INDICATOR BASED DECISION MAKING TOOL FOR MINE PIT REHABILITATION

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ABSTRACT

A structured approach based on indicators has been developed as a technical tool to aid the decision making process of mine pit rehabilitation. The tool is a generic one and can be applied universally. The indicators identified and chosen are based on a combination of field experience and wide-ranging discussions with experts in the allied fields. Two-fold decision spectrum with water storage in the mine pit on one hand and backfilling the mine pit with rejects on the other hand has been adopted while choosing indicators. Each of these indicators was assigned ***a weight,*** *and* ***importance ratings*** *for the variables based on the Delphi technique (consensus approach). In Phase I the total indicator score derived by summing the individual indicator scores obtained by multiplication of importance ratings with the corresponding indicator weight is used as decision-making criterion. The phase-I derived decision classes related to aquatic use of the pit lake are further subjected to safety checks in phase-II using three additional safety indicator parameters. The two aquatic use classes of phase-I hence get reclassified into three groups as in phase-I after the safety check. End use options of the rehabilitated mine pit either with water or with backfill have been included as an integral part of the indicators.*

INTRODUCTION

The mining industry has had a number of positive and significant impacts on the economic development of a country. Several negative environmental impacts have also occurred, some directly related to the unique features of mining and others to bad mining practice and poor environmental management. The high volumes of mine rejects combined with land constraints generally compel the miners to back fill mined out pits with rejects.

Mining experts have identified open cast mine pit rehabilitation as one of the key environmental problems that needs to be tackled. The following structured approach has been developed to determine overall preferences among alternative options, as an aid in the decision making process of mine pit rehabilitation. This approach consists of using a set of indicators that refer to various conditions that are necessary for improved decisions.

THE OBJECTIVE

The prime objective of this research is to develop a consensus based decision-making tool for mine pit rehabilitation based on multi-parameter indicators. The indicator tool should provide a simple numerical score to mine managers to decide as whether to backfill the mine pit or use it for water storage or both so that maximum post-fill environmental and socio-economic benefits are derived from the rehabilitation exercise.

METHODOLOGY

In the present context two important factors influence the adoption of an indicator-based tool of decision-making. They are; level of technical knowledge of the user community to adopt complex decision making models, and availability of data required for adopting any other complex models of decision-making.

Therefore it is necessary to adopt a decision making tool that is simple enough to understand and apply using the data that is generally available and yet is capable of making best use of these data in a technically valid and useful manner. The adoption of an index has the added advantage of in principle eliminating and minimizing subjectivity in the ranking process. *An indicator in the present context is a parameter, which influences the decision making process regarding rehabilitation options of an abandoned/exhausted mine pits for a particular use.*

An abandoned mine pit is one where the mining activity has been suspended for the time being due to some or the other reasons despite the lease having the ore reserves of present and future values. On the other hand, an exhausted mine is one where all the ores of present and future economic importance have been mined out and there is no scope for further mining activity.

The various steps followed in the evolution of the present indicator tool include:

i. Identification of all the ***indicators*** influencing the decision making process. This task was achieved through extensive discussions and consultations with the mine managers, experts, academicians etc. The final list of relevant indicators was however arrived at by the panel of experts.

ii. Indicator ***weights:*** Indicator weights depict the relative importance of the indicator to the decision process. After identifying the indicators which can influence the decision making regarding the mine pit rehabilitation, a group of people consisting of geologists, hydrogeologists, environmentalists, students, mining engineers, in-house experts were asked to weigh these indicators in the order of importance to the decision process. The feedbacks from all such interactions were analyzed statistically and the final consensus list of indicators weights was prepared. The most significant indicators have weights of **2** and the least a weight of **1** indicating parameter of less significance in the process of decision-making.

iii. Assigning of ***importance rates*** to indicators using a scale of 1 to 10: Each of the indicators is subdivided into variables according to the specified attributes (as indicated in the last column of the table in the summary page) to determine the relative significance of the variable in question on the decision making process. The importance ratings range between 2.5 and 10. Higher importance rating indicates favors water storage while least is for backfilling.

iv. *Decision criterion:* Is the total sum of the individual indicator scores obtained by multiplication of values of importance ratings with the corresponding indicator weights.

The system presented here allows the user to determine a numeric value called **MPR Index** for any hydro-geophysical setting of an area by using an additive model. This model is an open-ended model allowing for addition and deletion of one or more indicators. However, under normal circumstance present set of indicators should not be deleted and any addition of the indicator would require re-deriving of the weights and the classification table.

INDICATOR DESCRIPTIONS

Indicator 1: *Intensity of water stress condition in the watershed where the mine pit in question is located;* By computing the stage of groundwater development the area can be classified into *non-critical (White), sub-critical (Gray), critical (Black) and most critical (Red).* It is usually much wiser to strike a balance between groundwater extraction and availability at a high level of groundwater heads to avoid adverse impacts on groundwater regime. The extraction rates should be below the long-term natural replenishment rate. In the present study the following scheme has been adopted for assessing the groundwater development status in a mining watershed (**Table-1**). Thus allowing a mine pit, as water buffer storage is rated most important if pit is located in water stressed area.

Table-1: Intensity of water stress condition in the watershed where the mine pit in question is located

Indicator	Weight	Indicator Variables	Importance Rating
Intensity of water stress condition in the water- shed where the mine pit in question is located.	2	*Non-critical (White):* Where the stage of groundwater development is less than equal to 50%	2.5
		Sub-critical (Gray): Where the stage of groundwater development is more than 50% and less than 75%	5
		Critical (Black): Where the stage of groundwater development is more than 75% and less than 100%	7.5
		Most critical (Red): Where the stage of groundwater development is more than 100%, overdraft conditions	10

The stage of groundwater development can be computed by adopting Groundwater Estimation Committee (1997) norms.

Indicator 2: *Hydraulic conductivity of mine pit and the surrounding aquifers;* Mine pit hydrogeology and surrounding aquifer properties, and nature and extent of aquifer(s) play an important role in for water storage in the mine pits. The basic objective of water storage in the pits should be to retain significant quantity of water in the open pit throughout the year while allowing sizable quantity of pit water to percolate into the surrounding aquifers. This situation would allow an overall hydrogeological regeneration and sustainable water availability in the area. If the hydraulic conditions do not permit to meet the above objectives then the pit water storage may not serve its full purpose. **Table-2** provides descriptions of various hydraulic conditions and the corresponding importance ratings for computing the score of this indicator. Thus keeping a mine pit as water buffer storage is rated most important if hydraulic conductivities of the mine pit and the surrounding aquifer is moderate.

Table-2: Hydraulic conductivity of mine pit and the surrounding aquifers

Indicator	Weight	Indicator Variables	Importance Rating
Hydraulic conductivity of mine pit and the surrounding aquifers.	2	Very low conductivity (Kd"5m/day)	5
		Low conductivity (K >5 and < 15m/day)	7.5
		Medium conductivity (K>15 and <40 m/day)	10
		High conductivity (K >40 m/day)	2.5

Note: The hydraulic conductivity K ranges are adopted from DRASTIC model of USEPA (1987) with rounding of values. Very low and very high K values are given low ratings as these situations do not favor sustainable aquifer storages.

Indicator 3: *Potential uses of pit water;* Besides mine Pit Lake serving the needs of local water demands the options of using the pit lake for other economic activities may also be considered in the decision-making. Such socio-economic activities may provide self-employment opportunities leading to better quality life and health through economic gains. These activities may involve tourism, aquaculture, pisciculture, wetland agriculture, water marketing etc. In Table-3 different likely activities are listed along with the relative importance ratings. Thus keeping a mine pit for water storage is rated most important if the pit water is used for domestic water supplies with conventional treatment. The importance increases if there are multiple uses of the pit water.

Table-3: Potential uses of pit water

Indicator	Weight	Indicator Variables	Importance Rating
Potential uses of pit water	2	Domestic water supply and water marketing	10
		Propagation of wild life, fisheries and groundwater recharge	7.5
		Agriculture and related uses	5
		Industrial uses including tourism	2.5

Note: The indicator variable classification is based on ISI (1982) surface water use standards (IS: 2291).

Indicator 4: *Constraints of space for mine waste dumping in the mine buffer zone;* The constraint of availability of sufficient space for disposal of mine rejects in the mine buffer zone is equally important as it involves unproductive large economic investments and environmental implications. Keeping this in mind the following indicator options have been identified **(Table-4)** and importance ratings have been assigned to compute indicator score. Keeping a mine pit for water storage rather than backfilling is rated most important if there are no constraints of space for dumping the mine rejects in the buffer zone with environmental safety.

Table-4: Constraints of space and environment for mine waste dumping in the buffer zone

Indicator	Weight	Indicator Variables	Importance Rating
Constraints of space and environment for mine waste dumping in the buffer zone	2	High constraints	2.5
		Moderate constraints	5
		Low constraints	7.5
		No constraints	10

Indicator 5: *Composition and nature of back filling material;* A decision to back fill the mined out pit should ensure that the final impact of the back filled material will not affect the neighboring intrinsic aquifer properties and groundwater quality. The important parameters that need to be considered are (i) the physical properties of the back-fill matrix like grain size, texture and permeability and (ii) the chemical composition of the matrix as it may adversely affect the water quality if the matrix is chemically unstable and contain toxic chemicals in it. **Table-5** provides detailed information of the importance ratings for different variables. It is therefore evident that the high toxicity levels of backfill material reduce the importance of the backfilling option.

Table-5: Composition and nature of back filling material

Indicator	Weight	Indicator Variables	Importance Rating
Composition and nature of back filling material	2	No toxicity	2.5
		Low toxicity	5
		Medium toxicity	7.5
		High toxicity	10

Indicator 6: *Accessibility of the pit lake to the users;* The necessity of water storage in the abandoned/exhausted mine pit would arise only if there is an indicated depletion or likely depletion of ground and surface water resources in the watershed and the users are in dare need of water to meet their present and future demands. Secondly if Pit Lake is created for its direct use its proximity and all time accessibility to the users is important. **Table-6** provides indicator variables and corresponding importance rating for computing this indicator score. Thus keeping a mine pit for water storage is rated most important if the pit lake is easily accessible round the year and is located close to potential user groups.

Table-6: Accessibility of the Pit Lake to the users

Indicator	Weight	Indicator Variables	Importance Rating
Accessibility of the pit lake to the users	1	Accessible all the time and in proximity	10
		Accessible only during certain periods of the year	7.5
		Can be made accessible	5
		Inaccessible and far away	2.5

Indicator 7: *Likely community uses of back-filled and partially backfilled mine pit;* The likely end uses of the backfilled mine pit area based on local needs of the community should play a role. Under this indicator several end use options can be identified and classified into different categories as shown in the following **Table-7.** Thus backfilling a mine pit rather than keeping it for water storage is rated more important if and only if the backfilled mine pit area has a high potential for different community uses such as agriculture, horticulture, pasture land development, forestry, waste disposal, sports etc.

Table-7: Likely community use of back-filled and partially backfilled mine pit area

Indicator	Weight	Indicator Variables	Importance Rating
Likely community use of back-filled and partially backfilled mine pit area	1	High potential use	2.5
		Medium potential use	5
		Low potential use	7.5
		No potential use	10

COMPUTING OF MINE PIT REHABILITATION INDEX

Each of the seven indicators has a pre-determined fixed weight that reflects its relative importance to rehabilitation decision-making. The **Mine Pit Rehabilitation Index (MPR-Index)** is then obtained by computing the individual indicator scores and summing them as per the following expression:

$$\text{MPR-Index} = \sum_{i=1}^{7} \{(W_i)R_i\} / \sum_{i=1}^{7} W_i \qquad \textbf{...(1)}$$

Where W_i is the weight of the i^{th} indicator and R_i is the importance rating of the i^{th} indicator.

The "**maximum MPR-Index**" is obtained by substituting the maximum importance ratings of the indicators as shown below:

$$\text{Max} = \{(2)*R_1 + (2)*R_2 + (2)*R_3 + (2)*R_4 + (2)*R_5 + (1)*R_6 + (1)*R_7\} / \sum_{i=1}^{7} W_i$$

by substituting the maximum importance rating values in the above expression and dividing by the total weights of the indicators we get

$$= \{(2)*10 + (2)*10 + (2)*10 + (2)*10 + (2)*10 + (1)*10 + (1)*10\}/12$$

$$= 10 \qquad \textbf{...(2)}$$

Similarly,

The "**minimum MPR-Index**" is obtained by substituting the minimum importance ratings of the indicators as shown below:

$$\text{Min} = \{(2)*R_1 + (2)*R_2 + (2)*R_3 + (2)*R_4 + (2)*R_5 + (1)*R6 + (1)*R_7\} / \sum_{i=1}^{7} W_i$$

$$= \{(2)*2.5 + (2)*2.5 + (2)*2.5 + (2)*2.5 + (2)*2.5 + (1)*2.5 + (1)*2.5\}/12$$

$$= 2.5 \qquad \textbf{...(3)}$$

Therefore the minimum and maximum MPR Index varies between 2.5 to 10. The feasibility of a particular mine pit for a specific rehabilitation purpose is assessed based on the magnitude of the MPR Index. In a general way higher MPR-Index betters the feasibility for using the pit for water storage. Like wise lower values of MPR-Index emphasis for backfilling of the pits with mine rejects. The intermediate values dictate combination of both options of backfilling and water storage in the pits.

DECISION CRITERIA

Phase-I: *General Decision:* From *annexure I,* the MPR index can be computed for all the seven parameters. **Table 8** provides the rehabilitation options into three categories.

Table-8: Rehabilitation options; Phase-I (Also refer flowchart)

Sr. No.	MPR-Index	Rehabilitation options
1	^{3} 7.5	Mine pit should be used exclusively for water storage
2	5 to <7.5	Mine pit should be partially backfilled with mine rejects with the provision for water storage
3	< 5	Mine pit should be used exclusively for backfilling with mine rejects

Note of caution: If the MPR-Index indicates middle option but the indicator "composition and nature of the backfill material" is showing very high score (i.e. the backfill material is unsuitable for backfilling) then in such situations caution should be exercised because material of low chemical quality may badly affect the groundwater quality in the neighboring area. Therefore besides using model score, the decision maker should exercise his/her wisdom and make use of the local area experience while making the final decision.

Phase-II: Safety Evaluation for Aquatic Use of Mine Pit

The safety to humans, cattle, wild life and natural environment should therefore be taken into account while deciding storage of large quantity of water in the mine pits. The possible dangers of breaching of the mine pit lakes during the earthquakes and other natural calamities must also be considered.

The classification options of mine pit water storage have safety consequences. In phase-II of the classification water storage options have been subjected safety checks. In order to achieve this three criteria are considered one dealing with the physical safety of the mine pit itself involving slope stability, ground gradients, potential for siltation, vulnerability to natural calamities etc. and the second dealing with the safety aspects arising from the impounded water in the mine pit. This involves parameters of outbreak of waterborne diseases, groundwater contaminations through seeping pit water of poor quality, threat to life and property, water logging of potential agricultural and settlement areas, quicksand formations etc. The third safety parameter is related to capital investment towards making the pit lake safe. However, this third safety check is evaluated in relation to community gains arising from the presence of Pit Lake.

Annexure II provides the weights and rates for the three identified parameters related to safety.

CONCLUSIONS

The MPR-INDEX tool has been developed keeping in mind the technical limitations of the mining community to make best use of this model for decision-making. The indicator variables have been described in a nutshell for ease of reference.

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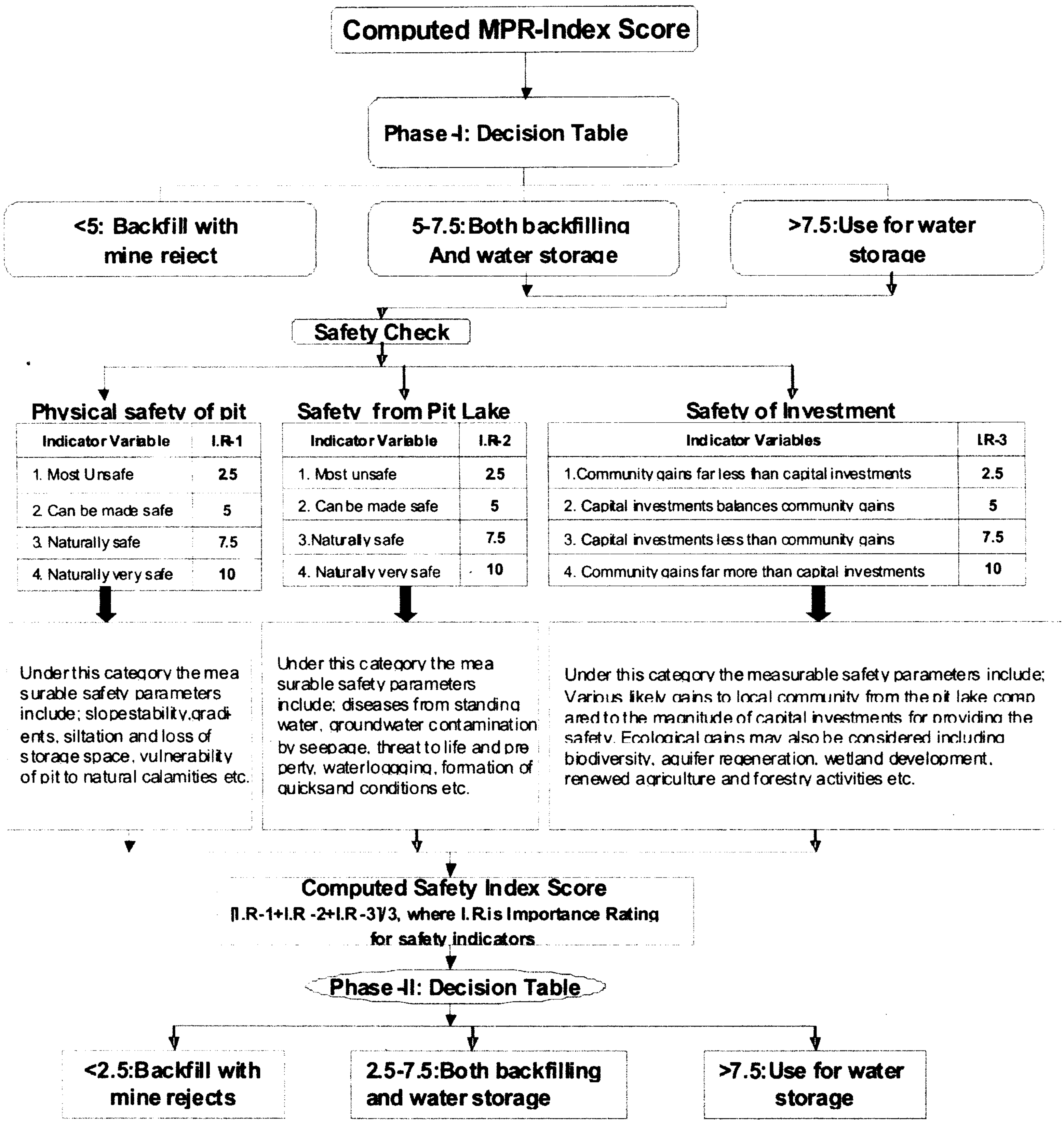

Physical safety of pit

Indicator Variable	I.R-1
1. Most Unsafe	2.5
2. Can be made safe	5
3. Naturally safe	7.5
4. Naturally very safe	10

Safety from Pit Lake

Indicator Variable	I.R-2
1. Most unsafe	2.5
2. Can be made safe	5
3. Naturally safe	7.5
4. Naturally very safe	10

Safety of Investment

Indicator Variables	I.R-3
1. Community gains far less than capital investments	2.5
2. Capital investments balances community gains	5
3. Capital investments less than community gains	7.5
4. Community gains far more than capital investments	10

DECISION MAKING FLOW CHART REGARDING MINE PIT REHABILITATION

Annexure-1

Computation of *MPR-Index*; Phase-I Evaluation

S.no.	Indicator	Weight	Range of importance ratings				Range of scores (weight*Imp rating)			
			Min	In between		Max	Min	In between		Max
1	Intensity of water stress in the area where the pit in question is located	2	2.5	5	7.5	10	5	10	15	20
2	Hydraulic conductivity of the mine pit and the surrounding aquifers	2	2.5	5	7.5	10	5	10	15	20
3	Potential value added from the pit water	2	2.5	5	7.5	10	5	10	15	20
4	Constraints of space for mine waste dumping in the buffer zone	2	2.5	5	7.5	10	5	10	15	20
5	Composition and nature of backfill material	2	2.5	5	7.5	10	5	10	15	20
6	Accessibility of pit lake to users	1	2.5	5	7.5	10	2.5	5	7.5	10
7	Likely community use of the backfilled and partially backfilled mine pit area	1	2.5	5	7.5	10	2.5	5	7.5	10
				Total score (T.S)			30	60	90	120
				MPR-Index=T.S/12			2.5	5	7.5	10

Annexure-2

Computation of *Safety-Index*; Phase-II, Evaluation

S.no.	Indicator	Weight	Range of importance ratings				Range of scores (weight*Imp. rating)			
			Minimum	In between		Maximum	Min	In between		Max
1	Physical safety of the pit	3	2.5	5	7.5	10	7.5	15	22.5	30
2	Safety from the pit lake	3	2.5	5	7.5	10	7.5	15	22.5	30
3	Safety of investment	3	2.5	5	7.5	10	7.5	15	22.5	30
				Total Safety Score (T.S.S.)			22.5	45	67.5	90
				Safety-Index=T.S.S./9			2.5	5	7.5	10