTRACT

The growth of mining activities reduces the area covered by natural ecosystems and the value of ecosystem services (ES) provided by them. It is necessary to estimate the impacts of land-use changes on the ES value of the ecosystems located in the areas directly and indirectly influenced by mining activities as well as the cost of environmental damages inflicted on the ecosystems. Green mining makes it possible to develop a suitable and effective mechanism for the policymakers and planners to optimally and sustainably upgrade resources utilization. Estimating the cost of the environmental damage of mining activities would effectively preserve ES values and prevent the degradation of ecosystems. It is also an efficient approach in making effective decisions and plans for the restoration of mines. The recent study is the first research to investigate the relationship between mining activities and their impact on reducing/losing the value of ecosystem services by offering a comprehensive and specific framework. The total estimated cost of environmental damages inflicted on ecosystem services influenced by the mining activities in the Sungun Copper Mine was estimated at Int $ 7543232 (1734943 million IRR). This research aimed to develop a comprehensive framework for the stages involved in estimating the changes and losses inflicted on the values of ecosystem services provided by the ecosystems within the scope of direct and indirect effects of mining activities. This framework can help policymakers, stakeholders, and land use planners at regional and national levels preserve ecosystem services and make sustainability plans for the mining regions.

Keywords: *Environmental damage cost, Copper mine, Mineral extraction, Sungun-Ahar*

1. Introduction

In the mining cycle, including the steps of exploration, exploitation, enrichment, and termination, ecosystem services (ES) (e.g., woodlands, wetlands, and ore reserves) are subject to noticeable changes [1]. Open mining can degrade ecosystems and lead to the loss of service values of neighboring ecosystems through direct capture and indirect consequences on adjacent ecosystems. The values of local ES decrease with the expansion of mining areas. The effect of spatial proximity is accelerated by the loss of ecosystem service values, particularly the value of wetland services and the function of hydrological regulation. The greater the extent of mining and the unit value of the surrounding ES, the greater the loss of ecosystem service value due to mining activities. The scattered and irregular exploitation of mining areas will lead to a rapid increase in the loss of ecosystem service values. In contrast, mining in areas with less ecosystem service value is more beneficial [2]. The operation/production stage of mining mainly includes the activities of the explosion, drilling, ore and waste handling, ore crushing, and mineral waste handling/transport. These activities can be the source of many negative environmental impacts, including but not limited to "chemical pollution of surface and groundwater", "decrease in the population of species", "toxicity of organisms", "decline of water table", "increased erosion and sedimentation", "acid mine drainage", "waste slurry overflow (affecting terrestrial ecosystems)", "increased greenhouse gas emissions due to energy consumption" [3]. Acid mine drainage is considered the most serious problem of water pollution in mining activities. Acid mine drainage contains iron sulfate and other elements that can affect the intake of water areas [4]. Mining is essential for producing goods and services [5], but it sometimes causes irreparable damage to ecosystems [6]. Mining is one of the main sources of environmental considerations for human societies. [7,8]. For example, according to its nature, coal mining and processing have a very high potential in creating different types of environmental pollution [8]. In the Colombia region, environmental costs range from the US $ 0.02 per tonne to US $ 0.16 per tonne of extraction per year. Numerous studies confirm this claim and prove that the balance in environmental and socio-economic priorities is in the interest of all stakeholders of mining companies [9]. In a study by Mishra et al. [10], recreational damage to five lakes affected by coal mining was estimated at $ 21 million a year. After reclamation, the recreational benefits of declined sulfate concentrations by 6.5% and 15% in the five affected lakes were estimated at $ 1.89 to $ 4.92 million per year, with a net present value of $ 14.56 million to $ 37.79 million, respectively [10]. Findings from the research by Gu and Sun [11] showed that coal mining per tonne reduces 1.32 cubic meters of water resources, pollutes up to 0.88 cubic meters of

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water resources, and degrades an average of 0.17 square meters of ecological water environment and also, resulting in a total cost of about 50.61 Yuan. Considering the thermal power plant industry, each ton of coal's operation reduces 26.35 cubic meters of water resources and a total cost of 86.61 Yuan [11]. Wang et al. [12], in a research on the external costs of a coal life cycle in southwestern China, reported that the externality of coal mining was USD 73.5 billion in 2018, accounting for 6.5 % of the provincial GDP in the same year. The external costs of health outcomes were estimated at 87.2% of the total costs, of which endemic skeletal fluorosis and lung cancer accounted for the largest share. A study by Wasis et al. [13] showed that sand mines use an open-pit mining system, which can lead to environmental and economic damage. The environmental damage caused by sand mining in Gumulung Tonggoh village, with an area of 2 ha, was calculated by the sum of the values related to ecological damage, economic damage, and environmental improvement and estimated at Rp. 39.349.860.000, and sand mining was claimed to make a significant contribution to environmental damage in Gumulung Tonggoh [13]. It is clear that the unreasonable exploitation of natural resources due to rapid urbanization and industrialization has caused environmental problems worldwide. It is now necessary to assess the environmental and ecological damage caused by resource utilization and establish an effective ecological compensation mechanism to promote sustainable resource use. Based on the results of a case study on Mentogo District, the coal mineral resources were valued at US$ 870 million. The coal mining damage to ES was estimated to be US$ 2001 million. The study concluded that the environmental and ecological damage caused by coal mining far outweighs its economic benefits [14]. Tost et al. [15] estimated the total cost of ES due to metal mining at about $ 5.4 billion in 2016, amounting to about two-thirds of the forest area. Overall, the cost of ES for the four metals gold, iron ore, copper, and bauxite is about $ 5.4 billion in 2016, which is far less than the cost of global land-use change in the period 1997-2011, ranging from $ 4.3 to $ 20.2 trillion per year. In terms of ecology, according to the four metals, the largest land use is used in "rangeland" (30%), and then in "temperate forest" (24%) and "tropical forest" (16%). The highest cost for ES belongs to "grasslands" (32%) and "tropical forest" (31%), followed by "temperate forest" (26%). In a study by Nkambule and Blignaut [16], the costs of coal mining and transporting in Kusile coal-fired power station in eMalahleni were estimated using monetary valuation. According to the results, coal-mining activities will impose an annual cost of R[1] 6538 million on the environment and R12 690 million on humans. According to the case studies mentioned below, the costs of environmental damages caused by mining activities in forest ecosystems can be estimated by damage cost estimation methods. Most studies, in this regard, are related to the experiences of Indonesia. Juniah et al. [17] claimed that exploitation of natural coal resources in open-pit mines is one of the activities that cause land-use change and can be considered a threat to the economic value of natural resources and forest ecosystems. This study estimated the environmental damage during the life of the mine for the period 1997-2023 PV 2009, Rp 2 73.98 trillion. The results showed that the environmental damage caused by exploitation in open coal mining cause the loss of forest resources worth Rp 834 billion and the loss of coal reserves in nature worth Rp 73.47 trillion. Rehabilitation activities on coal mines are expected to offset environmental damage and benefit forests at a value of Rp 324.23 billion. The value of this benefit is negligible compared to the environmental damage amount of Rp 73.98 trillion. [17]. Another study entitled “Economic valuation of coal mining activity in Samarinda City, East Kalimantan, Indonesia” was conducted by Prasodjo et al. [18]. The economic valuation was performed by calculating the reduction of coal resources, reducing wood resources, and the total economic value of lost forests. The results showed that the non-rehabilitated damaged area with an area of 156.07 ha and a production level of approximately 1.7 million tons in 2012, with a gross profit of approximately US$ 40 million. The reduction in coal resources was estimated at US$ 32 million, the reduction in timber resources at about US $ 92 million, and the total economic loss of the forest is estimated at the US $ 74,000. As a result, the total environmental damage is about 78.9% of the total gross profit [18]. In a study entitled "Environmental costs assessment for the improved environmental-economic account for Indonesia" conducted by Pirmana et al. [19], the estimated environmental costs had two components: air pollution damage and decline of natural resources. The estimated damage costs were Rp 915.11 trillion, divided by Rp 348.35 trillion (38.07%) due to environmental degradation by air pollutants, Rp61.43 trillion (6.71%) due to declined renewable resources (divided into Rp33.09 trillion for the value of excessive logging and Rp 28.35 trillion for the loss of ES) and Rp 505.33 trillion (55.22%) due to the reduction of non-renewable resources [19]. Environmental costs of environmental degradation, ecosystem degradation, and reduction of natural resources in Indonesia reached Rp 915.11 trillion in 2010, equivalent to 16.36% of Net Domestic Product (NDP) or 13.33% of Gross Domestic Product (GDP) [19].

The estimation of environmental losses as a required tool for effective planning in ecological rehabilitation is considered. The approach is to facilitate policy actions to prevent environmental damages and upgrade ecological rehabilitation [20]. The mining industry is seeking to increase its efforts to maintain sustainability by reducing the negative effects of mining activity. Ecological rehabilitation is effective for ecosystem regeneration in mining areas. With effective and timely scientific planning, the ecological environment being rehabilitated and new economic growth for sustainable development can be expected in mining areas [21]. Maintaining the balance between the utilization of resources, environmental protection, and mining in the direction of sustainable development is a global issue in the utilization of resources. Green mining is in line with the balance between the development model of the mining area, which is known as the sustainable development model. Green mining in the field of mining is not only the way to develop the mining area but also the only way to ensure sustainable development. It is a new way of benefiting generations. New green mining technology aims to achieve a coordinated mining production and ultimately achieve the great goal of creating a harmonious community [22]. Despite the demand for sustainable mining, the revival of vegetation and rehabilitating destroyed areas by Mining is still challenging [23]. Ecological restoration and rehabilitation of mines is a key issue for the sustainable development of mining activity [21]. Green mining is a new technology that many mining companies worldwide are attempting to use to minimize the environmental damages caused by mining. Green mining replaces the conflicts in the relationship between mines and the environment with interactions between them. Optimal exploration is the key issue in green mining that reduces land surface degradation. Underground mine construction is another modern method of implementing green mining. [24]. The emphasis in green mining is on reducing land degradation and mine reclamation. Green mining is a modern type of mining model that comprehensively considers efficiency and environmental impacts of extracting resources and maximization of mining efficiency (resource recovery), minimization of the environmental impacts of mining, and establishment and optimization of a balance between the interests of investors in mining and of the society. Adopting the principles and goals of green mining is a strategy for optimal management of any mining project that leads to developing a generally positive attitude towards mining activities, increased productivity, green economic development, sustainable social development, and environmental and ecological management [25]. Evaluating ES and quantifying the consequences of human activities on ecosystems is through the concept of ES, which is

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[1] Rand (Currency in South Africa)

defined by the Millennium Ecosystem Assessment (MEA) as the benefits that people derive from ecosystems. So far, limited studies have been conducted on the effects of mining on ES. No estimate has been made of the cost of mining on ES in Iran. According to the relevant studies reviewed, mining has typically adverse effects on the services produced by ecosystems. In other words, mining has costs for ecosystems. Politicians discuss how to prevent or reduce ecosystem degradation that leads to better decisions. This paper aims to use methods to estimate the cost of damage to ES resulting from mining activities.

2. Materials and methods

Monitoring the changes in ES over specific intervals is one of the most common methods of assessing the damage done to ecosystems. Thus, the incurred damages can be estimated by comparing changes in ecosystems over different periods. When changes in data are caused by project implementation, these changes must be monitored both before and after the project implementation. Furthermore, in some instances, before project implementation, only the potential damages are estimated. The conceptual framework of the methodology in conducting this research is presented in Fig. 1.

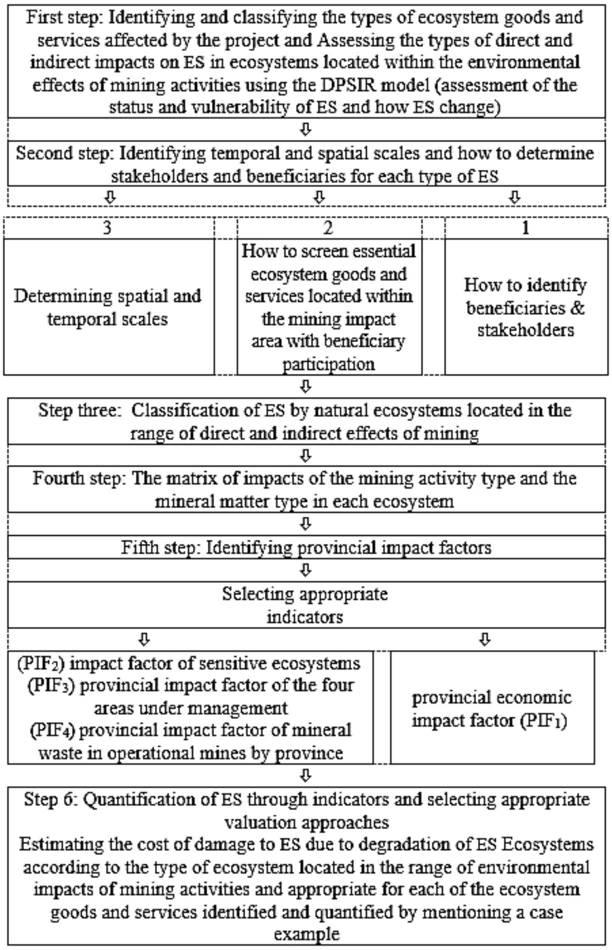


Fig. 1- Conceptual framework of research methodology

The methodology rested on the fact that the project is affected not only by ES but also by the type of ecosystem, mining activity, and mineral matter. In addition, the cost of degradation is affected by the provincial impact factors in the ecosystem sector, the Provincial impact factor of mine mineral waste, the four protected areas, and the economic sector. Accordingly, Equation 1 demonstrates how to integrate the practical factors.

$$ESC = \sum_{i=1}^{n} ESV \times A \times \left(\frac{\left(\frac{PIF_1 + PIF_2 + PIF_3 + PIF_4}{4} + 1\right) + L_2 + L_1}{3} \right) \qquad (1)$$

Where each of the factors is defined as follows;

ESC represents an estimation of the environmental degradation cost

n represents the time

i represents the study period

ESV represents ecosystem service value in each interval per hectare

PIF_1 represents the provincial economic impact factor (production of operational mines by province, water consumed by operational mines by province, and value-added of operational mines by province)

PIF_2 represents the provincial impact factor of sensitive ecosystems (forest, grassland, desert, and wetland)

PIF_3 represents the provincial impact factor of the four regions under the management of the department of environment

PIF_4 represents the provincial impact factor of mineral waste in operational mines by province

L_2 represents the importance Coefficient of the mineral matter type

L_1 represents the importance Coefficient of the mining activity type

A represents the area under the influence per hectare

The double importance of the wetland is calculated based on the member listed in the Ramsar Convention of Iranian sites and also the Montreux Record based on the following Equation:

$$\underset{\substack{\uparrow \\ \text{wetland} \\ \text{listed in} \\ \text{Ramsar} \\ \text{Convention}}}{L_2} = \underset{\substack{\uparrow \\ \text{Calculation} \\ \text{from the} \\ \text{table}}}{L_2} + (0 \underset{\substack{\uparrow \\ \text{low} \\ \text{importance}}}{\text{up}} \text{ to } \underset{\substack{\uparrow \\ \text{high} \\ \text{importance}}}{0.25)} \times \underset{\substack{\uparrow \\ \text{Calculation} \\ \text{from the} \\ \text{table}}}{L_2} \qquad (2)$$

$$\underset{\substack{\uparrow \\ \text{final and listed in the} \\ \text{Ramsar Convention}}}{L_2 = 0.84} \qquad L_2 = 0.84 + \underset{\substack{\uparrow \\ \text{high importance}}}{(0.25)}\ 0.84 = 1.05$$

The combination formula can be expressed as follows: In the first step, the value of ES is calculated per hectare, and in the second step, the area under mining activity is determined per hectare and multiplied by the value of services. In what follows next, the provincial impact factors resulting from the three areas of influence on the ecosystem, the four protected areas, and the economic issues related to the province's mining activity are determined. After averaging the four provincial coefficients, the PIF of the obtained average is summed with two other factors: (impact factor resulting from the importance of the mineral type (L_2) and also impact factor resulting from the importance of the type of mining activity (L_1). Then a coefficient is obtained by averaging, which indicates the destructive impact of the essential factors. By adding 1 to this factor relation, an incremental impact of degradation estimation is obtained.

The critical aspect of this relationship is that depending on the continuous mining activities such as stripping, extraction, transportation of minerals and mineral waste, etc. If the mining activity is assumed to last for one year, the calculations end at once. However, for each year passing from the mining activity, its destructive environmental impact multiplies in the same proportion, so that Sigma determines this relationship in the mathematical Equation 1.

3. Result and discussion

3.1. Step 1: Identifying and classifying the types of ecosystem goods and services affected by the project and Assessing the types of direct and indirect impacts on ES in ecosystems located within the environmental effects of mining activities using the DPSIR model (assessment of the status and vulnerability of ES and how ES change)

The ES approach recommends using the DPSIR (drivers, pressures, state, impact, and response model) framework to understand the stakeholders better. The DPSIR model is used to develop appropriate management strategies to decrease the vulnerability of ES. DPSIR is a valuable tool for policymakers, planners, and program administrators to track and monitor access to effective measures. Numerous mitigation measures are associated with policies, plans, and programs that can eventually alter mining activities [26]. The DPSIR (drivers, pressures, state, impact, and response) model, which places 'Impact on ES at its core, has been provided for ecosystem-based management, leading to the formation of the DPSIR framework [27].

3.2. Step 2: Identifying temporal and spatial scales and how to determine stakeholders and beneficiaries for each ES type

It is essential to recognize the target group of stakeholders & beneficiaries and those who benefit from the interests, functions, and services of any wetland you want to evaluate and whose damage you want to estimate [28]. The spatial aspect includes such things as scale, dimension, and pattern. The temporal aspect of evaluation also analyzes such things as driving forces, changes, and scenarios [29]. Natural ecosystems' products and services are subject to natural factor constraints known as scale, without which various economic and ecosystem assessments cannot be realistically assessed. From an ecological or economic standpoint, scales are associated with the spatial and temporal dimensions of the occurrence of natural phenomena. In other words, specific spatial and temporal conditions at different scales underpin the emergence of ES. To identify the actual stakeholders, methods such as interviewing experts and members of local communities, among others, are used. Given that the purpose of this study is to estimate the environmental damage caused by mining activities in terms of costs for ecosystem goods and services, in addition to the proposed ecological scales, economic and social scales for stakeholders and those involved in the mining activity should be taken into account. The link between ecosystem goods and services and economic and social well-being is taken into account here. International, national, provincial, local, household, and individual scales are the most important considerations when analyzing stakeholders.

3.2.1. How to identify beneficiaries and stakeholders

Interaction with beneficiaries and their participation is critical in ensuring that they can identify, mitigate, and monitor the impacts. The proposed plan is implemented in the most beneficial way for society. A beneficiary is a person/group who receives an obvious or conceivable benefit from a particular subject. Beneficiaries can take many forms, sizes, and capacities, including unorganized individuals, organizations, or groups [29].

It is essential to identify beneficiaries to understand the site better and identify the key ES and those who can benefit from them [30].

The beneficiaries of ecosystem goods and services can be divided into the following three main groups:

Affected Beneficiaries: This group consists of individuals, groups, and organizations that are within the immediate sphere of influence and direct effects of the project; i.e., are directly (or potentially) affected by the project and/or are identified as the aptest for changes concerning the project.

Other Beneficiaries: This group consists of individuals, groups, and organizations that may not be directly influenced by the project but whose interests are considered affected by the proposed project or those who can somehow influence the project and its implementation process.

Underprivileged or Vulnerable Strata: This group consists of people affected by the project due to their vulnerable conditions. This group mainly includes indigenous and rural communities adjacent to the proposed project, whose livelihoods rely heavily on the health and proper functioning of natural assets and ecosystem goods and services [29].

3.2.2. How to screen essential ecosystem goods and services located within the mining impact area with beneficiary participation

In whatever manner he/she consults with identified beneficiaries, the assessor must first consider the current and potential future situation in the provision or non-provision of ecosystem goods and services related to ecosystems located in the study area for different types of ecosystems. To this end, the assessor must fill out Table 1 separately for each of the natural ecosystems in the degradation assessment area, based on an average of different beneficiary perspectives [29].

Table 1. The screening of the list of ecosystem goods and services based on stakeholders feedback [29]

Ecosystem goods and services	Current status of procurement (0-5 points) 5=very high	services of the utmost importance (√)	Probable future procurement status (0-5 points) 5=very high	Services are most likely to decline in the future (√)
Provisioning services				
Regulating services				
Cultural services				

3.2.3. Determining spatial and temporal scales

Natural asset conditions have an impact on ecosystem functions, processes, and services at various scales. It is critical to consider the appropriate scale when monitoring and analyzing ecological landscape patterns and ES. Many ES, such as recreation, primary production, and microclimate regulation, are site-specific. In contrast, erosion control, flood control, and water supply are addressed on a landscape or watershed scale, and climate regulation works on a global scale to carbon sequestration. In general, the appropriate scale for analyzing ES can be defined by the spatial and temporal dimensions on which the services rely the most [31].

The time scale is also significant in two ways. First, infrastructure development projects are effective for more than one time; their influence lifespan may last for years. Therefore, it is important to consider the influence horizon of the project equal to the project lifespan so that the project damage costs can also be considered after construction. Moreover, the choice of the discount rate depends on the time scale of the project. If an appropriate discount rate is selected, the present value and the costs incurred from the ecosystem in subsequent years can be calculated. Therefore, the time scale in the present study is considered 50 years [32].

3.2.3.1. How to determine the scope (demarcation) of environmental damages assessment.

The environmental impacts of proposed mining projects are divided into three distinct ranges (immediate impacts, direct impacts, and indirect impacts). So that, these changes must be measured in the number of natural assets and related ecosystem goods and services. Typically, the direct and indirect impacts of the proposed plan are mostly structural changes in natural assets that occur as a result of the proposed plan's mining and exploitation phase. However, these changes may extend to broader boundaries, such as the range of indirect effects of the proposed design during the minerals' processing stage and increase of mineral concentration phase. Given that ecological functions and processes are not limited to the physical boundaries of the mineral extraction activity itself, it is critical to select the appropriate evaluation scale when assessing natural assets and ecosystem goods and services. As a result, determining the appropriate scale for assessing natural assets and then locating the scope of effects of the proposed plan within it is a critical step in ensuring the comprehensiveness of the damage assessment range. [29].

3.2.3.2. Determining the scope of environmental effects of the proposed plan

The scope of the impacts must be selected so that the immediate, direct, and indirect impact areas encompass all of the spatial options mentioned in the report.

The immediate scope of mining activities includes the extraction of minerals. This area contains the extraction site, in-mine processing facilities, mineral depots, and mineral waste. The direct scope is the area directly impacted by mineral extraction and reciprocally affects it. Indirectly affected areas are typically defined by the boundary between areas affected by side activities and mining activities. [29]

3.3. Step 3: ES Classification

When conducting damage assessment projects (and economic valuation of ecosystems), the list of key ES for each natural ecosystem should be counted separately and the classification's goal is to provide a framework for evaluating and assessing the impacts on ES. In this way, some services are considered a basis for each ecosystem's valuation, while other services can be valued at the assessor's discretion [32].

3.4. Step 4: The matrix of impacts of the mining activity type and the mineral matter type in each ecosystem

3.4.1. Matrix of the impacts of the mining activity type in each ecosystem

In this study, to identify the effects of the mineral matter type on the characteristics of ES, all aspects affecting the environment caused by the mineral matter type were investigated, and the parameters affecting each service were identified in detail. Thus, depending on which ecosystems or services are affected by the mineral matter type, the degraded ecosystems and services affected by that mineral matter type were identified. At this point, a matrix was used to determine which mineral matter type has had the most significant impact on ES and functions, and its effects were evaluated. Thus, general services were identified, and experts reviewed a questionnaire. The effects of the mineral matter type were divided into two classes and seven categories (sand and gravel, metal ores, alkaline salts, clay soils, precious stones, building stones, and coal and bitumen derivatives). Then its effects were scored from 0 to 3. Finally, the overall effect of each mineral was calculated by adding the effects from all seven categories (Table 2).

For example, to investigate the effects of sand/gravel mine on a neighboring agricultural ecosystem, first, 20 agricultural ES were assigned impact scores ranging from 0 to 3 due to the sand/gravel mine, and after adding scores and averaging based on 20 agricultural ES. The average number obtained is then multiplied by the normalized coefficient of the agricultural ecosystem's importance, and the result is saved from being summed with other measured ecosystems. Thus, after summing up the other ecosystems, the final number obtained is divided by the number of ecosystems (8 ecosystems). The essential factor of the type of L_1 mineral (sand/gravel) is obtained.

L_1 sand/gravel

$$L_1 = l_1 + l_1 + l_1 + \cdots + l_1 \tag{3}$$

coastal grassland forest desert-agricultural agriculture

$$L_1 = \left(\sum_{i=1}^{21} A_i\right) \times \text{normalized importance coefficient} \tag{4}$$

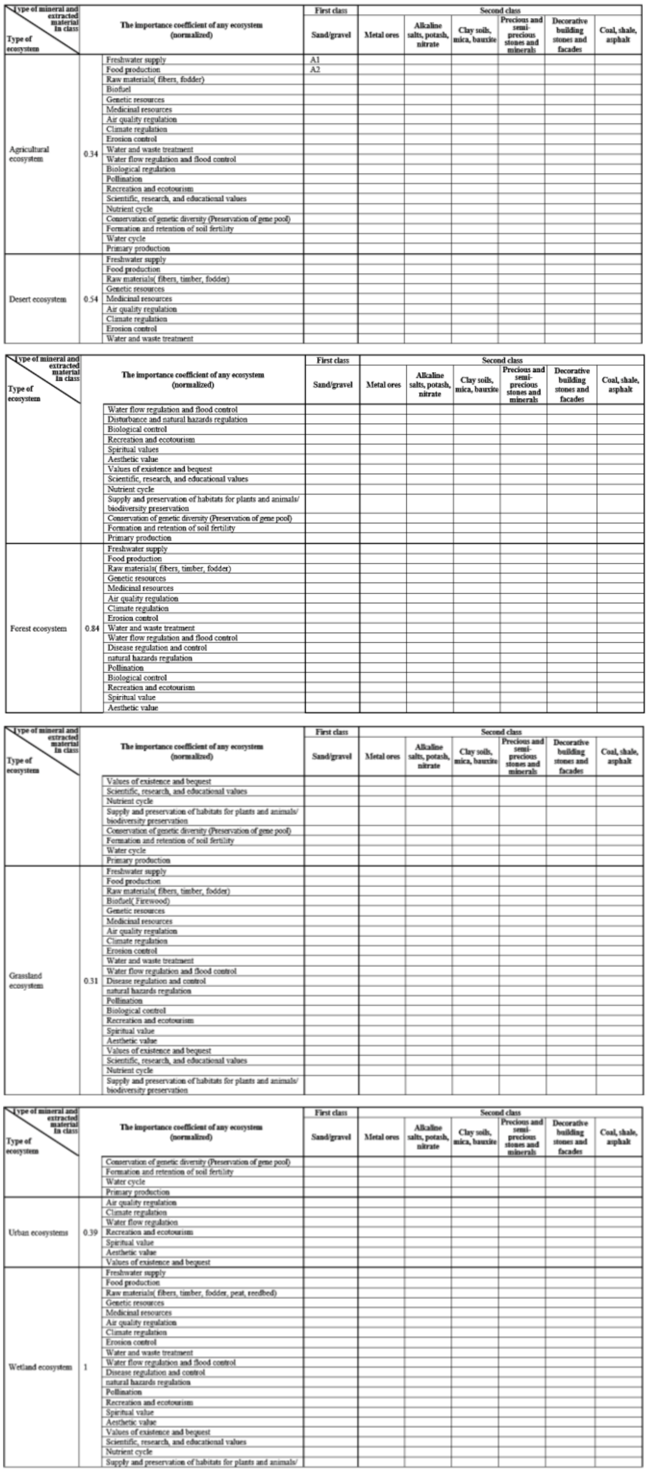
A_1= coefficient 0 to 3 attributed to the impact of sand/gravel mine on the ecosystem service of drinking water supply from agricultural ecosystem

A_2= coefficient 0 to 3 attributed to the impact of sand/gravel mine on the ecosystem service of food supply from the agricultural ecosystem (shown in Table 2).

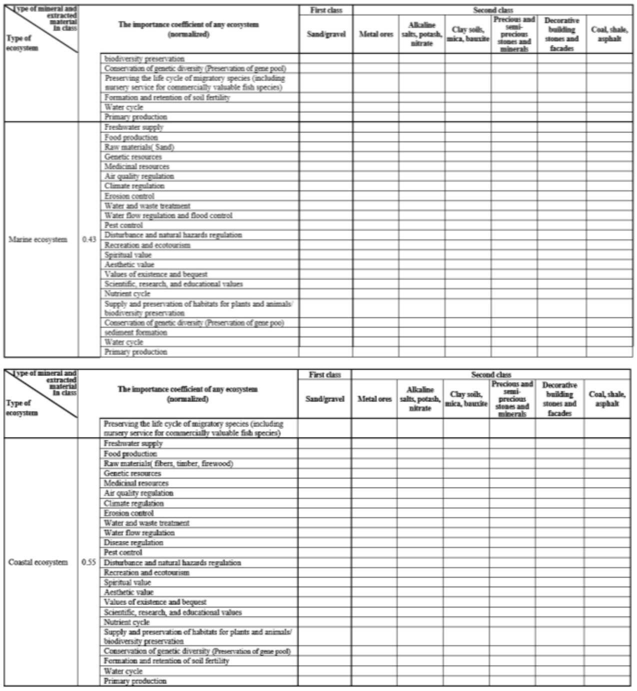
3.4.2. Matrix of the impacts of mineral matter type in each ecosystem

Each project's impacts were divided into five major activities: surface mining, underground mining, processing plants, ancillary facilities, and office building and road, and each of these primary activities for the related sections was subdivided, and its effects were scored on a scale of 0 to 3. Finally, the overall effect of each mining activity was calculated by adding the effects from all five categories. For example, to evaluate ES in the stripping overburden activity (mineral extraction) in a surface mine, after scoring ecosystem service items (provisioning, regulating, cultural, aesthetic, and supporting) for related subsections, they were averaged and calculated as the mining activity's L_2 importance factor (extraction of a surface mine) (Table 3).

Table 2. The matrix of effects of different types of mineral materials and their effects on key ecosystem services in ecosystems located within the scope of mining activity



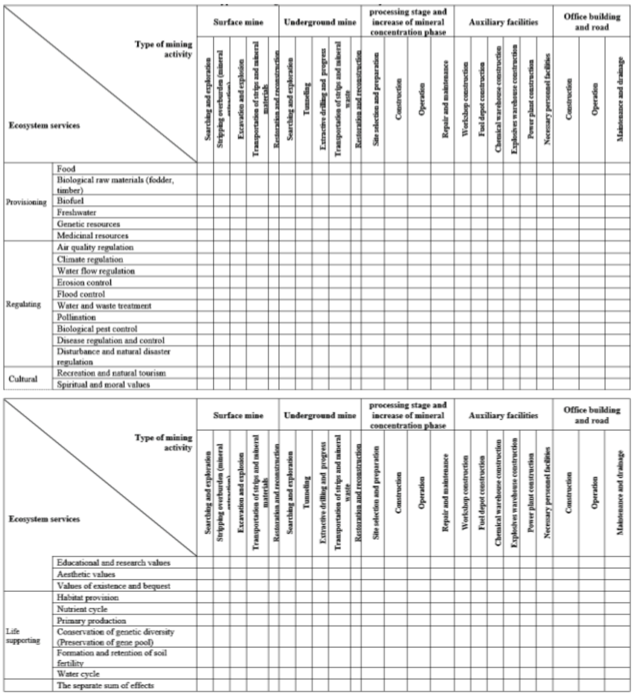
Type of mineral and extracted material in class / Type of ecosystem	The importance coefficient of any ecosystem (normalized)		First class	Second class					
			Sand/gravel	Metal ores	Alkaline salts, potash, nitrate	Clay soils, mica, bauxite	Precious and semi-precious stones and minerals	Decorative building stones and facades	Coal, shale, asphalt
Agricultural ecosystem	0.34	Freshwater supply	A1						
		Food production	A2						
		Raw materials(fibers, fodder)							
		Biofuel							
		Genetic resources							
		Medicinal resources							
		Air quality regulation							
		Climate regulation							
		Erosion control							
		Water and waste treatment							
		Water flow regulation and flood control							
		Biological regulation							
		Pollination							
		Recreation and ecotourism							
		Scientific, research, and educational values							
		Nutrient cycle							
		Conservation of genetic diversity (Preservation of gene pool)							
		Formation and retention of soil fertility							
		Water cycle							
		Primary production							
Desert ecosystem	0.54	Freshwater supply							
		Food production							
		Raw materials(fibers, timber, fodder)							
		Genetic resources							
		Medicinal resources							
		Air quality regulation							
		Climate regulation							
		Erosion control							
		Water and waste treatment							
		Water flow regulation and flood control							
		Disturbance and natural hazards regulation							
		Biological control							
		Recreation and ecotourism							
		Spiritual values							
		Aesthetic value							
		Values of existence and bequest							
		Scientific, research, and educational values							
		Nutrient cycle							
		Supply and preservation of habitats for plants and animals/ biodiversity preservation							
		Conservation of genetic diversity (Preservation of gene pool)							
		Formation and retention of soil fertility							
		Primary production							
Forest ecosystem	0.84	Freshwater supply							
		Food production							
		Raw materials(fibers, timber, fodder)							
		Genetic resources							
		Medicinal resources							
		Air quality regulation							
		Climate regulation							
		Erosion control							
		Water and waste treatment							
		Water flow regulation and flood control							
		Disease regulation and control							
		natural hazards regulation							
		Pollination							
		Biological control							
		Recreation and ecotourism							
		Spiritual value							
		Aesthetic value							
		Values of existence and bequest							
		Scientific, research, and educational values							
		Nutrient cycle							
		Supply and preservation of habitats for plants and animals/ biodiversity preservation							
		Conservation of genetic diversity (Preservation of gene pool)							
		Formation and retention of soil fertility							
		Water cycle							
		Primary production							
Grassland ecosystem	0.31	Freshwater supply							
		Food production							
		Raw materials(fibers, timber, fodder)							
		Biofuel(Firewood)							
		Genetic resources							
		Medicinal resources							
		Air quality regulation							
		Climate regulation							
		Erosion control							
		Water and waste treatment							
		Water flow regulation and flood control							
		Disease regulation and control							
		natural hazards regulation							
		Pollination							
		Biological control							
		Recreation and ecotourism							
		Spiritual value							
		Aesthetic value							
		Values of existence and bequest							
		Scientific, research, and educational values							
		Nutrient cycle							
		Supply and preservation of habitats for plants and animals/ biodiversity preservation							
		Conservation of genetic diversity (Preservation of gene pool)							
		Formation and retention of soil fertility							
		Water cycle							
		Primary production							
Urban ecosystems	0.39	Air quality regulation							
		Climate regulation							
		Water flow regulation							
		Recreation and ecotourism							
		Spiritual value							
		Aesthetic value							
		Values of existence and bequest							
Wetland ecosystem	1	Freshwater supply							
		Food production							
		Raw materials(fibers, timber, fodder, peat, reedbed)							
		Genetic resources							
		Medicinal resources							
		Air quality regulation							
		Climate regulation							
		Erosion control							
		Water and waste treatment							
		Water flow regulation and flood control							
		Disease regulation and control							
		natural hazards regulation							
		Pollination							
		Recreation and ecotourism							
		Spiritual value							
		Aesthetic value							
		Values of existence and bequest							
		Scientific, research, and educational values							
		Nutrient cycle							
		Supply and preservation of habitats for plants and animals/							



Type of mineral and extracted material in class Type of ecosystem	The importance coefficient of any ecosystem (normalized)		First class	Second class					
			Sand/gravel	Metal ores	Alkaline salts, potash, nitrate	Clay soils, mica, bauxite	Precious and semi-precious stones and minerals	Decorative building stones and facades	Coal, shale, asphalt
		biodiversity preservation							
		Conservation of genetic diversity (Preservation of gene pool)							
		Preserving the life cycle of migratory species (including nursery service for commercially valuable fish species)							
		Formation and retention of soil fertility							
		Water cycle							
		Primary production							
Marine ecosystem	0.43	Freshwater supply							
		Food production							
		Raw materials(Sand)							
		Genetic resources							
		Medicinal resources							
		Air quality regulation							
		Climate regulation							
		Erosion control							
		Water and waste treatment							
		Water flow regulation and flood control							
		Pest control							
		Disturbance and natural hazards regulation							
		Recreation and ecotourism							
		Spiritual value							
		Aesthetic value							
		Values of existence and bequest							
		Scientific, research, and educational values							
		Nutrient cycle							
		Supply and preservation of habitats for plants and animals/ biodiversity preservation							
		Conservation of genetic diversity (Preservation of gene poo)							
		sediment formation							
		Water cycle							
		Primary production							
Type of mineral and extracted material in class Type of ecosystem	The importance coefficient of any ecosystem (normalized)		First class	Second class					
			Sand/gravel	Metal ores	Alkaline salts, potash, nitrate	Clay soils, mica, bauxite	Precious and semi-precious stones and minerals	Decorative building stones and facades	Coal, shale, asphalt
		Preserving the life cycle of migratory species (including nursery service for commercially valuable fish species)							
Coastal ecosystem	0.55	Freshwater supply							
		Food production							
		Raw materials(fibers, timber, firewood)							
		Genetic resources							
		Medicinal resources							
		Air quality regulation							
		Climate regulation							
		Erosion control							
		Water and waste treatment							
		Water flow regulation							
		Disease regulation							
		Pest control							
		Disturbance and natural hazards regulation							
		Recreation and ecotourism							
		Spiritual value							
		Aesthetic value							
		Values of existence and bequest							
		Scientific, research, and educational values							
		Nutrient cycle							
		Supply and preservation of habitats for plants and animals/ biodiversity preservation							
		Conservation of genetic diversity (Preservation of gene pool)							
		Formation and retention of soil fertility							
		Water cycle							
		Primary production							

Source: Research findings

Table 3. Interaction matrix for the effects of different types of mining activities on various ecosystem services



Type of mining activity Ecosystem services		Surface mine					Underground mine					processing stage and increase of mineral concentration phase				Auxiliary facilities						Office building and road		
		Searching and exploration	Stripping overburden (mineral extraction)	Excavation and explosion	Transportation of strips and mineral materials	Restoration and reconstruction	Searching and exploration	Tunneling	Extractive drilling and progress	Transportation of strips and mineral waste	Restoration and reconstruction	Site selection and preparation	Construction	Operation	Repair and maintenance	Workshop construction	Fuel depot construction	Chemical warehouse construction	Explosives warehouse construction	Power plant construction	Necessary personnel facilities	Construction	Operation	Maintenance and drainage
Provisioning	Food																							
	Biological raw materials (fodder, timber)																							
	Biofuel																							
	Freshwater																							
	Genetic resources																							
	Medicinal resources																							
Regulating	Air quality regulation																							
	Climate regulation																							
	Water flow regulation																							
	Erosion control																							
	Flood control																							
	Water and waste treatment																							
	Pollination																							
	Biological pest control																							
	Disease regulation and control																							
	Disturbance and natural disaster regulation																							
Cultural	Recreation and natural tourism																							
	Spiritual and moral values																							
Type of mining activity Ecosystem services		Surface mine					Underground mine					processing stage and increase of mineral concentration phase				Auxiliary facilities						Office building and road		
		Searching and exploration	Stripping overburden (mineral extraction)	Excavation and explosion	Transportation of strips and mineral materials	Restoration and reconstruction	Searching and exploration	Tunneling	Extractive drilling and progress	Transportation of strips and mineral waste	Restoration and reconstruction	Site selection and preparation	Construction	Operation	Repair and maintenance	Workshop construction	Fuel depot construction	Chemical warehouse construction	Explosives warehouse construction	Power plant construction	Necessary personnel facilities	Construction	Operation	Maintenance and drainage
	Educational and research values																							
	Aesthetic values																							
	Values of existence and bequest																							
Life supporting	Habitat provision																							
	Nutrient cycle																							
	Primary production																							
	Conservation of genetic diversity (Preservation of gene pool)																							
	Formation and retention of soil fertility																							
	Water cycle																							
	The separate sum of effects																							

Source: Research findings

3.5. Step 5: Identifying provincial impact factors

3.5.1. The process of extracting provincial impact factors

3.5.1.1. The purpose of determining the provincial impact factors

At this point, it was necessary to define the study's objective. This study aimed to weight, categorize, and determine the influence of Iranian provinces in mining activities and vice versa using effective environmental and economic indicators. These indicators were used to calculate the coefficients and the score for each province based on various indicators. Decision-makers can use the findings of this study to calculate the costs of degradation caused by mining activities (affected by the type of mining activity and mineral) in each province. Furthermore, they should then be transformed into complete, comprehensive, and spatial coefficients under administrative-political boundaries.

3.5.1.2. Determining the level of study

Regional studies are carried out at different levels such as the village, district, county, and province. Determining the level of study is the first step in taking the next steps. The availability of statistics and data is the essential factor in determining the level of study. Because statistics and data collected by statistical centers or other organizations and ministries are primarily used, the level of access to statistics and the type of statistics, and the ability to communicate and implement decisions play a critical role in determining the level of study. As a result, under the project's objectives, the provincial level was selected as the study level. Thus, the 31 Iranian provinces served as the basis for comparison.

3.5.1.3. Selecting indicators

One of the tools required to analyze the current situation and determine the desired goals is to identify indicators for evaluating and comparing different sections or divisions and measuring the quality or extent of achievement of goals in that section.

In some cases, it is not possible to select a suitable indicator for each section, and there is a significant difference in the number of indicators in each section; the best way to avoid one section dominating over others is to first calculate the weights separately for each section, and second to calculate the combined weight of the indicator by multiplying the different parts together.

Four provincial indicators/impact factors were used in regulating this instruction:

PIF_1 represents the provincial economic impact factor (the amount of production of operational mines by province, amount of water consumed by operational mines by province, and value-added of operational mines by province)

PIF_2 represents the provincial impact factor of sensitive ecosystems (forest, grassland, desert, and wetland)

PIF_3 represents the provincial impact factor of the four areas under management

PIF_4 represents the provincial impact factor of the amount of tailing in operational mines by province

Forming and determining dimensions and indicators:

The Delphi method and experts' opinions were used to extract the indicators and their dimensions. As a result, the studied indicators were first listed. The final indicators were selected after reviewing each indicator regarding information and data availability, sorting, and revision. The indicators investigated are listed in the table below. Table 4 shows economic and environmental indicators.

Table 4. Economic and environmental indicators

Dimensions	Indicator
Economic PIF_1	The total amount of production from operational mines in Iran by province
	The amount of water consumed by the operational mines by province
	Value-added of the operational mines in Iran by province
Environmental	The province's sensitive ecosystems (forest, grassland, desert, and wetland) PIF_2
	Four regions under the management of the provinces PIF_3
	Amount of mineral waste in the operational mines by province PIF_4

Data collection method: Official government reports and reputable statistics centers include:

- Statistics on the four regions of the country: Statistics obtained from the four regions of the country, the website of the Environment Protection Organization (accessed at https://www.doe.ir)
- Statistics for sensitive ecosystems (forest, grassland, desert) of each

province per hectare: Reports on the natural resources of the provinces, the website of the Forests, Range and Watershed Management Organization (accessed at https://frw.ir)

- Statistics on sensitive ecosystems (number of wetlands in each province): Report on Iran's wetlands, the website of the Environment Protection Organization (accessed at https://www.doe.ir)
- Statistics on the number of mineral waste in operational mines in Iran by province, the amount of water consumed in operational mines in Iran by province, the amount of production of mines in operation, and the added value in operational mines in Iran by province: Data and statistical information of the Statistical Center of Iran (accessed at amar.org.ir) and the report on the operational mines in Iran (2018), Statistics Center of Iran the report on mines on the website of the Ministry of Industry, Mine and Trade (accessed at https://www.mimt.gov.ir/).

The type of indicator, calculation method, and source are all shown in Appendix 1. Appendix 2 shows the amount and share of mining production in the provinces, the amount and share of water consumption and value-added of the operating mines in Iran, and its share in terms of the province in 2018. Appendix 3 shows the share of sensitive ecosystems, four regions, and mineral waste in provinces (%). Following normalization, each province was assigned a table number between 0 and 1, the same numbers being the four provincial coefficients. Finally, PIF_1, PIF_2, PIF_3, and PIF_4 were calculated for Equation 1. Normalized aggregate coefficients of each province (PIF_1), environmental coefficients for the province with sensitive ecosystems (forests, grasslands, deserts, and wetlands), normalized aggregated coefficients of each province (PIF_2), environmental coefficients for the share of the four regions of the department of the environment by province, normalized aggregate coefficients for each province (PIF_3), the environmental coefficients for the share of tailing by province, and normalized aggregate for each province (PIF_4) are presented in Tables 5 to 8, respectively.

Table 5. Aggregate normalized economic coefficients by province breakdown (PIF_1)

Share of economic coefficients Province				Share of normalized mine production	Normalized share of water consumption in provinces	Normalized share of value-added of the provinces	Normalized aggregate coefficients of each province PIF1
East Azerbaijan				0.110	0.0368	0.285	0.432
West Azerbaijan				0.185	0.0008	0.000	0.185
Ardabil				0.031	0.0005	0.000	0.032
Isfahan				0.350	0.0262	0.000	0.376
Alborz				0.084	0.0003	0.001	0.086
Ilam				0.000	0.0006	0.002	0.002
Bushehr				0.226	0.0016	0.002	0.229
Tehran				0.327	0.0067	0.002	0.336
Chaharmahal and Bakhtiari				0.056	0.0004	0.003	0.060
South Khorasan				0.077	0.0096	0.003	0.089
Razavi Khorasan				0.458	0.0017	0.004	0.463
North Khorasan				0.040	0.0017	0.004	0.046
Khuzestan				0.192	0.0100	0.004	0.206
Zanjan				0.068	0.0003	0.005	0.073
Semnan				0.170	0.0010	0.005	0.176
Sistan and Baluchestan				0.089	0.0072	0.006	1.103
Fars				0.381	1.0149	0.009	0.405
Qazvin				0.031	0.0001	0.009	0.040
Qom				0.030	0.0003	0.010	0.040
Kurdistan				0.125	0.0003	0.011	0.137
Kerman				1.000	1.0000	0.013	2.013
Kermanshah				0.061	0.0005	0.017	0.078
Kohgiluyeh and Boyer-Ahmad				0.087	0.0189	0.017	0.123
Golestan				0.073	0.0158	0.023	0.112
Gilan				0.072	0.0000	0.023	0.095
Lorestan				0.057	0.0010	0.0320	0.090
Mazandaran				0.145	0.0092	0.032	0.186
Markazi				0.176	0.0013	0.042	0.219
Hormozgan				0.211	0.0151	0.046	0.272
Hamedan				0.143	0.0001	0.386	0.529
Yazd				0.507	0.1016	1.000	1.609
total							8.84

Source: Research findings

The total normalized economic aggregate coefficients of all provinces were approximately 8.8. In contrast, all provinces' total normalized environmental aggregate coefficients were estimated to be 17.9, indicating the importance of environmental coefficients.

Appendix 4 shows the score of each province in terms of impact factor. As can be seen, the highest rank (first rank) and the lowest rank belong to Kerman and Alborz provinces, respectively.

3.6. Step 6: Quantification of ES through indicators and selecting appropriate valuation approaches

An example of the ecosystem service valuation methods is presented in Table 9.

Table 6. The normalized aggregate of environmental coefficients about provinces with sensitive ecosystems (forest, grassland, deserts, and wetland) by province breakdown (PIF_2)

Share of sensitive ecosystems Province	Share of the forest by province breakdown (%)	Share of grassland by province breakdown (%)	Share of the desert by province breakdown (%)	Share of wetlands by province breakdown (%)	Aggregate coefficients of each province	Normalized aggregate coefficients of each province PIF2
East Azerbaijan	1.22	3.31	0.24	3.23	8	0.214
West Azerbaijan	0.71	3.58	0.39	16.77	21.45	0.608
Ardabil	0.41	1.36	0	3.87	5.64	0.145
Isfahan	2.66	8.44	6.91	1.29	19.3	0.545
Alborz	0.1	0.5	0.09	0	0.69	0.000
Ilam	4.15	1.05	0.92	1.29	7.41	0.197
Bushehr	1.32	1.69	0.72	2.58	6.31	0.164
Tehran	0.38	1.23	0.23	1.94	3.78	0.090
Chaharmahal and Bakhtiari	1.99	1.46	0.26	3.87	7.58	0.202
South Khorasan	4.79	2.32	27.92	0.65	35.68	1.024
Razavi Khorasan	6.45	8.8	11.99	1.29	28.53	0.815
North Khorasan	2.65	1.37	1.27	0	5.29	0.135
Khuzestan	6.29	3.35	2.81	5.81	18.26	0.514
Zanjan	0.74	1.52	0.17	0	2.43	0.051
Semnan	2.28	5.01	11.04	0	18.33	0.516
Sistan and Baluchestan	7.76	13.73	10.79	2.58	34.86	1.000
Fars	14.36	9.81	2.59	7.74	34.5	0.989
Qazvin	0.17	1.14	0.06	1.94	3.31	0.077
Qom	0.03	0.97	0.38	1.94	3.32	0.077
Kurdistan	2.42	1.89	0.01	0.65	4.97	0.125
Kerman	8.23	8.36	10.93	1.94	29.46	0.842
Kermanshah	3.41	1.6	0.06	1.94	7.01	0.185
Kohgiluyeh and Boyer-Ahmad	3.58	1.17	0.09	2.58	7.42	0.197
Golestan	2.69	1.16	0	4.52	8.37	0.225
Gilan	2.53	0.36	0	5.81	8.7	0.234
Lorestan	7.88	1.19	0.03	3.23	12.33	0.341
Mazandaran	2.79	0.79	0	4.52	8.1	0.217
Markazi	0.1	0.55	1.06	0.65	2.36	0.049
Hormozgan	6.82	5.49	3.27	13.55	29.13	0.832
Hamedan	0.01	0.89	0.06	1.29	2.25	0.046
Yazd	1.1	5.9	5.72	0	12.72	0.352
total						10.74

Source: Research findings

Table 7. The normalized aggregate of environmental coefficients of the share of the four regions of the department of environment for each province (PIF_3)

Share of the four regions Province	Percentage of the area of four regions by province breakdown	Normalized aggregate coefficients PIF3
East Azerbaijan	3.4	0.24
West Azerbaijan	3.79	0.27
Ardabil	0.78	0.04
Isfahan	7.27	0.52
Alborz	0.41	0.02
Ilam	0.88	0.05
Bushehr	0.89	0.05
Tehran	2.47	0.17
Chaharmahal and Bakhtiari	1.18	0.07
South Khorasan	1.11	0.07
Razavi Khorasan	6.01	0.43
North Khorasan	10.7	0.78
Khuzestan	3.92	0.27
Zanjan	1.39	0.09
Semnan	12.09	0.88
Sistan and Baluchestan	5.06	0.36
Fars	7.06	0.51
Qazvin	0.68	0.04
Qom	0.2	0.00
Kurdistan	1.1	0.07
Kerman	13.74	1.00
Kermanshah	0.95	0.06
Kohgiluyeh and Boyer-Ahmad	1.19	0.07
Golestan	0.79	0.04
Gilan	0.76	0.04
Lorestan	1.01	0.06
Mazandaran	3.02	0.21
Markazi	0.76	0.04
Hormozgan	4	0.28
Hamedan	0.36	0.01
Yazd	3.04	0.21
total		6.93

Source: Research findings

Table 8. The normalized aggregate of environmental coefficients of tailing for each province (PIF_4)

Share of stripping / Province	Share of tailing (%)	Normalized aggregate coefficients
East Azerbaijan	7.46	0.147
West Azerbaijan	1.37	0.027
Ardabil	0.68	0.013
Isfahan	2.13	0.042
Alborz	0.07	0.001
Ilam	0.19	0.004
Bushehr	0.11	0.002
Tehran	0.52	0.010
Chaharmahal and Bakhtiari	0.05	0.001
South Khorasan	0.53	0.010
Razavi Khorasan	7.25	0.142
North Khorasan	0.08	0.002
Khuzestan	0	0.000
Zanjan	2.01	0.039
Semnan	0.39	0.008
Sistan and Baluchestan	0.06	0.001
Fars	2.33	0.046
Qazvin	0.28	0.005
Qom	0.03	0.001
Kurdistan	1.2	0.024
Kerman	50.92	1.000
Kermanshah	0.06	0.001
Kohgiluyeh and Boyer-Ahmad	0.16	0.003
Golestan	0.18	0.004
Gilan	0.14	0.003
Lorestan	0.37	0.007
Mazandaran	0.04	0.001
Markazi	0.98	0.019
Hormozgan	0.19	0.004
Hamedan	0.39	0.008
Yazd	20.11	0.395
total		1.96

Source: Research findings

Table 9. An example of ecosystem services valuation methods [33]

Ecosystem services	MEA classification	The most appropriate valuation method	Approach	Type of value
Water supply	Provisioning	M	Price-based	Direct and indirect use
		RC	Cost-based	
Food		M	Market price	
		P	Production function	Indirect consumption
Gas regulation	Regulating	CV	Stated preference	Use / non use
		RC	Cost-based	Direct and indirect use
Waste regulation		AC		
		RC		
Nutrient cycle	supporting	AC	Stated preference	Use / non use
Soil retention		CV		
Recreation	Cultural	TC	Revealed preference	
Educational		R	Stated preference	

M: market price, RC: replacement cost, P: production approach, CV: contingent valuation, AC: avoided cost, TC: travel cost, R: ranking

3.6.1 Estimating the Ecosystem Service Valuation (ESV) in the current situation and the future through the benefit transfer approach

The benefit transfer method developed by Costanza et al.[34] Alternatively, de Groot et al. [35] can be used in the study to estimate the ecosystem service values (ESVs) of each Land Use/Land Cover (LULC) as follows:

$$ESV_k \sum_f A_k \times VC_{kf} \quad (5)$$

$$ESV_f \sum_k A_k \times VC_{kf} \quad (6)$$

$$ESV = \sum_f \sum_k A_k \times VC_{kf} \quad (7)$$

ESV_k is the ESV_s of each class k of LULC. ESV_f is ESV_s of each f of biome. ESV represents the total value of estimated ES. A_k represents the area (ha) of any type of k of LULC. $Vckf_{kf}$ is the equivalent value coefficients (USD/ha/year) of each type of k of LULC and ecosystem performance of f, respectively. Changes in ESVs are estimated as follows:

$$\Delta ESV = \frac{ESV_{end} - ESV_{start}}{ESV_{start}} \times \frac{1}{t} \times 100 \quad (8)$$

ΔESV refers to ESVs change in a particular k type of LULC, ESV_{end}, and ESV_{star} represent ESVs from previous and current years, respectively, and t represents the period [36].

3.6.2 Analysis of the trade-off between the benefits arising from mining and the loss of ecosystem values

The term "loss of ecosystem service values" refers to the decrease in the value of ES caused by mining development compared to the base year's ecosystem service values. The exact method for calculating it is as follows:

$$ESVi_{loss} : ESV_{\text{of the beginning year}} - ESVi \quad (9)$$

Where;

ESV_{loss} is the loss of ecosystem service value due to mining development, i represents the year, ESV is the basis of the value of the ecosystem service source, ESVi is the value of the damaged ecosystem service [2].

3.6.3 Estimating changes in the economic values of ES (Assessment of ES)

The following calculation is performed to obtain a net result based on the balance of ES.

$$ESA = \Delta ES_n = \sum ES_a - \sum ES_b \quad (10)$$

In this formula, ΔESn is the net value of ES in US$ or IRR/year, and ES is the total value of all ES offered before (b) and after (a) the mining activity in US$ or IRR/year. This only applies when a land-use change is directly involved in the project [33]. Table 10 shows how to summarize the estimation of changes in ecosystem goods and services.

Table 10. Summary of estimates of changes in ecosystem goods and services

Ecosystem goods and services	Metric measure ment unit	Basic/Current quantity	Current/ future quantity	Change rate
Provisioning services				
Regulating services				
Cultural services				

3.7. The manner of estimating the costs of damage to the environment (loss of ES values) due to mining in the forest, grassland, agricultural, wetland, and marine-coastal ecosystems using the benefits transfer method:

Suppose there is insufficient time to conduct studies to estimate the economic value of the costs of environmental damage. In that case, the benefits transfer method can be used to estimate the economic value of each of the relevant ES.

For each biome's ES costs calculation, It should be noted that the estimation of values per hectare of ecosystems located in the mining impact area using the average standardized values of ES per biome (USD / hectare/year: 2020 price level) based on de Groot et al. [35] and has been adjusted for Iran using the following Equation 11. Then, the adjusted values of ES for Iran in each biome are estimated based on the NIMA exchange rate (IRR 230,000).

$$WTP_{PS} = WTP_{SS}(GDP_{PS}/GDP_{SS})^{e} \tag{11}$$

e: is the income elasticity of willingness to pay

WTP_{PS}: willingness to pay at the target site (country in which the value is to be used)

WTP_{SS}: willingness to pay at the site under study (origin) (country where the transferred values are originally calculated and transferred)

GDP_{PS} and GDP_{SS}: GDP per capita in PPP (Purchasing Power Parity) dollars (destination) and the study site (origin), respectively [37].

It should be noted that the ratio of Iran's per capita GDP to the global average, as well as the income elasticity of willingness to pay, are estimated using the World Bank website's economic indicators (GDP per capita, PPP (current international $). Data.worldbank.org/indicator).

3.8. Selecting the appropriate discount rate

In the absence of a social discount rate and due to lower fluctuations in interest rates on facilities and interest on long-term deposits in the agricultural sector, the average of these two rates for previous years can be considered as a discount rate for discounting values over the next years. In the absence of a social discount rate, the real interest rate of the agricultural sector and natural resources can be used. The average long-term official deposit interest rate reported by the central bank minus the average inflation rate of the agricultural sector and natural resources can be used to calculate the real interest rate in this sector [38]. To calculate the discount rate, one can use the average of previous years interest rates on facilities in exchange contracts in the agricultural sector, the average of previous years of interest rates on long-term investment deposits in the agricultural sector, and the average of previous years inflation rate in agricultural and natural resources [39].

A maximum social discount rate of 5% is recommended for the valuation of environmental assets, the assessment of environmental damage in development projects, and the economic evaluation of investment projects in natural resource and environmental areas [40].

3.9. An example for estimating the cost of damage to ES resulting from mining projects

As previously stated, there are methods for calculating the cost of destruction. In this regard, the methodology is that after determining the type of mineral material and the type of mining operations, ecosystems and vegetation areas are identified, and their coefficients are determined according to the provided tables. The calculated and normalized provincial coefficients are then entered into the calculation formula. The amount of environmental damage fine resulting from the mining activity is determined using the presented Equation 1.

Based on the Equations 1 and 2:

copper mine

$$\mathbf{L_1} = \; l_1 \quad + l_1 \quad + l_1 \quad + \cdots + l_1$$

Coastal grassland forest desert agriculture

$$l_1 = \frac{\left(\sum_{i=1}^{n} A_i\right)}{n} \times \text{normalization coefficients} \tag{12}$$

A_1= coefficient 0 to 3 attributed to the impact of a copper mine on the ecosystem service of drinking water supply from agricultural ecosystem

A_2= coefficient 0 to 3 attributed to the impact of a copper mine on the ecosystem service of food supply from the agricultural ecosystem

Locations of Sungun Copper mine's extraction pit: The Sungun Copper mine's extraction pit, located in the northeast of Iran, near the Arasbaran forests of East Azerbaijan Province, has impacted 800 hectares (area under extraction operations). The main mineralization of the deposit includes copper and molybdenum minerals and is the second-largest producer of copper in Iran. It should be noted that the impact of mining activities extends to the forest, grassland, wetland, and agricultural ecosystems. This area consists of 450 hectares of forest ecosystems, 150 hectares of grassland ecosystems, 150 hectares of agricultural lands, and 50 hectares of inland wetland ecosystem. Suppose the value of ES in one hectare of forest is Int $ 4588 in 2020. In that case, the value of ES in one hectare of grassland in East Azerbaijan Province is Int $ 1361 in 2020. The ES value in one hectare of wetland ecosystem is Int $ 31243 in 2020. The ES value in one hectare of agricultural land is Int $ 6842 in 2020.

Figure 2 shows the locations of the Sungun Copper mine's extraction pit in the study area (Fig. 2)

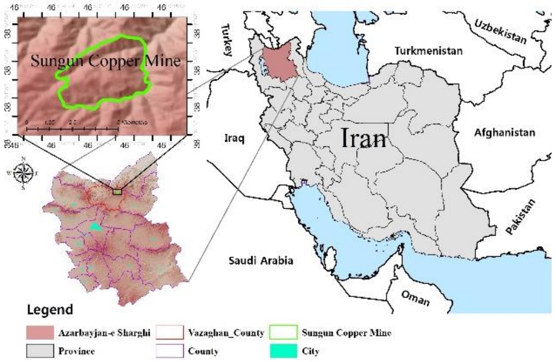


Fig. 2 Geographical situation of the study area

The following calculations are used to estimate the cost of environmental damages caused by the said operating mine over a year:

The Aggregate normalized economic and environmental coefficients of each province are presented in Appendix 5, respectively.

The Matrix calculations of the effects of various mineral materials and their effects on key ES and Calculations related to the interaction matrix of the type of mining activity on different ES types are presented in Appendices 6 and 7, respectively.

Calculations for Example 1:

East Azerbaijan Province PIF_1=0.432

East Azerbaijan Province PIF_2=0.214

East Azerbaijan Province PIF_3=0.240

East Azerbaijan Province PIF_4=0.147

$$ESC = \sum_{i=1}^{n} ESV \times 450 \times \frac{\left(\frac{0.432 + 0.214 + 0.240 + 0.147}{4} + 1\right) + 2.024 + 1.379}{3}$$

Forest ecosystem =

ESC=ESV*450*1.553=4588*450*1.553=In $ 3206324

$$ESC = \sum_{i=1}^{n} ESV \times 150 \times \frac{\left(\frac{0.432 + 0.214 + 0.240 + 0.147}{4} + 1\right) + 2.024 + 1.379}{3}$$

Grassland ecosystem =

ESC=ESV*150*1.553=1361*150*1.553= In $ 317045

$$ESC = \sum_{i=1}^{n} ESV \times 50 \times \frac{\left(\frac{0.432 + 0.214 + 0.240 + 0.147}{4} + 1\right) + 2.024 + 1.379}{3}$$

Wetland ecosystem =

ESC=ESV*50*1.553=31243*50*1.553= In $ 2426019

$$ESC = \sum_{i=1}^{n} ESV \times 150 \times \frac{\left(\frac{0.432 + 0.214 + 0.240 + 0.147}{4} + 1\right) + 2.024 + 1.379}{3}$$

Agricultural ecosystem =

ESC=ESV*150*1.553=6842*150*1.553= In $ 1593844

ESC=Total In $ 7543232

The cost of degradation of the Sungun Ahar Copper Mine in the main mining pit section of the mine can be calculated for a year by substituting the ES values in each period in units per hectare in the respective ecosystems.

The total cost of hypothetical environmental damage for the Sungun Copper mining activity in East Azerbaijan is presented in Table 11.

Table 11. The total cost of hypothetical environmental degradation for the Sungun Copper mining activity in East Azerbaijan

No.	Ecosystem	Area	Total provincial impact factor	Impact factor of minerals on ES (L_2)	Impact factor of mining activity on different ES types (L_1)	Ecosystem value (In $/hectare/2020)	Total coefficient	Cost of environmental damage per ecosystem (In $/ 2020)
1	Forest	450	1.258	2.024	1.379	4588	1.553	3206324
2	Grassland	150	1.258	2.024	1.379	1361	1.553	317045
3	Agricultural lands	150	1.258	2.024	1.379	6842	1.553	1593844
4	Inland wetland	50	1.258	2.024	1.379	31243	1.553	2426019
5	Total							7543232 (1734943 million IRR)

- The total cost of environmental damage to ES for all ecosystems affected by Songun Copper mining activity was estimated to be US $ 7543232.
- It should be noted that the Sungun Ahar Copper Mine produced approximately 5 million tons of copper ore in 2020, which is based on a global price of $174 per tone of 0.7-grade copper ore in this mine, the estimated value of production in 2020 is around $ 870 million. Therefore, paying approximately US $ 7543232 for environmental degradation caused by this portion of the mining activities of the mine is not out of the question.

4. Conclusion

Monitoring the ES[†] changes over certain intervals is one common method for assessing the costs of damage to ecosystems. Thus, the incurred damages can be estimated by comparing changes that have taken place in each of the ecosystems over different periods. The changes must be monitored in both the pre- and post-implementation phases of projects. By monitoring the changing trend ES values, it is possible to quantify and compare the extent of degradation and lost ES values (costs of ecosystem services and goods) within the scope of influence of mining activities. It thus becomes possible to determine which services have the highest value and which, as a result of degradation, will bear the greatest cost of ecosystem degradation. The priorities for preventing ES degradation in areas affected by mining development can also be determined. A combination of applying environmental standards using unique technologies and economic tools and determining corrective taxes to compensate for environmental damages, or internalizing the externalities of mining activities in the study area, should be used. Since reclamation has been neglected in the mining plans and environmental considerations have never been as important as today, the destructive effects of mining activities on the environment have not been fully addressed.

The environmental effects of extraction activities, which are largely related to the type of method used and the type of mineral material used, are pervasive and account for many challenges facing the mining industry and the environment. Estimating changes in the ES values is an effective tool for preserving ES and can better facilitate decision-making by environmental policymakers. It can also assist managers in developing investments to prevent and/ or compensate for damages to ES in mining-affected areas and develop optimal conservation strategies for managing, conserving, and restoring ecosystems.In this study, peat extraction in the Sungun Copper Mine adjacent to Arasbaran Forests in East Azerbaijan Province has impacted 800 hectares (area under extraction operations). It should be noted that the scope of influence of mining activities includes forest, grassland, wetland, and agricultural ecosystems. The estimated annual cost of environmental damage caused by the mentioned mine's activities was calculated. The total cost of environmental damage to ecosystem services for all ecosystems affected by Songun Copper mining activities was estimated to be US $ 7543232 (1734943 million IRR). Therefore, paying approximately US $ 7543232 for environmental damage caused by this portion of the mining activities is not unexpected.

As shown in a study on the costs of ecological services for metal mining by Tost et al. (2020) [15], metal mining significantly affects the cost of damage to ecosystem services. In this study, a significant amount of damage to the ecosystem services of ecosystems located within the scope of influence of copper metal mining activities has been investigated and estimated. In the Global Study, the cost of renewed damage caused to ES for copper was estimated at $ 1397069751 for 2020 [15], which is the share of the cost of ecosystem services (loss of value of ecosystem services) for the Sungun Copper mine's extraction pit of Iran is estimated to be 0.53% compared to the global study of ES cost for copper mining in 2020, which is a significant figure.

Calculating the cost of damage will result in faster restoration of the ecosystems affected by the mining activities. Following the estimations, a dynamic assessment of the effect of ecosystem degradation on the supply of ES and the resulting economic damage should be carried out to develop an ES model for sustainable land management.

A legal mechanism should be established for the optimal

[†] Classification of Millennium Ecosystem Assessment:

The most common classification of ecosystem goods and services is related to the Millennium Ecosystem Assessment, which has been conducted in 2005 with the participation of more than 1,300 international scientists and experts from over than 95 countries and and its report was published by the United Nations. According to the global assessment, ecosystem goods and services are classified into four main groups:

1-Life support services that are necessary to produce other services. These services include soil formation, primary production, nutrient cycle, pollination and habitat formation.

2-Regulating services consist of broad scale benefits of life - support functions that result from the regulation of ecosystem processes. Such as gas, climate and water regulation, disturbance regulation, erosion control and sediment stabilization, waste treatment and biological control (eg pests and connections between prey and hunter).

3-Provisioning services include products derived from ecosystems, including water, food, fiber, agricultural products, and genetic resources.

4-Cultural and aesthetic services include the immaterial benefits that people derive from nature and ecosystems. These services include spiritual, scientific, educational, and recreational benefits [41].

management of the ecosystem in mining activities. [42]. The environmental costs of mining are evaluated as externalities and should be internalized in the mining operational plan optimization models [43]. Environmental regulations (tax and subsidy) are offered to promote green mining performance [44]. Internalize ecological services in cost-benefit analysis, and the inclusion of the cost of their degradation in fine calculation using environmental valuation methods is recommended. To implement such recommendations, the government can improve the valuation and monitoring of ES lost due to mining operations throughout the country [45]. In the long term, research activities on these issues can provide valuable technical advice for all aspects of ecosystems management, thus contributing to the sustainability of mining activities [23]. It is hoped that this study will help kick-start a continuous process of developing methods to accurately estimate the actual environmental damage and costs within the scope of influence of mining activities. Finally, a decision support system can be designed for optimal ecosystem management. By performing restoration and improvement operations in the study area, steps can be taken to mitigate the adverse impacts as mining reclamation, and environmental restoration at the end of mine life is necessary for preserving the ES values of the study area.

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Appendix

Appendix 1. The manner of calculating and data sources of indicators of provincial impact factor

Indicator	Description	Data source
The total amount of production from operational mines in Iran by province (tons) PIF_1	- The total share of production from operational mines in Iran by province (%)	- Data and statistical information, statistical tables of mines, Statistical Center of Iran - Survey results of operational mines in Iran (2018), Statistics Center of Iran
The amount of water consumed by the operational mines by province (m^2) PIF_1	- The amount of water consumed by the operational mines by province (%)	- Data and statistical information, statistical tables of mines, Statistical Center of Iran - Survey results of operational mines in Iran (2018), Statistics Center of Iran
Value-added of the operational mines in Iran by province PIF_1 (IRR million)	- Value-added of the operational mines in Iran by province (%)	- Data and statistical information, statistical tables of mines, Statistical Center of Iran - Survey results of operational mines in Iran (2018), Statistics Center of Iran
Having sensitive ecosystems (forest, grassland, desert, and wetland) PIF_2	- Share of sensitive ecosystems (forests, grassland, deserts, and wetlands) in each province (%)	- Reports on the natural resources of the provinces, the website of the Forests, Range and Watershed Management Organization (accessed at https://frw.ir)
Four regions under the management of PIF_3	- Share of the four regions of the provinces (%)	- Statistics on the four regions of the country, the website of the Environment Protection Organization (accessed at https://www.doe.ir)
Amount of mineral waste in the operational mines by province PIF_4	- Share of the mineral waste in provinces (%)	- Data and statistical information, statistical tables of mines, Statistical Center of Iran - Survey results of operational mines in Iran (2018), Statistics Center of Iran

Appendix 2. The amount and share of mining production in the provinces, the amount and share of water consumption and value-added of the operating mines in the country, and its share in terms of the province in 2018

Province	Amount of production in operating mines in the country (tons)	Amount of water consumed (m³)	Value-added of operating mines in the country ($ million)	Share of operating mine production in the country (%)	Share of consumed water (%)	Value-added share of mines (%)
Total	**361367876**	**159340992**	2566.6			
East Azerbaijan	8069895	4542080	359.8	2.23	2.85	14.02
West Azerbaijan	11942808	89924	22.9	3.30	0.06	0.89
Ardabil	3959150	63077	2.1	1.10	0.04	0.08
Isfahan	20505651	3227918	54.1	5.67	2.03	2.11
Alborz	2724525	32616	4.4	1.86	0.02	0.17
Ilam	2351133	86993	2	0.65	0.05	0.08
Bushehr	14059430	189646	7.4	3.89	0.12	0.29
Tehran	19335228	821657	14,3	5.35	0.52	0.56
Chaharmahal and Bakhtiari	5271691	51543	2.2	1.46	0.03	0.09
South Khorasan	6322248	1178665	59.5	1.75	0.74	2.32
Razavi Khorasan	26091986	1210994	31.3	7.22	0.13	1.22
North Khorasan	4394462	213274	6.8	1.22	0.13	0.26
Khuzestan	12285006	1220705	7.5	3.40	0.77	0.29
Zanjan	5904183	35304	15.8	1.63	0.02	0.62
Semnan	11175651	132581	18.8	3.09	0.08	0.73
Sistan and Baluchestan	6980726	898794	8.2	1.93	0.56	0.32
Fars	22104620	1833339	41.5	6.12	1.15	1.62
Qazvin	3935127	22742	4,0	1.09	0.01	0.16
Qom	3903087	25681	3.3	1.08	0.02	0.13
Kurdistan	8840244	38901	23.9	2.45	0.02	0.93
Kerman	54244598	123294857	1255.4	15.01	77.38	48.91
Kermanshah	5486086	59120	6	1.52	0.04	0.23
Kohgiluyeh and Boyer-Ahmad	6865047	2319016	6.1	1.90	1.46	0.24
Golestan	6137659	1945573	9.9	1.70	1.22	0.39
Gilan	6075503	691	4.3	1.68	0.00	0.17
Lorestan	5303283	121236	8.3	1.47	0.08	0.33
Mazandaran	9876794	1132966	13.7	2.73	0.71	0.54
Markazi	11508739	153356	42.6	3.18	0.10	1.66
Hormozgan	13297500	1860189	13.2	3.68	1.17	0.52
Hamedan	9742891	8290	31.4	2.70	0.01	1.22
Yazd	28672924	12529176	485.2	7.93	7.86	18.91

Source: Data and statistical information, statistics of mines, Statistical Center of Iran, (amar.org.ir)

Appendix 3- Share of sensitive ecosystems (forests, grasslands, deserts, and wetlands), four regions of the department of environment, and tailing of provinces (%)

Share of environmental indicators / Province	Share of the forest by province breakdown	Share of grassland by province breakdown	Share of the desert by province breakdown	Share of wetlands by province breakdown	Percentage of the area of four regions by province breakdown	Share of tailing in operating mines by province breakdown
East Azerbaijan	1.22	3.31	0.24	3.23	3.40	7.46
West Azerbaijan	0.71	3.58	0.39	16.77	3.79	1.37
Ardabil	0.41	1.36	0.00	3.87	0.78	0.68
Isfahan	2.66	8.44	6.91	1.29	7.27	2.13
Alborz	0.10	0.50	0.09	0.00	0.41	0.07
Ilam	4.15	1.05	0.92	1.29	0.88	0.19
Bushehr	1.32	1.69	0.72	2.58	0.89	0.11
Tehran	0.38	1.23	0.23	1.94	2.47	0.52
Chaharmahal and Bakhtiari	1.99	1.46	0.26	3.87	1.18	0.05
South Khorasan	4.79	2.32	27.92	0.65	1.11	0.53
Razavi Khorasan	6.45	8.80	11.99	1.29	6.01	7.25
North Khorasan	2.65	1.37	1.27	0.00	10.70	0.08
Khuzestan	6.29	3.35	2.81	5.81	3.92	0
Zanjan	0.74	1.52	0.17	0.00	1.39	2.01
Semnan	2.28	5.01	11.04	0.00	12.09	0.39
Sistan and Baluchestan	7.76	13.73	10.79	2.58	5.06	0.06
Fars	14.36	9.81	2.59	7.74	7.06	2.33
Qazvin	0.17	1.14	0.06	1.94	0.68	0.28
Qom	0.03	0.97	0.38	1.94	0.20	0.03
Kurdistan	2.42	1.89	0.01	0.65	1.10	1.2
Kerman	8.23	8.36	10.93	1.94	13.74	50.92
Kermanshah	3.41	1.60	0.06	1.94	0.95	0.06
Kohgiluyeh and Boyer-Ahmad	3.58	1.17	0.09	2.58	1.19	0.16
Golestan	2.69	1.16	0.00	4.52	0.79	0.18
Gilan	2.53	0.36	0.00	5.81	0.76	0.10
Lorestan	7.88	1.19	0.03	3.23	1.01	0.37
Mazandaran	2.79	0.79	0.00	4.52	3.02	0.04
Markazi	0.10	0.55	1.06	0.65	0.76	0.98
Hormozgan	6.82	5.49	3.27	13.55	4.00	0.19
Hamedan	0.01	0.89	0.06	1.29	0.36	0.39
Yazd	1.10	5.90	5.72	0.00	3.04	20.11

Sources: Reports related to the natural resources of the provinces, the Forests, Rangelands, and Watershed Management Organization) frw.ir (, Statistics related to the four regions of the country on the site of the Department of Environment (doe.ir), Statistics data and information section, statistical tables of the mining sector, National Statistics Portal, Statistics Center of Iran, Survey results of mines in operation in the country (2018), Statistics Center of Iran

Appendix 4. The score of each province in terms of impact factor

Sum of total indicators Province	Sum of economic coefficients	Sum of environmental coefficients	Sum of total indicators	Rank
East Azerbaijan	0.43	0.45	0.88	11
West Azerbaijan	0.19	0.73	0.91	10
Ardabil	0.03	0.18	0.21	27
Isfahan	0.38	0.78	1.16	7
Alborz	0.09	0.01	0.10	31
Ilam	0.00	0.22	0.22	26
Bushehr	0.23	0.19	0.42	18
Tehran	0.34	0.17	0.50	14
Chaharmahal and Bakhtiari	0.06	0.23	0.29	24
South Khorasan	0.09	1.04	1.13	8
Razavi Khorasan	0.46	1.11	1.57	4
North Khorasan	0.05	0.44	0.48	16
Khuzestan	0.21	0.61	0.82	12
Zanjan	0.07	0.13	0.20	28
Semnan	0.18	0.86	1.03	9
Sistan and Baluchestan	0.10	1.12	1.23	5
Fars	0.40	1.21	1.62	3
Qazvin	0.04	0.10	0.14	29
Qom	0.04	0.08	0.12	30
Kurdistan	0.14	0.18	0.31	22
Kerman	2.01	2.21	4.23	1
Kermanshah	0.08	0.21	0.29	25
Kohgiluyeh and Boyer-Ahmad	0.12	0.23	0.35	20
Golestan	0.11	0.25	0.36	19
Gilan	0.10	0.25	0.35	21
Lorestan	0.09	0.37	0.46	17
Mazandaran	0.19	0.30	0.49	15
Markazi	0.22	0.09	0.31	23
Hormozgan	0.27	0.93	1.20	6
Hamedan	0.53	0.06	0.59	13
Yazd	1.61	0.83	2.43	2

Appendix 5. Aggregate normalized economic coefficients for each province (PIF_1)

Province	Normalized aggregate coefficients of each province PIF1	Normalized aggregate coefficients of each province PIF2	Normalized aggregate coefficients PIF3	Normalized aggregate coefficients PIF4
East Azerbaijan	0.432	0.214	0.24	0.147
West Azerbaijan	0.185	0.608	0.27	0.027
Ardabil	0.032	0.145	0.04	0.013
Isfahan	0.376	0.545	0.52	0.042
Alborz	0.086	0.000	0.02	0.001
Ilam	0.002	0.197	0.05	0.004
Bushehr	0.229	0.164	0.05	0.002
Tehran	0.336	0.090	0.17	0.010
Chaharmahal and Bakhtiari	0.060	0.202	0.07	0.001
South Khorasan	0.089	1.024	0.07	0.010
Razavi Khorasan	0.463	0.815	0.43	0.142
North Khorasan	0.046	0.135	0.78	0.002
Khuzestan	0.206	0.514	0.27	0.001
Zanjan	0.073	0.051	0.09	0.039
Semnan	0.176	0.516	0.88	0.008
Sistan and Baluchestan	0.103	1.000	0.36	0.001
Fars	0.405	0.989	0.51	0.046
Qazvin	0.040	0.077	0.04	0.005
Qom	0.040	0.077	0.00	0.001
Kurdistan	0.137	0.125	0.07	0.024
Kerman	2.013	0.842	1.00	1.000
Kermanshah	0.078	0.185	0.06	0.001
Kohgiluyeh and Boyer-Ahmad	0.123	0.197	0.07	0.003
Golestan	0.112	0.225	0.04	0.004
Gilan	0.095	0.234	0.04	0.003
Lorestan	0.090	0.341	0.06	0.007
Mazandaran	0.186	0.217	0.21	0.001
Markazi	0.219	0.049	0.04	0.019
Hormozgan	0.272	0.832	0.28	0.004
Hamedan	0.529	0.046	0.01	0.008
Yazd	1.609	0.352	0.21	0.395

Appendix 6- The matrix of effects of different types of mineral materials and their effects on key ES in ecosystems located within the scope of mining activity

Agricultural		Desert	Forest		Grassland		Urban	Wetland		Coastal
3		None	2		3		None	3		None
2			3		3			3		
1			3		2			1		
2			3		2			3		
1			2		3			2		
1			2		2			3		
1			3		3			1		
0			2		3			2		
3			3		3			3		
3			2		3			3		
2			3		3			3		
1			2		2			2		
1			2		2			1		
0			3		3			2		
1			3		3			1		
0			2		2			3		
2			3		2			3		
2			3		2			2		
3			3		3			3		
3			2		2			3		
1			3		2			3		
			3		2			3		
			3		2			2		
			3		2			2		
			2		3			3		
			2		2					
			2		2					
33.00	Total	0.00	69.00	Total	66.00	Total	0.00	60.00	Total	
1.57	Average/21	0.00	2.56	Average/27	2.44	Average/27	0.00	2.40	Average/25	
0.52381	Normalized	0	0.851852	Normalized	0.814815	Normalized	0	0.8	Normalized	
0.34	Importance coefficient	0.54	0.84	Importance coefficient	0.31	Importance coefficient	0.39	1.00	Importance coefficient	
0.196714	L2 Agricultural	0	**0.7259259**	L2 Forest	**0.261425**	L2 Grassland	0	**0.84**	L2 Wetland	
2.024	**Sum of L2 coefficients**									

- ❖ L2 Wetland, if the wetland in question is listed as wetlands protected by the Ramsar Convention, etc., according to the importance of the wetland, L2 is calculated using the following equation:

$$\underset{\substack{\uparrow \\ \text{wetland listed in} \\ \text{Ramsar Convention}}}{L_2} = \underset{\substack{\uparrow \\ \text{Calculation} \\ \text{from the table}}}{L_2} + (\underset{\substack{\uparrow \\ \text{low importance}}}{0} \text{ up to } \underset{\substack{\uparrow \\ \text{high importance}}}{0.25}) \times \underset{\substack{\uparrow \\ \text{Calculation} \\ \text{from the table}}}{L_2}$$

$$L_2 = \underset{\substack{\uparrow \\ \text{final and listed in the Ramsar Convention}}}{0.84} \qquad L_2 = 0.84 + \underset{\substack{\uparrow \\ \text{high importance}}}{(0.25)} \; 0.84 = 1.05$$

Appendix 7. Calculations for the interaction matrix of the type of mining activity on various ES

Stripping overburden (extraction from the pit)	Excavation and explosion	Transportation of mineral waste and minerals	
3	3	3	
3	3	2	
2	2	1	
1	2	1	
3	2	1	
2	2	1	
1	3	2	
2	1	1	
2	2	1	
3	3	2	
3	3	2	
3	2	3	
1	1	1	
1	1	1	
1	1	1	
1	1	0	
2	2	1	
0	2	3	
2	2	2	
1	2	1	
1	1	3	
2	1	1	
3	3	3	
2	3	2	
2	2	2	
3	2	1	
3	1	2	
3	2	1	
56	22	22	Total
1.9310	0.7586	0.7586	Average/29
0.6437	0.2529	0.2529	Normalized values/3
		1.379	**The normalized value of the sum of the L1 values**

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