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Techno-Economic Aspect of Dimension Stone Mining In Chitral, Khyber Pakhtunkhwa

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Abstract: In developing countries like Pakistan which are bestowed by nature with huge deposits of minerals are largely run by small scale mining, and mostly result in wasting precious deposits by adopting conventional mining methods neglecting the health and safety aspect. This research endeavour analyzed the techno-economic aspects of various mining methods for extraction of dimension stone in chitral region and proposed a suitable mining method based on these aspects. Seven different deposits of dimension stone were taken as case studies to evaluate the proposed approach. For each deposit, twelve criteria were compared as per the procedure of Analytical Hierarchy Process (AHP). These aspects are quality, quantity, mining cost, infrastructure, mining and processing losses, mining time, equipment's performance, skilled labour, work capacity to fragment the deposits, benching and safety. Whereas, the alternatives are mechanized mining, material expansion/controlled blasting and conventional mining. The criteria were compared and methods suitable for each deposit were suggested.

Keywords: Dimension stone, small scale mining, marble quarrying, dimension stone, analytical hierarchy process.

Introduction

Dimension stone is ornamental stone and mostly used in construction for decoration purposes. Despite enormous resources and maneuvers for more than half a century, the dimension stone industry of Pakistan has failed to develop to the anticipated level. The delay is primarily due to multifaceted reasons. In today's age of advancing innovative technologies, Pakistan's dimension stone sector is still in its infancy (Asrarullah & Hussain, 1985). The province of Khyber Pakhtunkhwa (KP) and Baluchistan have a major share of dimension stone reserves. Major dimension stones reserves of the country are located in KP (Raza & Jadoon, 2021). Balochistan's onyx marble and Sindh premium pink granite are in great demand in the stone market (DGMM-Baluchistan, 1999). Previously estimated at 166 billion tons, and the current estimate of marble and granite reserves in Pakistan is around 297 billion tons. However, the marble and granite reserves of Pakistan have not been fully and systematically explored. Over 85% of these reserves are believed to be located in Khyber Pakhtunkhwa (KP) province and the former Federally Administered Tribal Areas (FATA). Balochistan and Sind also have significant reserves (SMEDA). On the export side, 6176 tons of rough stones, 3976 tons of intermediate products (slabs) and finished products i-e tiles of 3335 tons were exported. The cumulative worth of these exports was assessed at US$4.9 million, plus US$11.1 million worth of marble and onyx handicrafts. Domestic consumption remained at 1.37 million tonnes or 97% of total mined out resources. Details of estimated reserves are given in Table. 1 (DGMM-Baluchistan, 1999) (Raza & Jadoon, 2021)

In the district Chitral, marble is quarried using traditional methods, where high working faces are developed and holes are drilled at the toe to place explosives. This marble mining practice is not good for the deposit nor for the social environment, because by this method of extraction most of the deposit is wasted into small pieces producing cracks in the extracted blocks adversely affecting the entire deposit. In addition, the practice of extraction of blocks by means of blasting also has negative impacts on the environment of the region and the social life of the inhabitants. The blasting also results in environmental pollution like; noise factors, etc. Detailed exploration of the deposit on scientific grounds will aid the investors to identify fissures, fractures, discontinuities, textures, colors as well as physical and aesthetic characteristics of deposits, while scientific exploitation will cover socio-e, ground vibrations, dust, toxic gases, etc. This type of conventional mining is not sustainable due lack of consideration of basic procedure, i.e. scientific exploration and development, socio-economic and environmental conomicand environmental factors in quarries (Khan & Reinmund, 1981).

Mining carried out in a sustainable way can have an important role to reduce poverty through economic development (Mosch, 2011). For the long-standing sustainability of the dimension stone sector, it is essential for producers to invest in the upgrading of local infrastructure such as sanitation, water supply, education, employment of local residents and encouraging micro-enterprises in the region (Cronjé & Chenga, 2009). This requires alteration of socio-economic as well as environmental objectives that can be realizedby use of scientific mining methods (Maponga & Munyanduri, 2009). In addition, the sustainable exploitation of dimension stone deposits

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rests on the standard size of the dimension stone blocks acceptable in the market and must be free of micro-cracks and joints (I. Ashmole, 2008).

In district Chitral, marble is quarried using traditional mining techniques where explosives are used for breakage of rocks thereby producing irregular blocks. This type of mining not only destroys valuable mineral resources but also causes numerous environmental and socio-economic problems. However, greater mechanization, i.e. latest technology for dimension stone can enhance the life of reserves by reducing the excessive waste and improving heaslth and safety. In this connection, the federal government has developed one quarry under the umbrella of Paksitan Stone Development Corporation (PASDEC) at village Pacheri Tehsil Drosh. The quarry has been developed by using a scientific quarrying system for extraction of geometric blocks in various benches. Modern mining/cutting machinery like wire saw, chain saw, DTH and other relevant machinery has been used in the quarry. Other potential deposits can also be developed in the same pattern using scientific mining methods and latest technology used in the modern quarrying system.

Another quarry in Parwak Tehsil Mastuj village was developed scientifically using chain saws and wire saws but at the same time this quarry was barely productive due to micro cracks in the deposit. The problem arised due to a lack of previous research on the deposit and poor planning before starting exploitation operations. Therefore, it is very important to conduct proper research on the deposit before starting mining operations (Mancini, 2011).

Table.1: Marble and granite reserves in Pakistan.

Locality	Reserves in Million Tons	
	Marble	Granite
KPK	2,900	4500
Baluchistan	2.2	-
Sindh	N.A	N.A
Punjab	-	-
Northern Areas	N.A	4140
FATA	0.1	-
Total	2,902.3	8,640

Table.2 Ranking Scale/Scaling Weight (Bayazit, 2005).

Rank	Description		Inverse Rank	Description	
1	i = j	equal significance	1	i = j	equal significance
3	i> j	i is a little more significant than j	1/3	i< j	i is a little less significant than j
5	i>> j	i is more significant than j	1/5	i<< j	i is less significant than j
7	i>>> j	i is much more significant than j	1/7	i<<< j	i is much less significant than j
9	i>>>> j	i is hugely more significant than j	1/9	i<<<< j	i is hugely less significant than j
Note: 2,4,6,8 can be used to indicate in-between values (same for 1/2, 1/4, 1/6, 1/8)					

Each criteria has its own influence in suggesting the most suitable mining method. Table. 2 shows the legend for ranking scale or scaling weight. Description of each criteria is given in Table. 3.

Table.3 Criterion description.

S.No.	Criterion	Description
1	Quality	Quality
2	Quantity	Quantity
3	I	Infrastructure
4	MC	Mining Costs
5	ML	Mining Losses
6	PL	Processing Losses
7	MT	Mining Time
8	EP	Equipment Performance
9	WCCD	Working Capacity in Cracked Deposit
10	SL	Skilled Labor
11	S	Safety
12	B	Benching

These criteria will introduce multi-factor optimization to determine the most appropriate mining method for commercial sized dimension stone blocks.

1. Case Study

For the case study, we have selected seven different marble deposits in district Chitral. The area hosts a large number of marble resources of diverse variety and color. Some of these deposits have been developed whereas the remaining require detailed exploration and sampling. The marble quarries have been developed by traditional methods, i.e. drill and blast. Due to this obsolete mining technique, most valuable deposits are wasted and the environment is polluted causing severe consequences for the inhabitants. Therefore, great care is required to avoid and prevent this reckless depletion of resources and harm to the environment. Also, mineral resources are non-renewable, therefore, the need for mechanization is increasing day by day. In this research, the Analytical Hierarchy process is used to compare different criteria for each deposit to select the best suitable mining technique for a particular marble deposit in the selected region.

1.1 Case-I (Gahrait-I)

1.1.1 Location and Accessibility

Location of the case-I site is on the shoulder of main Dir-Chitral Highway. It can be accessed by travelling 28 km south of chitral on the highway. The site is accessible for easy transportaion of materials and machinery. Channels supply water to neighboring villages and power transmission lines cross the deposits.

1.1.2 Geological Data

The deposit is lenticular, having attractive white color and a substantial slope. Deposits are large with some color variations.

1.1.3 Mining Method

The deposit was excavated by the age-old drill and blast method, which created a staggering amount of waste. There is an urgent need to adopt the latest mining technologies to reduce the waste of non-renewable materials. To this end, the twelve deposit criteria are compared according to the Analytical Hierarchy Process in order to propose the most suitable mining method for the deposit.

Table.4 **Error! No text of specified style in document.**Pair-wise Comparison of Deposit Conditions.

	Quality	Quantity	I	MC	ML	PL	MT	EP	WCCD	SL	S	B
Quality	1 / 1	2/ 1	2/1	1/1	1/7	1/3	1/3	5/1	1/2	5/1	3/1	5/1
Quantity	1/2	1 / 1	2/1	3/1	1/7	1/3	1/3	5/1	3/1	3/1	3/1	5/1
I	1/2	1/2	1/1	1/2	1/3	1/2	1/3	3/1	1/1	3/1	1/1	3/1
MC	1/1	1/3	2/1	1/1	1/3	1/1	3/1	5/1	5/1	3/1	2/1	3/1
ML	7/1	7/1	3/1	3/1	1/1	3/1	3/1	5/1	5/1	3/1	2/1	3/1
PL	3/1	3/1	2/1	1/1	1/3	1/1	2/1	2/1	2/1	2/1	2/1	2/1
MT	3/1	3/1	3/1	1/3	1/3	1/2	1/1	2/1	1/2	3/1	1/1	2/1
EP	1/5	1/5	1/3	1/5	1/5	1/2	2/1	1/1	1/2	1/1	1/2	2/1
WCCD	2/1	1/3	1/1	1/5	1/5	1/2	2/1	2/1	1 / 1	2/1	2/1	1/1
SL	1/5	1/3	1/3	1/3	1/3	1/2	1/3	1/1	1/2	1/1	1/1	2/1
S	1/3	1/3	1/1	1/2	1/2	1/2	1/1	2/1	1/2	1/1	1/1	1/1
B	1/5	1/5	1/3	1/3	1/3	1/2	1/2	1/2	1/1	1/2	1/1	1/1

The matrix given in Table. 4 is solved by AHP and eigenvector for each criterion is obtained. Similarly, radar chart of each criterion is also plotted. Eigenvector values are given in Table 5 and radar chart of each criterion is shown in Figure 1.

Table 5 Eigenvector values of each criterion.

Criterion	Sum of Rows	Eigenvector
Quality	299.6016	0.0901808
Quantity	298.5305	0.0898584
I	177.7646	0.0535076
MC	361.9495	0.1089477
ML	814.1012	0.2450464
PL	373.0918	0.1123015
MT	315.9886	0.0951133
EP	120.7511	0.0363464
WCCD	210.948	0.0634958
SL	105.4768	0.0317488
S	145.9445	0.0439297
B	98.08518	0.0295239
Total	3322.233	1

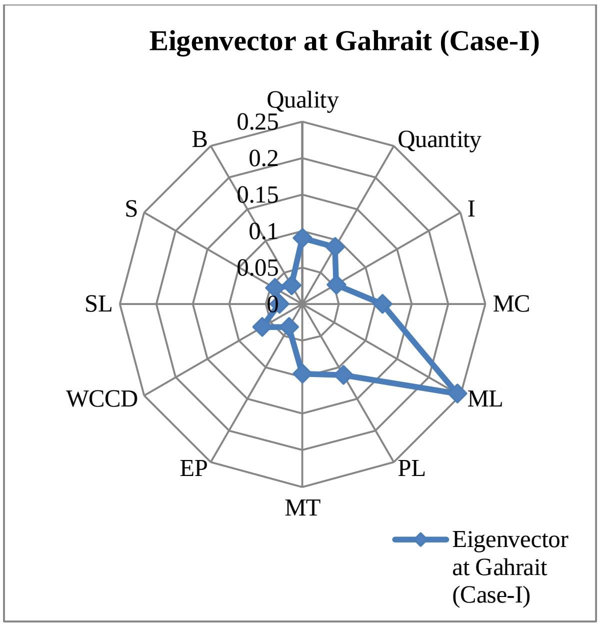

Fig. 1 Radar Chart of Each Criterion.

Once we have values of eigenvector, we will calculate eigen value (λ_{max}) in order to find consistency index by the formula $CI=\frac{\lambda max-n}{n-1}$. Similarly, consistency ratio is also determined by using the formula; $CR=\frac{CI}{RI}$, where CI is the consistency index and RI is the random sconsistency index. The values of random consistency index RI, has been proposed by Prof. Saatyfor different matrices (Teknono, 2006).

In the present case (Gehrait-I), the values of eigen values, consistency ratio and consistency index are calculated respectively as: λ_{max} = 14.07639, CR = 0.127543 and CI = 0.188762923.

The procedure mentioned above is repeated for each criterion and values of eigenvector, λ_{max}, CR and CI are calculated.

Table 6 Eigenvector values of each criterion for different Alternatives.

	Quality	Quantity	I	MC	ML	PL	MT	EP	WCCD	SL	S	B
MM	0.256	0.186	0.256	0.102	0.653	0.653	0.060	0.197	0.069	0.134	0.653	0.562
EM	0.640	0.735	0.640	0.256	0.276	0.276	0.211	0.711	0.277	0.304	0.277	0.351
CM	0.102	0.078	0.102	0.640	0.069	0.069	0.727	0.091	0.653	0.560	0.069	0.086

The eigenvectors are calculted by solving a 3x3 matrix of alternatives for each criterionand are shown in Table. 6. Final weights of the alternative with the highest rank is determined by multiplying the matrix above by the eigenvectors calculated for the twelve criteria (Table 7).

Table 7 Final Weight for the Highest Ranked Alternative.

Final Weight for the Highest Ranked Alternative	
MM	0.365385
EM	0.380782
CM	0.253834

In the selected deposit i-e Gahrait-1, the alternative/mining method of using expansion material is the most suitable method as it has the highest final weight as shown in Table. 7 above.

All other six case studies i.e.Gahrait-II, Gahrait-III, Pachili, Shidi-I, Shidi-II and Parwak are studied and analyzed in the same pattern mentioned above and finding of each case/deposit is given as under:

In **Case-I,**quality of the marble is good but size of the deposit is comparatively small. The best approach for this deposit in terms of quantity and equipment performance is expansion material/controlled blasting. Also, regarding mining and processing losses, appropriate mining methods are mining time-wise and mechanized mining methods. Although equipment performance and the mining cost in cracked deposits favours conventional mining, but expansion materials are of greater importance after mechanized mining in certain criteria. The overall results therefore suggest mining by using expansion material for this deposit.

In **Case-II,**infrastructure, quantity, performance of equipment and quality favours the use of expansion material. Mining time, mining cost and working capacity of the fragmented deposit favored traditional mining, whereas mining and processing losses, benching and safety favored mechanized mining, but the overall end result indicated that the best suitable mining method for this deposit is the use of expansion material/controlled blasting.

In **Case-III**, the infrastructure, quality, quantity,andequipment's performance favors mechanized mining methods. Thoughtraditional mining is of greater importance in terms of mining time and mining losses, the end result supports mechanized mining.

In **Case-IV**, the deposit is dipping at a steep angle, but the majority of the deposit criteria are apt for mechanized mining, so mechanized mining is the best suitable alternative for this deposit.

In **Case-V,** the deposit's infrastructure has very less value in favor of mechanized mining, however, the majority of other criteria show addedimportance in favor of this alternative.

In **Case-VI,** most of the criteria including infrastructure are not conducive to conventional and mechanized mining alternatives, therefore, expansion materialis the appropriate alternative for this deposit.

In **Case-VII,** with respect to color, the deposit is attractive as it is white but severely cracked. Though the quarry was developed through mechanized mining, because of a large number of cracks, mechanized mining methods in this area remained unsuccessful. The expanded material/controlled mining method is appropriate for this deposit because most of the criteria are favoring it.

The findings of this study are also validated by another research carried out by Rehman. Z.U. 2018 et. al. which investigated different Mining methods for extraction of dimension stone (Granite) in district Manshera. The study focused on the most feasible mining technique to minimize losses, get higher recoveries, and ultimately maximize higher returns. The research concluded that wire saw cutting technique is best suitable for granite mining followed by expansion material technique (Rehman, 2018).

Conclusion

The results of the study showed that conventional mining methods were not appropriate for any of the seven deposits due to their higher mining and processing losses, although they had lower mining costs. Additionally, due to uncontrolled blasting in conventional mining, microcracks and macrocracks can be generated in the blasted material as well as in unblastedrock deposits. Furthermore, regular/geometric blocks cannot be obtained by conventional mining techniques, which is also the main disadvantage of this method. Traditional mining methods are causing health and environmental concerns and are also dangerous for workers and residents of the mining areas. Furthermore, the developing of a benching system by this method is also very challenging. Analysis of different criteria for all deposits by AHP method conclude that the best suitable alternative for case-I, case-II, case-VI and case-VII is the use of expansion materialor controlled blast extraction, whereas the most suitable extraction method for the remaining three cases is mechanized mining method.

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