Applied Mathematics & Information Sciences
An International Journal

http://dx.doi.org/10.18576/amis/170415

Assessing the Waste Management Practices in Stone and Marble Industry in Palestine: Practical Implications

Ahmad Ramahi[1,], Yahya Saleh[1], Ruaa Binsaddig[2], Rahaf Ghozzi[1], Bara' Abu Baker[1], Abdelraheem Khateeb[1], Saad Jodalla[1], Ramiz Assaf[1], Mohammad Kanan[3], and Abdalmuttaleb Al-Sartawih[4]*

[1]Industrial Engineering Department, Faculty of Engineering and Information Technology, An-Najah National University, Nablus, Palestine
[2]Department of Finance, College of Business Administration, University of Business and Technology (UBT), Jeddah 21448, Saudi Arabia
[3]Industrial Engineering Department, Jeddah College of Engineering, University of Business and Technology (UBT), Jeddah 21448, Saudi Arabia
[4]Accounting Finance & Banking Department, College of Business & Finance, Ahlia University, Manama, Bahrain

Received: 21 Feb. 2023, Revised: 22 Mar. 2023, Accepted: 24 Mar.2023.
Published online: 1 July. 2023.

Abstract: This paper aims at assessing the current status of solid waste management practices in stone and marble industry (SMI) facilities in Palestine. To this end, mixed qualitative and quantitative approaches have been adopted. Morse specifically, both field visits and semi-structured interviews as well as questionnaires have been employed to gather needed data from a randomly selected sample of Palestinian SMI faculties. Such data include facilities' demographics, their infrastructure and production inputs, solid and liquid waste estimated quantities as well as the current waste management practice. Statistical analyses show that SMI facilities are highly heterogeneous in their profiles and practices. Besides, it was found surveyed respondents from SMI facilities have high awareness on the importance of waste management and willingness to apply effective waste management practices in their facilities. To this end, a set of practical implications have been developed to help different stakeholders in the SMI in employing more effective waste management practices in their facilities and hence improve their social, environmental and economic sustainable organizational performance.

Keywords: Stone and marble industry, Stone-cutting waste, Waste management practices.

1 Introduction

Pharaohs, Greeks and Romans used stone to build temples, theatres, public and private buildings. Nowadays, the stone and marble industry (SMI) is one of the world's 50 largest and most powerful economic sectors; it includes quarrying, crashers, marble and stone processing facilities, and dumpsites; its annual sales reach about 10% of the global market and the annual consumptions of stone reaches about 600 million square meters worldwide [1]. However, SMI activities have a negative impact on the environment and humans. More specifically, its noise and dust cause several health problems for the people who live nearby, and its waste affects the soil and the green cover. In addition, SMI depletes large quantities of water, material and energy, which are increasingly becoming scarce resources [2].

Within the Palestinian context, the SMI is currently the largest industry in terms of number of facilities, sales quantities, and human labour; it is the world's 12th largest stockholder of construction stone, contributes 4% of global production. Palestinian stone is exported to more than 80 countries with annual revenue of around $600 million at 54% added value: 75% of the sales go to the Israeli market, 15% to the local market and 10% to global markets. SMI accounts for 4.8% of Palestinian GDP. It also employs 25,000 workers directly and 100,000 workers indirectly in over 1300 facilities; the majority of which (~74%) are stone fabrication facilities, (~22%) quarries, and (~4%) crashers [3-5]. Therefore, the SMI sector in Palestine is considered a major pillar of the local economy; however, this sector has negative impact on the human and the environment; according to estimates in 2013 this sector generates about 1.24 million tons of liquid and solid wastes annually [1]. Such wastes affect air quality, groundwater, and agricultural lands. The main types of waste generated include solid waste (residues) which consists of cracked, irregular, and broken stones resulting from quarrying, small broken and shattered stones resulting from fabrication, and stone powder (dust) resulting from fabrication as well. The other main type of waste is liquid waste in the form of slurry (slurry-water); which is mainly stone powder-mixed with water used to cool/lubricate the cutting and polishing tools. Other types of waste like damaged equipment and machine parts, and spent lubricants are also common in this industry. To minimize the effects of the large quantities of generated wastes, it is necessary for the Palestinian SMI to adopt an effective waste management system that makes benefit of international best practices and utilizes proper reduce, recycle, reuse, and safe disposal programs.

*Corresponding author e-mail: ramahi@najah.edu

The main objective of this paper is to review related environmental aspects, explore and update the status of the stone-processing waste management practices in Palestine, and come up with sound practical implications to help in developing a customized stone waste management system to contribute to the sustainability of the Palestinian SMI sector. This paper includes 6 sections; the first section is the introduction, the second section is a background on the Palestinian SMI, and the third is research methodology. The fourth section provides results and discussion, while the fifth section presents the practical implications. Finally, the sixth section is the conclusions.

1.1 BACKGROUND ON PALESTINIAN SMI

The SMI facilities are located in all governorates of the West Bank of Palestine; majority of these facilities are located in the southern governorates. Figure 1 shows the distribution of stone processing facilities in the West Bank [6].

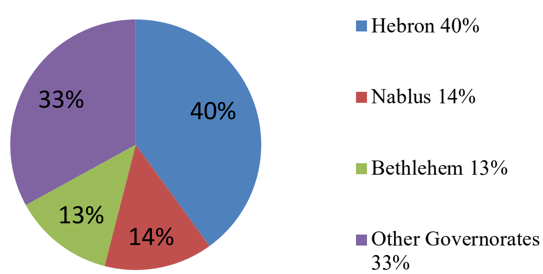

Fig. 1: Distribution of stone production facilities in the West Bank. (Source: developed by authors)

In effect, 13% of the SMI facilities in Palestine are located in natural areas, while 34% of the facilities are located in high and medium agricultural value areas, 40% of the SMI facilities are causing direct pollution to surface and ground water by disposing slurry water into valleys and open lands. About 38% of stone fabrication facilities are located within master plan borders. Also, about 35% of stone fabrication facilities cause great damage to both natural and built environments and about 51% of the SMI facilities have medium to high negative effect on the environment, which needs to be minimized [6]. On the other hand, the Palestinian SMI still encounters several challenges including: (1) Limited resources: most of the natural rock reserves are located in area C which is under the complete control of the Israelis who control the water and electricity resources as well; licensing new quarries for Palestinians in area C is almost impossible [1]. (2) Large amounts of waste: it is estimated that the annual solid and liquid wastes generated by the Palestinian SMI are about 1.24 million tons; among which 36% are solid waste (stones) resulting from stone processing facilities; which represents significant potential for recycling [1]. (3) High level of hazards to the soil, water, air and green cover. Specifically, the liquid waste (effluent) streams in nearby open areas causes an increase in the acidity of the soil and a decrease in its permeability and harms the green cover. In addition, part of the effluent may pollute the ground water by infiltrating down to the ground-water aquifer [7]. On the other hand, the resulting dust particles mix with the air, causing air contamination that exceeds WHO standards, which in turn leads to real health problems to the public and to the workers in the SMI [8]. (4) Unreliable electricity supply: the electricity supply is insufficient in certain regions in the West Bank due to low network capacity and/or amounts of electricity supply permitted by the Israelis to the Palestinian Authority [9]. (5) Inefficient use of water: the water distribution network and the available water quantities in some areas are inadequate for the needs of the SMI, provided that the SMI consumes about 0.5 million m^3 annually. Moreover, SMI firms do not practice water management efficiently; also, a large proportion of the stone cutting facilities do not have effective wastewater recycling systems or rainwater harvesting means. Even though the estimated annual generated slurry in 2013 is about 0.7 million tons, only large facilities have modern wastewater recycling systems. [1-9]. (6) Poor industrial safety and health management measures: the work environment in SMI facilities is hazardous; several facilities lack necessary occupational safety standards including measurement devices, personal protective equipment and procedures. (7) Inadequate machinery: the technology used in many SMI facilities is not cutting-edge technology; machines are relatively old and not upgraded and need frequent maintenance [3,10]. (8) Weak awareness of sustainable production: the awareness of sustainable production in the SMI facilities varies where some facilities apply selective sustainable practices that would have positive financial results; this indicates weak awareness and lack of governmental enforcement [11].

2 Methodologies

As previously stated, the SMI in Palestine generates large quantities of solid and liquid waste; which necessitate the adoption of effective waste management system to alleviate the impact of such waste on the environment and on the human well-being Therefore, the main goal of this research is to explore and update the status of the stone-cutting waste management practices in Palestinian SMIs, and come up with some practical implications that help in developing a customized stone-waste management system. To this end, a mixed qualitative and quantitative research methodology is adopted.

More specifically, the study covered the southern part, middle and northern parts of Palestine. Namely, five Palestinian governorates in the West Bank, are covered southern (Hebron, Bethlehem), middle (Ramallah) and northern (Nablus, and Jenin). A statistically calculated random sample of stone cutting factories was selected. Quantitative and qualitative data were collected using the following different tools: field visits to SMI facilities for direct observation of waste management practices, semi-structured interviews with facility owners, and officials at the Palestinian Union of Stone and Marble to collect relevant data as perceived by them. In addition, a questionnaire was used to collect related qualitative and quantitative data by being filled by each responding facility, and the questionnaire was designed based on literature found in [12-14]. The questionnaire was reviewed by experts and piloted on three facilities – one is small, one is medium, and one is large- before being finally modified. Also, the researchers conducted field visits to observe facts on the ground and to personally interview the facility owner or general manager to get their opinions regarding current waste management practices and their willingness to adopt and adapt sound affordable environment-friendly approaches for those purposes. The sample in this study covered all regions of the West Bank; northern, southern, and middle, and included large, medium, and small facilities. In addition, the sample selection reflected to a large extent the distribution of SMI facilities in the West Bank. As for the sample size, the total number of stone cutting facilities in the West Bank is about 1300; however, it is assumed that 1000 of them are mature and active and form the population of the study.

Using Steven Thompson formula stated in [15], shown below in equation (1), the sample size was calculated:

$$n = \frac{N \times p(1-p)}{\left[\left(N - 1 \times (d^2/z^2)\right) + p(1-p)\right]} \quad \ldots\ldots\ldots\ldots(1)$$

Where, n= the sample size, N=population size (N=1000), P=proportion of property offers and neutral (P=0.5), d=error margin (d=10%) and z= is the upper α/2 of the normal distribution (for 90% confidence level, z=1.65). Substituting the aforementioned parameter values in the above equation, the sample size equals n=64.

In this research, the questionnaire was the main tool used to collect data; the designed questionnaire included both closed- and opened-ended questions, with closed-ended question the respondents would choose from a given set of alternatives. The questionnaire consists of eight pages and includes four main sections. The first section was designed to collect demographic data and infrastructure-related information of the SMI facility. The second section was designed to collect data and information on facility’s average annual consumptions of water, energy, and raw stone, and on production quantities, in addition to estimates of solid and liquid waste quantities. The second section also was used to collect information about the waste management practices currently adopted by the facilities. The third section was designed to collect data and information about the methods, techniques and technologies currently used in the facilities for stone processing, packaging, material handling and transportation. The last section included open-ended questions to investigate the perspectives of facility owners or general managers regarding some SMI waste management aspects. The collected data was then analyzed using the Statistical Package for Social Sciences (SPSS) to obtain the needed results.

On the other hand, several challenges were encountered by the researchers during the conduction of this study. More specifically, the first challenge was in finding the location of the stone facilities in the West Bank; this is due to incomplete information obtained from the Palestinian Union of Stone and Marble, or from the municipalities. To overcome this challenge visits were conducted to the union's branches in the governorates to get more reliable information. The other challenge was that some facilities refused -at first- to meet the research team and participate in the study; however, this problem was resolved by providing them with official letters stamped from the Deanship of the Faculty of Engineering and Information Technology at An-Najah National University. Due to these challenges, only 53 of the contacted 64 SMIs facilities responded fully and were cooperative with the research team and provided valid questionnaires for analysis. This presents a response rate of about 83%.

3 Results and Discussion

Based on the interviews with facility owners/general managers and the observations on ground; the material flow in Palestinian SMIs could be mapped as depicted in Figure 2. More specifically, the industry starts with quarrying rocks in the form of large cubes of stones to be turned later into dimensional stones, other smaller defective stones are resulting during quarrying which are considered residues and transported to crushers. The cube stones are transported to the cutting and shaping facilities which are the key stage in this industry; these facilities make the various forms of dimensional stones which are then transported to the construction market for different uses. Quarries and stone processing facilities generate a large volume of residues in the form of irregular, broken, cracked, or shattered stones; most of these residues are transformed into useful products (aggregate) that are used in the construction sector as raw building materials. Small proportions of residues, as well as construction waste, are returned to quarries as filler for excavation sites, or sent to final disposal at dedicated or random dumpsites.

Moreover, fresh water is used in quarrying and stone fabrication processes to cool and lubricate tools during cutting and polishing; as a result, fresh water turns into slurry which is a mixture of water and stone powder. The slurry is then channeled to the treatment plant where it is separated into clarified water and sludge/cake. The clarified water is reused again for cooling and lubrication, while the sludge/cake is sent for final disposal in dedicated or random dumb sites. In some ‘limited’ cases, the slurry is directly disposed without treatment. The following subsections present the statistical analysis results and discussion.

Moreover, fresh water is used in quarrying and stone fabrication processes to cool and lubricate tools during cutting and polishing; as a result, fresh water turns into slurry which is a mixture of water and stone powder. The slurry is then channeled to the treatment plant where it is separated into clarified water and sludge/cake. The clarified water is reused again for cooling and lubrication, while the sludge/cake is sent for final disposal in dedicated or random dumb sites. In some 'limited' cases, the slurry is directly disposed without treatment. The following subsections present the statistical analysis results and discussion.

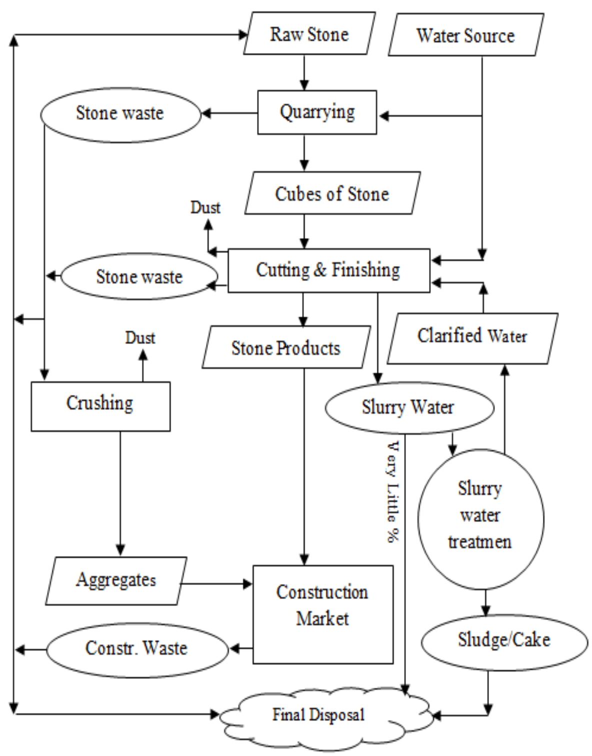

Fig. 2: Flow of material in the Palestinian stone production industry. (Source: developed by authors)

A. Demographic Characteristics of the Sample

A list of names and addresses of mature and active factories (excluding small workshops) was obtained from the Palestinian Union of Stone and Marble. The original sample of 64 factories was selected out of this list, however the number of respondents were only 53 facilities. Several demographic characteristics were considered in this study; among which are: city of facility location, facility location relative to residential area, facility size in terms of square meters, facility age, number of employees, and the type of certification the facility has. Figures 3 to 6 below present the descriptive statistical analyses of the demographic profiles of the sampled SMI facilities.

The selection of the original sample took into consideration the distribution of the stone cutting facilities in the northern, middle, and southern areas of the West Bank. However, due to the challenges mentioned earlier, more facilities were studied in Nablus governorate in the northern part, while a smaller number of facilities were studied in the southern part as seen in Figure 3.

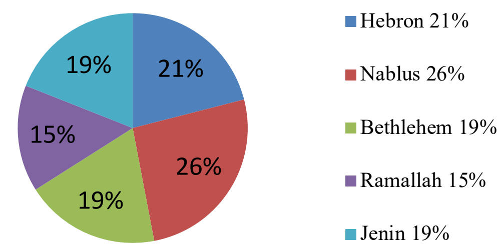

Fig. 3: SMI location distribution

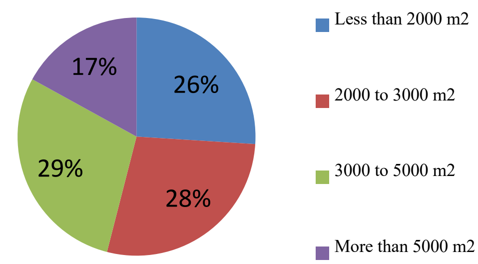

Fig. 4: SMI size distribution

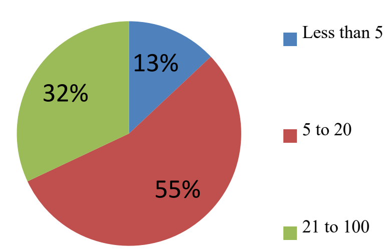

Fig. 5: Distribution of number of employees in SMI

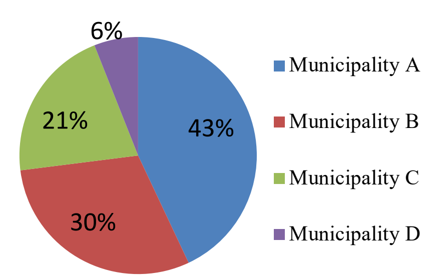

Fig. 6: SMI distribution according to municipality rank

Nevertheless, Hebron and Bethlehem together form about 40% of the studied facilities, which is a reasonable percentage compared with the facility distribution given in Figure 1. It is clear from Figure 4 and Figure 5 that the studied facilities are mostly medium and large facilities in terms of area and number of employees. According to Figure 6, more than 70% of the studied facilities are working under the regulations of A and B rank municipalities. Such municipalities usually practice more enforcement of bylaws on the SMI facilities. The analysis of the collected data has also shown that the age of 83% of the studied facilities is more than 10 years, while 50% of them are more than 30 years. The structure of the sample explains the result that 90% of the studied facilities are located out of officially classified residential areas. Regarding certification, it is found that about 88% of the studied sample has no certification such as ISO or PS (Palestinian Standards).

B. *Infrastructure and Inputs of Stone Cutting Industry*

The questionnaire included a subsection that collects information about whether the facility is connected to water, electricity, and sewage networks. The analysis found that about 75% of the facilities are connected to a water network, while 25% are not; they use mobile water tankers to bring water. All SMI sampled facilities are connected to electricity network, while only 60% of them are connected to sewage network. Quantitative data was also collected about the inputs (resources) of the stone cutting industry and the produced quantities. Tables 1 and 2 below show the results. The standard deviation values are somewhat large. This is because the sample included small and large facilities that results in relatively large differences in resource consumption and production quantities among sample members.

Table 1: Average annual consumption of resources

Resource	No. of Facilities	Mean Value	Standard Divination
Raw Stone (m^3)	53	2480	1820
Fresh Water (m^3)	53	970	430
Electricity (kW)	53	280000	140000
Use of renewable energy resources	4% of factories partially use solar energy		

Table 2: Average annual produced quantities

Product Type	No. of Facilities	Mean Value	Standard Divination
Building Stone (m^2)	53	33257	29590
Marble Slab (m^2)	15	13150	10131
Decoration stone	18	12453	11138

Table 1 shows that only 4% of the factories partially use solar energy to generate electricity. This is because most facilities need large quantities of electricity and do not have enough space to generate such quantities. In addition, some municipalities still do not have clear regulations regarding the feed of renewable electricity into the grid. The questionnaire included a question on the best estimates of stone processing yield by comparing quantities of raw stone and produced products. The results showed that the average yield is about 55%, hence the average percentage of solid waste (including powder) is about 45% which is slightly higher than that in other countries in the region such as Iran in which the average is 43.7%. [16]. In addition, from Tables 1 and 2, the average consumption of electricity and fresh water per m2 of product is about 6.8 kW and 0.024 m3, respectively. Furthermore, the results showed that the average annual quantity of slurry generated is approximately 900 m3 per facility. These results are comparable with similar results in [17]; however, the results in this study represent the current status, and are considered useful for environmental impact assessment and for economic considerations as well.

C. *Waste Management Current Practices*

This section presents the analysis of the current practices for managing the solid and liquid wastes in the Palestinian SMI.

Solid Waste Current Management Practices

Different techniques can be adopted to reduce waste. The questionnaire asked about some of such techniques. The results show that 69% of the sampled facilities use special cutting tools that suite the type of stone, 38% of them use special mechanisms to cut stones in regular shapes, 90% use suitable material handling equipment to avoid stone breakage, while 48% adopt cutting with standard dimensions, and 17% use other procedures. It is noticed that a small number of facilities adopt techniques to produce in regular shapes and standard dimensions. The results showed that only 6% of the sampled facilities reuse the solid waste, while 94% of the facilities dispose of it in different ways as shown in Figure 7 below. Most of the generated solid waste is disposed of in the crushers to be recycled into gravel, but usually at zero profit for the facilities. Figure 7 summarizes the solid waste disposal methods.

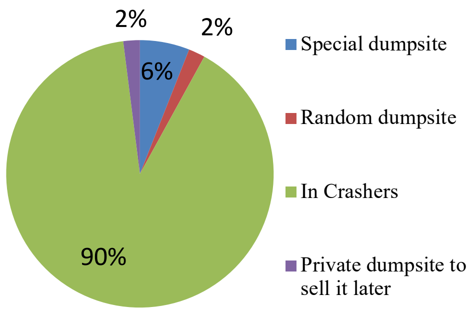

Fig. 7: Distribution of solid waste disposal methods

1) Liquid Waste Current Management Practices

The results showed that 96% of the facilities treat their liquid waste (the slurry), while 4% do not treat it. About 66% of those who do not treat the slurry; instead, they dispose of it randomly in nearby valleys, and 33% of them dispose of it in the public sewage system. The ones who treat the slurry adopt different techniques as presented in Figure 8.

It is clear that about 55% of the facilities use filter press integrated with clarifying mechanism, which indicated that the facilities realize the importance of treating the slurry to reuse water, hence reduce production costs, and eventually protect the environment.

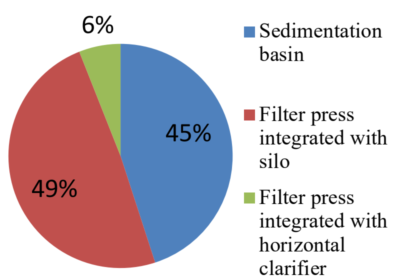

Fig. 8: Adopted liquid waste treatment techniques

On the other hand, about 45% of the facilities are still using sedimentation basins; nevertheless, this ratio was larger than that before ten years. Furthermore, the analysis has shown that 98% of the facilities make no use of the cake or sludge resulting from filter press or sedimentation basin, respectively. They just dispose of it, specifically, 67% of them dispose of it in special dumpsites while 33% dispose of it in random dumpsites.

1) Machines, Transportation and Packaging in SMI

The results showed that the average number of machines in a stone processing facility is 8 machines. The distribution of the average ages of these machines is presented in Figure 9.

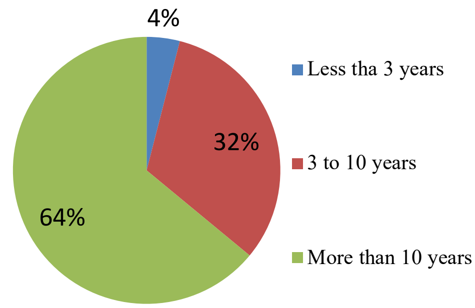

Fig. 9: Machine age distribution

The results showed that 64% of the machines being used in the SMI are more than 10 years old. This would cause larger quantities of waste to be generated, where modern machines are more sustainable in general. As for dealing with end-of-life machines and spent lubricants, about 45% of the facilities sell it as scrap, 36% dispose of it randomly around the facility area for waste pikers to take it for free, while 19% dispose of it in dedicated landfills. Stone transport is a additional source of dust and smoke generation in SMI. In the studied sample, 90% of the facilities always take into consideration that the transportation vehicle has to be compatible with the quantity to be transported. However, 50% of the facilities do not take into consideration the best time for transportation to avoid traffic rush hours, hence reduce fuel consumption and dust generation. Stone packaging is another source of waste generated by SMI. The study found that about 95% of the facilities use plastic films, plastic ropes, and wood pallets as a packaging material when transporting stones to the construction market. This packaging material is then disposed of randomly in the construction sites. Finally, from the perspective of the respondents, all sampled facilities agree that stone waste can be reduced and either reused or recycled. Also, about 68% of them are aware of the harm that stone waste may cause to the environment, and about 82% of them agree to adopt more sound waste management system at affordable extra cost in coordination with their corresponding local municipalities.

4 Practical Implications

The main goal of SMI waste management is to reduce the generated waste and its negative impact on human well-being and the environment; hence any waste management plan must consider 3 hierarchal principles [17], namely, (a) waste prevention and/or reduction, (b) waste recovery, and (c) safe disposal. Based on the results of this study and in light of stone waste management best practices mentioned in [2] and [16-21]; the following practical implications are presented to improve the efficiency of the stone cutting waste management in Palestine and help the SMI to be more sustainable.

A. Practical Implications for Stone Waste Reduction

1) Conducting exploratory tests before excavation so that stone extraction is optimized, and less waste is generated.
2) Choosing correct direction of cut in quarry to reduce waste and obtain quality stone.
3) Avoiding use of blasting as extraction method; belt and wire saws are better choice.
4) Using cutting equipment and process settings to be appropriate with type of stone.
5) Choosing thinner cutting tools whenever possible for smaller kerf.
6) Making proper cutting measures to reduce scrap; use of CNC machines is best choice for scrap minimization.
7) Reinforcing mechanically unsound stone cubes/slabs before being processed.
8) Upgrading current equipment, adopt new technologies, and employ trained workers.
9) Using decantation and pressing techniques rather than precipitation basins to minimize sludge quantities.
10) Choosing cutting/crushing machinery that produces less fines.
11) Making regular diagnosis to insure that cutting tools are not dull; worn out blades generate excessive dust and stone chips.
12) Using packaging material that can be recycled or reused; stop using plastic films, and
13) Paving the private road connected to the facility, optimizing vehicle size selection to suit transported quantity, and avoiding material transport during rush hours.

B. Practical Implications for the Recovery of Different Types of Stone-Cutting Waste

1) Defective cubes can be used to produce low price products for external use. Large irregular stones can be sold to be used for retaining walls, landscaping, and curb stone,
2) Cracked or rejected slabs can be sold as low-cost rustic flooring and stone pavers.
3) Smaller pieces of broken stones can be used for decorative purposes; architects can help in designing marketable products out of scrap stones.
4) Debris can be used as filler in quarries or in road construction projects.
5) Big factories/quarries can make profit from scrap stone by investing in a mobile crasher to produce aggregates for the construction market, including road pavement.
6) Most of the raw stone in Palestine is limestone and marble [1], hence the resulting sludge/fine waste can be reused in agriculture as a fertilizer, in artificial stone industry, in ready mix concrete industry, in paint and resin industry, in bituminous mix, and in feed industry.
7) Collecting spent oil and sell for oil re-refining plants or sell it as a burner fuel for “controlled” heat generation.
8) Out-of-service equipment can be sold for second-hand spare parts or as scrap metal.
9) Old tires can be sold to produce fuel (there is a potential in Jenin) or rubberdy flooring (there is a potential in Hebron), and
10) Using filter press instead of precipitation basin to reduce sludge (wet waste) and increase recycled water quantities, hence decrease the consumption of fresh water.

C. Practical Implications for Stone Waste Safe Disposal

1) Related authorities should pay more attention and follow up on the collection and disposal of the waste resulting from SMI and should update corresponding official regulations.
2) It is necessary for related authorities to assess the impact of current disposal sites on the environment and take the necessary actions.
3) Identifying proper locations of new disposal sites that have minimal impact on the environment.
4) Disposal sites must be close as much as possible to SMI areas for efficient material transport; they must have defined borders and surrounded by trees.
5) Solid stone waste and sludge/cake must be disposed of separately in the disposal site.
6) Temporary collection sites at factories and the permanent common disposal sites must be surrounded by drainage channels to catch possible surface runoff.
7) Waste disposal has to comply with related official regulations, penalties should be charged for any violation,
8) Raising awareness of SMI owners on the necessity of safe waste disposal and on good housekeeping.
9) Spent oils/lubricants, if to be disposed, must be stored safely in tanks and then transported to specialized plants for proper treatment, and
10) All metallic waste including damaged machine parts or broken cutting tools must be temporary stored in a non-permeable place in the factory.

5 Conclusions and Recommendations

Based on the previously mentioned analyses and results, it is concluded that the Palestinian SMIs differ with respect to their demographic profiles in terms of their geographical location and size. Also, there is a significant difference among these SMI facilities in terms of their usage of input resources (water, energy and raw stone). They also differ in their production capacities and yields of their products (building stone, marble slabs and decoration stone). Such differences imply that this sector is very heterogeneous, and the majority of its facilities are not mature and active yet in solid and liquid waste management practices. The analyses of the solid and liquid waste current management practices are done respectively, in crashers (about 90%) for solid wastes and in sedimentation basins and filter press integrated with silo (totally 94%) for liquid waste. Generally, the average number of machines in each SMI facility is eight, with the majority (64%) of them having more than 10 years of usage age. The results show that vehicles used in SMIs are not compatible with load sizes, not-environmentally-friendly in terms of dust and emissions generations and green driving behaviours, besides incompatibility with traffic non-peak hour time schedules. There is also a random disposal of packaging materials on the construction sites. The respondents reported that there is a potential for alleviating the problems of generated wastes in the SMIs via the 3Rs (reduce, recycle and reuse) strategies. They are also aware of the adverse effects of this waste on the environment and human well-being and show their willingness to adopt more effective waste management practices. Through cooperation with their local municipalities. To this end, the paper ends with some practical implications for waste reduction, recovery and disposal which would be transformed into engineering and administrative interventions that would be taken by the various relevant decision makers and stakeholders in the Palestinian SMI facilities. If implemented properly, such interventions are expected to improve the economic, environmental and social sustainable performance of this sector in Palestine.

Conflicts of Interest Statement

The authors certify that they have NO affiliations with or involvement in any organization or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript.

Acknowledgment:

The authors would like to thank the collaboration of the Stone and Marble industry in Palestine in the preparation of this work.

References

[1] H. S. Salem, Evaluation of the Stone and Marble Industry in Palestine: environmental, geological, health, socioeconomic, cultural, and legal perspectives, in view of sustainable development, *Environmental Science and Pollution Research*. 28 22, 58–80, (2021). https://doi.org/10.1007/s11356-021-12526-4

[2] A. Ramahi, H. Arman, N. Othman, F. AbuBashs, A Practical Model to Assess and Improve Sustainability in Stone and Marble Industry in the Palestinian Territories, *Journal of Applied Science and Engineering*, 25, 4, 551-566, (2021). https://doi.org/10.6180/jase.202208_25(4).0001

[3] M. Ihsheish, B. Falah. Regulating and Improving the Competitiveness of the Stone & Marble Industry: Challenges and Required Interventions. Palestine: *Palestine Economic Policy Research Institut* (MAS), 2018 https://www.mas.ps/files/server/20192301130316-1.pdf

[4] PIPA (Palestinian Investment Promotion Agency).. Stone and marble, 2020. http://www.pipa.ps/page.php?id=1aaf99y1748889Y1aaf99.

[5] PCBS, Final Results - Establishment Report, 2017. https://www.pcbs.gov.ps/Downloads/book2384.pdf.

[6] S. Qanazi, Z. Zawawi, Stone-Industry in Palestine: Bridging the Gap between Environmental Sustainability and Economical Value, *Papers in Applied Geography*, 8,1, 12-34, 2022, DOI: 10.1080/23754931.2021.1941206

[7] N. Al-Joulani, Soil contamination in Hebron District due to stone cutting industry" *Jordan Journal of Applied Science,* 10, 1, 37–50, 2008.

[8] T. Sayara, Environmental impact assessment of quarries and stone cutting industries in Palestine case study of Jammain *J. Environ. Prot. Sustain. Dev*. 2, 32-38, 2016.

[9] PALTRADE. The state of Palestine, "National Export Strategy 2014 to 2018 - Stone and Marble sector in Palestine, 2014. https://paltrade.org/uploads/16080477701846317454.pdf

[10] Kanan, Mohammad, Assessment of the COPQ due to Poor Maintenance Practices in Saudi Industry. *SSRG International Journal of Engineering Trends and Technology*, 68,11, 163-172., 2020.

[11] H. Arman, A. Ramahi, F. Abubasha, N. A. Othman, H.Safadi, and M. Kmail. Assessment of perspectives

and challenges on sustainability in Palestine. In: Berlin: GCSM, 2013.

[12] U. Sekaran, R. Bougie, Research methods for business: A skill building approach. John Wiley & Sons, 2016.

[13] G. Neirokh., Implications of Organizational Variables on Waste Management of the Stone and Marble Sector in the City of Hebron, M. thesis, Hebron University, Hebron, Palestine, 2014.

[14] A. Abu Hanieh, S.AbdElall, A. Hasan. Sustainable development of stone and marble sector in Palestine. *Journal of Cleaner Production*, 84, 581–588, 2014. doi:10.1016/j.jclepro.2013.10.045

[15] R. Krejcie, D. Determining sample size for research activities. *Educational and Psychological Measurement*, 30, 607-610, 1970.

[16] M. Mosaferi, I. Dianat, K. Iman; S. Mohammad; Mansour, S. Nemati; Fahiminia, Mohammad; A. Hashemi, A. Ahmad, . Review of environmental aspects and waste management of stone cutting and fabrication industries. *Journal of Material Cycles and Waste Management*, 16, 4, 721-730, 2014. doi:10.1007/s10163-013-0193-y

[17] N. Al-Jolani, N. Saleh, The Stone Slurry in Palestine from Environmental Burden to Economic Opportunities—Feasibility Analysis, *Journal of Environmental Protection*, 5, 1075-1090, 2014. http://dx.doi.org/10.4236/jep.2014.512106

[18] F. Mendoza, J-Manuel; C. Cinzia; P. Giorgia; J. Alejandro; R. Joan; G. Xavier, Environmental management of granite slab production from an industrial ecology standpoint. Journal of Cleaner Production, 84, 619\-628, 2014. doi:10.1016/j.jclepro.2014.03.056

[19] P. Strzałkowski, Characteristics of Waste Generated in Dimension Stone Processing, *Energies*, 14, 7232, 2021. https://doi.org/ 10.3390/en14217232

[20] G. Papantonopoulos, M. Taxiarchou, N. Bonito, K. Adam, and I. Christodoulou. A study on best available techniques for the management of stone wastes". 3rd International Conference on Sustainable Development Indicators in the Minerals Industry, Milos island, Greece, 2007.

[21] Best Practices of the Natural Stone Industry Solid Waste Management at the Quarry and Fabrication Facility. Tennessee: The University of Tennessee Center for Clean Products., 2009. https://psmc.ppu.edu/sites/default/files/REF%20-3-%20BestPractice3_SolidWasteManagement_FINAL_0.pdf