Chapter 8
Environmental Hazards of Limestone Mining and Adaptive Practices for Environment Management Plan

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Abstract Limestone is a fundamental raw material in various industrial sectors. It is formed due to biochemical precipitation of calcium carbonate, and further compaction over long periods of time. A high market for limestone products and its use in a growing number of industries has led to its widespread exploration and excavation. The most widely adopted method of limestone mining is through opencast pits with bench formation. Limestone mining causes widespread disturbance in the environment. Myriad impacts are observed as changes in land use pattern, habitat loss, higher noise levels, dust emissions and changes in aquifer regimes. These environmental concerns have brought about the need for sustainable Environment Management Plan in the mining sector, so as to reduce environmental degradation during operation as well as restoration of degraded lands after final mine closure. A well-formulated Environment Management Plan will help in mitigating the impacts of mining on the environment. The best practices adopted by industries around the world can be adapted as per site characteristics is to ensure sustainable mining along with the prevention of environmental degradation.

Keywords Limestone · Karst topography · Quarrying · Environmental pollution · Restoration

8.1 Introduction

Limestone is a carbonate sedimentary rock, consisting of calcium carbonate and in some cases magnesium carbonate as a secondary component. Limestone is most often mined from a quarry; however, underground limestone mines are found in some places of the world like central and eastern USA. Some of the biggest quarries in the world are in the state of Michigan in the USA, specifically near the Great

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Lakes' coastline (Critchfield 2017). Countries like China, the USA, Russia, Japan, India, Brazil, Germany, Mexico and Italy are some of the world's largest limestone producers today. It has numerous uses: as a major component in cement concrete, raw material in glass and metal-processing industries; as aggregate for the base of the road, building materials, chemical feedstock for the production of lime; as soil conditioner, industrial water treatment and many more. Due to the high demand for limestone and its products, it is mined in very large quantities around the world.

Impacts of limestone mining on the environment are manifold. Mining leads to landscape deformation and ecosystem destruction, which changes in groundwater regimes, dust and noise generation, during various mining operations like site excavation drilling, blasting and overburden. A major component of the mining activity includes mine closure and reclamation which gives a scope to alleviate the impacts caused due to the mining operations. Hence, adaptive and innovative measures are essential to incorporate sustainable limestone mining.

8.2 Limestone: Geological Formations and Mining Process

Limestone is a naturally formed mineral, primarily composed of calcium carbonate (Oates 2008). It forms commonly in shallow, calm and warm marine waters, as found in the Caribbean Sea, the Indian Ocean, the Persian Gulf and the Gulf of Mexico (King 2005). Another way of limestone that forms is through evaporation, with this type of limestone growing in caves around the world (Critchfield 2017).

8.2.1 Geological Formation

Limestone rocks are formed by the combination of dissolved calcium ions and carbon dioxide in sedimentary depositions. The sedimentation of calcium carbonate occurs with organic and inorganic mechanisms. The organic mechanism involves a variety of organisms that build shells, skeletons or secrete carbonate (e.g. bivalves, gastropods, brachiopods, corals, sponges, various algae), while the inorganic mechanism involves direct precipitation from sea and inland water, which has resulted in some commercially significant deposits of oolitic limestone and travertine. Some minor dolomite sediments are formed by direct precipitation from sea and lake waters (Oates 2008).

Some of the common structures of the limestone formations are the bedding planes which are formed due to tectonic activities, resulting in structures like anticlines, synclines, overthrust folds and faults. These bedding plane structures are formed as depositional structures over time and can also be formed after burial by the dissolution of limestone. Karstic dissolution of the limestone can also occur tens or hundreds of metres below the ground surface, producing cavity structures that varying in size from small cavities to large potholes and caves. Cavities near the surface are often filled with clay or overburden washed down from the surface (Oates 2008).

White coloured limestone is of high purity, while yellow, cream and red hues are indicative of iron and manganese impurities. Limestone exhibits an earthly odour due to the presence of carbonaceous matter (Lide 1998). Solubility of limestone increases in the presence of carbon dioxide forming calcium and magnesium bicarbonates. Limestone readily reacts with acid and is generally used for neutralization (Oates 2008).

8.2.2 Uses of Limestone

Limestone has myriad uses, depending on its chemical and physical specifications. It is applied to soil to combat soil acidity and to promote favourable conditions for the growth of essential microorganisms. Some of the Industrial applications of limestone include manufacturing of dye intermediates, in sugar production as a refining agent, as a flux in blast furnaces and in open hearth for steel production and as a raw material in cement production. It is also used as a neutralizing agent in the treatment of industrial wastes (Lamar 1961).

8.2.3 Limestone Mining Process: A Brief Review

The sum total of all activities that are undertaken during the lifetime of a mine can be categorized into four phases: mineral exploration, mine development, mining operation and mine closure (UNDP and UN Environment 2018).

8.2.3.1 Mineral Exploration

Mineral exploration phase consists of exploratory study and prospecting operations conducted through various geophysical and chemical analyses to identify ores from which minerals can be extracted. In India, the Ministry of Mines has recently initiated the National Mineral Exploration Policy, 2016, to promote research and exploratory study through the provision of baseline data in the public domain. The Ministry also undertakes geophysical survey throughout the country to find concealed mineral deposits (CUTS International 2018).

8.2.3.2 Mine Development

Mine development includes feasibility studies and environmental impact assessment studies. It is followed by land acquisition and displacement of population, if required.

Thus, this phase has major environmental and social impacts. Site preparation process involves land clearance of vegetation, construction of roads and other amenities (UNDP and UN Environment 2018).

8.2.3.3 Mining Operation

The activities involved in mining operation depend on the methodology adopted for mining. Method of mining largely depends on the characteristics of mineral deposits. For minerals that occur near the surface and larger deposits, like limestone, opencast mining process is used. Underground mining is conducted for deep-seated minerals like coal (UNDP and UN Environment 2018).

Opencast mining involves drilling and blasting to remove topsoil and overburden. The mineral-bearing ground is cut in the form of bench systems to excavate the ore. The extracted ore is hauled to the surface and subsequently transported using trucks or dumpers to the crusher, where the ore is converted into smaller pieces. This is followed by beneficiation of minerals, i.e. separation of the minerals from the ore. What remains the following milling of ores and separation of minerals is called tailings which need to be properly disposed. Minerals then undergo final processing (Haldar 2013).

8.2.3.4 Mine Closure

After the entire mineralized zone is excavated, mine closure phase commences. The ancillary facilities are decommissioned. Land reclamation including backfilling of pits and landscaping is an essential part of mine closure and is done to prevent further degradation of land and associated environment (UNDP and UN Environment 2018).

8.3 Environmental Hazards of Limestone Mining

Carbonate rock resources like limestone cannot be obtained from quarrying or mining activities without causing some environmental impacts although modern technologies have made it possible to reduce the associated environmental impacts. Mining operations induce change in geomorphology and land-use pattern with loss of habitat, dust, generation of high levels of noise, vibrations, erosion, subsidence and sedimentation. Limestone mining also causes changes in groundwater flow, groundwater quality and overall water quality. Many studies have described the potential hazards of mining limestone, some of which include Gatt (2001), Geomin Consultants (P) Ltd. (2009), Ochieng et al. (2010), Naja et al. (2010) and Barksdale (1991).

8.3.1 Impacts on Land and Soil

Opencast mining has been associated with a change in land use and land cover of a region. The process of clearing trees and vegetation in preparation for mineral excavation has huge impacts on prevailing ecosystems. In eco-sensitive areas like forests and hilly regions, loss of native and unique species is also coupled with habitat loss of the biodiversity of the region. The topsoil which is excavated is the most fertile component of the soil structure and takes thousands of years to form. Stripping of topsoil cannot be easily compensated, even with rigorous methods of land reclamation (Sharma and Ram 2014). For extraction of mineral, the layers of materials overlying the ore have to be removed. This layer is called the overburden. The quantity of overburden is usually very high and often consists of waste substances. These materials are dumped on open land at times and used for backfilling of pits after mineral extraction (ELAW 2010). Deterioration of soil quality and alteration in soil properties are known to occur due to prolonged dumping of lime mixed waste material (Lamare and Singh 2016).

Excavation results in the destruction of active caves, natural sinkholes and relicts. The extent of the geomorphic impact is a direct function of the size of the quarry, the number of quarries and the location of the quarry, with respect to the overall landscape and landform (Langer 2001). Gunn and Bailey (1993) report that crushed stone quarrying has removed an entire karst hill and large portions of other nearby karst hills in the Mendip Hills, UK.

8.3.2 Impacts Due to Blasting

Blasting is a technique where large amount of explosives is used in crushed site operations to obtain approximate size rubble of limestone. When an explosive is detonated, high amount of energy is released a part of which displaces the rocks from the quarry face while the rest is transmitted in the form of vibrations into the ground surface and through the air. Blast induced vibrations can cause naturally formed stalactites and stalagmites to break off and cause cave roofs to crack or collapse. It may also cause fracturing of quarry walls and increasing the permeability and drainage towards the quarry face (Langer 2001). Lolcama et al. (2002) describe a situation wherein blasting opened a conduit under a quarry floor which was connected to a local water storage basin and a river. Extensive grouting was required to stop the inflow of water from these sources (Fig. 8.1).

High noise levels are generated due to the use of machineries like excavators and during drilling and blasting; loading and unloading operations. The cumulative impact of all the noise created in the mining site can affect humans as well as the biodiversity present within the mine lease area (Ahmed et al. 2014). The distribution and impact of noise in the mine lease area depend on the sources of noise generation as well as on geographical attributes of a region. Meteorological factors like rain and

Fig. 8.1 Rock is drilled and blasted for use as crushed stone. In some isolated areas where people are not located nearby, larger amount of explosives may be used (Langer 2001)

storm add to the propagation of noise levels (Manwar et al. 2016). The mineworkers are the most affected due to the high noise levels, followed by residents of settlements surrounding the mine lease area.

Study conducted by (Manwar et al. 2016) on noise level mapping for an opencast mine in a hilly region identified high noise areas like drilling sites and crushers with increased noise levels during the night. With the results of the study, suitable locations for dumping overburden to act as a barrier to noise levels were also predicted.

8.3.3 Impacts on Air Quality

Emission of particulate matter is associated with various mining operations like excavations, construction of haul road and approach roads, drilling and blasting and transportation of minerals. Dust emissions are of great concern related to air quality surrounding mines. Air-blown particles from the stockpile of excavated material also raise the content of particulate matter in the air. Gaseous pollutants like sulphur dioxide (SO_2) and oxides of nitrogen (NO_x) are emitted from the Heavy Earth Moving Machineries (HEMM) like dumpers and excavators (Lamare and Singh 2016).

Studies have also suggested the impact of mining operations on global carbon budget. The loss of trees causes a loss of carbon dioxide uptake while heavy vehicles emit large quantities of carbon dioxide. Mining is a highly energy-intensive industry. The use of explosives for detonation and vehicles used for transportation consumes large amounts of fossil fuel and electricity. Thus, areas, where large-scale mining activities are concentrated, can contribute towards the worldwide phenomenon of climatic changes (ELAW 2010; Ruttinger and Sharma 2016).

8.3.4 Impacts on Water Resources

8.3.4.1 Impacts on Surface Water

Engineering activities associated with quarrying can directly change the course of surface water. Sinkholes created by quarrying can intercept surface water flow. Conversely, groundwater being pumped from quarries changes streams from gaining streams to losing streams and can drain other nearby surface water features such as ponds and wetlands. Similarly, blasting (see above) can modify groundwater flow, which ultimately can modify the surface water flow. Discharging quarry water into nearby streams can increase flood recurrence intervals (Langer 2001; Bhatnagar et al. 2014).

8.3.4.2 Impacts on Groundwater

Limestone mining is likely to result in relatively local impacts such as reduced water quality, rerouting of recharge water in aquifer, increased run-off and thereby leading to localized reduction in groundwater storage (Hobbs and Gunn 1998). The major impact of quarrying on water relates to mine dewatering and the associated decline of the water table. If a quarry intersects phreatic aquifer, it severely affects the transport of groundwater in such situations. The water may just flow out of the phreatic aquifer into the mine pit at very high velocity. The pit has to be dewatered to facilitate mineral excavation, and the water such pumped out is usually discharged to nearby areas. Thus, there is wastage of huge volume of water in the mining area while the water level in the downstream. Water pumped from a quarry is likely to be lost from the local groundwater system. Within the cone of depression, wells, springs and streams can go dry or have their flows significantly reduced, and the overall direction of groundwater flow may be changed (Hobbs and Gunn 1998). It is within this cone of depression that many human-induced sinkholes are formed.

Figure 8.2a, b shows how groundwater table is declined due to mining activities and the formation of sinkholes as a result of collapsing of the cavities in the karst system.

Karstic system (limestone) has a very low self-purification capacity (Kresic et al. 1992) which makes the water flowing through the karst system very susceptible to pollution. Mining activities can substantially change the direction of discharge and thereby change water quality (Bhatnagar et al. 2014). In aggregate mining, the target limestone, if unsaturated, may also act as a protective cover for the underlying aquifer. If this cover is removed due to mining, the hole created by the mining may direct the surface water to the groundwater, and if the surface water is contaminated, the quality of the groundwater can quickly degrade. Quarrying can also cause the formation of sinkholes that result in the capture of surface water. Dust can enter conduits and smaller openings and can be transported to the groundwater (Hobbs and Gunn 1998). Large amounts of silt and other effluents from quarries (oil, fuel

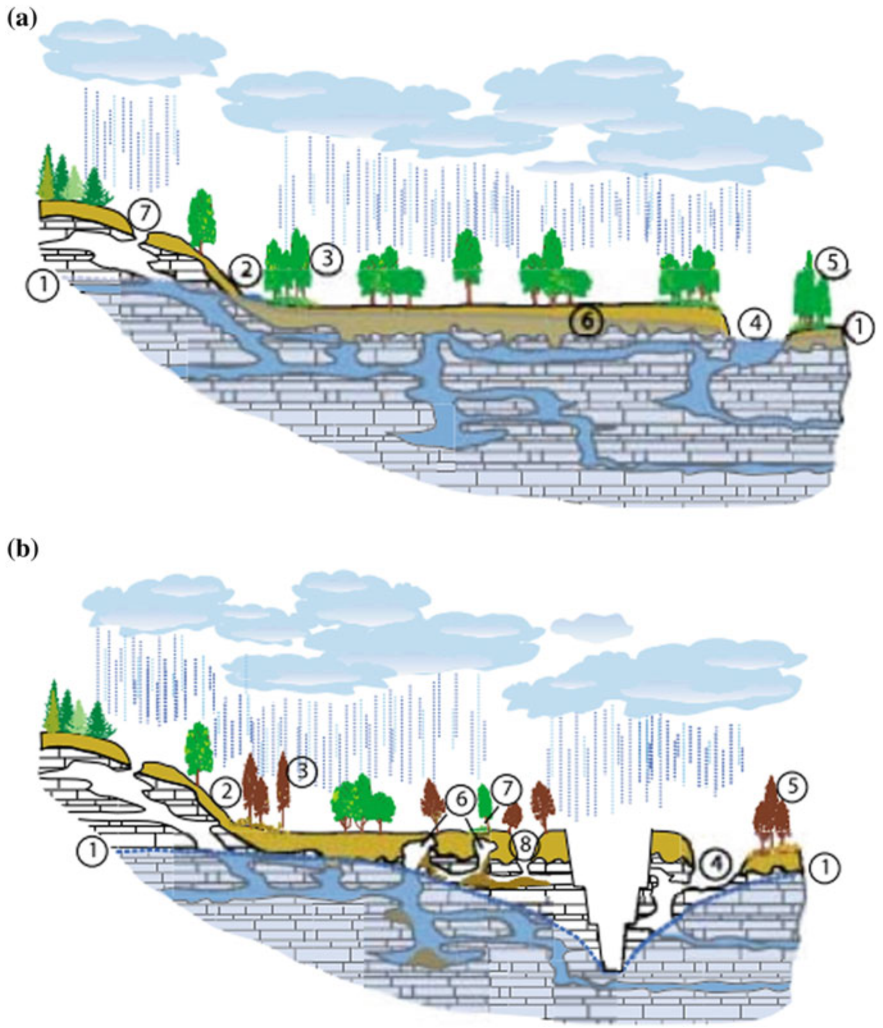

Fig. 8.2 **a** Hypothetical cross section showing karst area under conditions prior to quarry development. The water table (1) is generally above the soil/bedrock contact. Natural groundwater discharges to a spring (2), and a perennial stream (4), which supports wetland (3) and a riparian woodland (5). The surface of the bedrock is highly irregular (6) and is referred to as pinnacle bedrock. A natural sinkhole occurs where the water table is below the soil/bedrock contact (7) (Langer 2001). **b** Hypothetical cross section showing karst area under worst-case conditions after quarry development. Under actual conditions, none, some or all of these conditions may exist. Quarry dewatering has lowered the water table (1) below the soil/bedrock contact. Natural groundwater discharge to a spring (2) and perennial stream (4) has stopped, resulting in the destruction of the wetland (3), drying up of the stream (4) and destruction of the riparian woodland (5). Underground cavities formed in the soil in the area of the pinnacle bedrock due to the loss of buoyant support and piping (6). The ground above the cavity has subsided, resulting in the formation of a wet area, and the tilting of fence posts or trees (7). Ultimately, these cavities could collapse, creating a collapse sinkhole (8) (Langer 2001)

and waste) can pollute the nearby surface water and groundwater bodies within and far beyond the boundaries of limestone (Langer 2001).

Dissolution of calcium associated with limestone due to rain can also affect the water quality. Similarly, surface run-off from limestone can laden nearby seasonal streams with dissolved calcium, increasing the solid content in water and making it unfit for potable use (Sharma and Ram 2014). Based on the investigation conducted by (Eugene and Singh 2014) on water quality due to limestone mining in East Jaintia Hills, Meghalaya, India, it was concluded that in most cases water quality showed elevated levels of pH, electrical conductivity, total dissolved solids, hardness, alkalinity, calcium and sulphate concentrations due to the mining and processing of limestone. This was true for both the seasons of pre-monsoon and post-monsoon. The deterioration in water quality was concluded to have resulted due to additional accumulation, transportation, mixing and dispersion of pollutants (organic or inorganic) from the mining operations into the local water bodies.

8.4 Sustainable Mining for Environmental Hazard Management

Best practices for limestone mining are derived from a robust diagnosis of the environmental hazards, impacts of associated population and an accurate delimitation of the area of influence due to mining activity (Sanchez and Lobo 2018).

The goals mentioned for taking up adaptation measures are shown in Fig. 8.3.

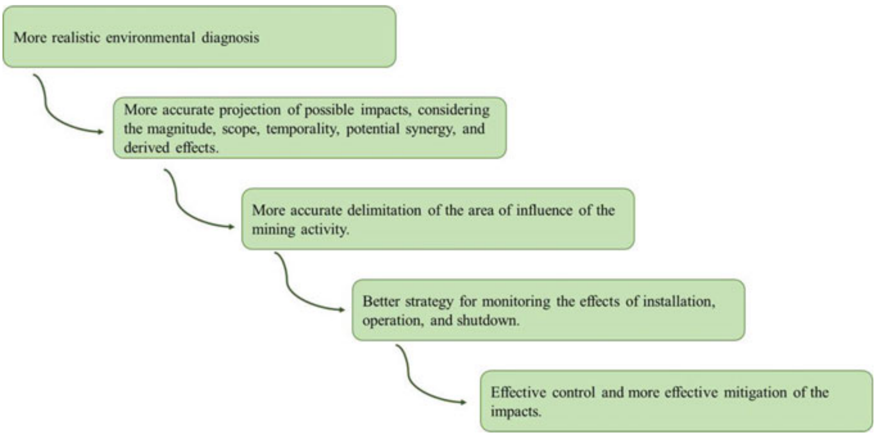

Fig. 8.3 Requirements to ascertain best practices in limestone mining (Sanchez and Lobo 2018)

8.4.1 Environment Management Plan

Environment Management Plan (EMP) is essential to be undertaken during active mining operations and post-completion of the project. It is important to re-establish the ecosystem lost due to the limestone mining activities. Involvement of stakeholders in post-closure monitoring of the mining area is equally essential as it is maintaining active care of the area (Sanchez and Lobo 2018). To achieve the same suitable policies and regulations for pre-mining, mining and post-mining activities need to be incorporated and proper EMP has to be done.

8.4.1.1 Mitigation Measures for Land and Soil Environment

During mining operations, the fertile topsoil requires to be stored separately from overburden that gets generated. It is necessary to reuse the topsoil within the shortest possible time, for plantations and greenbelt development. Construction of drains around the stockpiles prevents erosion and further wastage. Land reclamation activities like backfilling of exhausted pits, slope stabilization or conversion of pits to water reservoirs can be undertaken. Land rehabilitation is an activity with results that are demonstrated only after a long period of time (Kundal 2017).

8.4.1.2 Mitigation Measures for Noise Environment

Controlled blasting, between favourable hours (avoiding early morning or night time), helps to lessen the impact of high noise in the mining area. Machinery used in blasting and hauling should be equipped with noise muffling systems. Development of greenbelt of adequate width and thick canopy all-around mining lease area helps in the reduction of noise. The workers working in high noise generating areas should be provided with personal protective equipment to prevent hearing disorders (Kundal 2017; Final Environmental Impact Assessment Report of Zinzarka Limestone Mine 2016).

8.4.1.3 Mitigation Measures for Air Environment

To reduce fugitive emissions, during drilling and blasting activities, wet drilling should preferably be practised. In areas where water is scarce, drills equipped with dust collectors can be used. Haul roads used for the transportation of limestone require regular water sprinkling. Similarly, limestone crusher should be operated using dust collectors. Development of greenbelt along with the 7.5 m safety zone helps in capture of particulate matters. Vehicles with valid PUC Certificate should be allowed to operate in the mine lease area.

8.4.1.4 Mitigation Measures for Water Environment

As mine pits are dewatered, huge volume of water is generated which can be utilized in the mine office and ancillary facilities, thus reducing freshwater withdrawal. Effective network of drains with sedimentation pits should be developed to prevent the flow of eroded material to nearby drainage. Harvesting rainwater in mined-out pits will help towards maintaining the groundwater regime of the region (Kundal 2017).

8.4.1.5 Mitigation Measures for Biological Environment

The plantations around the mining lease area including the 7.5 m safety zone should include local species to maintain the ecological and biological environment of the site. Species survival rate should be recorded and accordingly, and plantation should be undertaken (Sagewill Limestone Quarry Environmental Management Plan & Reclamation Plan 2018).

8.4.2 Industry Best Practices from Around the World

8.4.2.1 Semi-Open Box Cut Mining by Siam Cement Kaeng Khoi Co. Ltd. (SKK), Thailand

SKK adopts semi-open-cut mining that combines open-cut mining and open-pit mining by leaving some forest area (about 40% of the mine lease area) as a buffer zone along with the quarry boundary line. This reduces noise and dust pollution, preserves significant forest cover and allows for mined land rehabilitation to be undertaken simultaneously with the production process (The Association of Southeast Asian Nations (ASEAN) 2017).

8.4.2.2 Use of Surface Miner in Tular Limestone Mine, Tamil Nadu

Fully mechanized opencast mining has been adopted by the Tular Limestone Mine of Madras Cement Works in Tamil Nadu, India. Excavators are used to remove the topsoil and surface miners were used to mine limestone. As no drilling and blasting are involved, there is a reduction in air pollution and high noise generation. The surface miners also have an inbuilt dust suppression system (Indian Bureau of Mines 2014).

8.4.2.3 Dump Stabilization at Halki Limestone Mine, Muddapur

Aloe vera saplings were planted over inactive overburden dumps by JK Cement Ltd. The process helps in the stabilization of the dump as well as prevents erosion due to wind or water (Indian Bureau of Mines 2015).

8.4.3 Recommendations

Some ways in which sustainable mining process can be achieved are mentioned below.

1. Use of the resistivity method to locate the precise location and size of underground caves to guide operations and anticipate with higher levels of safety procedures.
2. Improvements in blasting techniques such as the use of delaying fuse and air deck to reduce blasting materials. Observing the blasting schedules and finding the scope of improvement. Adoption of other methods of limestone size reduction such as surface miner, rock splitter, breaker and ripper to avoid secondary blasting and to reduce environmental impact of the blasting operations. Detonators and explosives used only during the day, while providing prior intimation to the nearby residents. Ensuring all drilling machines are equipped with dust filtration systems.
3. Storage of topsoil and overburden separately, in designated areas and provision of retaining walls. Provisions of drains along with dumps to arrest the flow of silt during the event of rainfall.
4. Retaining of native vegetation and development of green cover along with dust generation areas like haul roads.
5. Implementation of land reclamation plan after mineral excavation is complete. Reclamation work should be done after a thorough understanding of local geology and ecology. Landscaping will help recover the lost stability and contain immediate damages (The Association of Southeast Asian Nations (ASEAN) 2017; Natural Stone Council 2009).

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