

Volcanoes as a Sustainable Resource for Engineering Applications: A case study from Harrat Ash Shaam Basalt (HASB), NE Jordan.

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ABSTRACT

Volcanic rocks have long been utilized in engineering applications due to their unique physical and mechanical properties. However, the sustainability of these practices remains an area of concern. This paper examines the importance of volcanoes as a sustainable resource for engineering applications, focusing on a case study of NE Jordan at Harrat Ash Shaam Basalt (HASB). The study evaluates the geotechnical properties of basalt rocks and pyroclastic materials of volcanoes and their potential applications in construction, such as aggregate and asphalt production, as well as their use in road construction and as building or decoration stones. Additionally, the paper assesses the environmental impact of exploiting volcanic resources and explores potential measures to mitigate adverse effects. Results suggest that Jordan basalt presents promising properties for engineering applications and that its sustainable use can support economic development while minimizing environmental impacts. However, careful management and monitoring are necessary to ensure sustainable exploitation and preservation of natural resources. This study provides insight into the potential of volcanoes as a sustainable resource and highlights the importance of sustainable practices in engineering applications. The study revealed that the sustainable use of volcanic resources requires careful management, monitoring, and enforcement of regulations. Stakeholder engagement and community involvement are also critical to ensure the preservation of natural resources and minimize social and environmental impacts.

Keywords: Volcanoes, HASB, sustainability, pyroclastic, resources

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1. INTRODUCTION

Basaltic rocks are commonly used in construction as aggregate for concrete and asphalt, as well as for building and decoration stones. The use of local basaltic resources can reduce transportation costs and carbon emissions associated with long-distance transportation of materials. Basaltic rocks have desirable properties for engineering applications, such as high compressive strength, low porosity, and good resistance to weathering and erosion. The exploitation of volcanic resources can have negative environmental impacts, such as habitat destruction, soil erosion, and air and water pollution. Therefore, sustainable management practices are necessary to ensure the preservation of natural resources and minimize environmental impacts. In Jordan, basaltic rocks are abundant and widely distributed, making them a valuable resource for construction and infrastructure development. The use of local basaltic resources can reduce reliance on imported materials and support economic development. The exploitation of Jordan's basaltic resources has been historically unregulated, leading to environmental degradation and health hazards. However, recent initiatives by the government and private sector aim to promote sustainable management practices and minimize environmental impacts. Case studies in Jordan have demonstrated the successful use of basaltic resources in road construction, aggregate production, and building stones. Additionally, research is ongoing to explore the potential use of basaltic fibers in composite materials. The sustainable use of volcanic resources requires careful management, monitoring, and enforcement of regulations. Stakeholder engagement and community involvement are also critical to ensure the preservation of natural resources and minimize social and environmental impacts.

The basalt of NE Jordan is part of a 45,000 km^2 lava plateau stretching over about 700 km in a NW-SE direction, from Syria through Jordan to Saudi Arabia. Basalt covers an area of 12,000 km^2 in HASB at NE Jordan (Fig. 1).

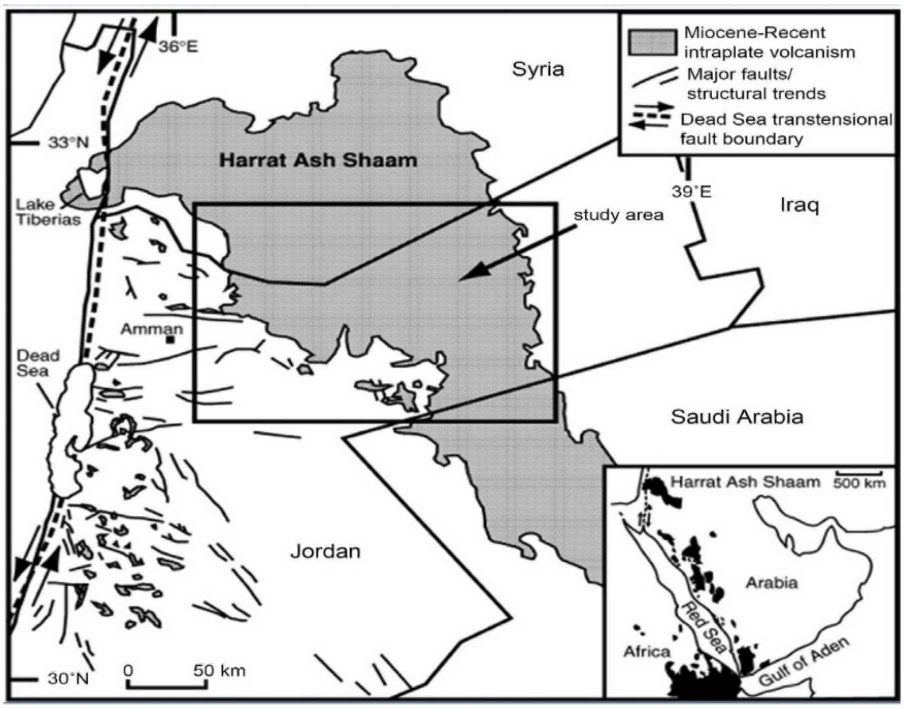

Figure 1. The location of the study area (HASB) at Northeast Jordan.

The lava varies in thickness from 1 m up to 1000 m. The outcrops expose basaltic lava as well as pyroclastic materials, which contain abundant mineral xenoliths of mantle from crustal origin (Camp & Roobol, 1992; Ilani *et al.* 2000; Tarwneh, *et al*. 2002). The regional trend of the volcanic province is NW-SE, parallel to the local Sirhan Fault System and the Red Sea axis (Tarawneh, 1999 & Tarawneh, *et al.* 2002, Ibrahim, 1993). A series of geological and geochemical studies have been performed during the last few years in the study area (Ibrahim *et al.* 2003; Illani *et al*. 2000; Ibrahim *et al*. 2000; Ibrahim *et al.* 2006). Bibliographies of early work in the North Arabian Volcanic Province including the HASB can be found in many publications, among them (Al Malabeh, 1993; Guba & Mustafa, 1988; Ibrahim *et al*. 2003; Tarawneh, *et al*. 2000; Ibrahim, 1993; Tarawneh *et al*. 1999, Tarawneh, 2003). The outcrops expose "aa" and "pahoehoe" lava flow as well as scoria and pyroclastic materials, which contain abundant accidental xenoliths of mantle and crustal origin (Tarawneh, 2020; Al Malabeh, 1993). Ibrahim (1993) subdivided the basaltic flows in the NE Jordan into five volcanic groups belonging to the HASB. These groups comprise the Wisad, Safawi, Asfar, Rimah and Bishriyya. Age dating of the basalt in northeast Jordan was carried out during the last years. Based on new K-Ar dating of the basalt Tarawneh *et al.* (2000) and Ilani *et al*. (2001) subdivided the HASB into three major volcanic phases. The first phase is of Oligocene age (22.0-26.0 Ma), the second phase is of late Miocene (12-8 Ma) , and the third phase is mostly of Pliocene – Quaternary (6 - <0.5 Ma). Geochemical, mineralogical and petrographic studies can be found in many publications, among them (Tarawneh *et al.* 2002; Ibrahim *et al.* 2003; Ibrahim et al, 2006, Ibrahim *et al.* 2000). Studies of basalt in Jordan also can be found in unpublished reports that have been carried out by the Natural Resources Authority during three decades. Most of these reports are focused on geology, petrography and chemical composition of the basalt and pyroclastic materials at the study area.

The mineral resources of the HASB region are very important to the national economy of Jordan, due to the fact that unlimited reserves of industrial commodities are widely distributed in the region. Therefore, one of the main aims of this paper is to shed light the occurrences and distribution of the volcanic centers (volcanoes) and basalt resources in this region with aim to assess its sustainability, evaluate and exploit these natural resources for the investors in this sector. The paper summarizes the available data published on the mineral commodity and the results of the analysis, which were carried out as a part of this work. These results will enhance the use of basalt and its derivatives in the sustainability required to encourage investments and increase engineering projects related to industrial applications.

2. METHODOLOGY AND MATERIALS

The paper examine the geotechnical properties, chemical and mineralogy composition of the basalt, pyroclastic materials and zeolite minerals to explore their potential applications in construction, such as aggregates and asphalt production, road construction, building and decoration stones, semiprecious stones and for agricultural uses. To achieve this goal, this paper relied on previous works and studies conducted during this research to assess the natural resources in this region and how to manage them through sustainability to achieve the greatest benefit for use in the development of industries resulting from the use of basalt rocks and all its derivatives in a sustainable way. Most of the previous engineering tests were relied on, in addition to what carried out in this research, such as the chemical, mineral and mechanical properties of various types of basalt, pyroclastic materials and zeolites. Different tests were carried out as chemical, mineralogical, specific weight and durability, unconfined compressive strength, absorption, crushing value, impact value, water absorption, abrasion, crushing strength, cohesive strength, thermal conductivity for melt (cal/cm^2) and heat capacity at constant pressure (cal/c/g). All these tests have been carried out regarding ASTM (1989), BS tests (1989), and ISRM (1994). Results of all tests analysis are discussed. Reserve estimation, production and export were based on published papers and annual reports from Ministry of Energy and Mineral Resources for the period from 2016 to 2021.

3. RESULTS AND DISCUSSION

The results show that the most sustainable resource is the basalt due to its widespread resources in the HASB, covering more than 80% of the study area. Several quarries were mined, around Qa'a Khanna, Tell Hassan, Al Artitain, El Rfaiyat, and Tlul Al Shagef. Most of these quarries have been used for rock wall industry, cement industry or can be used as a decoration stones (Tarawneh *et al.* 2022), and some xenoliths that can be used as semiprecious stones (Tarawneh *et al*. 2020). The main type mining method used for basalt and pyroclastic materials is open pit mining method. This study indicated that the area holds unlimited reserves of basalt and because of its wide availability, it was formerly used for construction purposes. During the Nabatian, Roman Byzantine and early Arabic periods, basalt was extensively used in NE Jordan. It is evidenced from the ancient castles in the area such as Qasr Al Azraq, Qasr Usaykhim, Qasr Uaynid, Qasr al Huwaynit, Deir el Kahf and Umm el Jimal, which are built completely from the basalt. In the present time, basalt is widely used as a decoration building stone in many parts of the country and it is consider as important material for infrared and super structures in Jordan. All results related to this part are discussed here with more details.

3.1. Basalt

The physical and mechanical characteristics of basalt as resistance to weathering and corrosive chemicals, durability and strength with a low porosity and permeability makes it a potential source as a decorative stone (Table 1). The results that were carried out by Tarawneh *et al.* (2022) indicated that most of physical and mechanical properties are met the required international standard to be used as a building or as decoration stones (Table 2). The results show that the abrasion (500 revolution) test varies from 13 to 43.2, specific gravity between 1.59 and 2.81, absorption between 1.29 and 3.21, crushing value between 13.33 and 25.3%, and impact value between 12.65 and 17.23%.

Table 1. The results of the abrasion test, Specific gravity (Gs), Absorption, Crushing and Impact Values.

Sample No.	Abrasion (500 revolution) %	Specific Gravity (Gs)	Absorption %	Crushing value %	Impact value %
B1	39.2	2.56	2.53	17	15.66
B2	13.1	2.81	3.21	16	13.88
B3	19.2	2.72	2.20	18	14.11
B4	21.5	2.72	1.94	20	15.21
B5	23.16	2.72	1.80	22.90	16.33
B6	21.40	2.73	1.60	21.40	12.65
B7	29.18	1.87	2.22	18.5	15.88
B8	32.38	1.74	1.40	15.98	16.78
B9	19.64	2.73	1.60	21.72	14.21
B10	17.2	2.78	1.60	13.7	13.33
B11	21.2	2.72	1.40	14.2	17.23

B12	23.1	2.75	1.80	13.33	13.50
B13	33.4	1.80	1.29	22.2	14.72
B14	43.2	1.59	2.33	25.3	14.91

One of the most sustainable sources of the basalt is the rock wool, that can be considered as an artificial product which is composed of extremely thin silicate fibers, where basalt forms more than 70% of the raw material with siliceous or argillaceous rock, make up the rest. As was indicated earlier, basalt is the most widespread mineral resource in the area, however, those areas suitable for rock wool and cast basalt. For this reason detailed studies to verify their physical and chemical properties was carried out by Tarawneh *et al.* (2022) (Table 2). The results show that the unconfined compressive strength varies from 218.5 to 560.3 Kg/cm^2, the crushing strength is from 1590 to 2311(atm), cohesive strength (atm) is from 290-469, thermal conductivity (cal/cm^2) up to 37, and the heat capacity at constant pressure (cal/c/g) is from 0.21 to 0.70.

The evaluation of the HASB for cast industry and rock wall industries is highly recommended. This will be part of sustainability of these resources for engineering application including precast basalt, lightweight aggregates or as decoration stones. Rock wool is used in insulation and energy conservation. It can be used as loose "wool", but can also be bonded together with resin binders to form rolled mats, rigid panels and pipe sections. Rock wool has the following properties: Low coefficient of heat transfer; high acoustical insulation; damp proof; light in weight; noncombustible; non corrosive. All mentioned properties give the importance of the basalt resources as sustainable materials that will save our building and to minimize the carbon emission to the atmosphere.

Table 2. The Main physical and mechanical properties of the HASB basalt.

Test	Value
Unconfined compressive strength (kg/cm^2)	218.5-560.3
Crushing strength (atm)	1590-2311
Cohesive strength (atm)	290-469
Thermal conductivity (cal/cm^2)	1-37
Heat capacity at constant pressure (cal/c/g)	0.21-0.70

These results indicated that the basalt is suitable for the wool industry. For this sustainable use it needs to have low $Ti0_2$, MgO, and FeO oxides, and high alkali contents. Homogeneity of the raw material, fine-grained texture and low melting point are also important in this case. The basalt exposed in HASB are almost similar to those quarried by the Jordan Rock Wool Company and are of good potential for rock wool industry. The standards requirements for rock wool are as follows:

Ma of acidity = $(SiO_2+Al_2O_3)/(MgO+CaO)$ = 2.5-3.0

For sustainable applications, the basalt also can be used as a cast basalt. For this use it requires a raw material similar in composition to that used by rock wool industry. Table 3 show the chemical composition of the basalt needed for cast basalt. For this reason the basalt must be alkaline, undersaturated with respect to silica, homogeneous with a constant composition, fine-grained and not highly weathered. A raw material with a low melting point is necessary i.e. melting is executed on an industrial scale broken into sizes of 20 – 50 mm in shaft furnaces at temperatures around 1,300°C, followed by casting into the desired moulds. Of fundamental importance is the subsequent tempering process, in which the molten basalt forms uniform, spherulitic crystals that contribute to its physical properties such as extreme hardness and abrasion resistance (Kusno, et al. 2020).

Table 3: The XRF results of selected basalt samples from HASB

Oxide %	B1	B2	B3	B4	B5	B6	B7
K_2O	1.13	0.78	0.71	0.53	0.86	0.98	1.10
P_2O_5	0.25	0.34	0.11	0.36	0.22	0.17	0.21
SiO_2	45.19	47.22	48.66	44.65	45.18	45.19	44.86
CaO	15.34	11.44	10.36	12.31	10.08	9.86	9.93
MgO	8.12	9.05	10.25	7.50	8.09	8.54	7.64
Fe_2O_3	10.11	10.04	10.35	12.29	13.98	14.54	12.18
Al_2O_3	13.6	14.93	13.87	15.22	15.97	15.78	16.73
TiO_2	1.5	1.4	1.25	1.89	0.93	0.78	0.83
MnO	0.12	0.11	0.14	0.25	0.21	0.23	0.18
Na_2O	2.32	2.41	2.20	0.78	1.08	1.29	3.14
LOI	2.15	2.18	1.74	3.23	1.28	1.69	2.87

3.2 Scoria (Pozzolanic Tuff)

The scoria (pozzolanic tuff) is widely distributed in the study area in many several volcanic cones or centers, such as Tell Rimah, Tell Hassan, Jibal Zumal al Hashshad, Jabal Mafarid al Asfar, Jibal al Aritayn, Jibal al Manasif al Gharbya, Jibal al Manasif ash Sharqiyya, Jabal al Fahem, south and southeast of Jabal al Asfar, Tulul Ashaqif, Jabal ed Dhirwa, Tulul el Bassus and Tulul el Ghussaun. Many studies have been carried out on the scoria materials from HASB with aim identified their physical, chemical and mechanical properties. The sustainability of these material is well recommended due to the wide distribution of these resources in the study

area. One of the main problem of their use is considered in randomly mining by private companies, and are still used as bulk materials in cement industry, without any processing of their content of very important zeolites minerals and semiprecious stones. For this reason this study recommend to think again in the rules and regulations that should take into consideration the importance of secondary mineralization associated the scoria and all pyroclastic materials like zeolites and semiprecious minerals. This will be carried out by using selective mining of the zeolites from scoria during the mining screening process. What is required of government agencies is to develop laws and legislations related to mining and the environment to preserve natural resources and to take into account the sustainability of these ores. Selected mining and mineral processing in this case is well recommended, in addition to change some regulation of the mining law in the country with aim to minimize the loose of the zeolite minerals and all associated semiprecious stones (xenoliths) that encountered these materials. The sustainability of the zeolite minerals is one of the main issue for future mining industry in Jordan due to its widespread uses in fertilizers or as catalysts and purification of water and waste.
The scoria deposits or pozzolanic tuff in the study area are of great potential for use in cement industry, in agricultural applications and as lightweight aggregates. For instance, in the cement industry, pozzolana is added to the cement for two purposes: A corrective material for Fe content in the cement mixture in proportions up to 10% by weight before the reaction in order to produce Portland cement; or an additive material, to standard Portland cement in proportions from 10-30% by weight at low temperature and then ground finely to produce Portland pozzolanic cement (Nawasreh *et al.* 2014). Exploitation of scoria is a relatively simple through surface mining operation. Expected reserves of pozzolana in the study area are huge and unlimited. Pozzolana is currently quarried by private sector from several volcanic cones for use in cement industry and for agricultural applications as fertilizers.

Table 4 shows the production basalt and pozzolanic tuff for the period from 2016 to 2021 (MEMR, 2021), while Table 5 shows Jordan's total exports of basalt aggregates, puzzolanic tuff and basalt for the period from 2018 to 2021.

Table 4. The total Production of basalt and pozzolanic tuff in Jordan (2016-2021)

Ore	2016	2017	2018	2019	2020	2021
Basalt	100,716	62,500	562,500	89,950	141,000	71,046
Pozzolana and Zeolitic tuff	848,774	803,525	917,490	682,827	710,707	1,005.972

Table 5. The quantity (ton) exports of Jordanian basalt and pozzolanic tuff in Jordan (2018-2021).

Year	2018	2019	2020	2021
Basalt aggregates	-	991,016	19,792	105,965
Puzzolanic tuff/ ton	30,041	33,568.0	33,122	74,863
Basalt	36,522	9154	45,761	72,227

For cement industry, the hydraulic factor is an important parameter, the higher is this factor the more suitable is the material. The hydraulic factor of the pozzolana varies from 19 to 52.5. It was reported by the Jordan Cement Company (1985) that was indicated by the presence of zeolites which enhances significantly the hydraulic factor of the pozzolana. The study revealed that pozzolana is characterized by bad cementing, good sorting and with specific gravity of 1.6 g/cm^3. The chemical composition of the pozzolanic is shown in Table 6.

Table 6. The selected physical and mechanical properties of the Pozzolana of HASB. Data from Jordan Cement Company (1985).

Locality	Hydraulic Factor	Strength (Nt/cm^2)	Specific Gravity (g/cm^3)
Fahem	41	1212	1.4
Aritayn	52.2	1190	1.57
Ufayhimat (N)	31	810	1.85
Ufayhimat (S)	39	1112	1.78
Jillad	37.5	729	1.64
Al Manasif Ash Gharbiyya	22	546	1.7
Al Manasif Ash Sharqiyya	19	280	1.58
Ushayhib	28	210	1.64

3.3 Zeolites

One of the main important minerals associated the pyroclastic materials of volcanic centers are the zeolite minerals. These are a group of hydrated alkali alumino- tektosilicates, which are characterized by their open crystalline structure. In the study area, zeolites were indicated in several areas including Jabal Aritayn (N) and Jabal Aritayn (S), Tell Rimah, Tell Hassan, Tulul Al Ashaqif and Jabal Hannoun and many other localities. Phillipsite tuff was discovered by Dwairi (1987) in Jabal Aritayn (S), whereas, the economic zeolite deposits in the other localities in the NE Jordan were discovered also by Ibrahim (1996b) occurring in the Aritayn Volcaniclastic Formation and are restricted to a diagenetic zone with variable thickness from few meters up to 20 m. Based on their unique structure, zeolites can be used in the many applications. This give this group of minerals sustainable domain and will be considered as future source for agriculture uses and other engineering applications. The most aspects can be drawn as: slow release fertilizers and soil amendments; industrial and municipal wastewater treatments; gas and oil purification; animal nutrient, fish and poultry farming and reduce strong odor intensity and ammonia gas concentration from farms. Many applied experiments on zeolites have been carried out by a group of researchers through master's and doctoral dissertations in several fields have proven successful in many sustainable agricultural, waste management and purification of water and other industrial applications.

Quantitative determination of zeolites indicate that the mineral content range between 20% to 65% by weight (Ibrahim, 1996b; Ibrahim & Inglethorpe, 1996). Preliminary studies indicate the presence of a huge reserve. Small quantities of the zeolitic tuff is extracted from Jabal Aritayn (N) every year (Table 7) by an American-Jordanian Company (Green Technology) (Nawasreh *et al.* (2014). The zeolitic tuff product by this company is mainly used for agricultural and gardening uses and activated by synthetic fertilizers. Unfortunately, zeolite deposits from Tell Rimah and other localities in the area are over exploited as being mined along with pozzolana for the cement industry. This is one of the main unsustainable method for using of zeolites as mentioned before, for this reason regulations should be corrected against the randomly mining of these resources for cement industry as mentioned. Using simple mineral processing techniques, zeolite grade could be concentrated to the range between 85% and 96% (Ibrahim, 1996b; Ibrahim, 1997; Ibrahim & Ingelthorpe, 1996). The identified zeolite minerals are phillipsite, faujasite and chabazite. From the NE Jordan 8 zeolite concentrates were produced, and were given the symbols: Zeordan 1 to Zeordan 8 (Ibrahim, 1996b). Experimental investigations on the zeolitic tuff emphasized the importance of the Jordanian zeolites for use in wastewater treatment plants and as a soil conditioner and as slow-release fertilizer. Grain size distributions, zeolite percentage, cation exchange capacity, attrition resistance, acid resistance and packed bed density of zeolitic tuff from NE Jordan are considered the most important physical properties. This is indicated by the results of cation exchange capacity (0.94- 3.59 meg/g), attrition resistance (4.50-7.2 wet loss) and its density (0.94-1.15 g/cm^3) (Reshiedat, 1991; Dwairi, 1987).

Table 7. The geological reserves of zeolitic tuff (million tons)

Area	M/t
Tell Rimah	46.0
Al-Aritayn	170.0
Tlul Al-Shahba	9.2
North East Areas	472.0
Other areas	1340.0

3.4 Semiprecious stones

Semiprecious stones like olivine, pyroxene and garnet xenoliths are widely distributed and scattered in the basalt and pyroclastic materials of the study area. Cutting and polishing tests indicated that some of the studied xenoliths are suitable for manufacturing attractively colored gemstones and could be considered as a semiprecious stones. The geological chances for the discovery of some hundreds of tons of these gemstone raw materials are considered to be good in volcaniclastic materials that are associated within different volcanic centers or cones at NE Jordan (Tarawneh. *et al.* 2020).

Most of the xenoliths considered here as semiprecious stones are concentrated within Asfar, Bishriyya and Rimah groups, and less commonly within Wisad Group, that are exposed in the HASB. These groups, partially composed of pyroclastic materials included different types of xenoliths that could be used as semiprecious stones. The gemstone and sustainable development knowledge is very important for future small companies to work in this field, and improve the sector's contributions to sustainable development. There is a growing need for sustainable development training for local community to share this kind of business due to its benefits. This need investigate and support the development of best practices in the sector. To support this issue society program, participate in stakeholder workshops and roundtables for the development of the marketing and using of different varieties of these gemstones is well recommended.

4. CONCLUSION

This paper highlights the examination of the importance of volcanoes as a sustainable resource for engineering applications, focusing on the case study of NE Jordan basalt at HASB. It describes the geological characteristics of the area, including the distribution of basaltic lava and pyroclastic materials. The study area is divided into five volcanic groups: Wisad, Safawi, Asfar, Rimah, and Bishriyya.

The study evaluates the geotechnical properties of basaltic rocks and pyroclastic materials as pozzolna and zeolite minerals and their potential applications in construction, such as aggregate and asphalt production, road construction, building and stones and in agriculture. The study emphasizes the need for careful management, monitoring, and stakeholder engagement to ensure sustainable exploitation and preservation of natural resources in the study area. This will provides an overview of the use of basaltic rocks in construction, emphasizing their desirable properties for engineering applications. It mentions that the exploitation of volcanic resources can have negative environmental impacts and highlights the need for sustainable management practices. The results and discussion section of the paper provides information on the occurrences, reserves, and production of basalt in the HASB region. It mentions several quarries that have been mined and used for various purposes such as rock wall industry, cement industry, building and decoration stones. The physical and mechanical properties of basalt, including density, compressive strength, specific gravity, water absorption, and abrasion resistance, are presented and met the required specification in many industries. The paper also discusses the use of basalt in the rock wool industry, which involves the production of insulation and energy conservation materials. The occurrences, physical and mechanical properties, and uses of basalt in the rock wool industry are described. The chemical and mineral composition requirements for rock wool and cast basalt are mentioned. The gemstone and sustainable development knowledge is very important for future small companies to work in this field, and improve the sector's contributions to sustainable development of semiprecious stones in the area. Overall, this paper highlights the potential of Jordan basalt in engineering applications and emphasizes the importance of sustainable management practices for the exploitation of volcanic resources. It provides valuable insights into the sustainable utilization of volcanic resources and the need for future careful management, stakeholder engagement, and community involvement to minimize environmental and social impacts.

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