# Chapter 5
# Impact of Sandstone Quarrying on the Health of Quarry Workers and Local Residents: A Case Study of Keru, Jodhpur, India

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## 1 Introduction

Stone has been a very popular building material in India for hundreds of years due to its availability in huge quantities and its remarkable quality. India produces more than 27% of the total stone produced throughout the world. Rajasthan is the largest producer of sandstone in India and sandstone produced in Rajasthan is considered to be of the highest international standards. Jodhpur is the second largest city in Rajasthan and one of the major sandstone quarrying and craftsmanship centres in India. Due to the high strength, abundance and availability of a wide variety of colours and textures, Jodhpur's sandstone is in huge demand in the domestic and international market. Due to the surge in exports in the last two decades, there has been an increase in the number of sandstone quarrying and processing units in Jodhpur especially in the areas around Fedusar, Keru and Mandore (Bhadra et al. 2007). Currently, sandstone quarrying and processing is one of the most important economic activities in Jodhpur providing jobs to millions of people in the city. About 2.5 million workers are employed in the mining sector in Rajasthan and involved in activities like drilling, stone crushing, blasting and loading-unloading of stone slab from vehicles (Mine Labour Protection Campaign 2005; Sishodiya et al. 2011).

The dark side of this stone industry is the unsustainable practices used in quarrying and the huge amounts of waste generated every year. These wastes are dumped unsafely, eventually affecting the local environment and health of the quarry workers and nearby local residents. During extraction and processing, around 50–70% of the extracted stone is wasted in the form of waste slurry and scrap stone (Papantonopoulos et al. 2007). Slurry is basically stone dust mixed with water, which is generated from the wet cutting of stone. Slurry and stone dust have very small sizes which can lead to air pollution due to the presence of particulate matter.

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Further, the slurry dries quickly due to high temperatures in the Jodhpur region and the dust becomes airborne due to the slightest disturbance causing respiratory, ocular, or dermal irritation in the employees involved in quarrying activities. It can be a visual or respiratory burden for the local communities. Stone dust or slurry contains mostly silicate particles, many of these are less than 10 micron in size and enter the lungs directly through respiration. This leads to obstruction and restriction in respiration of the quarry workers and considerable reduction in lung capacity (Ghotkar et al. 1995; Singh et al. 2006). Silicosis and tuberculosis can potentially afflict employees involved in quarrying and transportation processes because the sandstone dust contains high percentage of silica (50–90%) in it. Long-term exposure to stone dust leads to silicosis and pneumoconiosis which are associated with breathlessness, chronic bronchitis, recurrent chest illness and heart failure (Scott and Grayson 2003). Other complications include tuberculosis, microbial infections, and chronic silicosis. Most of the workers are addicted to various forms of tobacco or drugs, which degrade their health even more. Due to excessive use of tobacco, many oral and dental health problems are also observed among these quarry workers (Solanki et al. 2014).

Due to the poor working environment and lack of use of any safety equipment, accidents occur resulting in heavy injury and threat to the lives of workers. These occupational injuries are one of the reasons for some major health problems that all developed, developing, and underdeveloped nations are currently facing (Solanki et al. 2014). Due to poverty, lack of awareness and education among the workers, the majority of the workforce is deprived of occupational health services. Every year all over the world around 100 million occupational injuries occur (Leigh et al. 1991). The hazardous conditions at the working site greatly affect the health and life expectancy of quarry workers due to long-term exposure from biological, chemical, and physical agents which appear at the workplace. The average life expectancy of a mine worker is approximately 52($\pm$12) years respectively, which is 10–12 years less than the life expectancy of workers who are not involved in any kind of mining activity (Mathur 1996; Verma et al. 2002). Due to these harsh conditions, many of the workers are affected by some health problem or are seriously injured and unable to work properly. Affected workers are unable to work and earn an income during their illness or injury, thus, creating economic pressure on their family. They, often, become a socioeconomic burden on others for the remaining part of their life. There are many other health and environment-related problems associated with quarrying which needed to be addressed. In the past, many studies were done in the Jodhpur area to evaluate the impacts of sandstone quarrying on the health of quarry workers (Sishodiya et al. 2011; Mathur 1996; Yadav et al. 2011; Chopra et al. 2012; Ahmad 2015). These studies were used to identify trends in health problems among workers from 1990 to 2017. Keru is a vital region in Jodhpur providence for extracting sandstone of various colours in huge amount but the worker population in the Keru quarrying area was never studied.

The objective of this study was to evaluate living conditions and the magnitude of health problems in the workers and nearby residents in the Keru quarry area. Workers and residents were interviewed and their responses to questions regarding their health, working environment and impact of quarrying activities on their life were collected and analysed. Extensive site survey was done to identify major reasons behind these health problems and injuries. To evaluate the potential for pollution by stone slurry particles in the environment, particle size analysis of the slurry particles was also done.

## 2 Description of the Study Area

Jodhpur is the second largest and most populated city in Rajasthan and is also the zonal headquarters for controlling most of the mineral-related activities in western Rajasthan. The geological formations in Jodhpur district date back to the pre-Cambrian era. The main types of rocks that are found in this area are sandstone, granite, limestone, rhyolite, phyllite, and slate (Central Ground Water Board 2013). There are many sandstone quarrying areas in the north-west and western areas around Jodhpur city. The study area is situated (26°20′40″N and 72°54′27″E) near the village of Keru and Badli, North-West of Jodhpur city (17.5 and 14.3 km away from the centre of the Jodhpur city) (Fig. 5.1b in red box). The site is located near Bikaner-Barmer National Highway Road (NH-125).

The temperature in the area can vary from 28 to 48 °C during summers and 8–28 °C during winters. The solar radiations throughout the year are very high, having annual average solar radiation of 22 MJ/m$^2$/day which can reach upto 26.5 MJ/m$^2$/day in summers. The wind speed remains quite low (5–8 km/h) during winter and high (20–30 km/h) during summer. Strong winds upto 28 km/h are often observed during June and the wind speed may reach 50–80 km/h during severe dust storms. The southwest monsoon contributes more than 85% of the total annual rainfall, extends from July to September. August is the wettest month with normal monthly rainfall of 128.9 mm. Mean annual rainfall of the city is 377.65 mm (1969–2014) whereas, the India Metrological Department (IMD) Normal Annual Rainfall is 314 mm.

There are a large number of quarries near Keru and Badli from where sandstone of different colour (pinkish brown, light brown, golden brown and light maroon) is extracted in huge amounts. Many of these quarries have depths of more than 5–10 m in the quarrying area. There are 113 stone cutting units in the study area from where sandstone is reshaped into slabs, strips and bricks for further finishing or selling. On 01-Dec-2016, the total area of the quarrying site was 14.2 square km with an outer perimeter of 82.4 km. The location and Google image of the site are shown in Fig. 5.2, which is currently situated on barren and vacant land.

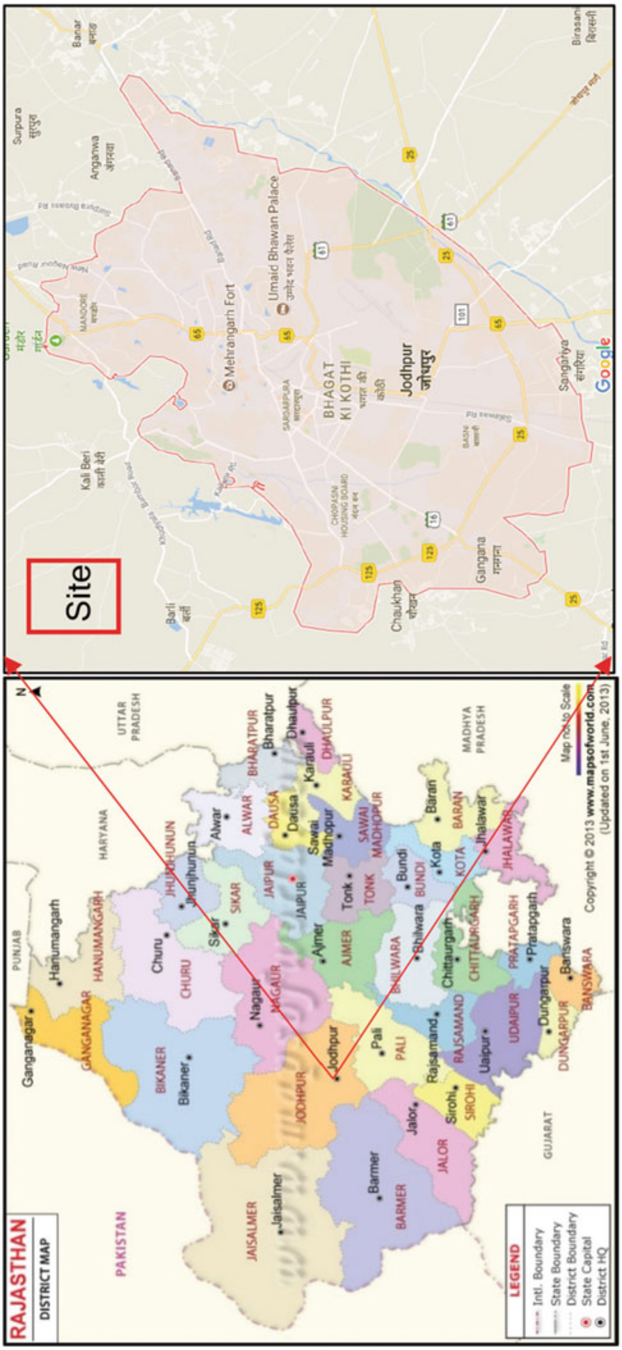



**Fig. 5.1** (**a**) Location of Jodhpur city on Rajasthan state map; (**b**) Location of site with respect to Jodhpur city

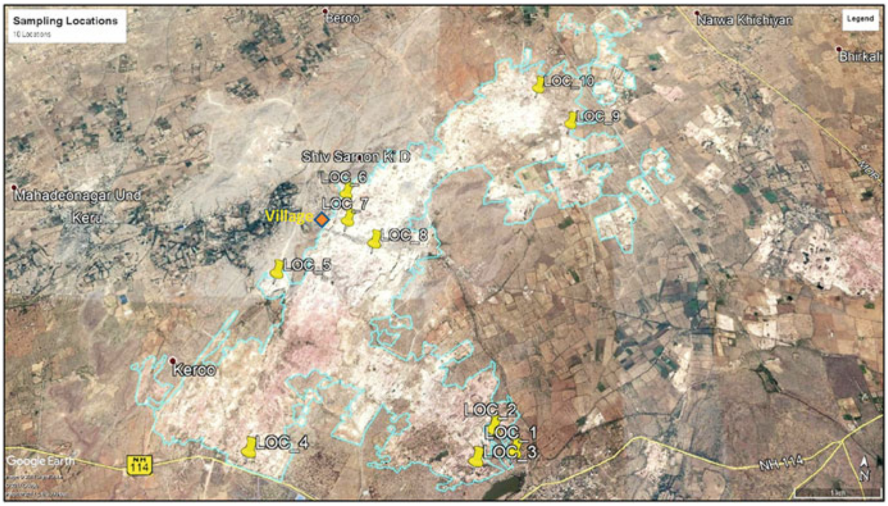



**Fig. 5.2** Locations covered during survey and sample collection. (Blue line is the boundary of quarrying area)

## 3 Materials and Survey Methodology

### *3.1 Sample Collection*

Samples were collected from eight different randomly selected locations in the study area as shown in Fig. 5.2. Eight slurry samples were collected from the stone cutting units for particle size analysis; two samples from LOC-1,2 and one sample each from LOC-3,4,5,7. Out of these slurry samples, five were collected directly from the cutter/cutting unit ($S_4$, $S_6$, $S_9$, $S_{11}$, $S_{12}$) and the remaining three ($S_7$, $S_{10}$, $B_1$) were collected from the slurry settling pond which is usually built near the cutting unit to separate waste slurry particles from water. All slurry samples were collected in glass bottles and preserved at low temperature.

### *3.2 Particle Size Analysis*

All slurry samples were dried overnight and dry slurry was used for particle size analysis. Before particle size analysis, the dried slurry samples were sieved through a 4.75 mm sieve. Particle size analysis was done using Malvern Mastersizer 3000 instrument which measures particle size distributions of the sample from 10 nm to 3.5 mm by using laser diffraction technique. From the volume density curve, percentage of particles having size less than 2.5 micron and 10 micron were calculated separately to evaluate the potential for air pollution from the slurry samples in terms of PM10 and PM2.5 concentrations.

### 3.3 Health and Field Survey

The main aim of the survey was to assess the impact of stone waste on the health of the people working on the site, and the residents living near the quarrying area. A total of 10 quarrying and stone cutting locations and a village near the quarrying area (village near locations 6 and 7 in Fig. 5.2, village name: "Shiv sarnonkidhani") were visited for the health survey and survey of living conditions. For site survey and quarrying impact analysis, Google Earth Pro was used to obtain satellite images. Impact of waste at the site and in nearby areas was studied by visiting the quarrying site in different seasons and at different times of the day. Impact on people living nearby and working at the site was evaluated by talking to the locals. A questionnaire was prepared to evaluate the impact of stone waste and the effect of working conditions on the health of workers and residents. Specific questions were asked about health problems in workers and nearby residents, the energy sources used for cutting and drilling, the total production of stone in a day after cutting, the processes involved in mining and cutting of sandstone, the transportation system, use of safety equipment, education, and sanitation conditions at the site.

Most of the workers had problems related to breathing and eyes, so detailed questions were asked about the health problems they experience, symptoms, effect on health and frequency of medical check-up. Responses of 95 people (58 workers involved in quarrying process, 10 workers involved in stone cutting process and 27 nearby village residents) was recorded individually. Questions were also asked about working and living condition of workers and residents, impact of stone dust in different seasons, hours during which dust was less or more, noise levels and their sources, and about accidents in the past. For the study, the workers were divided into two categories on the basis of their work profile. The 1st category of workers were involved in quarrying processes and 2nd category of workers were involved in the cutting process. On the basis of their feedback, some common and specific problems related to sandstone waste and quarrying were identified. The questionnaire was prepared in English language but language of communication with the workers or residents was either Hindi or Marwari (local language).

## 4 Results and Discussion

### 4.1 Site Survey

Major activities that are part of sandstone processing and the waste generated are shown in a flowchart in Fig. 5.3.

During sandstone processing, 50–90% of the excavated sandstone is wasted in the form of scrap stone, slurry and stone dust. After excavation and cutting, sandstone is sent to the city for further processing. After quarrying and cutting, 30–50% of the excavated stone is wasted and the waste goes directly to the dumping

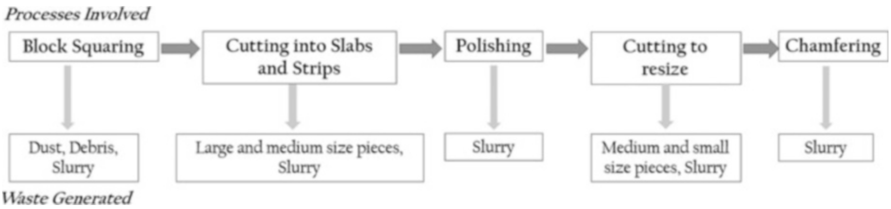



**Fig. 5.3** Steps involved in sandstone processing and nature of waste generated in each step

ground near the quarrying and cutting area. Major problems related to unsustainable quarrying practices in the area are:

- Use of rapid pneumatic or electric drills (jackhammer) for stone cutting which results in huge emissions of dust in the area. Dust emissions from jackhammer and continuous movement of trucks in the area are polluting the air in this area.
- Cutting units require huge amounts of electricity, thereby increasing their carbon footprint in the environment. At many places in the study area, electricity is not available, so electricity generators are used for electricity generation which require a huge amount of diesel as fuel (6.8 L/h). These diesel-based generators run 10–12 h daily which leads to huge GHGs, PM, NOx, SOx emissions. These emissions degrade the nearby air quality which is already in poor shape due to dust emissions from various quarrying activities.
- Each cutting unit generates 8–10 MT/d of waste. There are 113 cutting units in the area which generate about 1000 MT of stone waste per day which is dumped directly in the open area.
- Trucks and tractor-trolleys are used to transport stone from quarry to cutting unit and from cutting unit to the market or for further finishing. As per local government regulations, each truck is allowed to carry no more than 10 metric tonnes of stone. However, to reduce transportation costs by reducing number of trips, owners often overload the trucks by 2–2.5 times of the allowable capacity (20–25 MT). This practice is very dangerous and has resulted in many accidents in the past due to steep slopes inside the quarrying area.
- In many areas, due to unsystematic dumping of waste in the open area, many artificial mountains of stone waste that are 5–10 m high can be seen (Fig. 5.4a). Chances of slope failure at these dumps are quite high and truck accidents occur frequently in this area.

## 4.2 *Particle Size Analysis*

Results of particle size analysis of slurry particles are shown in Table 5.1. The slurry had the characteristics of silt/clay and sand (slightly more silty). On an average, most slurry particles are very small, i.e., less than 330 micron (0.33 mm) in size and have very high specific surface area (94–1013 $m^2$/kg). Their small size indicates that these particles have high air pollution potential and their high specific surface area shows

**Fig. 5.4** (**a**) Dumping of waste slurry and scrap stone resulting in artificial mountain of waste (5–10 m in height) (**b**) Dry drilling in the stone strip using a jackhammer without any safety mask or equipment

they may be high in reactivity and leaching tendency resulting in contamination of water and soil. From particle size analysis, it was found that slurry particles of size less than 2.5 microns constituted 0% to 12.74% of each sample and an average of 4.87% of the total volume of the slurry samples tested. Further, percentage of particles with size less than 10 microns ranged from 2.62% to 52.13% with an average of 20.50% of the total volume of the slurry tested. Presence of such particulate matter in slurry can lead to air pollution and health problems if the person is exposed to this material for a prolonged period of time.

In the quarries, large amounts of stone waste slurry are produced on a daily basis. Each cutting unit is used to shape around 10–20 tonnes/day of sandstone. The slurry and scrap stone from these cutting units ends up in open dumps where some of the stone dust/dry slurry is scattered by wind or rainwater and spreads over the whole quarrying area (Fig. 5.8b). From experiments and field observations, it was apparent that these slurry particles are very small and are likely to quickly disperse in the air with very little disturbance. Due to constant disturbance by wind, dry-drilling machines (jackhammer) (Fig. 5.4b) and transportation vehicles, there are always labourers exposed to airborne dust on a regular basis. During the survey, it was found that 65.52% of the workers involved in quarrying are affected by some kind of breathing problem (Fig. 5.7a). Most common health problem among workers is silicosis, which is a result of long-term exposure to stone dust which contains mostly silica (50–80% of total composition). Presence of significant amount of particulate matter in the dry slurry and stone dust and long-term exposure (8–10 h daily) may be the reason for breathing problems among quarry workers. Many dumps are situated 200–500 m away from the residential areas in the village (Fig. 5.5). Due to high wind velocity and open area, these stone dust and slurry particles also reach nearby residential areas causing pollution in the local residential areas.

**Table 5.1** Results of particle size analysis of slurry samples

| Parameter | B1 | S6 | S7 | S9 | S10 | S11 | S12 | S4 | Average |
|---|---|---|---|---|---|---|---|---|---|
| Gravel % (>4.75 mm) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Sand % (0.075–4.75) | 68.60 | 62.43 | 49.29 | 27.32 | 35.94 | 37.29 | 3.41 | 29.12 | 39.175 |
| Silt/clay % (<0.075 mm) | 31.40 | 37.57 | 50.71 | 72.68 | 64.06 | 62.71 | 96.59 | 70.88 | 60.825 |
| D10 (in mm) | 0.030 | 0.032 | 0.018 | 0.006 | 0.005 | 0.004 | 0.003 | 0.002 | 0.013 |
| D50 (in mm) | 0.126 | 0.11 | 0.085 | 0.045 | 0.05 | 0.044 | 0.012 | 0.054 | 0.066 |
| D90 (in mm) | 0.525 | 0.239 | 0.214 | 0.161 | 1.06 | 0.19 | 0.046 | 0.212 | 0.330 |
| Uniformity | 1.78 | 0.57 | 0.71 | 1.05 | 5.23 | 1.41 | 1.13 | 1.71 | 1.70 |
| Specific surface area $m^2/kg$ | 134.8 | 94.6 | 172.9 | 459.7 | 456.5 | 630.2 | 1013 | 422.5 | 423 |
| Particles less than 2.5 μm, % | 1.1 | 0 | 1.3 | 5.2 | 4.6 | 8.4 | 12.7 | 5.7 | 4.9 |
| Particles less than 10 μm, % | 4.8 | 2.6 | 6.7 | 20.2 | 21.3 | 30.5 | 52.1 | 25.7 | 20.5 |


**Fig. 5.5** Location of dumpsite close to village houses (150–200 m away, the height of dumpsite is approximately 8–10 m, near village 'Shiv Sharnon ki Dhai')

## *4.3 Survey Results*

Responses of workers and owners of quarrying and cutting sites about different health problems are summarized in Fig. 5.6. Responses from 58 quarry workers, 10 workers who are involved in cutting and 27 nearby village residents were collected. Workers who are involved in cutting were not affected by any health problem related to sandstone processing. Therefore, the major focus of the study was on 58 workers who were involved in the quarrying process. All labourers who participated in the survey were male and those involved in quarrying belonged to the age group of 20–50 years and workers involved in the cutting process were in the age group 20–60. Most of the quarry workers who took part in the survey were illiterate, especially those who are older than 30 years. Both groups of workers worked for 8–10 h a day (Table 5.2). Labourers involved in quarrying process work from 8:00 AM to 5:00 PM while workers involved in cutting start their work late compared to the quarry workers and work from 9:30 AM to 6:30 PM.

### 4.3.1 Workers and Local Residents Affected by Health Problems

Based on the responses, minimum 20% and maximum 87.5% of the labourers involved in drilling and other quarrying processes at ten different locations were affected by some breathing problem (either silicosis or tuberculosis or asthma); these results are shown in Fig. 5.6a. No health issues were found in workers involved in the cutting process. Problems related to eyes (poor vision, irritation or infection) were recorded as minimum 0% to maximum 37.5% (Fig. 5.6b). Workers affected by both health problems are a minimum of 0% to a maximum of 37.5% (Table 5.3). Based on these results, 65.5% of the workers who took part in the survey are affected by some breathing problems, 19.0% are affected by problems related to eyes and 13.8% are affected by both breathing and eye problems.

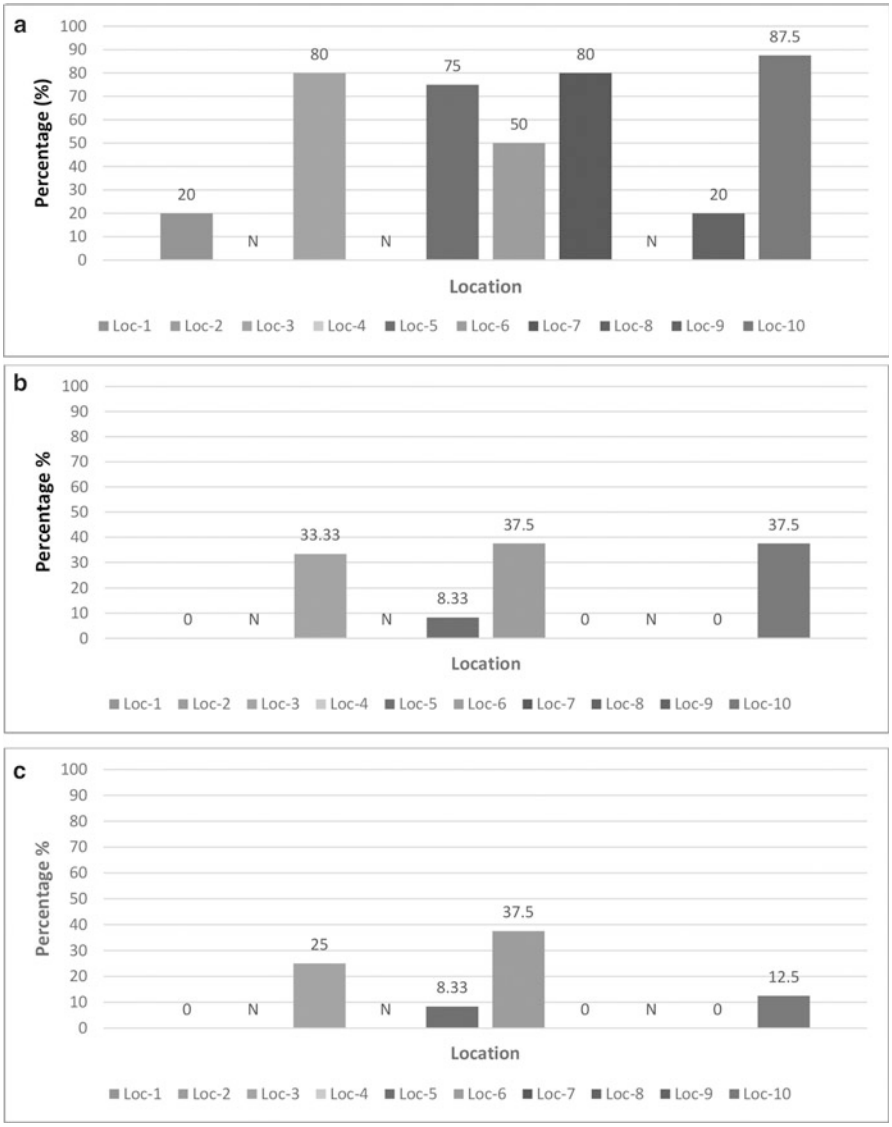



**Fig. 5.6** Percentage of positive responses from quarry workers at the observed locations about (**a**) breathing problems, (**b**) problems related to eyes and (**c**) having both ("N" shows no response for this site)

A survey on quarry workers health was conducted in Jodhpur in 2015 and it was found that 70.59% of workers who took part in the survey were affected by lung disease and breathing problems (Ahmad 2015). Another study conducted on stone mine workers in Karauli district, Rajasthan shows 78.5% (73 out of 93 subjects) were affected by breathing problems of which silicosis was the most common

**Table 5.2** Demographic variables of the study population

| Variables | N = 58 |
|---|---|
| *Age* | |
| Below 20 | 8 (13.79%) |
| 20–35 | 23 (39.66%) |
| Above 35 | 27 (46.55%) |
| *Gender* | |
| Male | 58 (100%) |
| Female | 0 (0%) |
| *Education* | |
| Illiterate | 34 (58.62%) |
| Primary education | 23 (39.66%) |
| Graduate | 1 (1.72%) |
| *Tobacco or alcohol user* | 49 (84.48%) |
| *Number of years of working* | |
| 1–5 | 16 (27.59%) |
| 5–10 | 8 (13.79%) |
| More than 10 | 34 (58.62%) |
| *Working hours* | |
| Less than 8 h | 7 (12.07%) |
| 8–10 h | 48 (82.76%) |
| More than 10 h | 3 (5.17%) |
| *Monthly income* (in Rs) | |
| <5000 | 3 (5.17%) |
| 5000–10,000 | 22 (37.93%) |
| >10,000 | 33 (56.90%) |
| *Health problems related to* | |
| Breathing | 38 (65.5%) |
| Eyes | 11 (19.0%) |
| Both | 8 (13.8%) |

(Sishodiya et al. 2011). Results in the current study are comparable to the results found in Ahmad (2015) and Sishodiya et al. (2011). In another study conducted by Desert Medicine Research Centre (DMC), Jodhpur in 1992–1994, 25.5% positive cases of silicosis or tuberculosis (TB) were found in the sandstone quarry workers who took part in health survey. Another study conducted by Mathur (1996) in the sandstone mines of Jodhpur, showed positive cases of TB and silicosis in 42% (120 out of 288 subjects) of sandstone workers who took part in the survey. Another study conducted by Chopra et al. (2012) showed that out of the 300 workers who participated in the study, 143 (47.7%) had sputum that was positive for silico-tuberculosis. Since 1992 to the present time, all studies show that with increment in time, the number of quarry workers with breathing problems is increasing (Table 5.4). The increase in breathing problems can be directly related to an increase in quarrying activities in the area without proper safety measures. Due to huge

**Table 5.3** Responses collected from labourers at quarry site regarding health problems

| Site location | Total number of response collected | Positive response on breathing problems | Positive response on vision problem | Both (breathing and visual) |
|---|---|---|---|---|
| Loc-1 | 5 | 1 | 0 | 0 |
| Loc-2 | N | – | – | – |
| Loc-3 | 15 | 12 | 4 | 3 |
| Loc-4 | N | – | – | – |
| Loc-5 | 12 | 9 | 1 | 1 |
| Loc-6 | 8 | 4 | 3 | 3 |
| Loc-7 | 5 | 4 | 0 | 0 |
| Loc-8 | N | – | – | – |
| Loc-9 | 5 | 1 | 0 | 0 |
| Loc-10 | 8 | 7 | 3 | 1 |
| Total | 58 | 38 (65.52%) | 11 (18.97%) | 8 (13.79%) |

**Table 5.4** Summary of the literature regarding incidence of breathing-related problems in sandstone quarries

| Year | Workers affected from breathing problems (in %) | Increment compared to past years available data (in %) | Increment compared to 1992–1994 (in %) | References |
|---|---|---|---|---|
| 1992–1994 | 25.5 | – | – | Mathur (1996) |
| 1996 | 42 | 64.71 | 64.71 | Malik (2005) |
| 2012 | 47.67 | 13.5 | 86.94 | Chopra et al. (2012) |
| 2015 | 70.59 | 48.08 | 176.82 | Ahmad (2015) |
| Current-2017 | 65.52 | −7.018 | 156.94 | Singhal (2018) |

demand for Jodhpur sandstone in national and international markets, extraction of sandstone has increased many-fold compared to the 1990s. Since 1990, the quarrying area has increased by 4.55 times (Fig. 5.7). In the present study, there is a slight decrease in the percentage of workers affected by breathing problems as compared to a study conducted in 2014 (Ahmad 2015). This may be due to improvement in living and/or working conditions or the result of a smaller population sample size in the current study.

Probable reasons for these health problems are poor working environment, poor quality of machinery used at the site and habit of not using any safety equipment

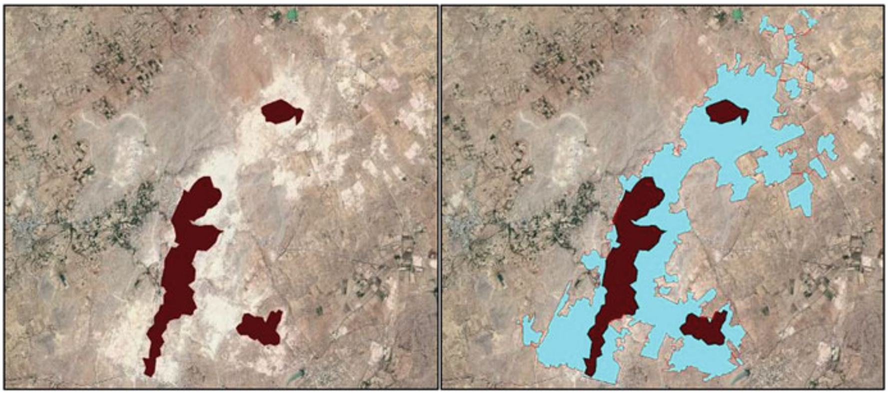


**Fig. 5.7** Increment in quarrying area from 1990 to 2017 (3.12 $km^2$ area in 1990 and 14.2 $km^2$ in 2017)

during work. Rapid pneumatic or electric drills (jackhammer) are used for cutting the stone and they are run by diesel-based electricity generators. These drills generate large amounts of stone dust and most workers operate them without using any protective masks and goggles (Fig. 5.4b). These quarry workers are also exposed to stone dust at the time of loading/unloading of stone in the truck and movement of heavy vehicles releasing dust for 8–10 h every day. This long-term exposure may lead to health problems like asthma, silicosis, tuberculosis, irritation and infection in eyes. Most of the workers at the site are poor and uneducated due to which only some of them visit a doctor for diagnosis and treatment of their ailments. The rest do not get any medical attention or opt to do nothing even after being diagnosed. Common symptoms reported by workers are chronic coughing, chest pain, problems in breathing and feeling dizzy especially when working near dust. These symptoms are related to silicosis or silico-tuberculosis. Those who visit a doctor are often diagnosed with asthma, tuberculosis and silicosis (10 out of 58). Many workers have the same symptoms but they have not been diagnosed by any doctor. Therefore, there is no proof that the workers are suffering from asthma or acute silicosis or tuberculosis. Persons involved in quarrying for more than 10 years have very high chances of having silicosis or silico-tuberculosis, but cases of less than 10 years of exposure are also seen frequently (Sishodiya et al. 2011). Silicosis is a non-curable life-threatening disease and prevention is the only option for its control (Yadav et al. 2011).

The quarry workers complained about problems related to eyes during the survey. Common problems are irritation in eyes, eye infection, poor vision and swelling in eyes. The major reason behind these problems is the same as for breathing problems, which is working in a dusty environment and lack of safety equipment like protective goggles during work. None of the workers involved in drilling was observed to be using any kind of protective gear, which is necessary for protection of eyes during the drilling process. Also, at some locations, the stone is dipped in a solution of stone softening powder (lime with some other chemicals) and water. If this dry stone softening powder contacts the eyes, it can result in eye problems. Many workers who have experienced this said that it causes itching or irritation in eyes for several hours or days.

In addition, it was seen during the survey that most of the workers (84.48% of the total workers who took part in the survey) are heavily addicted to tobacco, "beedi" (a local cigarette) or liquors or some kind of drug/weed (especially opium), which further worsens their health conditions. Many oral health problems are reported due to unhygienic lifestyle and excessive use of tobacco (Solanki et al. 2014). Many studies show that the incidence of silicosis, tuberculosis, silico-tuberculosis in mine workers is much higher in those addicted to tobacco, liquor, cigarettes or opium than in those who do not use these substances (Sishodiya et al. 2011; Yadav et al. 2011; Chopra et al. 2012; Mathur 2005). Reasons for excessive use of liquor or harmful drugs was that "it helps them to release tiredness from a whole day's work and helps them to sleep well at night". According to Ahmad (2015), daily expenditure on these substances is Rs 50 and results of another study in Chhattisgarh found that one third of the income of the workers was spent on alcohol (Dabhadker et al. 2013).

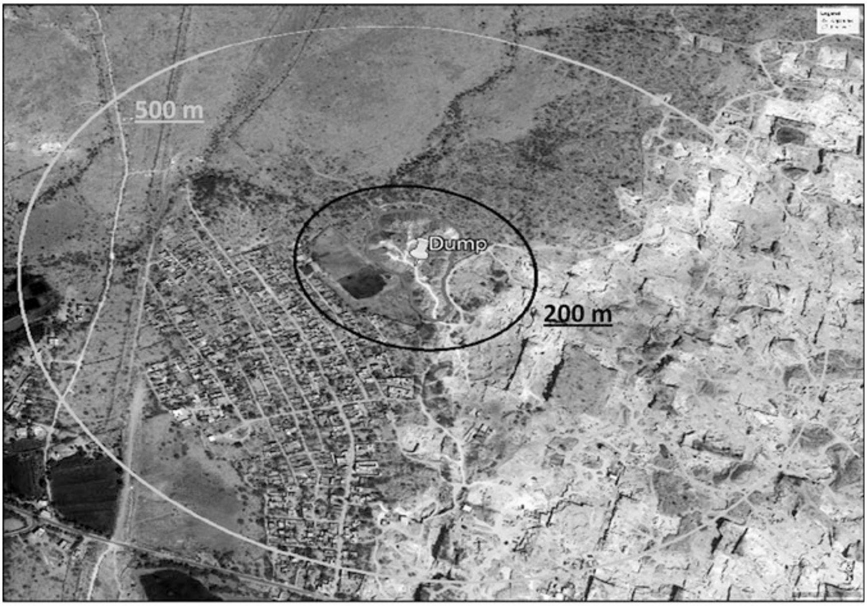
No health issues were reported during the survey at the cutting site, which is somewhat cleaner and less dusty compared to the quarrying area because of wet-cutting of sandstone. Also, most workers at the cutting units are relatively more educated and economically stronger compared to workers at the quarry; hence they are more attentive to their personal health and care.

Out of the 27 residents whose responses were recorded, five of them were affected by acute and major asthma. All five were in the age range of 50 and 69 years and were diagnosed by a medical doctor. They also mentioned that most of their elders (above 55 years of age) and some children (below 10 years of age) in the village were affected by asthma, common cough and chest pain (only in elders) due to the dusty situation. On the basis of these results, it can be said that elders and children are more vulnerable to respiratory problems compared to adults. None of the residents were affected by problems related to vision or eyes during the survey.

### 4.3.2 Problems Related to Quarrying in the Local Area

Responses of 27 residents of nearby villages were collected to find problems related to quarrying in the site area. There are three types of problems that were mentioned: health, dust and noise problems. Health effects were described in the previous section and the other two problems are described in this section.

Most people who participated in the survey mentioned that quarrying activities and movement of trucks carrying stones during the daytime releases a large amount of dust. Many sandstone waste dumps are situated in the vicinity of the village residential area (Fig. 5.8a). Villagers also reported that due to high wind velocity in the area there is a continuous input of dust into houses. This is stone dust or dry slurry having significant amounts of particulate matter contributing to air pollution.




(a)


(b)

**Fig. 5.8** (**a**) Satellite image showing houses and agricultural land within 200 and 500 m of the dumping area (Dump size 2.78 ha; height about 9 m). (**b**) Dust in the agricultural lands close to the quarrying areas (*Q* showing quarrying area, *R* showing stone dust in the fields due to discharge of wastewater containing stone dust/slurry and due to wind)


**Fig. 5.9** Percentage of positive responses regarding: (**a**) seasonal variations in air-borne dust levels in area and (**b**) dust limited to working hours

The huge amounts of dust in the air eventually settle on nearby homes, vehicles and agricultural land resulting in nuisance conditions for village residents. Residents also reported that dust settles in agricultural areas resulting in poor agricultural productivity. Deposition of dust over leaves reduces stomatal conductance leading to decreased plant biomass yields and poor agricultural productivity (Zia-Khan et al. 2015).

As per resident's comments and field survey results, visible airborne dust is the main reason for respiratory problems. This dust is mainly from due to the movement of vehicles carrying stones. Responses of residents and nearby workers about daily and seasonal variations in dust levels in the air are shown in Fig. 5.9a. On being asked about the significant presence of stone dust from quarries in different seasons, all 27 people respondents said yes, the worst impact was in summers. Also, 10 people responded yes for monsoon and 20 people responded yes for winter. Also out of 27, 22 reported that conditions are dusty in the nearby area throughout the year, and are worst during sandstorms and summer seasons. Further, 18 residents responded yes to the statement that "Dust is only limited to working hours which is generally daytime and evening till 7 PM" (Fig. 5.9b).

About the problems related to noise from the quarrying process, 16 out of the 27 people responded with a yes. Normally, cutting is a noisy process but its noise cannot be heard beyond 500 m. Study of noise levels was done in various quarry areas in Jodhpur showing maximum noise level of 69.4 dBA which is less than standards (Borana et al. 2014). However, the noise from the cutter may affect the hearing capability of workers who are involved in the cutting process, yet no case of any hearing problem was reported during the survey. Trucks coming in and going out of the quarry area produce most of the noise in these villages.

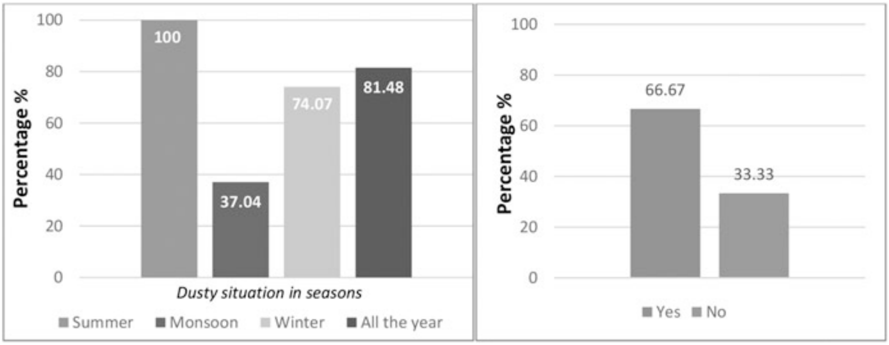



**Fig. 5.10** Accidents recorded at quarrying site locations

### 4.3.3 Accidents in the Past Years at the Quarrying Site

Based on the survey, it can be said that working conditions at the quarry area are very unhealthy and unsafe for anyone who is working at the site. Chances of musculo-skeletal problems increase many-fold in the case of quarry workers due to these unsafe and tedious activities. Responses regarding accidents, injuries and deaths that happened in the past are summarized in Fig. 5.10.

Results of the survey show that labourers from 8 out of 10 locations had seen accidents related to vehicles in the site at some point at their life. The most common accidents reported were the toppling of trucks or tractor-trolleys during transportation or loading-unloading, stuck in a small pit during dumping waste at the dump sites, on collision with other vehicles on the highway. Overloading of trucks is also another major reason behind accidents related to driving and toppling. With overloading, chances for toppling of trucks increase many-fold on steep slopes inside the quarrying area. Some accidents were also reported at the dumping sites due to the wheel of the vehicle being stuck in the dump, which is a result of uncontrolled and unsystematic dumping of stone waste on the dump. Most of the dumping sites in the area look like artificial mountains of loose, scrap stones and stone dust which can be up to 10 m high at some locations (Fig. 5.4a). Roads built over these dumps have very loose sub-base and due to very large height and uneven slope, there is always fear of slope failure. This can lead to fatal accidents since quarry workers frequently work or rest near these dumping areas.

Results of the survey also show that people from all the sites (all 10 locations) had seen cases of bone or ligament fracture and some permanent injury in their time working at the site. Some common reasons behind these injuries are not using safety equipment during work, unsafe practices in loading-unloading of stone in vehicles, drilling process, etc. At two locations (Loc-2 and Loc-7) workers reported the deaths of some workers during work at the quarry. Main reason behind the death of these workers was slipping of the foot at the top quarry pit which is approximately 9–11 m deep from the ground level and sliding of base stone block (akin to a landslide) during drilling. Depth of the locations where quarrying activities are done are sometimes more than 10 m and quarry pits in these areas are usually filled with water which may be the reason for death or fatal injury if somebody falls into them. To prevent these fatal accidents, proper protective measures should be taken by quarry owner or government authorities.

## 5 Recommendations to Improve Present Conditions

On the basis of the site and health survey, it can be concluded that the current health conditions of the quarry workers and local residents is in very bad shape. Main reasons behind these problems are unsustainable quarrying practices and huge quantity of waste associated with them. First step to improve health conditions of the population is to provide proper medical care to the quarry workers and nearby residents. Also, with the help of Non-Government Organizations (NGOs) and local government authorities, educational and training programmes should be conducted regarding health impacts associated with quarrying and sandstone dust. To tackle problems associated with unsustainable quarrying practices, three measures can be taken. First and most important measure is reduction of generated waste (source reduction) and emissions by providing proper machinery and equipment. Second measure is to reuse waste or convert waste into useful construction materials. Third measure is safe disposal of waste. Suggested measures which can be taken are described here.

1. *Improvement in machinery and equipment*
    - Instead of dry-drilling or use of jackhammer, wet cutting should be used at the excavation site to reduce dust emissions. This will protect workers from dust exposure and significantly reduce the potential of deadly threats like silicosis and silico-tuberculosis.
    - Most injuries and health problems are due to lack of safety equipment. Therefore, personal protective equipment (PEE) like helmet, dust mask, goggles, and rubber boots should be provided by quarry owners and their use should be mandatory.
    - Instead of diesel generators, more power efficient battery based electricity inverters should be used for drilling. They will result in massive reduction in GHGs, PM, $SO_X$ and $NO_X$ emission at the working site.
    - Overloading of vehicle should be strictly prohibited and this regulation should be implemented thoroughly to prevent accidents. Also, trucks and mini-trucks should be used instead of tractor-trolleys because tractor-trolleys are not designed to carry heavy materials like stones and are unstable vehicles on loose surfaces.
    - There are several abandoned and empty quarry pits in the area which can be used for rain water harvesting. This water can be used for wet drilling and cutting, reducing dust emissions at site by water sprinkling and for other quarrying activates. Due to water scarcity in the region it could be very helpful in fulfilling water demand for quarrying.

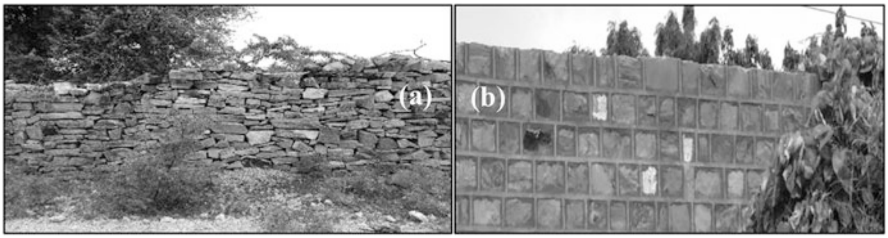



**Fig. 5.11** Reuse of scrap stone waste in boundary wall construction (**a**) with mud-water paste and (**b**) cement paste

2. Reuse of waste products

- Scrap stone and fine stone slurry can be used as construction material along with cement and concrete. Many researchers have tried to reuse marble and granite waste as aggregate in concrete (Almeida et al. 2007; Mahzuz et al. 2011). However, research on reusing sandstone waste in concrete is still limited. Aciu (2014) have tried to use fine sandstone slurry waste as 33% and 50% replacement of fine aggregates in the mortars resulting in significant improvement in compressive and bending strength with better adhesion of aggregates and cement. Sandstone dust can replace sand to a certain extent and can be used for local and government construction in the nearby areas.
- Scrap stone and fine stone dust can be used for constructing low-cost masonry wall by using stone dust as a fine aggregate and scrap stones as coarse aggregate. In some rural areas of Jodhpur district, it is used for building walls by piling scrap stones on each other and binding them with a mixture of mud and water (Fig. 5.11).
- Fine stone dust and dry slurry can be used for strengthening the base layer in road construction. According to Papantonopoulos et al. (2007), Almeida et al. (2007) and Al-Joulani (2012), using fine stone dust below the road layers reduces water intrusion in base layer and resulting in more strength in base layers. Very small size of stone dust leads to reduction in permeability and hydraulic conductivity with increment in strength and bearing capacity of the soil. Also, addition of stone dust to clays reduces their plasticity and increase silty behaviour which is quite favourable in terms of workability (Sivrikaya et al. 2014).
- Waste scrap stone can be used to make low-cost pathways in gardens or by the roadside. Different natural colour availability in sandstone provide better look and also eliminates costs associated with artificial colouring.

3. *Sustainable dumping of stone waste*

- A large number of dumping locations exist in the vicinity of the quarry areas. Dust emissions from these gigantic dump sites is a major problem due to high wind velocities in this region. So, dumping locations should be provided 500–1000 m away from the residential area or working place. The stone waste can be used to fill empty quarries in the area.

- Most of the dumping locations in the area are of gigantic size and upto 8–10 m high. This poses the threat of slope failure while dumping. So, design and slope of these dump sites should be improved. Designing a proper landfill for dumping stone waste is necessary.

## 6 Conclusions

The results obtained from particle size analysis, site survey and health survey show that there are serious adverse effects on the health of quarry workers, residents and on the environment at the Keru site. Result of site survey shows that fine stone slurry is the major pollutant and current unsustainable quarrying practices are the main reason behind the environmental degradation and health problems in the area. Particle size analysis shows that dry slurry has very small particles, mostly less than 330 micron (0.33 mm). Slurry contains small amounts of particles of size less than 2.5 micron (average of all tested slurry samples was 4.87%, maximum was 12.74%) and significant amounts of particles of size less than 10 micron (average of all tested slurry samples was 20.50%, maximum was 50.13%). Quarrying, transportation activities, local wind effects and the presence of significant amounts of PM10 particles in slurry/stone dust make dust a major air pollutant at this site.

Results of the health survey also show that out of the 58 quarry workers who took part in the survey, 65.52% workers were affected by some kind of breathing problem, 18.97% were affected by some kind of eyesight problem and 13.79% were affected by both problems. Survey of the site showed that poor quality of machinery used with no safety equipment has led to injuries and major health problems among quarry workers. Results of the health survey are comparable with recent studies in the area and show an increment in comparison to older survey data of the area. As per responses from nearby residents, about 18.5% of the local residents are also affected by breathing problems. Results of the survey also show that due to unhealthy and unsafe quarrying practices, there are a number of accidents in the area with the workers and vehicles resulting in fatal injuries (permanent and temporary) and even deaths in some cases. Improvement in quarrying processes and machinery with better awareness programmes regarding safety and health issues amongst workers and residents are essential for better living and health conditions.

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