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Environmental impact assessment studies for mining area in Goa, India, using the new approach

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Abstract The mining industry is a fundamental source for building infrastructures and an enabler for a country's growth. Over the last decade, the act of mining has been among the top in the list of human activities which has the most disturbing and catastrophic impacts on environment, therein extensively affecting the ecological, economic, and social elements in the vicinity. There is an exigency for a pragmatic balance to exist between the global demand satisfaction of metal and environmental sustenance. In this paper, a comprehensive case study on Environmental Impact Assessment (EIA) of a mining site has been presented using the new approach. This new approach is an improved version of the traditional matrix method, incorporating a modified version of Rapid Impact Assessment Matrix (RIAM) integrated with analytical hierarchy process (AHP), thereby knocking out the limitations in the existing EIA techniques. The data used in this study is an outcome of a broad survey conducted among the people associated in both direct and indirect ways to the project actions related to the mining industry and, hence, minimizing issues such as assessors' reproducibility, subjectivity, and non-inclusivity of all stakeholders' opinion, which can contribute to misleading outcomes. This new approach delivers more precise and practical results for the assessment of environmental impact data.

Keywords Mining industry · Environmental Impact Assessment (EIA) · Analytical hierarchy process (AHP) · Rapid Impact Assessment Matrix (RIAM) method · Modified matrix method

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Abbreviations

EIA	Environmental Impact Assessment
AHP	Analytical hierarchy process
RIAM	Rapid Impact Assessment Matrix Method
RI	Random index
CI	Consistency index
CR	Consistency ratio
ES	Environmental scores
A_{ij}	*i*th row element in *j*th column of matrix *A*
$\sum_{j=1}^{n} A_{ij}$	$A_i1 + A_i2 + ... + A_i(n-1) + A_in$

Introduction

Everything we rely on for our basic needs to sustain life is directly or indirectly associated with minerals or relies on minerals for its production. Construction of roads and hospitals, building houses and automobiles, generation of electricity, manufacturing computers and satellites, and other goods and services that are necessary for sustenance of a healthy life are dependent on minerals (Yakovleva 2015). It provides employment to a substantial percentage of unemployed or partially employed population. Resourceful and industrious mining of noble and demanded metals and minerals is an important factor for economic growth of a country. If done proficiently, it can be an efficient promoter for social growth in developing countries (Bindu 1997). More than 100 countries around the world are meticulously involved in the global mining business among which more than 50 that can be considered "mining countries" contributing eminently to the global export and economic business including Australia, Botswana, Chile, Canada, Guinea, Kazakhstan, Papua New Guinea, Peru, and South Africa (Li 2008). It provides employment, dividends, and taxes that pay for hospitals, schools, and public facilities.

Mining has played a very significant role in the economic history and foreign exchange earnings for Goa. The mining belt of Goa is mostly concentrated in four talukas, namely, Bicholim of North Goa district and Salcete, Sanguem, and Quepem of South Goa district, spread over 700 km^2. Based on the concentration of the iron ore, the mining belt of Goa is divided into three regions, Northern, Central, and Southern Zone, as shown in Fig. 1.

In Goa, opencast mining techniques are used for the extraction of iron and manganese ores. Use of barges for transport of ores is one of the most economic option in comparison to road and rail transport. Goa is one of the major iron ore–producing states of India, with an average annual production of iron ore about 15 to 16 million

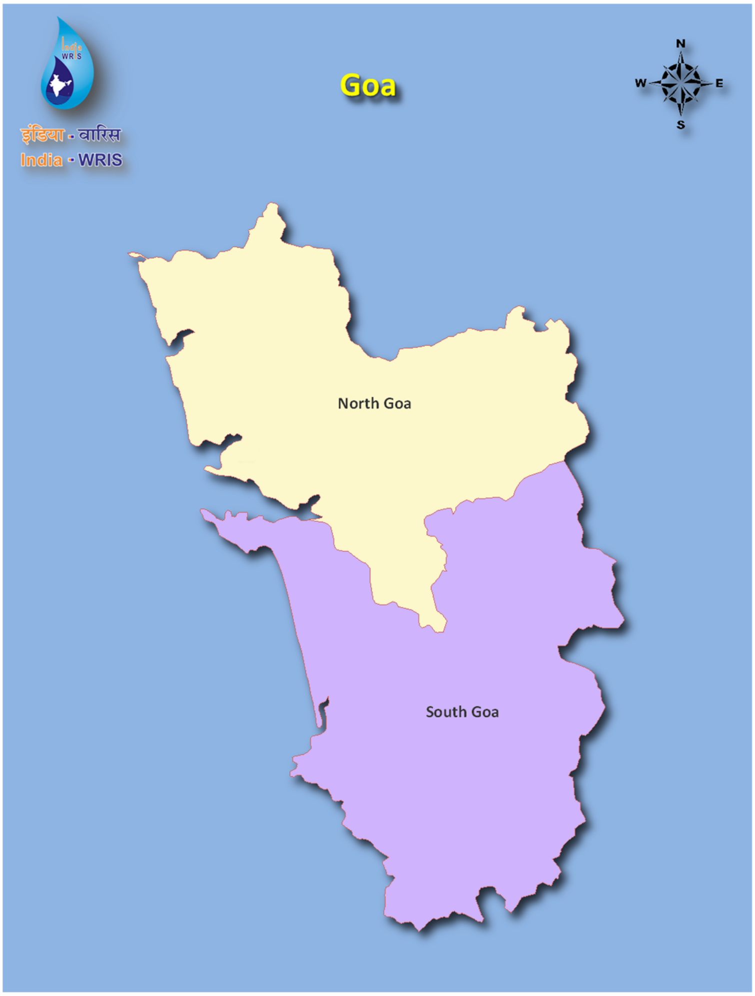

Fig. 1 Major mining belts in Goa, India (Image courtsey - India WRIS - Maps of Goa)

tonnes, contributing over 60% of Country's global iron ore export. It harvests an approximate foreign exchange earnings of Rs.1000 crore per annum. On an average about 2.5 to 3 tonnes of mining waste has to be excavated per tonne of iron ore production, generating about 40 to 50 million of mining waste. Improper disposal of such a huge quantity of mining waste generates problem, causing severe environmental pollution (Hughes et al. 2015; Hudson-Edwards et al. 2011).

Mining has degraded the environment to its core which is an important matter of concern (Yellishetty et al. 2013). Rejected dumps, pumping out of muddy waters from the working pits including cases where the mining operations are performed below the water table as shown in Fig. 2, are some of the factors contributing to destruction of our environment.

Several major environmental problems caused due to mining operations are (Xavier et al. 2013):

- Groundwater pollution
- Surface water pollution
- Air pollution
- Noise pollution
- Deforestation
- Land degradation
- Damage to beaches

The existing natural geography of Goa like the presence of coastline, a very good natural harbor at Marmugao and numerous navigable perennial rivers, has promoted the economic exploitation of mineral deposits. With the tremendously increasing demand of the products that depend directly or indirectly on mining, it is improbable for the mining industry to lose its place in the global economy. Maintaining a pragmatic balance between extraction of these natural resources to satisfy the global demand and, at the same time, sustaining the richness and fertility of our environment are very crucial and delicate tasks to perform.

In this paper, the authors have come up with a new rigorous mathematical approach towards EIA and sustainable mining. This new approach is an improved version of the traditional matrix method, incorporating a modified version of Rapid Impact Assessment Matrix (RIAM) integrated with analytical hierarchy process (AHP). A general comparison of established EIA techniques is also provided in this study. In the end, a conclusion of the results has been delivered by incorporating views of various environmental experts. This newly proposed method can be extended further by integrating fuzzy comprehensive logic (Mofarrah et al. 2010; Campos and De Mello 2006; Peche and Rodríguez 2009; Faramarzi and Soffianian 2014) for frequency, rate, and time analysis (Branch 2011) of different project actions, transforming this model into a much more rigorous and robust technique which can be further used for performing EIA study of multi-purpose projects.

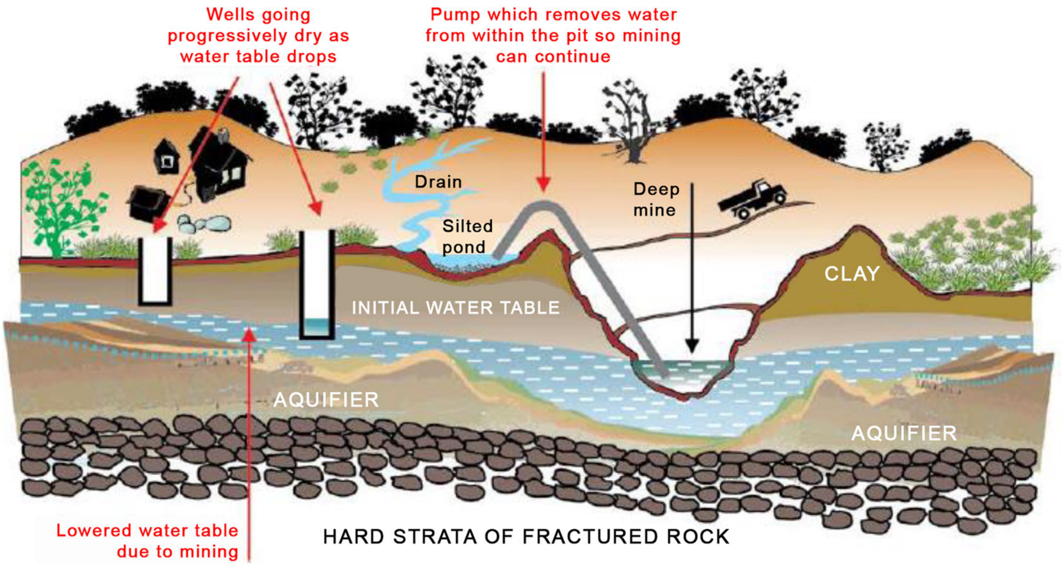

Fig. 2 Impact due to mining below water table (Xavier et al. 2013).

Sustainable development and EIA

Even though the mining actions are carried out on a relatively small land area, the impact of the pollution caused by these actions have a strong potential to damage the health of our ecosystem (Richards 2002). Such actions pollute the resources necessary for humans and the environment to survive altogether, dynamically. For past few years, as the awareness of the importance of sustainable mining is spreading to a large population, mining project actions are progressively performed in ways that minimizes their adverse impact on the surrounding environment, maintaining the productivity of the land and keeping it suitable for re-use by the stakeholders (Sahu et al. 2015; Carvalho 2017).

Numerous technologies, management methodologies, and strategies are being developed and used by the mining industry to mitigate the adverse impacts of mining. Towards Sustainable Mining (TSM) is one such program developed by the Mining Association of Canada (MAC) (Mining Association of Canada 2004). There are many more specific programs that are followed regionally for sustainable mining. Figure 3 demonstrates ways which are proven to positively contribute towards environmentally friendly mining activities.

The environmental performance is enhanced recently by the success of Green Mining Initiative (GMI)—where an automated mine ventilation system was installed in an underground mine in greater Sudbury, Ontario. This initiative resulted in a gradual reduction in energy consumption of up to 40%, reduction of greenhouse gas emissions, and a saving in costs of up to $4 million per year. Also, reuse of waste disposal has been taken up by the zero discharge water programs. Taking the wastewater produced by mining activities and make it suitable for reuse, aiming to bring the ratio of wastewater disposed of to water recovered to zero. This not only eliminates the need for costly disposal processes, rather also keeps the project's net water usage at an efficient level.

The implementation of sustainable development can be achieved by assimilation of the following three activities, namely:

- Technical and economic activities, ensuring economic growth (Dubiński 2005; Connolly and Orsmond 2011)
- Ecological, ensuring the protection of natural resources and the environment
- Social, taking care of the employee at the workplace and community development in the area of the mining environment.

For sustainable mining, one of the major tools used globally is Environmental Impact Assessment (EIA). EIA is a tool which incorporates different techniques and methodologies which are used in decision-making for new construction schemes and developmental projects. EIA is a very comprehensive tool, capable of predicting the economic, ecological, and social effects before implementation of a proposed development. EIA aims towards predicting the adverse impacts of a project plan and finding measures to mitigate these adverse impacts, making the project feasible to run smoothly without harming the environment and other living creatures living in the vicinity (Sánchez and Hacking 2002). All these estimated outcomes, predictions, and other alternatives are delivered to environmental experts to evaluate the data and provide their qualitative and quantitative input to improve the results. EIA is globally

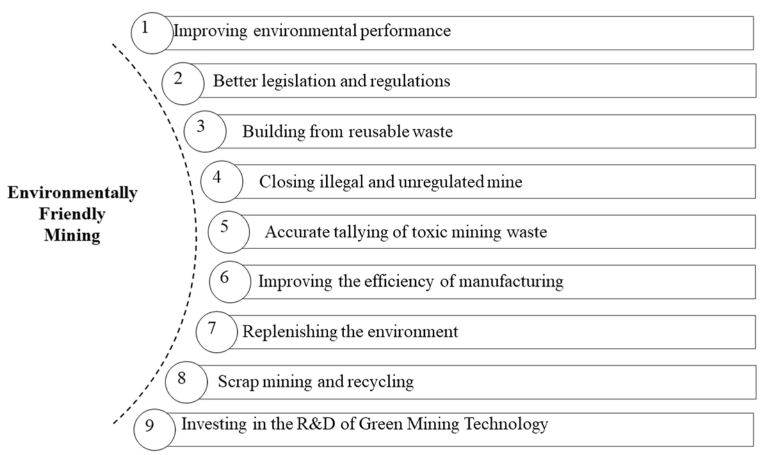

Fig. 3 Factors contributing towards environmentally friendly mining

Table 1 Advantages and drawbacks of EIA methodologies

Impact assessment methods	Advantages	Drawbacks
Ad hoc	• Experts analyze and assess the project and provide useful advice. • Easily understandable to the lay man • Useful for getting a more general idea of the impacts of different project actions on environment • Useful when time is a constraint for impact assessment studies	• It is inefficient since no information about cause-effect relationship between project actions and environmental components is provided. • Identification, prediction, and interpretation of impacts are quite poor. • A lot of assessment is done by guessing due to lack of data. • There is no actual quantification of the environmental impacts. • It is innately inefficient as it requires sizeable effort to identify and assemble an appropriate panel of experts for each assessment. • Not replicable
Checklist	• Can structure initial stages of assessment • Help to ensure that vital factors are not neglected. • Easy to apply, particularly by non-experts • They are useful in summarizing information to make it accessible to specialists from other fields. • They are partially replicable.	• They are too general or incomplete. • They do not illustrate interactions between effects. • The number of categories to be reviewed can be immense, thus distracting from the most significant impacts. • The identification of effects is qualitative and subjective.
Matrix	• Visually describes relationship between two sets of factors • Expanded or contracted to meet needs of the proposal being assessed • Identify impacts of different phases of project, construction, operation, etc. • Help separate site-specific impacts from impacts affecting region • Reasonably flexible method for impact assessment • Links project actions to environmental conditions	• Difficult to distinguish direct to indirect impacts • Very time-consuming • This method requires consultation from experts for assigning importance and magnitude of impact values. • Cannot be replicated
Network	• Visually quite appealing and easy to understand • Links action to impact • It can handle direct and indirect impacts • Partially replicable	• Can become extremely complex and difficult to handle if used beyond simplified version. • Qualitative
RIAM	• Rapid Impact Assessment Matrix and fast quantification • Easy to understand and implement • Decreased subjectivity due to use of pre-defined scales • Flexible while still being able to directly link action to impact • Improved structure for quantification resulting in better reproducibility • Better transparency	• Prevalence of subjectivity in judgment

accepted in a large number of nations (more than 100 in today's date) and has become a formal procedure in any activity affecting the environment directly or indirectly.

A number of methodologies are available for processing of EIA such as ad hoc method, checklist method, matrix method, network method, and Rapid Impact Assessment Matrix (RIAM) method (Pastakia 1998). The common limitations exhibited by all these methods are assessors' biases which are totally based on subjective information. The subjectivity exists because of factors like lack of reference data, incorporating individual's perception and opinion towards a problem, and time frame under which the data is acquired. These methods lack objectivity, discrete and robust solutions, and transparency in EIA. It is essential to recognize the shortcomings and limitations of these techniques in order to develop upon the existing assessment techniques. A comprehensive overview of the advantages and disadvantages of different EIA methods has been discussed in Table 1 (Gour 2017).

In this paper the authors have proposed a developed EIA technique, which incorporates the modified matrix

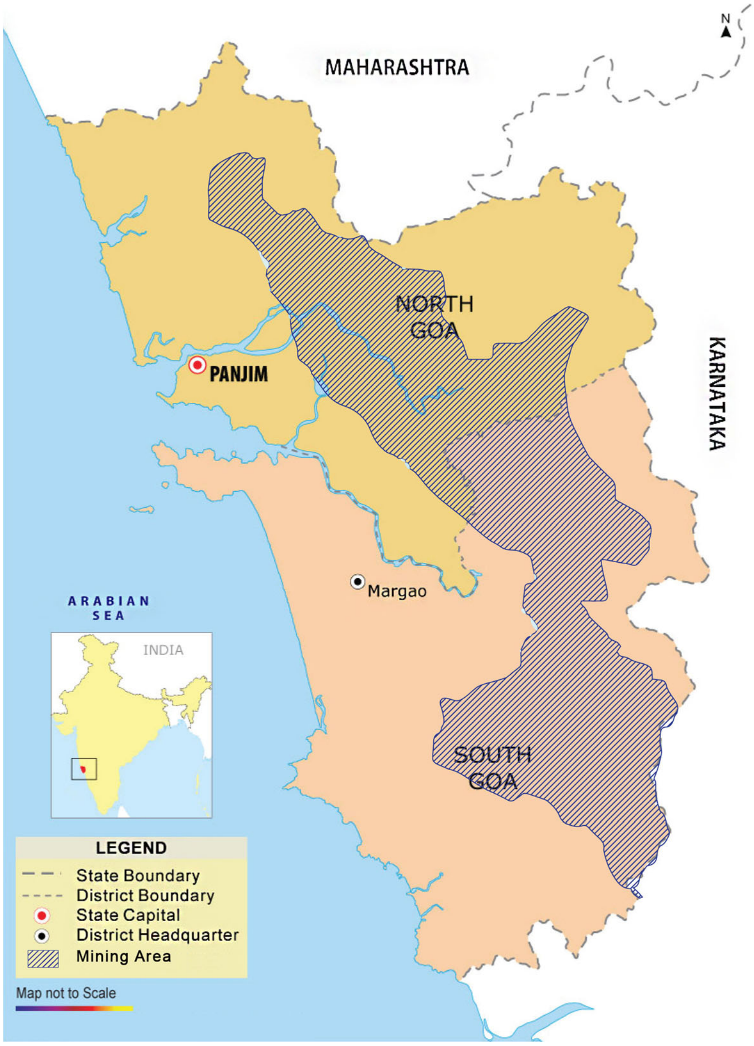

Fig. 4 Map of Goa showing major areas of mining activities (*Image Courtesy: Google Maps and own elaboration*)

method integrated with major aspects of RIAM, matrix assessment method, and AHP (Ramanathan 2001; Saaty 1980). This new technique brings more transparency and delivers much more comprehensive results as compared to the existing EIA techniques. It eliminates the biasness and subjectivity by incorporating views of a large number of stakeholders which are directly or indirectly connected to the mining project actions and their impact. A survey has been conducted among three major classes of the affected population viz. Goa State Pollution Control Board (GSPCB) officials; mining owners and people working in the mines; and, thirdly, among the local people living in the vicinity of mines or transportation routes. The aim of the survey was to know the personal priority of different stakeholders regarding the importance of various environmental factors. These priorities acquired through the survey are incorporated in AHP followed by other EIA techniques. The data in this study are based on surveys done among seven mines in Goa, producing iron ore and manganese in major quantities (Fig. 4), which are:

1. Colomba Iron ore mine—Tc No.—35/1952
2. Surpen Ironore Mine—Tc No.—3/1951, 4/1954
3. Polo dongor mine—Tc No.—65/1951
4. Godbaen–oo–Colt Ien Carpen Iron Ore Mine)—Tc No.—63/1951
5. Hunantalo Dongur Manganese Mine—Tc No.—17/1949
6. Vangi Bindi Advonce Iron ore mine—Tc No.—10/51
7. Nonoxitembo-de-Caurem Iron ore mine—Tc No.—14/1952

Table 2 Scale used in AHP for pair-wise comparison among two criteria

Intensity of importance	Definition	Description
1	Equal importance	Elements A_i and A_j are equally important.
3	Weak importance of A_i over A_j	Experience and judgment slightly favor A_i over A_j.
5	Essential or strong importance	Experience and judgment strongly favor A_i over A_j.
7	Demonstrated importance	A_i is very strongly favored over A_j.
9	Absolute importance	The evidence favoring A_i over A_j is of the highest possible order of affirmation.
2, 4, 6, 8	Intermediate	When compromise is needed, values between two adjacent judgements are used.
Reciprocals of the above judgements	If A_i has one of the above judgements assigned to it when compared with A_j, then A_j exhibits the reciprocal value when compared with A_i.	A reasonable assumption

In the end, authors have proposed suggestions and conclusions based on verbal quantitative feedback from various environmental experts, mine owners, local people living in the vicinity of mining sites, and Goa State Pollution Control Board (GSPCB) officials.

Mining scenario in Goa

In the last fiscal, 46 mines produced 10 lac tons of ore. Relative density of ore/mine = 2.7–3 kg/m3. Volume capacity of transport vehicle is around 7 m^3. The state can export 20 million tons of ore annually as per government rules. The working period of mines is approximately 8 months (October–May), excluding Sunday's and government holidays and transportation works in parallel with this. If 10 lac tons of mine is planned to be transported from the mining site to the export area then a total of 500 round trips per day is the estimated transportation rate, if the same target is to be achieved in 100 days then the transportation rate shoots up to 700–900 round trips per day. A mine is generally spread into 25–100 ha but the excavation area is around 2–3 ha only.

Modified matrix method to CARRY out EIA

The modified matrix method is an integrated form of analytical hierarchy process (AHP) and a modified version of Rapid Impact Assessment Matrix (RIAM) method. The AHP is a technique which has a particular application in organizing and analyzing complex decision problems. It provides a rational and comprehensive outline for organizing a decision problem, for quantifying its elements, and for establishing a relation of those elements to the overall goals. AHP is used globally in a wide variety of decision-making situations, in fields such as industry, government, business, and education. The RIAM is a tool to carryout EIA. It presents results of the impact assessment studies in an organized and transparent way. It incorporates a well-defined system for assigning values for magnitude of impact of different project actions on the environmental conditions. It considers different criteria of impact from project actions on environmental conditions like permanence, reversibility, cumulative effect, importance, and magnitude, which are usually neglected by other impact assessment techniques. The RIAM method involves in-depth analysis of selected components in a rapid and accurate manner, providing a holistic approach on EIA. The comprehensive step-wise procedure for the modified matrix

Table 3 Saaty's random index (RI) values for different matrix sizes

n (size)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

Table 4 Alonso and Lamata's random index (RI) values for different matrix sizes

n (size)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0	0	0.52	0.88	1.11	1.25	1.34	1.41	1.45	1.48	1.51	1.54	1.56	1.57	1.58

method using the AHP and a modified version of RIAM has been proposed below.

In this method, the two major evaluating components are:

i. *Importance/priority* of an environmental factor over the other
ii. *Magnitude of the impact* of project actions on these environmental factors

There are further sub-divisions for evaluating both the abovementioned components. These sub-divisions incorporate various factors like estimation about the nature of a project action; positive or negative, permanence, reversibility, and cumulative effect of these actions; and priority of different environmental elements for different stakeholders. The method for the step-wise evaluation of these sub-divided parameters is proposed below.

Table 5 Value system assigned to different analytical criteria in RIAM

Criteria	Scale	Description
A1: importance of condition	4	Important to national/international interests
	3	Important to regional/national interests
	2	Important to areas immediately outside the local condition
	1	Important only to the local condition
	0	No importance
A2: magnitude of change/effect	+ 3	Major positive benefit
	+ 2	Significant improvement in status quo
	+ 1	Improvement in status quo
	0	No change/status quo
	− 1	Negative change to status quo
	− 2	Significant negative disbenefit or change
	− 3	Major disbenefit or change
B1: permanence	1	No change/not applicable
	2	Temporary
	3	Permanent
B2: reversibility	1	No change/not applicable
	2	Reversible
	3	Irreversible
B3: cumulative	1	No change/not applicable
	2	Non-cumulative/single
	3	Cumulative/synergistic

Step 1 Importance of different environmental conditions/elements like air, water, soil, noise, economic factors, and social factors has been determined using AHP. The input data required for AHP studies have been acquired by surveys among different control groups encompassing all the stakeholders. Pairwise comparison is done among various criteria that are on the same level in the analysis hierarchy chart for priority calculation. These comparisons between different criteria are represented in a judgmental matrix. Every element of the judgmental matrix A, like A_{ij} is created by comparing the ith row element to the jth column element. The scale used in AHP to quantify the verbal judgment is a nine-point scale which is used as explained in Table 2.

The legitimacy of the entries in each judgmental matrix in the judgmental matrices is checked by calculating the consistency ratio (CR) (Alonso and Lamata 2006). The consistency ratio exhibits a parameter called random index. Saaty (1980, 2000) calculated the values of these random indices for up to 15th order matrix (Table 3). Similarly, Alonso and Lamata (2006) also calculated the RI values for higher order matrices (Table 4). As stated by Saaty, consistency ratio of values less than one for a matrix is considered acceptable. The judgment may not be reliable if the CR value overshoots 0.1, and hence, judgements will have to be effectually produced again.

Step 2 In this step, RIAM method is used to estimate the magnitude of impact by different mining project actions on various environmental factors considered in this study. The existing RIAM technique does not deliver a clear outcome of the impact on environmental factors due to mining actions in a constructive way. Therefore, in the following proposed method, authors have rationalized and vindicated structure by considering the

Table 6 Environmental scores (ES) for modified RIAM method

Environmental score	Normalized ES	Range bands	Description of range bands
$+72 < es \le +108$	$+6.67 < es \le +10$	+ E	Major positive change/impacts
$+36 < es \le +72$	$+3.33 < es \le +6.67$	+ D	Significant positive change/impacts
$+18 < es \le +36$	$+1.67 < es \le +3.33$	+ C	Moderately positive change/impacts
$+9 < es \le +18$	$+0.83 < es \le +1.67$	+ B	Positive change/impacts
$0 < es \le +9$	$0 < es \le +0.83$	+ A	Slightly positive change/impacts
0	0	N	No change/status quo/not applicable
$0 > es \ge -9$	$0 > es \ge -0.83$	− A	Slightly negative change/impacts
$-9 > es \ge -18$	$-0.83 > es \ge -1.67$	− B	Negative change/impacts
$-18 > es \ge -36$	$-1.67 > es \ge -3.33$	− C	Moderately negative change/impacts
$-36 > es \ge -71$	$-3.33 > es \ge -6.67$	− D	Significant negative change/impacts
$-72 > es \ge -108$	$-6.67 > es \ge -10$	− E	Major negative change/impacts

impact of each project action on notable environmental attribute individually.

The RIAM incorporates factors like permanence, reversibility, magnitude, and nature of the impact in a comprehensive way. Values are assigned to these factors for quantification of impact of project actions on environmental factors (Table 5). In the existing traditional RIAM technique, the range of environmental score (ES) ranges from + 108 to − 108 (Table 6). The authors have proposed new standardize ES values (Table 6) called normalized environmental score (NES) for more effectual results. But a more standard range observed for all analysis is from 0 to 10 (in this case − 10 to + 10). So, the range is converted to + 10 to − 10 by dividing the environmental scores with 10.8.

Step 3 The magnitude of impact estimated from step two are multiplied with the priorities obtained in step one, and these discrete quantities can be presented through the original matrix method, to get an overall quantification of various environmental impacts. One more productive output this matrix delivers is the cumulative impact of a project action on all the environmental elements and also cumulative impact on a particular environmental attribute by all the project actions. The former is achieved by summing up the scores in all row elements of that project action and the latter is achieved by summing up the final scores in all column elements of that environmental attribute.

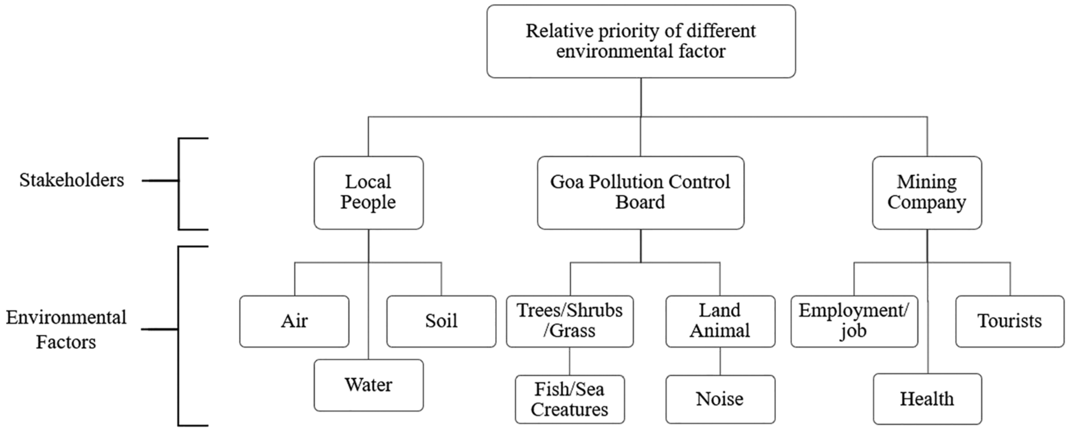

Fig. 5 Hierarchical bifurcation of subject parameters in this study

Table 7 Importance/priorities of stakeholders (CI—0.238; RI—0.58; CR—0.410)

	Local people	Mining owners	GPCB	Local priorities
Local people	1	8	8	0.76
Mining owners	1/8	1	1/7	0.06
(GSPCB)	1/8	7	1	0.22
Total	1.25	16	9.14	

Calculation for judgmental matrix

If A_{ij} represents the final impact score on *j*th environmental attribute by *i*th project action then:

$$\text{Cumulative impact of i}^{\text{th}}\text{ project action} = \sum_{j=1}^{n} Aij$$

$$\text{Cumulative impact on j}^{\text{th}}\text{ environmental attribute}$$

$$= \sum_{i=1}^{m} Aij \begin{matrix} \sum_{j=1}^{n} A_{ij} = A_{il} + A_{i}2 + \ldots\ldots + A_{i}(n-1) + A_{i}n \\ \sum_{i=1}^{n} A_{ij} = A_{lj} + A2_{j} + \ldots\ldots + A_{i}(n-1)_{j} + A_{ij} \end{matrix}$$

where *n* denotes the number of environmental attributes and *m* is the number of project actions.

Application of proposed method

The abovementioned technique is used to perform EIA of different mining sites in Goa. The first step will be placing the components involved in this study into their respective hierarchy. The hierarchical model is shown in Fig. 5.

Pair-wise comparison has been done among the components on the same hierarchical level (Fig. 5), and judgmental matrices are formed (Tables 7, 8, 9, and 10). The consistency ratio has been calculated for each judgmental matrix. The values of consistency ratio should ideally be less than 0.1, but considering the objectivity of this case study, it is close to 0.1 for all the matrices.

After discreetly incorporating the priorities of all environmental factors from every class of stakeholder, an overall relative priority has been calculated. Table 11 delivers a distinctive idea of the degree up to which each environmental factor is affected.

Below is Table 12 which gives the environmental score (ES) corresponding to every project action based on the magnitude of impact, the positive/negative nature of impact, permanence, reversibility, and cumulative effect of these actions. Every project action is then assigned a band range (BR). This ES is used in the final matrix (Table 13) as multiplicative subject where the priority of each environmental element in multiplied to the ES of each project action. The ES and BR values are corroborated by various environmental engineers and members of GSPCB.

Table 8 Importance/priorities of environmental impact with respect to local people (CI—0.263; RI—1.49; CR—0.176)

	Soil	Water	Air	Trees/shrubs/grass	Land animals	Fish and sea creature	Noise	Employment/jobs	Tourism	Health	Local priority
Soil	1	1/3	1/5	1/2	1/4	1/5	3	1/6	1/3	1/8	0.0244
Water	3	1	1/3	5	4	6	4	2	5	1/9	0.1162
Air	5	3	1	7	5	4	6	6	4	1/9	0.1758
Trees/shrubs/grass	2	1/5	1/7	1	1/3	1/4	3	1/4	3	1/9	0.0357
Land animals	4	1/4	1/5	3	1	1/3	5	1/5	5	1/9	0.0608
Fish and sea creatures	5	1/6	1/4	4	3	1	4	1/4	3	1/8	0.0688
Noise	1/3	1/4	1/6	1/3	1/5	1/4	1	1/4	1/5	1/7	0.0175
Employment/jobs	6	1/2	1/6	4	5	4	4	1	3	1/2	0.1138
Tourism	3	1/5	1/4	1/3	1/5	1/3	5	1/3	1	1/9	0.0367
Health	8	9	9	9	9	8	7	2	9	1	0.3504
Total	37.33	14.90	11.71	34.17	27.98	24.37	42.00	12.45	33.53	2.45	

Table 9 Importance/priorities of environmental impact with respect to mining company (CI—0.211; RI—1.49; CR—0.142)

	Soil	Water	Air	Trees/shrubs/grass	Land animal	Fish and sea creature	Noise	Employment/jobs	Tourism	Health	Local priority
Soil	1	1/3	1/5	5	1/3	1/3	3	1/8	1/3	1/6	0.0402
Water	3	1	3	3	3	2	6	1/6	3	1/7	0.0958
Air	5	1/3	1	2	2	6	5	1/3	3	1/7	0.0955
Trees/shrubs/grass	1/5	1/3	1/2	1	1/3	1/4	2	1/8	2	1/7	0.0301
Land animals	3	1/3	1/2	3	1	1/3	5	1/6	2	1/7	0.0548
Fish and sea creatures	3	1/2	1/6	4	3	1	3	1/6	4	1/7	0.0706
Noise	1/3	1/6	1/5	1/2	1/5	1/3	1	1/9	1/5	1/9	0.0161
Employment/jobs	8	6	3	8	6	6	9	1	6	1/3	0.2237
Tourism	3	1/3	1/3	1/2	1/2	1/4	5	1/6	1	1/8	0.0398
Health	6	7	7	7	7	7	8	4	8	1	0.3335
Total	32.53	16.33	15.90	34.00	23.37	23.50	47.00	6.36	29.53	2.45	

Results and discussion

Table 14 displays the normalized impact value corresponding to each environmental factor in descending order (top to bottom). The overall result indicates that in general the cumulative impact of the mining actions is maximum on health of the stakeholders. Analyzing further, air is the most severely affected environmental element followed by water, fish, and sea creatures. Out of all the abovementioned parameters, an overall positive impact has been observed on employment/jobs and trees/shrubs/grass. This is because the mining company officials employ the nearby village people for labor work in the mines, hence providing them with employment and wages to support their family. Also, when land is cleared for drilling of more mines, proper care is taken to replant trees and grass within the mining premises as per government rules and regulations. Hence, an overall positive impact has been observed in terms of employment and reforestation.

Table 15 highlights the normalized impact value of the magnitude by which every mining project action is

Table 10 Importance/priorities of environmental impact with respect to GPCB (CI—0.235; RI—1.49; CR—0.157)

	Soil	Water	Air	Trees/shrubs/grass	Land animals	Fish and sea creatures	Noise	Employment/jobs	Tourism	Health	Local priorities
Soil	1	1/2	1/2	1/2	1/4	1/5	2	1/7	1/2	1/9	0.0245
Water	2	1	3	2	4	2	6	1/5	5	1/9	0.0931
Air	2	1/3	1	2	3	6	5	1/7	6	1/9	0.0935
Trees/shrubs/grass	2	1/2	1/2	1	1/3	1/3	3	1/7	4	1/9	0.0435
Land animals	4	1/4	1/3	3	1	1/2	3	1/5	2	1/9	0.0519
Fish and sea creatures	5	1/2	1/6	3	2	1	4	1/4	3	1/9	0.0677
Noise	1/2	1/6	1/5	1/3	1/3	1/4	1	1/9	1/7	1/9	0.0160
Employment/jobs	7	5	7	7	5	4	9	1	5	1/4	0.2038
Tourism	2	1/5	1/6	1/4	1/2	1/3	7	1/5	1	1/4	0.0436
Health	9	9	9	9	9	9	9	4	4	1	0.3623
Total	34.50	17.45	21.87	28.08	25.42	23.62	49.00	6.39	30.64	2.28	

Table 11 Final priorities of different environmental criteria

Environmental Factors	Overall priority
Soil	0.0253
Water	0.1100
Air	0.1533
Trees/shrubs/grass	0.0371
Land animals	0.0585
Fish and sea creatures	0.0686
Noise	0.0171
Employment/jobs	0.1397
Tourism	0.0384
Health	0.3520
Total	1.000

affecting the environment, either in a positive or negative way. The project actions are arranged in descending order (top to bottom) of their normalized magnitude. The order indicates that landfills have the highest contribution towards affecting the environment in a negative manner, followed by drilling. Further, in the list, comes the act of reforestation, which has a positive impact on the environment. Among the above project actions, those having an overall positive impact are results of proper measures being taken and followed by the mining company in order to maintain a sustainable balance between human needs and keeping the environment healthy.

The tables above represent a relative estimate of magnitude of impact on different environmental factors and by different mining project actions. A quantitative analysis highlights those elements having the most

Table 12 Impact quantification and rating by using modified RIAM method

Components	ES	ESN	RB	A1	A2	B1	B2	B3
Impact of								
Land clearance (for mining) on soil	− 14	− 1.30	− B	1	− 2	3	2	2
Land clearance on trees and shrubs	− 18	− 1.67	− B	1	− 3	2	2	2
Land clearance on land animals	−32	− 2.96	− C	2	− 2	3	3	2
Land clearance on health	− 8	−0.74	− A	2	− 1	1	1	2
Erosion control (by plant cultivation) on soil	24	2.22	+ C	1	3	3	2	3
Erosion control on water	6	0.56	+ A	2	1	1	1	1
Erosion control on air	32	2.96	+ C	2	2	3	2	3
Erosion control on trees and shrubs	27	2.50	+ C	1	3	3	3	3
Reforestation on soil	24	2.22	+ C	1	3	3	2	3
Reforestation on water	28	2.59	+ C	2	2	2	2	3
Reforestation on air	14	1.30	+ B	2	1	2	2	3
Reforestation on trees	21	1.94	+ C	1	3	3	2	2
Reforestation on land animals	32	2.96	+ C	2	2	2	3	3
Drilling on soil	− 16	− 1.48	− B	1	− 2	3	3	2
Drilling on water	0	0.00	N	1	0	3	3	2
Drilling on air	− 14	− 1.30	− B	2	− 1	2	3	2
Drilling on noise	− 21	− 1.94	− C	1	− 3	2	3	2
Drilling on employment	− 24	− 2.22	− C	2	− 2	3	1	2
Drilling on tourism	− 6	− 0.56	− A	1	− 1	2	2	2
Drilling on health	− 10	− 0.93	− B	1	− 2	2	1	2
Surface excavation or strip mining on land	− 21	− 1.94	− C	1	− 3	3	2	2
Surface excavation or strip mining on water	− 7	− 0.65	− A	1	− 1	3	3	1
Surface excavation or strip mining on air	− 28	− 2.59	− C	2	− 2	2	3	2
Surface excavation or strip mining on noise	− 7	− 0.65	− A	1	− 1	2	3	2
Surface excavation or strip mining on employment	5	0.46	+ A	1	1	2	1	2

Table 12 (continued)

Components	ES	ESN	RB	A1	A2	B1	B2	B3
Surface excavation or strip mining on tourism	− 6	− 0.56	− A	1	− 1	3	2	1
Surface excavation or strip mining on health	− 6	− 0.56	− A	1	− 1	2	2	2
Rock blasting on land	− 24	− 2.22	− C	1	− 3	3	3	2
Rock blasting on air	− 28	− 2.59	− C	2	− 2	2	3	2
Rock blasting on noise	− 28	− 2.59	− C	2	− 2	2	3	2
Rock blasting on employment	5	0.46	+ A	1	1	2	1	2
Rock blasting on tourism	− 16	− 1.48	− B	1	− 2	3	2	3
Dewatering of underground water reserves on water	− 32	− 2.96	− C	2	− 2	3	3	2
Dewatering of underground water reserves on trees	0	0.00	N	1	0	3	2	1
Crushing on land	− 7	− 0.65	− A	1	− 1	3	3	1
Crushing on air	− 12	− 1.11	− B	2	− 1	2	3	1
Crushing on noise	− 6	− 0.56	− A	1	− 1	2	3	1
Crushing on employment	10	0.93	+ B	1	2	2	1	2
Screening on noise	− 6	− 0.56	− A	1	− 1	2	3	1
Ore enrichment and beneficiation processes on land	0	0.00	N	1	0	3	3	1
Ore enrichment and beneficiation processes on employment	3	0.28	+ A	1	1	1	1	1
Overburden and spoilage transportation on air	0	0.00	N	0	− 1	2	2	3
Overburden and spoilage transportation on employment	10	0.93	+B	1	2	2	1	2
Landfills on land	− 18	− 1.67	− B	1	− 2	3	3	3
Landfills on water	− 32	− 2.96	− C	2	− 2	3	2	3
Landfills on air	− 16	− 1.48	− B	2	− 1	2	3	3
Landfills on land animals	0	0.00	N	1	0	3	3	1
Landfills on fish and sea creatures	− 32	− 2.96	− C	2	− 2	3	2	3
Landfills on employment	5	0.46	+ A	1	1	2	1	2
Landfills on health	− 14	− 1.30	− B	2	− 1	2	2	3

negative and positive effects. The elements having the greatest negative impact should be of high concern. For example, in this study, health is the most severely affected element and mining actions related to landfill are having the most damaging impact. So, for such a result, environmentalists are recommended to first focus on analyzing the impact of mining actions associated with landfill on human health, followed by air, water, and so on. After a reviewing and reforming the process to mitigate the impact of landfill on health, air, water etc., the project action having the second highest negative impact, which is drilling in this study, needs to be analyzed. Impact of drilling on health, air, water etc. (in the order of decreasing negative impact on environmental factors) should be analyzed, and actions should be taken to lower the magnitude of negative impact on the affected environmental factors. The project actions and environmental factors which have an overall positive impact should also be taken into utmost care as it is important to not only maintain a consistent positive impact, but also to increase its value and quality gradually.

Conclusion and suggestions

This new approach to EIA of mining sites in Goa, India, delivers comprehensive results about the ecological, economic, and social effects of mining project actions on various environmental factor and different stakeholders. The existing limitations in the traditional EIA techniques like subjectivity and non-inclusivity of all stakeholders have been fairly eliminated in this newly developed methodology.

Table 13 Total impact by all the project actions on given environmental conditions

Environmental impacts	Soil	Water	Air	Trees/ shrubs/grass	Land animal	Fish and sea creature
Project actions						
A. Land alteration						
Land clearance (for mining)	0.0253 × (−1.3)	–	–	0.0371 × (− 1.67)	0.0585 × (− 2.96)	–
Erosion control (by plant cultivation)	0.0253 × (2.22)	0.11 × (0.56)	0.1533 × (2.96)	0.0371 × (2.5)	–	–
Reforestation (on mined region)	0.0253 × (2.22)	0.11 × (2.59)	0.1533 × (1.3)	0.0371 × (1.94)	0.0585 × (2.96)	–
B. Resource extraction						
Drilling	0.0253 × (− 1.48)	–	0.1533 × (− 1.3)	–	–	–
Surface excavation or strip mining	0.0253 × (− 1.94)	0.11 × (− 0.65)	0.1533 × (− 2.59)	–	–	–
Rock blasting	0.0253 × (− 2.22)	–	0.1533 × (− 2.59)	–	–	–
Dewatering of underground water reserves	–	0.11 × (− 2.96)	–	–	–	–
C. Processing						
Crushing	0.0253 × (− 0.65)	–	0.1533 × − 1.11)	–	–	–
Screening	–	–	–	–	–	–
Ore enrichment and beneficiation processes	–	–	–	–	–	–
Ore transportation	–	–	–	–	–	–
D. Waste dumping and treatment						
Overburden and spoilage transportation	–	–	–	–	–	–
Landfills	0.0253 × (− 1.67)	0.11 × (− 2.96)	0.1533 × (− 1.48)	–	–	0.0686 × (− 2.96)
Total impact on given env. condition	− 0.1219	− 0.3762	− 0.7374	0.1028	0.0000	− 0.2031

Environmental impacts	Air	Land animal	Noise	Employment/jobs	Tourism	Health	Total impact by a project action
Project actions							
A. Land alteration							
Land clearance (for mining)	–	0.0585 × (− 2.96)	–	–	–	0.352 × (− 0.74)	− 0.528
Erosion control (by plant cultivation)	0.1533 × (2.96)	–	–	–	–	–	0.664
Reforestation (on mined region)	0.1533 × (1.3)	0.0585 × (2.96)	–	–	–	–	0.785
B. Resource extraction							
Drilling	0.1533 × (− 1.3)	–	0.0171 × (− 1.94)	0.139 × (− 2.22)	0.0384 × (− 0.56)	0.352 × (− 0.93)	− 0.929
Surface excavation or strip mining	0.1533 × (− 2.59)	–	0.0171 × (− 0.65)	0.139 × (0.46)	0.0384 × (− 0.56)	0.352 × (− 0.56)	− 0.683
Rock blasting	0.1533 × (− 2.59)	–	0.0171 × (− 2.59)	0.139 × (0.46)	0.0384 × (− 1.48)	–	− 0.490
Dewatering of underground water reserves	–	–	–	–	–	–	− 0.326
C. Processing							
Crushing	0.1533 × − 1.11)	–	0.0171 × (− 0.56)	0.139 × (0.93)	–	–	− 0.066

Table 13 (continued)

Environmental impacts	Air	Land animal	Noise	Employment/jobs	Tourism	Health	Total impact by a project action
Screening	–	–	0.0171 × (− 0.56)	–	–	–	− 0.010
Ore enrichment and beneficiation processes	–	–	–	0.139 × (0.28)	–	–	0.039
Ore transportation	–	–	–	–	–	–	
D. Waste dumping and treatment							
Overburden and spoilage transportation	–	–	–	0.139 × (0.93)	–	–	0.130
Landfills	0.1533 × (− 1.48)	–	–	0.139 × (0.46)	–	0.352 × (− 1.3)	− 1.191
Total impact on given env. condition	− 0.7374	0.0000	− 0.1077	0.1816	− 0.0998	− 1.2426	

As there always exists, this possibility that the impact of a project action on a particular environmental attribute is very significant but its priority among the stakeholders might be of low significance. And thus, this newly proposed technique gives us straight and discrete correlations between the individual project actions and their impact on various environmental elements. The final results gave us a clear picture about which environmental factors are negatively affected and which are positively nourished by the mining actions. Also, the final matrix highlights the magnitude of destructive and constructive nature of different mining project actions on different environmental factors. Such discrete and relative results give a more accurate and transparent picture to the environmental engineers and analysts when resolving the issues and problems related to environment and mining.

As it is evident from the results delivered by this new approach, air and water are found to be the most adversely affected among the environment. After a thorough discussion with numerous environmental experts, the authors have come up with few constructive suggestions to minimize the adverse impact of mining actions on these two vital and life-sustaining elements of nature. Given below are few observations and suggestions:

1. Roads need to be broaden up to increase the capacity and ease of transportation. Due to continuous motion of heavy vehicles continuously on the transportation route, roads start to develop cracks which further propagates as the transportation continues. Such coarse roads result in spillage of material resulting to both air pollution and loss of material. Transportation can be made efficient by focusing on the overall design of road connectivity between mining sites and destination point.
2. Inefficient washing of trucks causes the water to mix up with the dust attached to the vehicle. The mixture becomes a semi-solid paste which gets detached from the vehicle during transport and settles on the road. A solution to this can be an additional dry-cleaning process after the washing stage to avoid the semi-solid paste formation on the vehicle.
3. Mines which are not in working conditions become a major source for air pollution. The excavated waste from earth is kept in lumps and no water is sprinkled on these and the deserted mine premises.

Table 14 Normalized impact value on environmental condition

Environmental factors	Normalized impact value
Health	− 1.0000
Air	− 0.5934
Water	− 0.3028
Fish and sea creatures	− 0.1634
Employment/jobs	0.1462
Soil	− 0.0981
Noise	− 0.0867
Trees/shrubs/grass	0.0827
Tourism	− 0.0804
Land animals	0.0000

This results in suspension of small dust particles under the impact of gushes of strong wind. Trees, grass, and plants get covered with fine layers of this suspended dust which blocks the surface pores resulting in a gradual decrease in their rate of photosynthesis thereafter affecting the natural fresh oxygen supply of this planet

4. For idle mining sites, during the rainy season, rain water gets accumulated in the mining pits. At the end of rainy season, the accumulated water becomes home to toxic ions and dust particles. Judicious management of this collected water will be a good step towards sustainable mining.

Table 15 Normalized impact value of mining project actions

Mining project actions	Normalized impact value
Landfill	− 1
Drilling	− 0.77994
Reforestation (on mined region)	0.659521
Surface excavation or strip mining	− 0.57356
Erosion control (by plant cultivation)	0.557753
Land clearance (for mining)	− 0.44373
Rock blasting	− 0.41148
Dewatering of underground water reserves	− 0.27338
Overburden and spoilage transportation	0.109086
Crushing	− 0.05564
Ore enrichment and beneficiation processes	0.032843
Screening	− 0.00804

A few positive activities adopted by the mines for sustainability of the ecosystem are as follows:

1. Mines which are in working conditions are doing plantation over the excavated earth within their premises.
2. The number of trucks per hour has been reduced for smooth flow of traffic from various sources (mines) to a particular destination.
3. Some mines close their work before the ordinary working hours, taking care of the villagers living nearby who demand peaceful environment for their family after 5 pm.
4. When mining resumes after rainy season, the water is pumped out and delivered to the nearby forest areas rather than directing it to water reservoir.

The final environmental impact scores obtained using the proposed method incorporates the opinions of all stakeholders making this new EIA methodology more exhaustive and comprehensive as compared to the existing EIA methods.

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