Evaluation of the Stone and Marble Industry in Palestine: environmental, geological, health, socioeconomic, cultural, and legal perspectives, in view of sustainable development

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Abstract

The Stone (limestone) and Marble (trade name) Industry (SMI) is one of the most important and active industries in Palestine, as being economically and financially rewarding and greatly beneficial to the public and private sectors. This industry, which employs about 15,000–20,000 workers, contributes 20–25% to the total industrial revenues of Palestine, and 4.5% to the total gross national product. Despite its benefits, SMI has adverse effects on public health, the environment, biodiversity, water systems (both surface and underground), green cover, and ecosystems in general, as it is considered one of the most air- water-, soil-, and noise-polluting sources. To achieve the purpose of this research paper, available data and literature are analyzed, evaluated, and used, in order to provide a comprehensive understanding of the status of SMI, in light of sustainable development. This relates to various perspectives, including limestone geology, geopolitics, socioeconomics, culture, technology, legislation, as well as climate change, acid rain, and harmful effects of the SMI scale on public health and safety, environmental well-being, and challenges facing the industry. Two field studies, carried out in northern and southern West Bank, dealing with particulate matter (PM₁, PM_{2.5}, PM₇, PM₁₀, and TSP) and environmental pollution, were analyzed, and their results were compared with each other, as well as with the World Health Organization's (WHO) guidelines. It is found that both West Bank's areas are heavily polluted, resulting in considerable adverse impacts on public health, the environment, and green cover. Based on the findings of this paper, it is recommended that SMI should properly adhere to WHO guidelines and international standards to make the industry safer and more durable and sustainable, with fewer negative impacts on public health, the environment, and green cover.

Keywords Stone (Limestone) and Marble (Trade Name) Industry · Socioeconomics, culture, and heritage · Geology · Air, water, soil, and noise pollution · Public health and environmental impacts · Sustainable industry, regulations, and law · Challenges and improvements · Palestine

The “marble” term used in the title of this paper is a trade (commercial) term, indicating the polished and finished limestone, which was naturally originated as a sedimentary rock. It is not the natural “marble” that was naturally originated as a metamorphic rock under high pressures and temperatures. Further details on this issue are given in the paper.

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Introduction

Origination of limestone and marble rocks

About 10–15% of the sedimentary rocks covering the Earth's surface are limestone (GSG 2020). These rocks and others, in various locations across the globe, are usually excavated by open-pit quarrying. Limestone, as a sedimentary rock, is a carbonate rock often composed of skeletal fragments of marine organisms, such as corals, foraminifera, and mollusks. Its major ingredients are the calcite and aragonite minerals, which have different crystal forms of calcium carbonate (CaCO₃). A closely related rock to limestone is dolomite, which is also a

carbonate sedimentary rock, but contains a high percentage of the dolomite mineral ($\text{CaMg}(\text{CO}_3)_2$). Limestone and dolomite that belong to the same rock's group (sedimentary carbonates) share usually the same color that ranges from white-to-gray to white-to-light brown, and sometimes yellowish, pink, or rosy. Marble, on the other hand, is originally a natural limestone rock that is primarily composed of carbonate minerals (calcite, aragonite, and dolomite). Marble is a metamorphic rock, originated through the metamorphism process under high pressures and temperatures, transforming the sedimentary rock—limestone—into the metamorphic rock—marble. The color of marble is usually white-to-light gray, and sometimes bluish, dark gray, pink, or yellowish. Notably, the “marble” term, included in the Palestinian industry's name—Stone and Marble Industry (SMI), as being the focus of this paper—is widely and wrongly used in Palestine as a trade or commercial term rather than a scientific name. However, the metamorphic rock—marble—is not exposed in Palestine as an outcrop rock, and if used at small scales in Palestine, it is imported from abroad. Figure 1 shows two examples of polished limestone (sedimentary rock—Fig. 1a) and polished marble (metamorphic rock—Fig. 1b), whereas both of them are used for decorative purposes.

Usages of sedimentary limestone and metamorphic marble

Both types of rocks (sedimentary limestone and metamorphic marble) have several usages. They are often used for both construction and decoration purposes (Fig. 1a, b), due to their beautiful coloration and glossy finish. There are two main types of building stones, which are dimension stone and decorative stone. Dimension stone is often extracted and prepared in blocks, according to standard specifications, and can be used without much processing; while decorative stone, after quarrying, is cut and/or carved to improve its appearance. Decorative stone is often used in indoor construction for decoration and monuments rather than as standard building

material. These two types of rocks are used in building construction, due to their good properties, such as durability, attractiveness, and economy. They have been used for centuries to create iconic buildings in many cities around the world. It is often associated with luxury and extravagance, and as such it is used in many stately buildings, memorial buildings, and monuments. These include mosques, churches, cathedrals, temples, cemeteries, theaters, universities, public libraries, palaces, villas, hotels, malls, and so forth. For example, marble was used in famous buildings, including the Taj Mahal in Agra, India; Parthenon in Athens, Greece; and the US' Supreme Court in Washington, DC, USA. These two types of rocks (limestone and marble) are not only used for construction and decoration purposes, but their global markets can be segmented into several fields, including architecture, agriculture, pharmaceuticals, and others. However, construction is the main consumer of both types of rocks, as they are used in various applications, including laying sidewalks, stairs, kitchen platforms, floors, sculpture, and exterior walls. Depending on the shape, limestone and marble products can be separated into widely used slabs and powders. The slabs are formed and shaped into tiles and blocks for suitable usages. Hence, stone markets in some countries around the world are booming, due to the great demand on both types of rocks. Also, the numerous applications and usages of both types of rocks have led to an increased demand for them, globally. The global demand for these two types of rocks is increasing, especially in the construction industry due to their aesthetics, such as beauty and sculpture, and their importance in other industries. The rapid growth of the construction industry, in particular, in many countries around the world is likely to increase the demand for both types of rocks—sedimentary limestone and metamorphic marble.

Global importance of Stone and Marble Industry

SMI is a big industry and considered one of the oldest industries, worldwide. It is part of the primary sectors of the

Fig. 1 **a** Brown oolitic (fossiliferous) sedimentary limestone (known as biomicrite) (after The MGC 2020). **b** White metamorphic marble with grayish veins (after Atlas MST 2020)

Table 1 A review of some previous studies, conducted in 10 developing countries of the world, during the period of 2006–2020, on air pollution and its impacts on public health and the environment, caused by the Stone and Marble Industry (SMI), as well as by the mining industry, in general

Purpose	Investigations/results	Studies
Investigated the health impacts of stone crushing in India.	Dust from stone crushing activities contains a large amount of inhalable material. The impact of particulate matter (PM) can be disproportionately large, even though PM only makes up a small fraction of the total suspended particles. The presence of high silica content in the dust indicates that the occupational environment of the workers and surrounding areas may be dangerous to human health. The air quality and sanitary survey conducted at the site indicated that the observed dust may cause significant damage to the health of the respiratory system of workers and others affected. The study, through a combination of an extensive air quality assessment and a limited set of health assessments, indicated the imminent need for a comprehensive occupational and environmental health management's strategy for this type of basic industry. It is hoped, however, that the information provided in the study will be used to provide additional impetus for environmental policy measures for the SMI's sector. The results showed high elevations in particulate air pollution, resulting from exposure under certain environmental and/or working conditions. Exposure of workers and their families to PM has the potential to impair lung function over a short period of time. Simple measures are needed to reduce exposure to PM from both occupational sources and the use of biomass fuels in homes in screened and similar sites. It is found that the overall environmental and local exposures to particles of 2.5 μm or less ($\leq \text{PM}_{2.5}$) were high.	Sivacoumar et al. (2006)
Health screening of workers involved in the stone industry in India, as they are exposed to breathable crystalline silica and a number of other particles in both occupational and domestic conditions.	Stone extraction and crushing involve a variety of processes that create exposure to a wide range of physical, chemical, and ergonomic hazards. Quarrying, drilling, blasting, breaking, loading, unloading, overhauling, crushing, and screening are just a few of these operations that work in all units, regardless of their size. Dust emissions represent considerable health risks to the workers involved in this industry, as well as to the inhabitants of local communities. Accordingly, the situation of occupational health and safety in this sector needs to be greatly improved.	Sample et al. (2008)
Investigated the benefits of adopting “environmental health” to recommend, implement, and create a framework for sustainable interventions that would contribute to reducing the environmental and occupational health risks faced by stone industry and the communities involved in it, and are affected by the industry in India.	It was found that the PM emitted into the air, especially particles of $\leq \text{PM}_{2.5}$, is one of the main causes of poor health in Pakistan. The particles can be suspended in the air for long periods of time. Some particles are emitted directly into the air. They come from a variety of sources, such as exhausts of cars, factories, construction sites, plowed fields, unpaved roads, stone crushing, and wood burning. Particulate matter can also be formed by atmospheric conversion of sulfur dioxide and nitrogen oxides to sulfates and nitrates. There is strong scientific evidence that high concentrations of nanoparticles of 1 μm or less ($\leq \text{PM}_1$) and microparticles ($\leq \text{PM}_{2.5}$) pose greater health risks than even particles of 10 μm or less ($\leq \text{PM}_{10}$). However, no systematic monitoring information about PM_1 or $\text{PM}_{2.5}$ is presently available in Pakistan.	Lakshmi and Balakrishnan (2009)
Evaluated the environmental impacts of air pollution sources in Pakistan, including those caused by stone industry.	Soil and water samples were collected at different locations in and around the study areas, in order to undertake laboratory analyses. Soil samples were analyzed for the determination of macronutrients and micronutrients, while water samples were analyzed for determination of the pH and several chemical constituents. The results obtained revealed that most of the deficiencies observed in chemical analyses of soil and water samples from the study areas have no direct link with previous mining operations carried out in the study areas. It was also revealed that the abandoned quarries of granite rocks have more of physical constraints than the chemical constraints.	The World Bank (2012)
Evaluated the environmental impacts of abandoned quarrying sites in Ibadan, Nigeria.	Chemical composition of quarry dust and the concentration of silica and heavy metals (chromium, cadmium, and lead) were performed using standard laboratory procedures. A questionnaire was sent to the workers to know the occupational safety, health risks, and the workers awareness' levels of those risks. The study revealed that the quarry workers' awareness of safety and health risks reached 94.5%, but only 16.5% used	Akande et al. (2013)
Aimed to know the occupational health risks that dust poses to quarry workers in Kajiado County, Kenya. The specific objectives of the study were to know the chemical composition of the limestone, phonolite, and pozzolana quarry dusts; concentrations of silica, chromium, cadmium, and lead in		Halwenge (2015)

Table 1 (continued)

Purpose	Investigations/results	Studies
the dust; and to assess the awareness of quarry workers of safety and health risks in those quarries.	<p>protective clothing. The study concluded that dust concentrations failed to meet Occupational Safety and Health Administration (OSHA) standards, thus putting workers at risk of developing respiratory, skin, and eye problems. Measures are recommended to mitigate the generation of high dust in quarries. Thus, workers should be educated to use protective clothing during work. Also, clinical research should be carried out on quarry workers to confirm any development of silicosis.</p> <p>The largest quarries in northern Jordan are located in urban areas. Due to the limestone quarrying activities (such as drilling, blasting, exploration, and transportation), a primary source of increased level of PM_{10} was observed, which has led to air pollution of the surrounding areas. The results showed that the PM_{10} concentration in the winter times during working days was equal to or less than the Jordanian standards. Meanwhile, in the summer times during working days, the PM_{10} concentration was higher than the Jordanian standards.</p>	Titi et al. (2015)
Studied the environmental effects of open-cast mining of limestone quarries in Irbid area, north of Jordan.	<p>A questionnaire survey was conducted in the Stone Crushing Industrial Zone of Sargodha, Pakistan, in order to assess their adverse health and socioeconomic impacts on workers involved in various activities of the stone industry, including crushing and production. The results of the survey showed that the majority of workers (94%) did not have any personal protective equipment. This means that most workers, while working in a polluted industrial environment, do not have a protection facility provided by their employers. The health impacts of the industry's workers included hearing problems (82%), skin irritation (75%), and respiratory problems (69%). Most of the workers of this industry receive salaries within the range of PKR (Pakistani Rupees) 8000–10,000/month (USD 50–63/month). This monthly salary is much less than the minimum monthly salary that the Government of Pakistan sets for unskilled workers. It was concluded that the stone crushing industry has adverse effects on the health of workers and, thus, there is an urgent need to provide training and personal protective equipment for them to reduce the health effects.</p>	Khan et al. (2016)
The stone crushing industry is a dominant but still unregulated sector in Pakistan. Its various processes have caused significant environmental impacts, including air and noise pollution, in addition to the effects of remote vibrations.	<p>Huge plant losses from unsustainable quarrying practices limit the role that vegetation plays in mitigating the global impacts of climate change. The study was conducted in Ebony State, Nigeria, where mining activities of 27 quarry sites in 6 local governmental areas operate. The results showed that the visual interpretation of the satellite images confirmed that the white spots on the images were areas affected badly by intensive quarrying activities.</p> <p>The stone dust generated from the crusher units (10–11 t/day) is not only harmful to human's health, but also to other valuable components of the environment, such as air, water, soil, and green cover (forests and vegetation). As a result, the temperature increases by 1–1.5 °C; the concentration of PM_{10} was $> 180 \mu g/m^3$ in the lower atmosphere; health of vegetation was badly deteriorated; the soils were specifically degraded, as they became highly alkaline and with low organic carbon; the water quality was badly deteriorated (i.e., high chemical oxygen demand (COD) and biochemical oxygen demand (BOD), and low dissolved oxygen); loss of 15–60% of agricultural productivity; loss of fish productivity; and noise emissions exceeding the maximum permissible specified (> 85 dBA). Also, some other things were very evident, including encrusting of the Dwarka River's bed, and the deterioration of the river's water quality.</p>	Akanwa et al. (2017)
Investigated the effects of rock quarries on green cover (vegetation and trees), using high-resolution satellite imagery and geographic information system (GIS) in Ebony State, Nigeria.	<p>A scientific literature search was conducted to know the licensing processes in other countries, and to compare them with the Brazilian reality. Regarding the Brazilian mining and stone industries, it was observed that although all the legal steps for obtaining licenses were met,</p>	Pal and Mandal (2017, 2019)
Explored the impacts of stone mining and crushing on environmental components in the catchment area of the Dwarka River Basin, eastern India.	<p>Aimed at analyzing the environmental impacts of three stone industries located in Monsenhor Gil, Piauí, Brazil,</p>	Monteiro and da Silva (2018)

Table 1 (continued)

Purpose	Investigations/results	Studies
with the focus on the potential of obtaining environmental and mineral exploration licenses.		
Investigated the large amounts of stone waste generated and dumped, which have led to environmental risks in Iran.	the environmental reports failed. This is because of the lack of a multidisciplinary team, and the fact that some data differ from reality, reducing the credibility of assessing the environmental impacts caused by the mining and stone industry. The stone industry waste can be used in various forms in different industries, especially construction and other industrial activities, such as paper, rubber, paints, medicine, ceramics, and glass. In addition, most of the stone industry waste can be used to improve agricultural soils. An important method for reusing stone waste is the one that can replace concrete. Investigations were carried out to study stone-waste management and the feasibility of reusing it in the concrete industry in Iran.	Reihani et al. (2018)
Investigated various problems affecting the stone industry in Ukraine, with the aim of defining the importance of this industry and its long-term sustainable outlook. Carried out a qualitative analysis of the impacts of the quarrying industry in the municipality of Wenchui, Ghana.	Investigated the current problems facing the stone industry in Ukraine, and proposed changes to improve the industry, in order to increase the competitiveness of the Ukrainian dimension stone in the international market. Information was collected from 90 households. The results indicated that the stone industry has positive and negative impacts on the economic, social, and environmental aspects of the Wenchui municipality, Ghana. Some of the positive effects include the support of local communities in providing social facilities and infrastructure. Some negative impacts were detected, namely soil degradation and loss of topsoil, pollution and vibration, as well as the development of cracks in buildings. Despite the negative impacts, the positive impacts seem to outweigh the negative ones, due to the corporate mitigation measures. It was concluded that quarrying has contributed to the socio-economic development of the Wenchui municipality in Ghana. The Environmental Protection Agency and the local council should monitor the companies regularly to ensure strict adherence to mitigation measures. Moreover, occupational safety and awareness programs, as well as medical and workers' screening should be implemented.	Filipova and Rasputna (2018) Baah-Ennumh et al. (2019)
Assessed environmental policies for the rehabilitation and sustainable restoration of the Mayo-Darlé mining sites, Adamawa region, Cameroon.	Investigated the limitations and lapses of national environmental protection policies, regarding abandoned mining sites in Mayo-Darlé, Cameroon. Attempted to model the socio-economic and environmental impacts in a sustainable manner. Proposed the prescription of a green network to encourage artisanal sustainable practices within mining fields. This “eco-sustainable” strategy should be specific to mine site’s development. The implementation of measures outlined in the proposed policy should considerably improve environmental conditions around the mining sites. This should involve the establishment of a rehabilitation plan and realistic restoration of the Mayo Darlé site for good preservation of the environment.	Essapo and Ekeddi (2020)
Investigated environmental impacts of stone quarrying on two river basins in southwestern Ghats, India.	Revealed that about 6.75×10^6 t/year of hard rocks are being extracted in the Netravati-Gurpur Basin, India, through 64 quarries. At the same time, the total number of quarries in the Periyar-Chalakudy River Basin, India, is 525, producing 10.47×10^6 t/year of rocks. Many of the hills in the area have turned into a group of ugly scars, degrading the environment and aesthetics of the area. Decline in groundwater levels, modification or disappearance of natural drainage, and environmental pollution are some of the other observations noticed in the investigated areas. The study emphasized the need for environmentally friendly quarrying alternatives with strict guidelines to improve the overall environmental quality of the region, on the one hand, and to meet the development requirements, on the other.	Vandana et al. (2020)

economy in many countries around the world, which is concerned with excavation of rocks, similar to the mining industry concerned with excavation of metals and minerals. SMI is a rewarding industry, economically and financially, as it brings large revenues to the coffers of governments, and provides employment opportunities to a great number of workers in various areas of the industry and other related industries, as well. These include quarrying; stone cutting, polishing, and finishing; home building; and decorating, in addition to the SMI's functional applications.

In 2017, Turkey, China, Italy, Greece, and Spain exported almost 78% of the global value and quantity of SMI's products, including marble blocks and finished marble products, with a total amount of ≈ 17 million ton and a total value of $\approx$ USD 7 billion (Stone News 2018). Turkey has become the largest exporter of SMI's products, worldwide, with a total amount of around 8 million ton and a total value of $\approx$ USD 2 billion (Stone News 2018). China, on the other hand, is the largest importer of marble blocks, and, at the same time, the largest exporter of finished marble products, worldwide. China absorbs most of the marble blocks, processes them, and then exports them at higher prices than the other four countries: Turkey, Italy, Greece, and Spain.

SMI is among the 50 largest and most influential markets in the world, including the global construction industry (PR Newswire 2015). The construction industry is projected to grow, globally, from USD 7.4 trillion in 2010 to USD 8.5 trillion in 2015, and to USD 10.3 trillion in 2020 (PR Newswire 2015). The construction's industry in the Middle East and North Africa (MENA) region, including Palestine, is predicted to be the fastest growing industry in 2016–2020, overtaking the Asia-Pacific region that held the top spot in 2011–2015. This reflects large investment in the infrastructure and building sectors that are taking place in the Gulf Corporation Council's (GCC) states, particularly Qatar, Saudi Arabia, and the United Arab Emirates (UAE), and to a lesser extent, Kuwait, Bahrain, and Oman, to which (all of the GCC states) Palestine exports some of its SMI's products (dimension stone and decorative stone), considering the fact that the major exports of the Palestinian SMI's products are still going to Israel.

Review of some previous studies on SMI in other regions of the world

While this industry—SMI—is greatly important, due to the fact that all kinds of rocks are available across the world, and most, if not all, of the countries benefit from this industry and its different products, along with the excavation of minerals and metals, researchers have studied SMI, with respect to various perspectives. These, for instance, include the industry's impacts (positive and negative) on socioeconomics,

the environment, public health, and green cover. Researchers have also studied the potential of rehabilitation of old and abandoned quarrying and mining sites, in addition to some of the laws and regulations that should control the industry, as well as the problems and challenges facing it. Table 1 presents some of the studies carried out in the last few years (2006–2020) on the stone and marble industry, as well as on the mining industry, in general, in 10 developing countries, similar to Palestine. These include India, Pakistan, Kenya, Jordan, Nigeria, Brazil, Iran, Ukraine, Ghana, and Cameroon. Some other studies are cited in various locations of the present paper.

Study purpose

The purpose of this study is to investigate, analyze, and evaluate the status of SMI in Palestine, in terms of various perspectives, including geology, culture, socioeconomics, the environment, health, and legislation, with respect to SMI's sustainable development. Available data and literature were analyzed, technically, culturally, environmentally, socioeconomically, health-wise, and legislation-wise. Also, some interviews were conducted with people living in the investigated areas. Particular emphasis is directed towards environmental and health impacts of the industry—SMI. It is noteworthy to mention that such environmental and health impacts were given very little attention by the Palestinian Government, as well as by researchers in Palestine. Most of the work published on the Palestinian SMI has focused on the SMI's positive impacts, particularly, the economic and financial ones. Therefore, this paper is the first of its kind, as it critically investigates, analyzes, and discusses several of the SMI's perspectives, mentioned above. Statistically, the data available on SMI in Palestine indicates that the published work in internationally peer-reviewed periodicals is very little, though some Palestinian universities are directly involved in SMI. However, some technical reports about the economic dimension of SMI are made available by local and international organizations.

The environmental economics as related to pollution trend caused by SMI is considerably high. This is in terms of the damages and adverse impacts caused by SMI to the environment, public health, and green cover. This can be attributed to the lack of control and monitoring system on the industry, and due to the lack of law enforcement. This requires from the Palestinian ministries and institutions in charge to undertake an evaluation of such damages and impacts resulted from the air, water, soil, and noise pollution caused by SMI. In view of this, some strategies are needed to be implemented, regarding SMI, in order to improve the industry, to make it environmentally friendly, and with less adverse impacts to the environment, public health, and green cover. At the same time, it is needed to keep SMI greatly productive and rewarding,

Fig. 2 **a** View of exposed limestone in Bethlehem area, West Bank, Palestine (after Hastings 2020). **b, c** Limestone quarries in the West Bank, Palestine (after Stone Contact 2020)

economically and financially, so that the private sector (companies, families, and communities) and the public sector (in terms of tax revenues) can greatly benefit from it. While the evidence from environmental and health points of view shows that pollution caused by SMI imposes an economic cost to the Palestinian society, urgent steps should be taken to control the sources of pollution originated from SMI. However, if nothing would be done to improve the industry, with respect to its laws and regulations, as well as to short-term and long-term strategies, the SMI's impacts will be devastating. This is particularly important in view of climate change impacts (higher temperatures, less precipitation, etc.), as well as the widespread of infectious diseases, such as Covid-19 and others.

Globally, the current estimates of the joint effects of ambient and household air pollution include an estimated 7 million premature deaths each year, representing one in eight of the total deaths, worldwide. On the economic side, as of 2010, the annual economic cost of premature deaths from air pollution across the countries of the WHO European Region stood at USD 1.431 trillion, and the overall annual economic cost of health impacts and mortality from air pollution, including estimates for morbidity costs, stood at USD 1.575 trillion (WHO ROE and OECD 2015).

Fig. 3 Beautiful plate made from the Jerusalem (Al-Quds) Limestone (after Al Ramah 2015)

Results and discussion

Geology of limestone in Palestine

Briefly, the geology of Historic Palestine includes deep Arabian Shield metamorphic rocks, overlain by sedimentary rocks that include sandstone, limestone, dolomite, gypsum, and clay from the Paleozoic, Mesozoic, and Cenozoic Geologic Eras (Orr 1915; Lowenstam 1942; Hudleston 2013). The outcrops in the West Bank, as being part of Historic Palestine, are mainly composed of limestone, dolomite, and dolomitic limestone rocks of Upper Cretaceous age, underlain by Nubian sandstone of Lower Cretaceous age (Orr 1915), ranging in color from white to pink, yellow, and tawny. Though there are some sandstone and dolomite outcrops, the land's surface of Palestine is covered mainly by limestone (Fig. 2a).

The outcrops of this rock—limestone—form the backbone of the mountainous and hilly areas, extending from northern to southern West Bank. The geological group of this rock is about 800 m (2625 ft) thick, composed of rich marine fossil assemblages of limestone, intercalated with dolomite, marl, chalk, and claystone, as well as some siliceous rocks in the form of chert nodules and quartz geodes (Snelling 2010). The limestone's outcrops in Palestine are collectively known as

Fig. 4 Some of the magnificent structures and masterpiece monuments, built from limestone, in the cities of Jerusalem (Al-Quds), Bethlehem (Beit Lahem), and Hebron (Al-Khalil), West Bank, Palestine, including **a** The Damascus Gate (also known as “Bab Al-Aamoud”), as being part of the Jerusalem’s Wall, surrounding the Old City of East Jerusalem, Palestine (after Lee 2020a); **b** Al-Aqsa Mosque (Al-Masjid Al-Aqsa), East Jerusalem, Palestine (after SamaNews 2017); **c** a landscape view of the Al-Haram Al-Qudsi Al-Sharif’s Compound, showing the Dome of the Rock (Qubbat As-Sakhrah) and the Al-Aqsa Mosque, East Jerusalem, Palestine (after 123RF 2020); **d** Tiled Façade of the Dome of the Rock, East Jerusalem, Palestine (after Wikipedia 2020a); **e**, **f** two views of the Church of the Nativity (Kanisat Al-Mahd), Bethlehem, Palestine (after Lee 2020b; Wikipedia 2020b); **g** The Church of the Holy Sepulchre (Kanisat Al-Qeyamah), East Jerusalem, Palestine (after BWC 2020); and **h** the Tomb of the Patriarchs (Al-Haram Al-Ibrahimi Ash-Sharif), Hebron, Palestine (after LMB 2020)

“Jerusalem (Al-Quds) Stone,” “Holy Land Stone,” or “Palestine Stone,” so that any rock excavated in Historic Palestine, used for construction and decoration purposes, bears any of these three names or all of them.

This discussion on the geology of limestone in Palestine helps improve the ambiguity and misunderstanding of the nature of limestone that is used in the SMI in Palestine, and of the nature of marble that was originated as a metamorphic rock, which is not existing in Palestine as an outcrop rock. So, it is believed that to avoid confusion and misunderstanding in terminology, the most appropriate name for this industry should be “Limestone Industry (LSI),” covering all activities and operations related to this industry in Palestine.

Palestinian limestone’s contributions to construction, culture, and heritage

Hundreds of quarries exist in Palestine, particularly in the occupied West Bank, for the purpose of limestone’s excavation (Fig. 2b, c). Quarries in Palestine have traditionally

produced blocks, slabs, building stones, decorative stones, and tiles. In northern Palestine, high-quality limestone has been excavated and used for the external cladding of buildings. The quality of limestone found in southern West Bank is comparatively different, so that it has been used in the form of hard polished limestone, which is commercially and wrongly called “marble,” as indicated above.

The glory of the limestone’s industry in Palestine illustrates knowledge, magnificence, creativity, ingeniousness, cultural sophistication, preserved heritage, and architectural wealth of the Palestinian people and their culture and civilizations throughout history (Fig. 3).

The Jerusalem (Al-Quds) Limestone (Fig. 3) is hard and generally pure, white to yellowish in color, durable, and fine-grained rock of good quality that has been used by Palestinians, over three Millennia, in building their homes and some remarkable structures in the country. These include a numerous number of cultural, historic, and heritage sites in the cities of Akko, Jaffa, Nazareth, Nablus, Jerusalem, Bethlehem, Hebron, Jericho, and many other Palestinian cities and towns throughout the several civilizations that took place in Palestine. Some examples are shown in Fig. 4a–h.

Economics of SMI

SMI is one of the largest industries in Palestine, as it provides 4% of the global production and generates USD 400–450 million in total revenues, annually. It employs around 15,000–20,000 full-time workers, dispersed in ≈1200–1700 (1500, on average) quarries, stone-cutting facilities, workshops, and crushers, existing in several governorates of the West Bank and Gaza Strip (USM 2011; Paltrade 2013; Hulileh 2017; Ihsheish and Falah 2018) (Fig. 5a, b). Notably, the Gaza Strip has only sand quarries.

Fig. 5 **a** Distribution of stone facilities in Palestine in 2013: blue: stone-cutting facilities (615), red: stone workshops (283), green: quarries (265), and violet: crushers (51) (after Al-Joulani and Salah 2014; Hushaysh

2014). **b** Distribution of quarries, stone-cutting facilities (factories), and workshops among the Palestinian governorates in the West Bank and Gaza Strip (after Abu Hanieh et al. 2014)

Fig. 6 a–f Examples of the wet and dry limestone slurry waste (LSW), generated from quarrying and stone-cutting sites, flowing to agricultural and residential areas in different localities of the West Bank (after Al-Joulani 2008; Salem 2015; DAAR 2020)

According to the National Export Strategy, limestone in Palestine has become, for many years now, as a national reserve with an estimated value of around USD 30 billion, reflecting an enormous export potential, future-wise (USM 2011; Paltrade 2013; Ghattas et al. 2016; Hulileh 2017). SMI is greatly a rewarding sector to the Palestinian gross national product (GNP), as being one of the top exporting

industries, with exports reached $\approx$ USD 214 million in value in 2017, accounting for 20–25% of all Palestinian exports, whereas Israel is a major export destination (as indicated above), taking in 75% of the total exports of the industry (PCBS 2018). During the 1990s, SMI's production grew at an average annual rate of 7.3% to reach an annual sale of USD 450 million. In the following years, SMI has shown, on

Table 2 Measurements of particulate matter (PM) (in $\mu\text{g}/\text{m}^3$) for the Beit Fajjar area, southern West Bank, and for the Jammain area, northern West Bank, Palestine, compared with the WHO guidelines

	$\leq \text{PM}_{10}$ ($\mu\text{g}/\text{m}^3$)	$\leq \text{PM}_{2.5}$ ($\mu\text{g}/\text{m}^3$)	$\leq \text{PM}_{10}$ ($\mu\text{g}/\text{m}^3$)	$\leq \text{PM}_{2.5}$ ($\mu\text{g}/\text{m}^3$)	TSP ($\mu\text{g}/\text{m}^3$)
Beit Fajjar (southern West Bank) ^a	0.0–2.0	5.3–17.0	32.7–237.0	24.7–441.5	273.3–724.0
Jammain (northern West Bank) ^b	3.6–6.9	34.4–79.2	236.7–651.6	325.0–1079.7	418.8–1535.9
WHO Air Quality Guidelines ^c	?	10–25	?	20–50	60–80

^a Data obtained from Vieli et al. (2009)

^b Data obtained from Sayara et al. (2016)

^c WHO standard values: The lower limits denote annual values, and the upper limits denote 24-h values. The WHO guidelines for PM_{10} and $\text{PM}_{2.5}$ are unavailable (after WHO 2005a; WHO 2005b; WHO 2018)

average, a yearly growth rate of 8.7% (Paltrade 2013; Hulileh 2017). However, despite the fact that the Palestinian economy is currently in a slow decline, investment opportunities continue to exist. These opportunities can be found in real estate development, light manufacturing, agriculture, and agro-industry. Information technology, the stone and marble industry, and tourism also remain promising areas for growth (USDS 2019). Nevertheless, due to the crises of the coronavirus (COVID-19), some of the economic sectors, such as tourism, have completely stopped (PMA 2020), and some others are continuously slowing down, especially SMI, as it has stopped its products' exportation.

Geopolitics of SMI

The main centers of SMI are in the regions of Nablus and Jenin in the northern parts of the occupied West Bank (OWB), in the regions of Ramallah in the middle of the OWB, and in the regions of Bethlehem and Hebron in the southern parts of the OWB (Fig. 5b), considering the fact that most of the quarries are located in *area C*. According to the Oslo Agreements signed in 1993/1995 between the Israeli and Palestinian leaderships, the OWB was divided into *area A* (forming about 18% of the OWB and is controlled by the Palestinian National Authority (PNA), security-wise and administration-wise), *area B* (forming about 22% of the OWB and is controlled by the PNA, administration-wise and by the Israeli Occupation Authorities (IOA), security-wise), and *area C* (forming about 60% of the OWB, and is totally controlled by the IOA, administration-wise and security-wise) (Salem 2019a; Salem 2020). Most of the quarrying sites and the major natural rock reserves are located in *area C*, whereas the PNA presumably imposes a ban on quarrying in densely populated regions located in *area A* and *area B*. According to a representative of the union of SMI in Palestine, the industry struggles from a set of different challenges, many of which are common to all Palestinian industries, such as those created by the Israeli Occupation Authorities. The major natural rock reserves are located in the Israeli-controlled *area C*, where acquiring permits for opening new quarries is extremely difficult and close to impossible. The SMI will soon face severe problems if quarries are unable to expand into *area C*, because the currently accessible reserves in *area A* and *area B* are being depleted (TPT 2019).

SMI's impacts on public health and the environment

SMI in Palestine has severely and adversely impacted the public health, including health of the workers involved directly in the industry itself, and health of the population living in SMI's neighborhoods, as well as the well-being of the surrounding environment and ecosystems. These impacts result from rock quarrying and crushing operations in open areas,

cutting and polishing of massive rock blocks in stone-cutting plants, pulverization, chemical alteration, and transportation of rocks, as well as from building and construction's activities. The SMI's activities result in air, water, soil, and noise pollution, in addition to their negative impacts on the green cover (trees and vegetation). Furthermore, this industry, as largely being an uncontrolled industry, has certainly increased the amounts of the waste generated from its operations, including the limestone waste (LSW).

LSW and its quantity and quality

When dealing with SMI's environmental impacts, a special attention should be given to the amount of water used during the various processes of SMI. Roughly, half a million cubic meter ($500,000 \text{ m}^3 = 0.5 \text{ MCM}$) of fresh water are used in this industry annually (Paltrade 2013). Though this water is used at various stages in the value chain of the SMI's excavation and production, the main purpose of the water consumed is to cool and lubricate the saws used to cut the massive blocks and large slabs of limestone. This large amount of fresh water is turned into an environmental hazard when mixed with the dust and powder generated from the processes of stone cutting, resulting in heavy, viscous wastewater in the form of wet mud, commonly known as "slurry" generated from the processes of cutting and shaping the limestone, with an annual quantity of around 600,000 t (600 million kg). This is in addition to the dry mud, with an annual amount of around 190,000 t (190 million kg). Additionally, the limestone's remains, resulting from the manufacturing processes, are estimated at an annual amount of about 450,000 t (450 million kg) (Al-Joulani 2008; Paltrade 2013; Al-Joulani and Salah 2014; Ihsheish and Falah 2018) (Fig. 6a–f). This means that the total solid and fluid waste generated annually from the Palestinian SMI is no less than 1.24 million ton (1.24 billion kg). If this amount of waste is multiplied by 25, it means that we have had approximately 31 million ton (31 billion kg) of waste just in the last 25 years alone. Accordingly, one can imagine the damages caused by such large amounts of waste to the public health, the environment, biodiversity, and ecosystems.

LSW contains suspensions of solids, varying between 5000 and 12,000 mg/l (Al-Joulani 2008), which (solids) consist mainly of high-purity calcium carbonate (CaCO_3) of between 94% and 98% (Al-Joulani and Salah 2014). Luckily, the hazardous heavy metals' concentration in the LSW in Palestine is very low, suggesting an inert waste (JICA 2017). The LSW, in the form of powder generated from the stone-cutting and turned into slurry when mixed with cooling water, is considerably large in volume. Approximately 49 m^3 of stone is wasted as powder when 181 m^3 of stone blocks were cut into stone slabs of 2 cm thickness, and approximately 78 m^3 of stone is wasted as powder when 365 m^3 of stone blocks were cut into stone slabs of 3 cm thickness (Alhaj 2013).

Accordingly, the quantity of stone, wasted as powder, ranges from about 21% (78/365) to about 27% (49/181) for 3-cm and 2-cm slabs' thicknesses, respectively. This indicates that an inverse relationship exists between the cutting thickness and the percentage of the generated powder waste, meaning that the less the thickness of the slabs cut, the greater the amount of the powder's waste generated.

LSW and its impacts on soil and water

The CaCO_3 , which is the major constituent of LSW, is accumulated in ditches and on the soil surfaces, causing the formation of lime-cemented hard pans that restrict the infiltration of rainwater and the penetration of roots of the plants into the soil's layer and the underlying layers, as well. The wet LSW either flows in open areas (Fig. 6c–f), causing harm to the soil and green cover, or is dumped in sewerage systems, creating blockage and damage to the pumping stations. LSW (wet and dry), generated through quarrying and cutting operations in Palestine (Fig. 6a–f), reduces soil fertility, due to changes in the pH-value, electric conductivity (EC), salinity, and total dissolved solids (TDS). According to laboratory measurements, the EC of different soil samples, contaminated by LSW, dropped by a range of 30–60%; and by adding more LSW to the soil's samples, the pH decreased from 6.72 to 6.63, meaning that it became more acidic; the TDS decreased by a range of ≈ 13 –31%; and by adding only 3% (by weight) of LSW to the investigated soil's samples, the samples' permeability (hydraulic conductivity) decreased by a range of 46–92% (Al-Joulani 2007; Al-Joulani 2008). Also, as time passing, some of the wet LSW infiltrates, at slow speed, the surface soils and subsurface layers through fissures, ruptures, and

cracks, reaching the groundwater aquifer systems and, thus, contaminating their water storage. On the other hand, when LSW becomes highly viscous, thick, and heavy, it prevents rainwater from infiltrating the surface to recharge the aquifer systems, as it considerably disturbs the physical properties of the affected soils and underlying layers and, thus, reduces the drainage system.

LSW and its impacts on air quality and green cover

After LSW got dried, fine dust and powder are blown away by the wind, covering, partially or totally, the agricultural soil and green cover, represented in the leaves and fruits of the plants (vegetation and trees). This can take place over large areas that may include agricultural lands (farms), herds, and people living in neighborhoods of the rock-quarrying sites and stone-cutting facilities. This situation gets even worse, especially in summer times, because of the high temperatures that cause higher rates of evaporation, making the stone's dust and powder's particulates go into the air, causing air pollution, and, in turn, resulting in public health and environmental problems, as also reported by researchers in other parts of the world (Table 1).

Results of two previous studies are analyzed in this paper, in relation to the air pollution in two different localities in northern and southern West Bank. Comparisons between the results of both studies, on the one hand, and between them and the WHO guidelines, on the other, are given in Table 2.

The first study was undertaken on the air quality in Beit Fajjar village, south of the city of Bethlehem, southern West Bank (Vieli et al. 2009), and the second study was undertaken on the air quality and green cover in Jamma'in village, south of the city of Nablus, northern West Bank (Sayara et al. 2016).

Fig. 7 **a** A diagram illustrating how acid rain is formed: (1) Emissions of SO_2 and NO_x are released into the air, where (2) the pollutants are transformed into acid particles that may be transported long distances, (3) these acid particles then fall to the Earth as wet and dry deposition (dust, rain, snow, etc.), and (4) those acid particles may cause harmful effects on soil, forests, streams, and lakes (after EPA 2020). **b** NASA's spectacular image of the sandstorm swept the Middle East (started on September 8, 2015 and lasted for more than a week) (after Salem 2015)

snow, etc.), and (4) those acid particles may cause harmful effects on soil, forests, streams, and lakes (after EPA 2020). **b** NASA's spectacular image of the sandstorm swept the Middle East (started on September 8, 2015 and lasted for more than a week) (after Salem 2015)

Both studies carried out measurements for different localities in each of the areas investigated, with respect to rock-quarrying sites and stone-cutting plants in both areas. The ground distance between the operational rock-quarrying sites and the stone-cutting plants, on the one hand, and the air-quality monitoring devices, on the other, is in the range of hundreds of meters. Those in situ monitoring processes included measurements of the particulate matter with all sizes (PM_s) and the total suspended particulates (TSP) in $\mu g/m^3$ ($\mu g = 0.001\text{ mg}$). The PM_s included measurements of $1\text{ }\mu m$ or less in diameter ($\leq PM_{10}$), $2.5\text{ }\mu m$ or less in diameter ($\leq PM_{2.5}$), $7\text{ }\mu m$ or less in diameter ($\leq PM_7$), and $10\text{ }\mu m$ or less in diameter ($\leq PM_{10}$) (Table 2).

Table 2, summarizing the results of the two studies, indicates that both areas investigated are highly polluted. However, the sites investigated in Beit Fajjar, southern West Bank, are less polluted than those investigated in Jammain, northern West Bank. It is noteworthy to mention that the Beit Fajjar's study was undertaken in mid-March 2009, while the

Jammain's study is not known when it was undertaken. Furthermore, the measurements' results for both areas show wide differences, in relation to the WHO guidelines for $PM_{2.5}$, PM_{10} , and TSP (Table 2). Table 2 also indicates that the emitted particulates from the limestone quarries in both investigated areas are believed to be comparatively big, as the readings increase gradually and obviously from PM_1 to $PM_{2.5}$ to PM_7 , and to PM_{10} . This could be an indication that the particulates emitted by the investigated rock-quarrying sites and stone-cutting plants are not carried on very long distances. This situation generally depends on the weather conditions, mainly wind speed and humidity, as well as whether it was raining or not at the time of measurements. The results given in Table 2 suggest that the very high concentrations of PM_s and TSP in both areas of investigation represent real problems, regarding public health, including the health of workers who are directly working on sites, and the health of population who are living in the near neighborhoods, as well as the well-being of the environment, ecosystems, and green cover.

Fig. 8 Images of Palestinian workers doing heavy jobs at various SMI's operational sites in the West Bank, Palestine, including **a–c** dangerous performance of handling massive blocks of rocks during the processes of stone cutting (after Salem 2015); **d** transportation of large blocks of limestone from the Yatta quarry, Yatta, Hebron Governorate, southern West Bank (after Stone Add 2020); **e** Palestinian worker dealing with quarried

massive rocks of limestone used for construction in the new Rawabi City, Ramallah Governorate, West Bank, Palestine (after USA Today 2014); **f** Palestinian worker using hand tools for stone decoration, Bethlehem (after Salem 2015); and **g** stone and marble (commercial name for limestone) workshop near the West Bank's City of Bethlehem, providing raw material to a factory in the Hebron City (after Silver 2016)

According to the results obtained from the questionnaire distributed among farmers in the Jammāin's area, 95% of the respondents stated that their yields of crops have decreased by at least 30% annually (Sayara et al. 2016). The adverse impacts of air pollution, resulting from SMI's activities, might be attributed to several factors, including (1) dust that covers the leaves of plants creates a thick white layer that decreases the total chlorophyll cells exposed to light and, thus, reduces the total photosynthetic activity; (2) dust can also reduce plant's growth (number of leaves, leaf surface and size, etc.), affecting, therefore, photosynthesis, respiration, and transpiration systems of the affected plants; (3) some released chemical compounds, accompanying the released dust from SMI, are injurious and can be considerably harmful to the plants affected; (4) dust can badly affect leaf trichomes (hairs) and, therefore, decrease the natural defense mechanisms of the affected trees and vegetation against pests and diseases; and (5) dust causes considerable degradation of the soil fertility characteristics, including changes in the physical, chemical, biological, and mechanical properties, such as the pore size (porosity), permeability, and electric conductivity of soils (as indicated above), leading to reduction of the water-holding capacity of the affected soils, which results in decreasing crops' yield over time (e.g., Hirano et al. 1990; Farmer 1993; Naik et al. 2006; Lameed and Ayodele 2010; Matsuki et al. 2016; Sett 2017). Many of these adverse impacts, affecting soils and the green cover (vegetation and trees), appeared in the Jammāin area, where the air pollution's measurements were carried out in northern West Bank (Sayara et al. 2016), and also in the Beit Fajjar area, where the air pollution measurements were carried out in southern West Bank, as discussed below.

Air pollution caused by SMI and its impacts on public health

Regarding the health impacts, air pollution can enter the thorax and cause or exacerbate chronic bronchitis, asthma, pneumonia, emphysema, lung cancer, stroke, heart disease, and both chronic and acute respiratory diseases, including lower respiratory tract diseases (Salem 2015; Salem 2017; WHO 2018; Salem 2019b; Al Nayeem et al. 2020; Enciclopedia.Com 2020). Ambient (outdoor air pollution) in cities and rural areas is estimated to cause 4.2 million premature deaths, worldwide, in 2016 (WHO 2018). Meanwhile, estimates of the joint effects of ambient and household (outdoor and indoor) air pollution include approximately 7 million premature deaths globally each year, representing 12.5% of the total deaths, worldwide (WHO ROE and OECD 2015), as indicated above.

This mortality is due to chronic exposure to small particulates, namely $\leq PM_1$ and $\leq PM_{2.5}$. While the particulates $\leq PM_7$ and $\leq PM_{10}$ can penetrate and lodge deep inside the lungs, the even more health-damaging particulates are the

finest ones ($\leq PM_1$ and $\leq PM_{2.5}$), which can penetrate the lungs' barrier and enter the blood system, causing various health problems, including cardiovascular, respiratory, and cancer diseases. The WHO adduces the particulates $\leq PM_1$ as the deadliest (group 1 carcinogens) among all sizes of PM_s , due to their finest size and ability to penetrate easily the lungs and bloodstream (WHO 2005a; WHO 2005b), and thereby, they cause DNA mutation, heart attack, and even infant mortality (EPA 2004). To reduce the impacts of air pollution, WHO (2005a, 2005b) recommended that by reducing the particulates $\leq PM_{10}$ from 70 to 20 $\mu g/m^3$ (this is by $\approx 30\%$), the air pollution-related deaths can be cut by around 15%. Therefore, the lower the air pollution's levels, the better the cardiovascular and respiratory health of the population will be, both on the short run and long run. In view of this, more research should be done in the Occupied Palestinian Territories, regarding the air pollution impacts on public health, resulting, particularly, from SMI.

SMI's waste and its contributions to acid rain and Khamsin (Khamasini) winds

As quarried limestone may contain layers of oolite, dolomite, chalk, marl, mud, and other kinds of rock deposits, as well as layers of intercalated soils, the waste generated during the rock-quarrying and stone-cutting operations may contain several chemical ingredients. These may have components that include minerals of calcium (Ca), magnesium (Mg), iron (Fe), silicon (Si), aluminum (Al), and others, as well as gases such as sulfur oxide (SO_2) and nitrogen oxides (NO_x), as happened in other regions of the world (Table 1). The presence of these pollutants in the atmosphere, especially SO_2 and NO_x , can cause acid rain, resulting from the reaction between these oxides and water, oxygen, and other chemicals in the atmosphere, forming sulfuric and nitric acids that fall to the ground as acid rain (Fig. 7a).

Kalu and Ogbonna (2019) tested some water and soil samples taken from vicinities of quarry sites in Nigeria, and found that the rainwater was acidic, containing many metallic ions. That was attributed to the suspended particulates $\leq PM_{10}$ released from quarries' dust to the air and soil. Compared with the dry season, the analyses indicated that the effect of acid rain was more evident directly at the quarry sites, and the negative environmental effects were more prevalent in the older quarry sites, due to the length of quarrying operations (Kalu and Ogbonna 2019). These observations were also noticed by Peter et al. (2018) through their study on other quarry sites in Nigeria.

Accordingly, acid rain is a form of precipitation that is significantly more acidic than normal rain or neutral water, and is often produced as a result of industrial operations, such as SMIs. If happened, acid rain can cause considerable damages to the environment and biodiversity, including fauna and

flora, as well as to surface water and groundwater. As related to the rock's quarrying and cutting operations (SMI) in Palestine, it is hard to tell if the rain is acid rain ($\text{pH} = 4.2\text{--}4.4$) or normal rain ($\text{pH} = 5.6$), because of the lack of measurements and monitoring systems.

The possible presence of the abovementioned chemicals in SMI's dust that is emitted to the atmosphere may result in further pollution to the air and, hence, it may cause the precipitation of acid rain (Fig. 7a), as already mentioned. Accordingly, it is recommended that rain samples are to be collected from some of the SMI's sites (rock quarrying and stone cutting) in Palestine, in order to be tested and to determine whether the rain in those sites is acidic or not.

Air pollution may also increase the impacts of the Khamsin (or Khamasini) winds (KWs) (Fig. 7b). However, as much as the SMI's activities intensify, the amount of SO_2 , NO_x , and CO_2 will also increase, especially in the presence of other air-polluting sources. These include other kinds of industrial activities (Salem 2009) and traffic, which can cause acid rain, and also intensify the heavy, adverse impacts of KWs. The term "Khamsin," derived from the Arabic word for "fifty," represents a 50-day period of dry, hot, sandy, silty, and dusty winds that originate mainly in the North-African deserts and move towards the Mediterranean Basin and, thus, affecting the region of the entire Basin. This 50-day period of KWs can be divided into two equal sub-periods: one in spring (from March to May) and the other in autumn (from September to November) (Philologos 2003). The KWs usually take place in these two sub-periods, but due to climate change impacts, they sometimes take place in other times of the year. When the KWs blow, causing sand, silt, and dust storms (Fig. 7b), and carrying heavy amounts of PM_{10} , their damages will be much more devastating, especially in the presence of SMI's activities. The combination of SMI's activities, KWs, and climate change impacts can result in considerable air pollution that may cause severe damages to public health, the environment, biodiversity, water systems, and ecosystems. Kittipongvises (2017) investigated the impact of SMI (limestone quarries) on climate change in Thailand, by using a life cycle assessment's approach. The study showed that the amount of process-related greenhouse gas (GHG) emissions in the SMI's operational sites were about $2.76 \text{ kg CO}_2 \text{ eq./t}$. However, the study revealed that the GHGs' emissions were mainly from the consumption of large amounts of diesel fuel to generate electricity that used to crush and grind limestone rocks. In view of this, more research should be done to investigate the linkage between the environmental pollution caused by SMI, on the one hand, and climate change impacts, on the other.

SMI's dangers

As mentioned earlier, SMI affects directly two groups of people, namely those who work in the field and in stone-cutting

plants, and those who live in neighborhoods close to SMI's operations (quarrying, drilling, crushing, cutting, polishing, finishing, decorating, transporting, etc.). As a matter of fact, some people lost their lives and others badly injured and became disabled, as being involved in this dangerous business—SMI. The residents of the village of Beit Fajjar, for instance, southern Bethlehem, which is a hub for rock-quarrying and stone-cutting businesses, and for which air pollution measurements were carried out, analyzed, interpreted, and discussed above, cannot forget the story of the three young men who died because of the lack of maintenance of a saw equipment, which caused the plate to slip out of its place and cut them into pieces, causing immediate death (Watan 2014). The other event happened, according to Watan (2014), when a young boy, under the age of 18, fell from the top of a stone-cutting plant, hit the saw machine, and was killed immediately. This happened though the Palestinian Ministry of Labor's law prevents the work of juveniles. In addition to these and other horrifying SMI's accidents, the residents of Beit Fajjar keep talking about the extinction of many fruitful trees that Beit Fajjar used to be famous of, such as olives, grapes, almonds, quince, peach, and grains—all of which used to be sold in the markets of the big cities of Bethlehem and Jerusalem. Today, Beit Fajjar's residents buy vegetables and fruits from other places of the West Bank. In brief, Beit Fajjar and other areas that host rock-quarrying and crushing sites, and stone-cutting facilities have turned into disastrous highly polluted areas, according to Palestinian residents living close to them (Watan 2014).

With reference to the images given in Fig. 8a–g and the accidents provided by Watan (2014) mentioned above, it can be concluded that the status of SMI, including rock-quarrying in the field and stone-cutting in plants or factories, is unprofessional, insecure, and, thus, unsafe. This is because the SMI's operations lack the very basic and necessary professional standards of security and safety, including devices and equipment, as well as safety regulations, in order to take the necessary cautions to protect SMI's workers and the residents living in SMI's neighborhoods. For instance, leaving an individual alone to face death, while handling such large masses of rocks, as seen in Fig. 8c, in the lack of proper machinery and equipment, in addition to the lack of alarming systems and minimum conditions for safety against air pollution, as seen in the images (a–g) given in Fig. 8, are wrong practices that need to be critically, seriously, and effectively addressed, and immediately fixed.

Law enforcement

The adverse health and environmental impacts of SMI in the Occupied Palestinian Territories are related to, among other things, the lack and weakness of laws and regulations that should control and monitor the industry. This is in addition

to the lack of adequate techniques and equipment, and the lack of environmental waste management's system. This means that proper laws and regulations should be legislated and enforced. Also, penalties should be applied against those who violate the laws and regulations in effect, in order to protect SMI's workers, public health, and the environment; to manage, in a sustainable manner, the natural resources, including limestone, as being a precious resource; and also to manage all kinds of waste generated from this industry—SMI. The lack of certain laws and regulations or the weakness in applying them, in relation to SMI in the OPT, has encouraged some people to seize lands that do not belong to them (especially in area A and area B) and to establish on those lands new quarries, crushers and/or stone-cutting plants, and also to expand the areas that they already use for their SMI's operations, without being questioned. The other problem is the irresolute governmental control over the industry—SMI—even in area A and area B, which are, as discussed above, under direct administration of the Palestinian National Authority. The provisions, concerning the licensing of quarrying activities and permitting the operations of quarrying and excavation of rocks, are expressly stipulated in the “Natural Resources Law No. 1/1999” (BZU 1999). For instance, the Fourth Chapter, Article (13) of the Natural Resources Law No. 1/1999 states, under “Search and Exploration of Natural Resources,” the following: *“No person may search, excavate, extract or exploit any natural or mineral source from the ground within the Palestinian lands, regional waters and its exclusive economic zone, except after obtaining a license to do so from the Ministry in return for a fee determined by the Ministry under a special system issued by the Ministry”* (BZU 1999).

Challenges facing SMI in palestine

Though the Palestinian SMI has entered the international market, as its products have been exported to many countries around the world, including the GCC states (as mentioned above), the industry has been facing big challenges, geopolitically, environmentally, and technically, as well as with respect to the lack of research and development's programs. These challenges and others have considerably hindered the development of SMI; weakened its strength and competitiveness (particularly since the Oslo Agreements were signed in 1993/1995 between the Israeli and Palestinian leaderships, as indicated above); and worsened the industry's circumstances and conditions.

Geopolitically The Palestinian SMI has been facing many restrictions imposed by the Israeli Occupation Authorities (IOA), which represent the most impeding challenge facing SMI in the OPT. This is due to the fact that most of the quarrying sites are located in area C, which forms more than

60% of the occupied West Bank's total area and is entirely controlled by the IOA, administration-wise and security-wise, as mentioned earlier. So, under these circumstances, this challenge forms a strategic threat that has been, actually, materialized and greatly realized since 1993/1995. The Israeli restrictions on SMI also include acquiring of new excavation's permits or renewal of the existing ones. These include heavy restrictions on excavation's facilities, tools, and equipment needed for SMI. According to the Palestinian Union of Stone and Marble (USM), acquiring permits from the IOA for excavation in new quarries is not an easy task at all (USM 2011; TPT 2019). The Palestinian owners of quarries, existing in area C, have to endure arbitrary procedures and continuous raids by the IOA, which result in heavy fines on them and confiscation of their equipment. Meanwhile, the Israeli companies, operating in area C, can quarry large amounts of rocks, freely, easily, and all the time (Ghattas et al. 2016), as well as without facing any of the IOA restrictions that are enforced on the Palestinian owners of quarries in the same area—area C.

In addition, an endogenous, national challenge facing SMI is the fact that the Israeli settlements built illegally on lands of the occupied West Bank are built with stones taken from Palestinian quarries and stone-cutting plants in the West Bank. This, in turn, prolongs the Israeli occupation of the Palestinian Territories, and strengthens the occupation's economy at the expense of the Palestinian economy which is already weak and fragile, in comparison with the Israeli economy (Khalidi and Taghdisi-Rad 2009; Kubala 2015; DAAR 2020). Moreover, SMI faces other challenges, including more predicaments and difficulties at the Israeli crossings. For instance, the process of back-to-back truck's loading and unloading impedes the transfer of products to the Israeli market and the exports to foreign destinations, and, thus, increasing shipping costs (Ihsheish and Falah 2018). By doing so, Israel strongly violates international law and treaties. It is prohibited, according to international law, to operate any kind of industries, such as the Israeli quarries existing in area C, which is due to the fact that this area is part of the West Bank occupied militarily by the Israeli Occupation Authorities in 1967. Paragraph 1 of the Principle of Permanent Sovereignty over Natural Resources (UNGA Res. 1803 (XVII)) states *“The right of peoples and nations to permanent sovereignty over their natural wealth and resources must be exercised in the interest of their national development and of the well-being of the people of the State concerned”* (UN 1962).

Technically The use of comparatively less advanced technologies to operate SMI usually results in more accidents to workers and in higher production costs, which eventually weaken the reputation and competitiveness of the industry. Pit miners still use traditional methods of quarrying, which

can lead to great losses, due to drilling in wrong places that include sites of rocks of bad quality. In addition, most, if not all, quarries and stone-cutting plants, as well as stone crushers lack modern equipment required to properly treat waste and, thus, suitable waste collection's sites are very scarce. Also, equally challenging is the lack of skilled labor with good management, planning, and marketing skills. In an effort to enhance capacity building, the Palestinian Stone and Marble Center (PSMC) was established in 2009 at the Palestine Polytechnic University (PPU), Hebron, West Bank, in cooperation with the Ministry of National Economy and the Union of Stone and Marble (USM). The PSMC aims at supplying SMI with skilled labor, and also aims at conducting the required tests for export-oriented stone products. The Center's deliverables are, unfortunately, still below expectations, according to Ihsheish and Falah (2018).

Environmentally SMI is a great source of polluting the environment, resulting in considerable levels of air, water, soil, and noise pollution, and it also harms the landscape and the green cover (vegetation and trees), biodiversity, and ecosystems, in general, as clearly discussed above. The noise and dust impacts have adversely affected the health of people, dwelling next to rock-quarrying sites and stone-cutting plants, let alone the hazards that result from the quarries that were left without restoration once the ore of limestone runs out, or if were found that the quarry site has bad quality of rocks and, thus, it was shut down at early stages of operation. For instance, a total of 87% of the studied quarries in Lebanon represents serious hazards to groundwater quality, and approximately 62% of the quarries are located in a highly unsuitable environment (Darwish et al. 2011). The situation in Lebanon, however, is not much different than that in the Occupied Palestinian Territories, though there is no data available about such issue in Palestine. Accordingly, the Palestinian governmental institutions in charge should pay attention to this issue—the rock-quarries and stone-cutting plants that are out of business—and, thus, should make every effort to rehabilitate and reuse them, effectively, for different purposes.

Lack of research and development's programs The absence of comprehensive studies on the distribution of quarries and their excavation's suitability, in terms of their physical, chemical, mechanical, and biological properties, as well as their geological, geophysical, hydrological, and hydrogeological settings and ecological dimensions, as stipulated in the Natural Resources Law (BZU 1999), has led to the deterioration of SMI over time.

Potential mechanisms to improve SMI

In view of the damages and dangers caused by the Stone and Marble Industry in Palestine, as discussed above in some

detail, the following mechanisms are suggested to improve the industry:

- (1) Make SMI a sustainable industry to benefit future generations, which may include the necessity to increase the production items and to decrease the consumption ones (Abu Hanieh et al. 2014);
- (2) legislate new laws and regulations and activate the existing ones, in order to control and monitor SMI, and work on law enforcement against those who violate the law;
- (3) reclaim the dumped areas, including the soils of SMI's neighborhoods that should be frequently reclaimed;
- (4) apply adequate soil conservational methods, like provision of garland, drains, bunds, and plantations;
- (5) build capacities to manage and deal with SMI's byproducts, including wet and dry waste, dust, powder, debris, etc.;
- (6) recycle and reuse efficiently SMI's by-products;
- (7) undertake geological, geophysical, hydrological, hydrogeological, biological, ecological, and archeological mapping and surveys to investigate the quality and quantity of the rocks and their sites before being excavated, as well as their surroundings' suitability;
- (8) perform environmental impact's assessment of SMI's operations, with respect to air, soil, water, and noise pollution, limestone's slurry waste (dry and wet), and solid waste management;
- (9) check regularly the machines (small, medium, and heavy) used in SMI's operations for the sake of safety of the workers and protection of the environment;
- (10) provide efficient safety programs, as well as health and life insurance programs to the workers involved in SMI's businesses;
- (11) conduct quarry restoration and rehabilitation mapping and surveys before the start of any quarrying operations, and also after the closure of the quarries and stone-cutting facilities when becoming abandoned, which pose hazardous effects to humans, animals, biodiversity, soils, surface water and groundwater, the environment, and ecosystems;
- (12) reduce over-extraction of ore rocks (particularly limestone in the West Bank, and sandstone in the Gaza Strip);
- (13) stop the delays in paying electricity and water bills that should be paid by SMI; and
- (14) reuse treated wastewater in SMI's operations (Salem et al. 2021), instead of using and wasting large amounts of freshwater, as indicated above.

Recommendations

The SMI in Palestine, as being not well-monitored, adjusted, controlled, and regulated, has already caused a great deal of problems, including damage to the public health and destruction of the environment, and has already put workers, local communities, and wildlife at risk. The Palestinian Government has shown disregard of Article (3) of the Natural Resources Law, which calls for carrying out research and conducting geological mapping and surveying of natural resources, including limestone that is heavily extracted by the Palestinian private sector. Limestone is also extracted by Israeli companies in the occupied West Bank, in violation of

international law. Therefore, careful use of natural resources; more monitoring, adjustment, and control of SMI's activities and operations; and effective laws and regulations are needed to be enforced, in order to make this industry less harmful to humans, animals, and biodiversity; more friendly to the environment; and more productive, durable, and sustainable. This means less water and energy consumption during operations, less pollution caused to the environment and ecological systems, more effective waste's (fluid and solid) management, and also efficient restoration and rehabilitation efforts of the quarrying sites and stone-cutting facilities after becoming exhausted, abandoned, and out of business. All of these acts can help limit the adverse impacts of SMI on humans' health and the environment, and can also lead to sustainable development of the industry and other related industries, as well.

Also, based on the studies carried out by researchers in other parts of the world and presented in this paper, the following points are recommended to be taken into account when dealing with SMI in Palestine: (1) Dust emissions from SMI represent considerable damage to the environment and health risks to the workers involved in the industry, as well as to the residents of local communities. Accordingly, a combination of extensive air quality assessment and public health assessment indicates a pressing requirement for a comprehensive occupational and environmental health management's strategy that is urgently needed for SMI. (2) There is strong scientific evidence that high concentrations of nanoparticulates ($\leq PM_1$) and microparticulates ($\leq PM_{2.5}$) pose greater health risks than other particulate matter, such as $\leq PM_7$ and $\leq PM_{10}$. It is noteworthy to mention that particulate matter is a term referring to airborne particles, including dust, dirt, soot, smoke, and liquid droplets. Systematic monitoring procedures of the particulates $\leq PM_1$ and $\leq PM_{2.5}$, specifically, should be regularly carried out at the SMI's sites. (3) Questionnaires should be distributed among SMI's workers and residents of SMI's neighborhoods to know the occupational safety, health risks, and the workers' awareness levels of those risks. (4) Based on the fact that SMI pollutes, not only the air, but also water and soil, samples of surface water, groundwater, and soil should be frequently collected at different locations in and around the SMI's sites, and laboratory analyses should be undertaken to find out the level of SMI's pollution affecting water and soil. (5) SMI's workers should be educated and well-trained on how to use protective clothing while working. Hence, there is an urgent need to provide them with training programs and personal protective equipment to reduce health impacts and safety risks affecting SMI's workers. (6) Clinical research should be carried out on SMI's workers to confirm any development of SMI's related diseases. (7) A multidisciplinary team of scientists, engineers, health care specialists, environmentalists, industrialists, economists, and other professionals concerned must be formed to conduct annual surveying on the SMI's sites, in order to check the licensing processes, and

monitor the mitigation measures related to the safety and health of the SMI's workers, the well-being of the environment and the residents living in the SMI's neighborhoods. (8) Occupational safety and awareness programs, as well as medical and workers' screening must be implemented. (9) Research must be conducted to study SMI's waste management and the feasibility of utilizing it in several industries. (10) Attempts should be done to model the socioeconomic, environmental, and health impacts, regarding SMI, in general, and the abandoned quarries and stone-cutting sites, in particular. (11) Such actions should be regularly undertaken to ensure strict adherence to the mitigation measures and the WHO guidelines. These steps, if taken, will certainly help improve SMI in Palestine and globally, and will also increase the industry's production and competitiveness in the national, regional, and global markets, which should lead to sustainable development of the industry—SMI.

Conclusions

Though mining and quarrying industries are considered a backbone for many countries around the world, these industries can also have destructive impacts on public health, the environment, and ecological systems. They have direct impacts on the countryside, in particular, as a result of the high pollution levels caused by them, and as a result of the great amounts of waste generated by them, and because of leaving on site pits and heaps of waste's material. The excavation and extraction processes of rocks, minerals, and metals can heavily cause air, water (surface and underground), soil, and noise pollution; can cause habitat's destruction and loss of biodiversity; and can badly affect the food chain, which are all reflected negatively on humans' health and well-being of the environment and ecosystems.

SMI in Palestine, that should correctly be called LSI, is generally not in a good shape, though it brings large revenues to the coffers of the Palestinian Government and the private sector involved in it, especially it nurtures the Palestinian economy very well, in terms of production, employment, and export's capability. This is due to the fact that SMI lacks good regulations and law enforcement, resulting in negative impacts on public health and the environment. SMI is one of the most poorly planned and badly regulated productive sectors in Palestine. Rock quarries, stone-cutting plants, and crushers spread randomly, from north to south across the West Bank. This random, nonharmonic, nonsystematic, and uncontrolled distribution of the rock-quarrying sites and stone-cutting facilities has, very badly, affected the arable land, the landscape, the environment, and residential areas; caused hazardous repercussions on public health and the environment; and depleted natural resources, particularly the quarried rock (limestone) and water, and damaged biodiversity.

To improve this industry, two approaches are urgently needed to be accomplished, which are (1) short-term and long-term plans, policies, and strategies should be formulated, in order to strike a balance between the efforts of enhancing SMI's development and competitiveness, on the one hand, and of regulating the industry, on the other, and (2) the WHO guidelines and other international standards and treaties related to this industry—SMI—should properly be applied and stick with, in order to carefully monitor, control, and adjust the industry, with respect to workers' safety and public health; and well-being of the environment, biodiversity, wildlife, and ecosystems, especially with respect to air pollution caused by particulate matter generated by SMI's operations and activities. To make these approaches successful, they should go hand-in-hand with the fulfillment and accomplishment of the United Nations' Sustainable Development Goals (UN's SDGs) at latest by 2030, as already planned by the UN.

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Data availability All the data used to serve the purpose of this paper is available within the paper itself.

Compliance with ethical standards

Ethics approval This paper was not published before and is not considered for publication by any other journals.

Consent to participate The research presented herein does not involve human participants and/or animals.

Consent to publish All material presented herein does not need consent to publish.

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