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# Sustainability Analysis of Marble Sector in Buner

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**Abstract:** Marble is an ornamental stone, extremely popular for use as architectural and sculptural purposes. Non-renewable marble resources in Khyber Pakhtunkhwa (KP), Pakistan are mostly mined by conventional mining methods (producing irregular shaped blocks) instead of using mechanized mining producing regular shaped blocks. Conventional mining methods are more economical but are less environment friendly due to more quantity of waste produced. While, mechanized marble mining has a better recovery, reduces mining cost (processing and transportation) and is less environmentally hazardous. In this study a situation and sustainability analysis of marble mining operations at Buner, the most productive marble mining cluster in KP, Pakistan, is carried out. Buner has about 1.4 billion tons of marble resources and contributes around 51 percent of total country's marble production. Analytical Hierarchy Process (AHP) is used on the basis of key sustainability factors (economic, technical, social, environmental and safety) for selection of most sustainable mining methods. The analysis revealed that conventional mining is least sustainable and produces maximum waste, cracks, irregular shaped blocks, high working faces, back break, rock falls and accidents. It was concluded and recommended that these conventional mining methods should be replaced with the more sustainable mining methods i.e. semi-mechanized (controlled blasting / expansion material) at sunny grey and get black marble deposits and mechanized mining (rope cutting) at Bampokha No.1 and Chagharzai white marble deposits.

**Keywords:** Sustainability, marble mining, AHP, Buner.

## Introduction

Marble resources of Khyber Pakhtunkhwa are around 2900 million tons (Muhammad, et al. 2014). Major occurrences of marble in KP and Federally Administered Tribal Areas (FATA) are particularly in Buner, Mardan, Nowshera, Chitral, Swabi districts and in Mohmand, Bajaur and Khyber agencies (Asrarullah and Ahmad 1985). These Major occurrences identified in the province are Asrarullah and Ahmad (1985).

1. *Buner marble belt* in the north central part of the province (Buner and Mardan) having geological resources of 1400 million tons
2. *Chitral marble deposits* in the northern extreme of the province having potential of more than 1000 million tons.
3. *Shangla par (Swat) marble* occurrences are more than 500 million tons.
4. *Swabi marble deposits* are about 200 million tons.
5. *Malakand marble* deposits are about 200 million tons.
6. *Nowshera pink marble* of limited extension, occurring as a hillock in the east central part of the province, having an estimated resource of about 100 million tons.

There are about 2000 quarries and 1500 processing plants in KP and FATA. These units produce around 100 million sq. feet of marble and granite every year (Mahmood et al., 2011). A model marble quarry is shown in Figure 1. Marble quarries and processing industries have an impact on the environment. This is one of the challenges for the mining sector and a sustainable development of marble industry is of vital importance (Hilson and Murck, 2000). The environmental impact depends on the surroundings and location of the marble deposits. Proper measures and strategies need to be adopted and implemented for effective reclamation and reduced negative environmental impacts (Ashmole and Motloung, 2008).

The challenges for marble industry stakeholders, i.e. governments, mining industry and the general public, are how to balance the techno-economic, socio-environmental and safety aspects in a way that gives maximum benefit and reduces losses under the preview of sustainable development (Worrall, et al. 2009). There is a need to have a sustainable development plan for marble resources.

## Background

Brundtland (1987) defined Sustainable Development as *"plan that meets the need of present without compromising the ability of future generation to meet their needs"*. Sahao (2013) proposed sustainability model for general small scale mining businesses. His sustainability model is based on scenario analysis and case studies. According to Sahaoa sustainable model must have three significant components, i.e. techno-economic, social and environmental, relating sustainable development as presented in Figure 2. He

Fig. 1 Sunny grey marble quarry in Bampokha, Buner.

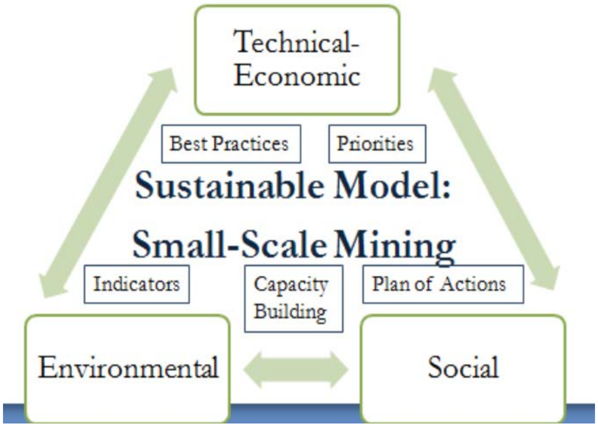


Fig. 2 Major Sustainable Development Components (Sahao 2013)

also explained by the linkages between these major components and the presence of sub-components like best practices, priorities, indicators, capacity building and plan of action.

The concept of Degree of Sustainable Development of Mineral Resources (DSDMR) was proposed by Jing (2005). He considered technology and capital factors in his concept of sustainable development model. DSDMR's conceptual model is expressed as: $DSDMR = f(u_1 , u_2)$

$$u_1 = (u_{11} , u_{12} , u_{13} , u_{14} , u_{15} )$$

$$u_2 = (u_{21} , u_{22} , u_{23} , u_{24} , u_{25} )$$

Where, $u_1$ is the degree of development and $u_2$ is the degree of coordination. Similarly $u_{11}$ is a condition in terms of development degree, $u_{12}$ indicated benefits and economic development, $u_{13}$ indicated quality of life and social development, $u_{14}$ indicates environmental impacts and $u_{15}$ indicates intelligence level. Similarly, $u_{21}$ representsconversion efficiency of resources, coordination degree of economy is represented by $u_{22}$ and $u_{23}$, $u_{24}$ and $u_{25}$ represents society, environments and intelligence respectively. Degree of coordination represents the ability of subsystem factors to contribute to human development by appropriate interconnection and interaction (Yu, et al. 2005).

Daniel et al (2011) proposed sustainable development principles for the waste disposal. This waste disposal is one of the major requirements of mineral industries and mining. He concluded that industries should look for the sustainable development principles and long-term waste disposal plans instead of short term.

## Materials and Methods

The research methodology is presented in Figure 3. The marble quarries of Buner were selected to assess the sustainability of ongoing mining operations. Data were collected through field visits, site investigation, and focused group discussions with various stake holders including lease holders, mining engineers and supervisors working at multiple marble quarries in Buner. Also, details of leases, production data, accidents record and other pertinent information was gathered from directorate of mines and minerals office in Buner. Economic, social, environmental, technical and safety aspects were analyzed through various case studies. Based on the collected qualitative and quantitative data, sustainability analysis of marble mining operations was carried out using AHP.

AHP is a multi-criteria decision support tool. It is generally used for the selection of best alternative. Three alternatives and five criteria were selected (Table. 1 and 2). Similarly, factors and sub-factors considered for the application of AHP are presented in Table 3. Based on their importance ranking is assigned, using a ranking matrix presented in Table 4 and to compare the importance of each criterion with respect to others. Priorities are established among all the elements in the hierarchy and pair-wise preference comparison and normalized matrix is created, as presented in Table 5).

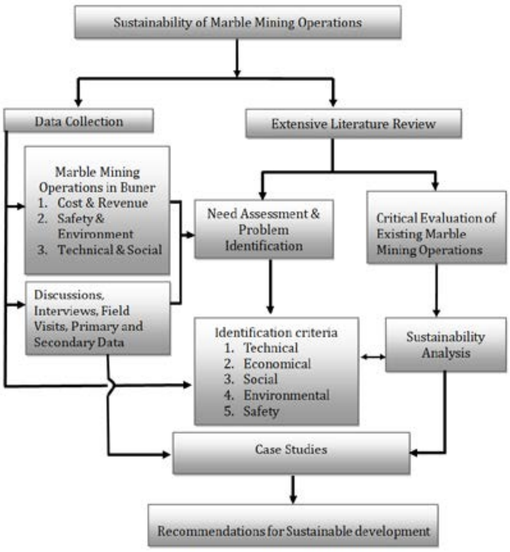


Fig. 3 Research methodology

Table 1 Description of alternatives.

| S. No. | Alternative | Description |
|---|---|---|
| 1 | MMM | *Modern Mechanized Mining Methods,*<br>Rope Cutting& Chain Saw |
| 2 | SMM | *Semi-Mechanized Mining Methods,*<br>Expansion Material |
| 3 | CMM | *Conventional Mining Methods*<br>Drilling and Blasting |

Table 2 Description of criteria.

| S. No. | Criterion | Description |
|---|---|---|
| 1 | Ec | Economic Factors |
| 2 | Tech | Technical Considerations |
| 3 | So | Social Aspects |
| 4 | En | Environmental Concerns |
| 5 | S | Safety Features |

Hierarchical structure of AHP for the selection of most sustainable marble mining method is presented in Figure 4**.**Key steps followed are as follows:

***Step – I*:** Identification of key sustainability factors and sub-factors for marble mining operations in Buner, i.e. Economic, Environment, Social, Technical and Safety.

***Step – II:*** Selection of AHP for analysis of key sustainability factors and sub-factors.

***Step – III:*** Identification of mining techniques, used for dimension stone mining operations, as three alternatives.

***Step – IV:*** Decompose the problem into hierarchy.

Table 3. Factors and associated sub-factors relating sustainability analysis of marble mining operations.

| Factors | Sub Factors (Governance) | Sub Factors (Operations) |
|---|---|---|
| Economic Factors | 1. Excise Duty<br>2. Royalties<br>3. Leases and Licensing<br>4. Production | 1. Production<br>2. Revenues |
| Technical Considerations | 1. Scientific extraction of marble resources<br>2. Technical and Skilled People<br>3. Machinery Pool through Pakistan Stone Development Company (PASDEC)<br>4. Rental Machinery through World Bank funding<br>5. Rock Mining Institute (Proposed by PASDEC) | 1. Mining Methods<br>a. Modern Mining Techniques<br>b. Controlled Blasting / Expansion Material<br>c. Conventional Mining through Drilling / Blasting<br>2. Supportive Industry |
| Societal Aspects | 1. Employment Opportunities<br>2. Surface Rent<br>3. Scholarships for labour employed in mines<br>4. Infrastructure<br>5. Dowry Grant for Miner's Families | 1. Engaging Local people in Mining activities<br>2. Employment Opportunities<br>3. Hotels and other minor business |
| Environmental Concerns | 1. Natural resources conservation<br>2. Land degradation<br>3. Resource Depletion<br>4. Wildlife | 1. Production of waste<br>2. Noise Pollution<br>3. Air Pollution |
| Safety Features | 1. Safety trainings<br>2. Accidents<br>3. Compensation to deceased family members<br>4. Dispensaries<br>5. Ambulance Service for Labour<br>6. Traffic congestion<br>7. Road safety | 1. First Aid<br>2. Personal protective equipment<br>3. Compensation for mine workers on minor, serious and fatal accidents |

Table 4. Ranking Scale Description (Metin, 2013).

| Rank | Description of ranking / importance | | Inverse Rank | Description of ranking / importance | |
|---|---|---|---|---|---|
| 1 | i = j | Equal Importance of i and j | 1 | i = j | equal Importance |
| 3 | i > j | i has little more importance than j | 1/3 | i < j | i has a little less importance than j |
| 5 | i >> j | i has more importance than j | 1/5 | i << j | i has less importance than j |
| 7 | i >>> j | i has much more importance than j | 1/7 | i <<< j | i has much less importance than j |
| 9 | i >>>> j | i has hugely more importance than j | 1/9 | i <<<< j | i has hugely less importance than j |
| ***Note:*** 2,4,6,8 can also be used to indicate the in-between values (similar for 1/2, 1/4, 1/6, 1/8) | | | | | |

Table 5. Pair-wise preference comparison and normalized matrix for AHP (Metin ERSOY, 2013).

| | A | B | C | D | E | F | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | i | j<br>Criteria Scores (Pair-wise Preference Comparison) | | | | | Normalized Matrix | | | |
| | | Ec | Tech | So | En | S | Ec | Tech | So | En | S |
| 1 | **Ec** | 1 | $= 1/a$ | $= 1/b$ | $= 1/c$ | $= 1/d$ | $= 1/k$ | $= 1/a \times 1/$ | $= 1/b \times 1/m$ | $= 1/c \times 1/n$ | $= 1/d \times 1/o$ |
| 2 | **Tech** | *a* | 1 | $= 1/e$ | $= 1/f$ | $= 1/g$ | $= a/k$ | $= 1/l$ | $= 1/e \times 1/m$ | $= 1/f \times 1/n$ | $= 1/g \times 1/o$ |
| 3 | **So** | *b* | *E* | *1* | $= 1/h$ | $= 1/i$ | $= b/k$ | $= e/l$ | $= 1/m$ | $= 1/h \times 1/n$ | $= 1/i \times 1/o$ |
| 4 | **En** | *c* | *F* | *H* | 1 | $= 1/j$ | $= c/k$ | $= f/l$ | $= h/m$ | $= 1/n$ | $= 1/j \times 1/o$ |
| 5 | **S** | *d* | *G* | *I* | *J* | 1 | $= d/k$ | $= g/l$ | $= i/m$ | $= j/m$ | $= 1/o$ |
| 6 | ***Sum*** | *k* | *L* | *M* | *N* | *o* | | | | | |

***Step – V:*** Quantification of key sustainability factors by giving them relative weight over the other.

***Step – VI:*** Generating pair-wise comparison matrix of sustainability factor based on judgment values using collected data.

***Step – VII:*** Generating normalized matrix by dividing each values of column element of pair-wise comparison matrix, created in the previous step, by the sum of that column.

***Step – VIII:*** Calculating priority matrix from the normalized matrix by averaging every element of its each row.

***Step – IX:*** Calculate Consistency Ratio (CR).This is used to measure and check the consistency of judgments relative to purely random judgments.

***Step – X:*** Quantification of alternatives through relative weight compared to the other alternatives for each factor (criteria). This process from step V to step VIII is repeated for each alternative i.e. MMM, SMM and CMM, with respect to each factor. As a result, five matrixes of order 3×3are obtained.

***Step – XI:*** Determining the relative weight for each alternative with respect to each criterion. Calculating the desirability value for each alternative.

***Step – XII:*** Final step is determining the most sustainable mining method. Calculated by multiplying the relative weight of factors of alternatives with the priority matrix of factors (Gupta, Jayal and Jawahir 2010).

AHP is a non-experimental, qualitative and quantitative research methodology. A sustainability analysis of existing marble mining operations in Buner is carried out using AHP. Based on the findings of this research endeavor, recommendations are proposed for the improvement and more sustainable mining of dimension stones in District Buner.

**Case Study**

Multiple varieties of marble are found at various locations in K.P. and especially in Buner. In this endeavor, data was collected from marble deposits of Buner. Four different marble deposits were selected as case studies. These include:

***Bampokha, Sunny Grey (Case Study – I)***: This is the most productive area of marble mining in Buner. The deposit is massive and thick bedded having widely spaced joints and fractures. Large size block can be extracted. Sunny grey is the most common, widely distributed and extracted marble in the locality. A quarry and commercial slabs of Bampokha sunny grey marble is presented in Figure 5 and 6 respectively.

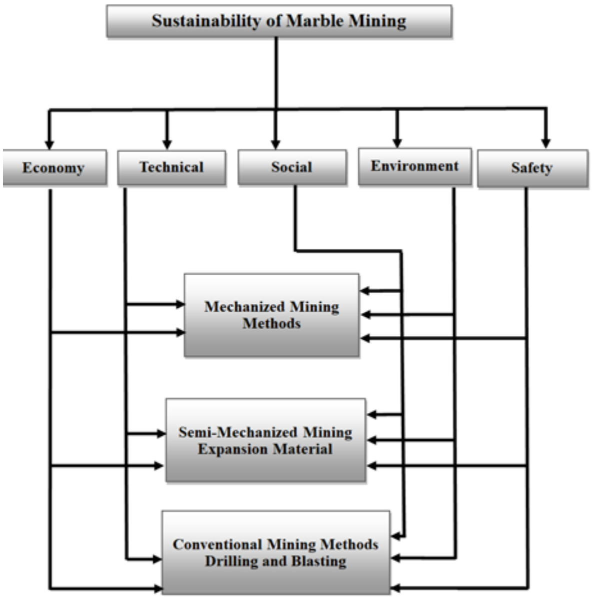


Fig. 4 Hierarchical structure of AHP for the selection of most sustainable marble mining method

***Bampokha 1 (Case Study – II):*** This is one of the best, export quality marble of Buner. It is white in color with small black spots or lines. The quarry consists of three benches and presently extraction of blocks is carried out with mechanized mining method (diamond rope cutting) as shown in Figure 7 and 8. Typical commercial slabs of Bampokha #1 are shown in Figure 9.

***Nanser Jet Black Marble (Case Study – III):*** Jet black marble is produced in the granted leases of village Nanser in Buner. The mining method employed at present is conventional drilling and blasting resulting in irregular potato shaped marble blocks as shown in Figure 10. At one of the quarry of Nanser Mining Company, mining was carried out with modern mechanized rope cutting technique. However, it failed due to excessive fractures and cracks in the deposit and limited working space at quarry site.

***Chagharzai White Marble (Case Study – IV):*** Chagharzai marble deposits are white in color and located in Chagharzai area of Buner as shown in Figure 11.

Fig. 5 A marble mining quarry of Sunny Grey Marble of Bampokha District Buner.

Fig. 6Typical commercial slabs of Sunny Grey Marble of Bampokha District Buner

Fig. 7 A marble mining quarry of Bampokha #1

Fig. 8 A marble block at Bampokha #1 quarry

Fig. 9 Typical commercial slabs of Bampokha# 1

Fig. 9(a) Marble quarry of Nanser Jet Black variety

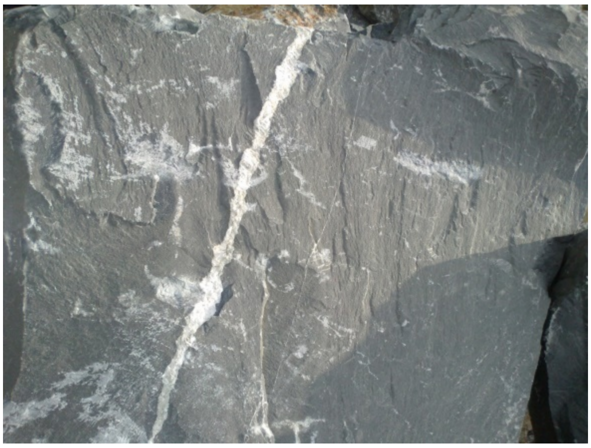

Fig. 9 (b) A marble block of Nanser Jet Black

Fig. 11 Marble quarry and typical slabs of Chagharzai Marble

## Results and Discussion

Significance of sustainability criteria for each mining alternative was quantified for the four case studies and the results are presented in Table 6. The criteria having maximum influence and desirability value are also highlighted in the (Table. 6). The overall sustainability analysis for alternatives is presented in Figure 12. Sustainability analysis of each criterion and most sustainable mining method for each deposit is presented as follows:

***Economic Factors:*** The results reveal that economic factors are significantly favoring the application of mechanized mining for case study 2 and 4 i.e. Bampokha # 1 and Chagharzai deposits (having values of 0.70 and 0.51 respectively). This is because of the high market value of the stone. Better financial gains are achieved through mechanized mining (rope cutting) as it produces regular shaped blocks and less waste. However, the economic factor is most significant towards application of conventional mining in case study 1. Because of the low market price and high demand of sunny grey marble, it is mined using more productive and low-cost conventional drilling and blasting mining methods. Finally, in case study 3 a maximum value of 0.46 of economic factor is more sustainable if mined by semi-mechanized mining method. This is because of low recovery rate of blocks by mechanized mining method due to the presence of cracks, rock condition of the deposit and higher cost of overall mining operations.

***Technical Considerations:*** Most sustainable mining methods from technological perspective are conventional mining for case study 1 and 2, semi mechanized mining for case study 3 and mechanized mining for case study 4. Although, conventional mining is technically more sustainable for case study 2 but mechanized mining has a higher desirability values for the all the remaining sustainability factors. Therefore, application of conventional mining is less sustainable, in case study 2, when the remaining aspects of sustainability are taken into account.

Presence of cracks and fissures reduces the technical sustainability score for mechanized mining in case study 3.

***Societal Aspects:*** Most sustainable mining method from societal aspects is mechanized mining, except in case study 3 where semi-mechanized mining method is most sustainable. These highest desirability values for mechanized mining are because of the fact that the locals are getting more surface rent for regular shaped blocks of case study 2 and 4. Also, regular shaped blocks are more convenient in respect of traffic and transportation issues.

***Environmental Concerns:*** Both mechanized and semi-mechanized mining methods are having a lesser environmental impact because of the use of advance mining equipment like chain saw, diamond wire and hydraulic excavator etc. Similarly, quarry development and regular shaped block extraction produces less quantity of waste i.e. less than 20%. Therefore, these are the most sustainable in term of environmental concerns. This aspect is reflected in the results and mechanized mining has high desirability values for case study 2 and 4 while, semi-mechanized is having high desirability values in case study 1 and 3. All other sustainability factors are also having high desirability values for semi-mechanized mining in case study 3.

***Safety Features:*** This is one of the most significant sustainability features having highest desirability values of 0.47 for mechanized mining for case study 2 and 4. Similarly, highest desirability values of 0.46 and 0.48 for semi-mechanized for case study 1 and 3 respectively. These high desirability values are because of the ease and safe handling of equipment's use during mining operations.

Table 6. Overall desirability values of key sustainability factors for all case studies.

| Criteria | Case Study – I: Bampokha, Sunny Grey | | | Case Study – II: Bampokha # 1 | | | Case Study – III: Nanser, Jet Black Marble | | | Case Study – IV: Chagharzai, White Marble | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | MMM | SMM | CMM | MMM | SMM | CMM | MMM | SMM | CMM | MMM | SMM | CMM |
| **Economic Factors** | 0.12 | 0.32 | 0.56 | 0.70 | 0.23 | 0.07 | 0.16 | 0.47 | 0.38 | 0.51 | 0.36 | 0.13 |
| **Technological Considerations** | 0.23 | 0.18 | 0.58 | 0.33 | 0.26 | 0.41 | 0.31 | 0.49 | 0.20 | 0.55 | 0.21 | 0.24 |
| **Societal Aspects** | 0.47 | 0.433 | 0.10 | 0.69 | 0.24 | 0.07 | 0.33 | 0.52 | 0.14 | 0.59 | 0.16 | 0.25 |
| **Environmental Concerns** | 0.39 | 0.44 | 0.17 | 0.71 | 0.23 | 0.06 | 0.39 | 0.44 | 0.17 | 0.58 | 0.31 | 0.11 |
| **Safety Features** | 0.39 | 0.46 | 0.15 | 0.47 | 0.38 | 0.15 | 0.35 | 0.48 | 0.17 | 0.47 | 0.38 | 0.15 |
| **Desirability Value** | **0.28** | **0.38** | **0.34** | **0.60** | **0.28** | **0.12** | **0.27** | **0.48** | **0.25** | **0.52** | **0.32** | **0.16** |
| **Most Sustainable Mining Method** | **Semi-Mechanized Mining / Expansion Material** | | | **Mechanized Mining Rope Cutting** | | | **Semi-Mechanized Mining / Expansion Material** | | | **Mechanized Mining / Rope Cutting** | | |

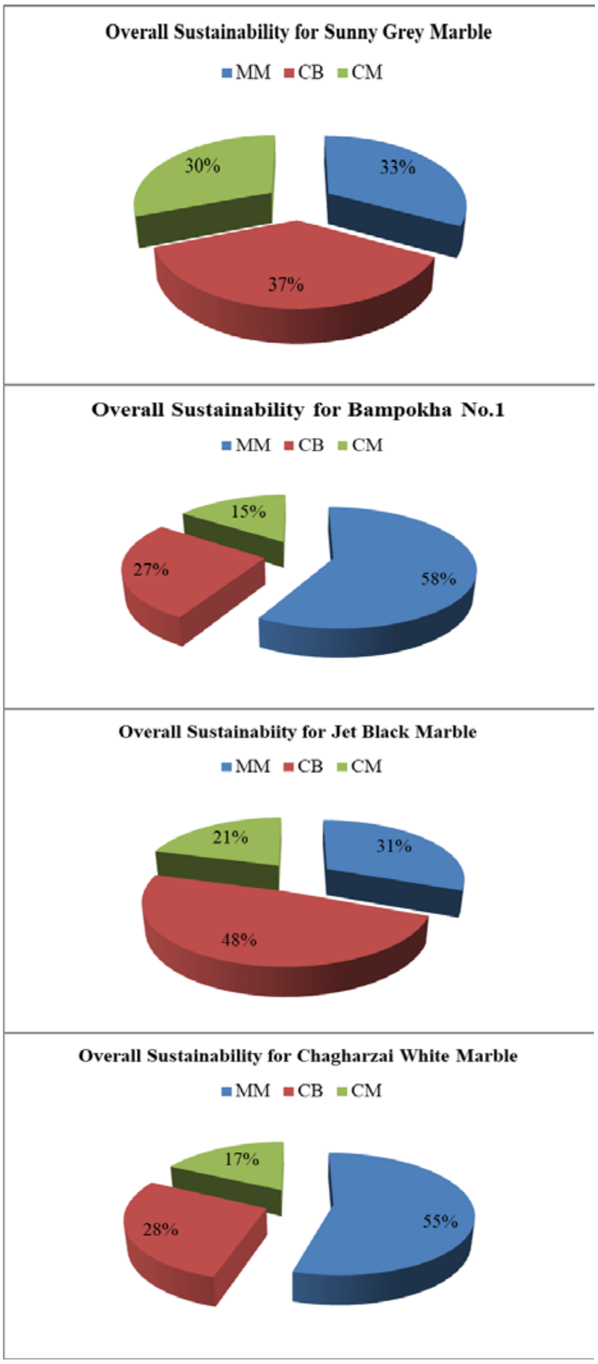


Fig. 12 Overall sustainability analysis.

## Conclusion

Major contributions of this research endeavor are:

Overall sustainability was analyzed through case studies. The results revealed that semi-mechanized mining is the most sustainable method having desirability values for jet black and sunny grey marble deposits. Similarly, modern mechanized mining is most sustainable for Chagharzai white and Bampokha No.1 marble deposits as compared to other alternatives.

Conventional mining is not sustainable for any of the deposit and should be replaced by semi-mechanized mining at Bampokha, sunny gray marble deposits and Nanser, jet black marble deposits.

Mining methods used at Bampokha # 1 and Chagharzai white marble deposits are most sustainable.

Other general factors like infrastructure, climate, rock condition, location and accessibility etc. can also be taken into considerations for further detailed sustainability studies.

Familiarization and awareness of sustainable development among the mineral sector stake holders can be done through seminars and trainings.

## References

Ashmole, M. M. (2008). Reclamation and Enviromental Management in Dimension Stone Mining. *The Southern African Institute of Mining & Metallurgy*, 155-178.

Asrarullah, Hussain A. (1985). Marble Deposit of North West Frontier Province.*Geological Survey of Pakistan.*

Brundtland, G. H. (1987).Our Common Future. United Nations World Commission on Environment and Development, *Oxford University Press*.

Dadalto, S. H. (2013). Responsible Small Scale Mining: Discussio of Socio-Environmenatal and Technical-Economic Aspects for a Sustainable Business Model. Thesis, *Politecnico Di Torino*.

Daniel, M. F., David, V. B., Claire, M. C., David, R.M. (2011). Sustainable development principles for the disposal of mining and mineral processing wastes. *Resources Policy*, **36** (2), 114-122.

Gupta, A. V. R., Jayal, D. A. Jawahir, S I. (2010). Proirity evaluation of product matrices for sustainable manufacturing. *Proceedings of 20th CIRP Design Conference*. Nantes, France.

Hilson, G., Barbara M. (2000). Sustainable development in mining industry: clarifying the corporate perspective. *Resources Policy*, **26** (4), 227-238.

Jing Yu, Shuzhen Yao, Rongqiu Chen, Kejun Zhu and Liandi Yu. (2005). A quantitative integrated evaluation of sustainable development of mineral resources of a mining city: a case study of Huangshi, Eastern China. *Resources Policy*, **30**(1), : 7-19.

Metin, E. L. (2013). Choice of marble block cutting machine by using analytical hierarchy process (AHP). *International journal of information technology and business management*, **19**.

Omair, M., Sahar, N., Shahid,M., Rashid, N. (2014). Assessment of sustainability in marble quarry of Khyber Pakhtunkhwa province of Pakistan. *International Journal of Engineering and Technology*, **14** (2014): 84-89.

Rhys,W., Neial, D., Brereton,D., Mulligan, D. (2009). Towards a sustainability criteria and indicators framwork for logacy mine land. *Journal of Cleaner Production*, **17** (16), 1426-1434.

Shaker, M., Akbar, S., Siddique, S. (2011). Technical Asistance for Development of Marble City Risulpur. *Pakistan Stone Development Company, Government of Pakistan*.