PLANT COLONISATION, SOIL DEVELOPMENT PROCESSES AND CHARACTERIZATION OF QUARRIED LAND IN NDARUGU, KIAMBU COUNTY

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DECLARATION

This thesis is my original work and has not been presented for a degree in any other University.

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DEDICATION

This thesis is dedicated to my mum, Mrs. Jane Wanjiru, for always believing in me and encouraging me to be who I wanted to be through focus and hard work. May God bless you abundantly.

"…being confident of this, that he who began a good work in you will surely carry it on to completion until the day of Christ Jesus." (Philippians 1:6, Holy Bible, NIV)

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LIST OF ABBREVIATIONS AND ACRONYMS

ASWAT	Aggregate Stability in Water
EFA	Ecosystem function analysis
GPS	Global Positioning System
JKUAT	Jomo Kenyatta University of Agriculture and Technology
KNBS	Kenya National Bureau of Statistics
LFA	Landscape Functional Analysis
NEMA	National Environment Management Authority
PCA	Principal Component Analysis
SPSS	Statistical Package for Social Sciences

ABSTRACT

In Kenya, demand for building materials has continued to increase due to growth in the real estate industry and rapid urbanisation in general. Ndarugu region in Juja, Kiambu County, is one of the zones where stone quarrying has intensified. The objectives of this study were; (i) to assess the management status, Cultural characteristics of post-quarry sites, and perception of stone quarry land owners on impacts of stone quarrying, (ii) to determine the type of plant composition and microsite organization of land surface materials, (iii) to assess level of post-quarry site substrate development and (iv) to determine soil macrofauna composition for land surfaces disturbed by stone quarrying. The assessment was done for quarry sites under different management regimes and at different periods of post-quarry activity as determined from a survey of quarry site landowners. Survey for landowner's perception and quarried land characterization was undertaken using a questionnaire survey instrument on systematically sampled homesteads. From the questionnaire survey, a total of 60 quarried sites were identified. Nine sites aged between 1 and 20 years were selected through the use of inclusion criteria and were used in assessing plant composition, microsite organisation of land surface materials (patch type, width, length, number; and inter-patch type and length), and soil development in both the wet and dry seasons, following the landscape functional analysis (LFA) method. Soil macrofauna composition was investigated by sampling five 25 cm by 25 cm quadrats per site, in which macrofauna was identified to family and species level and numbers recorded. All the data collected were analysed using a statistical package for social science (SPSS) v.25. Descriptive and inferential analysis (Kruskal Wallis test, Mann Whitney u test) were undertaken. From questionnaire survey, the oldest stone quarry was in 1989 although in majority of the quarry sites quarrying was ongoing. Creation of employment opportunities and opening up of the interior areas were perceived as the main positive impact of quarrying, while the influx of new people and dust pollution were perceived as the main negative impact of quarrying. Backfilling with local soil was the main method used to rehabilitate the quarried land, although most of the quarried sites were naturally rehabilitating. Lack of financial support and lack of a compulsive legal framework were perceived as main limitations to land rehabilitation. From the assessment of the microsite organisation, one inter-patch type, bare soil (BS); and four resource accumulation surface types (patch); plant stone complex (PSC), plant complex (PC), single plant (SP) and stone complex (SC) were identified. Patch and inter-patch densities were found to be high among the young quarries (1-5 years) and lowest in the old quarries (16-20 years). The difference in patch density was statistically significant between the age categories. Patch width and landscape organisation index was high during wet season and in older quarry sites and the difference only significant across age category. was not significant ($p<0.05$). For transect plant composition, a total of 178 plant species belonging to 41 plant families were identified; 163 and 173 plant species in dry and wet seasons respectively. The 16-20 years' category had the highest mean species number per 10 m along the transect while 1-5years category had the least both in the dry and wet season. Backfilled with local soil and not levelled rehabilitation category recorded the highest number of plant species. In soil development, infiltration, stability and nutrient cycle indices were higher during the wet season as compared to dry season and the difference was statistically significant ($p<0.05$). The soil indices were found to increase with increase in the quarry age. The rehabilitation methods used in quarried sites were found to significantly influence soil development. For macrofauna composition, a total of 100 quadrats were surveyed during the wet and dry season in the 9 quarry sites. A total of 72 species of macrofauna were identified belonging to 15 fauna orders. The order Coleoptera was the most common order represented by 25 species of macrofauna. The wet season was found to have higher macrofauna diversity as compared to the dry season. Mean fauna species richness per quadrat was found to increase with increase in quarried land age. Backfilled with local soil not levelled rehabilitation method recorded the highest species richness while backfilled levelled planted with trees saplings recorded the highest diversity index. The study identified existence of the impact of quarrying activities on the landowners and surrounding communities in the quarry zone. The study identified plants species that can grow in the stone quarried sites which provides basis for plants that can be used to rehabilitate quarried sites. Age and rehabilitation methods were found to influence soil development, macrofauna diversity and plant composition.

CHAPTER ONE

INTRODUCTION

1.1 Background information

Urbanisation and industrialisation globally have increased demand for building materials and increased quarrying activities, especially in urban and suburban areas that have left behind quarry landscape scars and destroyed many natural ecosystems (Unde *et al.*, 2010; Wang *et al.*, 2011). A quarry is a unique type of landscape that results from severe anthropogenic activities in resource extraction (Wenjun *et al.*, 2008). Quarrying of building materials is an economic necessity due to its demand for economic development. Quarrying of building stones is done through open cast mining in which all the overlying materials on the targeted rock layers are physically removed (Sinclair, 2012). This is usually the essential first step before stone cutting commences. Most developed countries use heavy machinery in quarrying process, while quarrying is majorly done in developing countries on a small scale (Wenjun *et al.,* 2008). The process of quarrying thus alters the ecosystem around the quarry area (Gathuru, 2011). Quarrying is a source of economic drive in most countries, especially the developed countries. Among the countries involved in intensive quarrying are India, China, Norway, Australia, Italy, and Spain (Grenne *et al.*, 2008; Dong-dong *et al.*, 2009; Parise, 2010).

Quarrying process results in land use and land cover change due to conversion of land utilisation to a quarry landscape. Land conversion is considered a significant challenge to fauna and flora population viability (Flavenot *et al.*, 2014). Quarrying activities have been considered among anthropogenic activities that result in critical land cover land use change (Zhang *et al.*, 2013). Quarry activities have a detrimental effect on the communities living around the quarry zone, the environment, and the quarry region's ecosystem. The negative impact of quarrying includes pollution of surface and ground water resources; disturbance of the ecosystem; displacement, and human health and safety deterioration (Weston et al., 1999; Chigonda, 2010; Darwish et al., 2011). Construction of road, clearing of quarrying sites, and transportation of quarry stones and other materials result in the loosening of top soil, leading to an increase in soil erosion (Chigonda, 2010; Darwish *et al.*, 2011). The abandoned quarried land also has negative impacts such as safety hazards when filled with water and low economic value (Dentoni *et al.*, 2006; Chenot *et al.*, 2017).

In Kenya, the rate of quarrying has increased to satisfy increased demand for quarry products for domestic, industrial, agricultural, and other uses (Wells, 2000; Wells & Wall, 2003). Urbanisation has been the main factor triggering increased quarrying across Kenya (K'Akumu, 2010). The main material of high demand in Kenya includes cement, building stones, ballast and sand. The market demand for such material increases daily, and so does the rate of land exploitation in search of mining resources (Syengo, 2015). In Kenya, quarrying is done at different scales depending on where and who undertakes the mining process. Industrial quarrying is done by large companies such as the cement companies and major road construction companies, while the informal sector does small-scale quarrying, such as artisanal stone quarrying (K'Akumu, 2010; Gathuru, 2011; K'Akumu, 2013).

Quarried lands are put under various uses by their owners, such as recreational sites, farming, agroforestry, building, water reservoir, or some are left abandoned without any use (Box, 1999; Siachoono, 2010). The abandoned quarries have many detrimental effects on the environment. They risk contamination of the underground water and the surface courses, changed landscape topography, loss of landscape aesthetic value, safety risk due to accidents, and soil erosion risks due to the steep slopes (Milgrom, 2008). Ndarugu quarry zone in Kenya is one of the regions with intense quarrying of building stones. The quarrying activities have resulted in increased quarry scarred landscape along river Ndarugu. The artisanal quarrying has resulted in river pollution resulting in poor water quality (Ndegwa *et al.*, 2007). The quarrying and other activities around the

Ndarugu areas also have other negative impacts on the environment and the communities around the quarried area (Hadgu *et al.*, 2014; Mwangi, 2014).

Restoration and rehabilitation of quarried land have received more attention in recent years due to the ever-increasing land conversion to quarry or mine sites and the disturbances resulting from such action to the environment and the society around the quarry zone (Neri & Sanchez, 2010). Restoration aims to alleviate the negative impact of the land left after quarrying and enhancing its economic use. A quarry site has various features such as the quarry cliff, the quarry floor, and the quarry dust, which acts as the substrate for plants that colonize the site in the natural colonisation process (Yuan *et al.*, 2006). The different section of the quarry site requires different rehabilitation methods that suit the characteristic of the section being rehabilitated. Many rehabilitation methods can be used to rehabilitate the quarried land area, such as reforestation, creation of water reservoirs, backfilling with external soil, among others (Holcim, 1987; Werner *et al.*, 2001; Mota *et al.*, 2004; Dong-dong *et al.*, 2009; Gathuru, 2011; Chenot *et al.*, 2017). Even so, a successful rehabilitation method requires a combination of chemical, biological and physical interventions. The influence of human-assisted restoration ensures the targeted restoration goal is achieved within the required time as compared to natural restoration of the quarried site (Jim, 2001; Gathuru, 2011).

1.2 Statement of the problem

Quarrying activities in Kenya and specifically in the Ndarugu quarry region have been ongoing and expected to continue due to the rich deposition of granite volcanic rock out crop in regions. The quarry landscape in the region has continued to increase as more quarrying is undertaken to meet the growing demand in the construction sector. The quarrying activities in the area impact the environment and the surrounding human communities although the current impact has not been fully quantified.

The state of quarried land in the Ndarugu stone quarrying site has not been assessed and documented; hence insufficient information is available on post quarried land use and rehabilitation status of the quarried sites. There are substantial research studies that have been undertaken on the post quarried land use for large quarried land sites such as Haller Park rehabilitation by Bamburi Cement Ltd in Mombasa, Kenya. Little has been done on the rehabilitation of small-scale stone quarried sites, which, although produces stones in small quantities, the impact of the quarry landscape on the environment and the communities around are similar to the large quarries.

Various rehabilitation methods have been pioneered for various quarried land to restore the ecosystem and improve the economical use of quarried land in various parts of the world. The post quarry management of quarried land in the study area has not been fully documented and its effectiveness has not been assessed as this is the first study to evaluate post quarry land use in the Ndarugu area. However, post quarry land uses have been evaluated in other parts of Kenya, such as Haller Park rehabilitation in Mombasa, Kenya that utilise tree plantation and natural colonisation in post quarry land use although the method may not fit in small stone quarried land. The influence of different post-quarry surface types (rehabilitation methods) on plant colonisation, quarried land restoration, and soil development in stone quarried sites has not been fully evaluated and documented. Lack of information on the influence of the different rehabilitation methods on plant composition makes it difficult to understand which plants are best suited to rehabilitate quarried land naturally. No scientific research has been done in the area to evaluate the most suitable and adapting pioneer plants to the quarry environmental and rehabilitation methods owing to the changes in the edaphic factors. Also, the most preferred cost-effective post quarry management system has not yet been established in the study area. Furthermore, the influence of time on a site since last quarried on plant and macrofauna composition and restoration state of land disturbed by stone quarrying has not been determined.

1.3 Justification

The quarrying activities in the study area were ongoing, and the quarry landscape was expected to increase in the future continuously. Currently, no scientific research has evaluated the post-quarried land use and the methods through which the quarry landowners have rehabilitated the quarried land. The research was the initial step in identifying the most effective and efficient post quarry management system. This research was vital for quarried landowners and policy makers in identifying preferred quarry management systems that can organically restore the ecosystem in the quarry zone and ensure that the quarried lands gain economic value in the post quarry period.

The quarry landscape has many negative impacts on the environment and the community around the quarry zones. Identifying the most appropriate rehabilitation method that is cost-effective will ensure that the quarried landscape is well rehabilitated to lower the negative impact related to abandoned post-quarry landscapes. Rehabilitation of the quarried site is crucial in facilitating the re-creation of habitats for flora and fauna and thus contributing to the area's biodiversity improvement. Enhancing landscape installation through planting designs could improve the aesthetic and economic value of quarried sites.

The study involved the local community along river Ndarugu, enabling them to be informed on matters related to quarrying and rehabilitation. The study filled the information gap on quarrying activities and rehabilitation of quarried landscapes in Ndarugu. The outcome of the study was significant in assisting quarry firms and owners in fulfilling the stringent environmental conservation regulation required by NEMA. The outcome of the study also benefited quarried land owners by comparing different rehabilitation methods, making it easier for them to identify one that they could adopt in restoring their lands and the pioneer plants they can use during the quarry restoration. The government agencies such as NEMA that are in charge of environmental conservation along the quarried area benefited by getting information on rehabilitation and lands owner perception that is important in managing the environment as well policy making that is suitable for present and future management of quarried sites in the region and the country at large. The research also contributed to the literature on stone quarry rehabilitation and quarrying impact through the thesis and journal articles publications.

1.4 Objectives

1.4.1 Main objective

To determine the influence of media substrate type on composition of colonizer plants, soil level of development, and the perception of people towards the management of post quarrying sites.

1.4.2 Specific objectives

I. To characterise post quarry sites based on perception towards management and social-economic impacts

II. To determine complexity of plant composition on land surfaces disturbed by stone quarrying under different management and over different periods of post-quarry activity

III. To determine degree of soil development on land surfaces disturbed by stone quarrying under different management and at different periods of post-quarry activity

IV. To assess soil macrofauna found on quarried land under different management regimes and different periods of post-quarry activities

1.5 Hypotheses

$H_0$1. There is no significant variation in characteristics of post quarried management.

$H_0$2. There is no significant difference in plant composition on land surfaces disturbed by stone quarrying under different management over different periods of post-quarry activity

$H_0$3. There is no significant difference in soil development on land surfaces disturbed by stone quarrying under different management and at different periods of post-quarry activity

$H_0$4. There is no significant difference in soil macro fauna composition found on quarried land under different management regimes and different periods of post-quarry activities

1.6 Scope

The research concentrated on the Ndarugu quarry zone in Juja sub-county, Kiambu county in Kenya. The study focused on quarried land owners who lived within the study area. The research involved assessing the perception of quarry owners, categorisation of post quarried lands status, evaluating plant composition and soil characteristics of selected quarried land under different management and of different time duration since last quarried. For soil characteristic, only the surface characteristic and stability in water was assessed and not the nutrient content of the soil.

1.7 Limitation and Assumptions of the Study

The study was undertaken within two years over two long rain seasons and dry seasons. Effective assessment of rehabilitation methods on colonizer plants and soil development is long-term research that could not be undertaken due to logistics limitations. The research assumption was that the information collected over the two different rainy seasons could be comparable. The research also assumed that the selected quarried sites were representative of the other quarried landscape within the same region. The climatic condition within the study area was assumed to be uniform and had the same effect in all the study sites.

CHAPTER TWO

LITERATURE REVIEW

2.1 Quarrying and management of quarried land

Quarrying of stones and other quarry products constitutes a large percentage of the economy of various countries across the world (Lameed & Ayodele, 2011; Russell, 2017). Many companies are involved in quarrying activities in different countries. For instance, in Greece, there are over 4500 companies involved in marble quarrying (Kaliampakos & Mavrikos, 2006). An increase in quarrying activities increases the quarried landscape in the world (Jim & Liu, 2001; Chatterjee, 2010; Moeletsi & Tesfamichael, 2017; Zhu *et al.,* 2018). However, most more developed countries such as Israel, China, India, and Italy have integrated technology on quarrying activities to ensure reduction of quarrying impacts through quarry rehabilitation and enhancing decision making (Berry & Pistocchi, 2003; Milgrom, 2008; Dong-dong *et al.,* 2009). Various quarrying methods are utilised worldwide, the most common being opencast and underground quarrying in Karst regions (Milgrom, 2008; Parise, 2010). Sustainable quarrying has been advocated in many countries with emphasis on quarry rehabilitation with the aim to return the quarried land to its original state (Jim, 2001; Kaliampakos & Mavrikos, 2006; Rushworth & Budnik, 2012). Some of the sustainable rehabilitation legislation and methods failed to work as stipulated in some countries (Kaliampakos & Mavrikos, 2006). It is thus vital for successful quarry rehabilitation methods and rehabilitation legislation for developing countries and for small-scale farming to be developed.

Many research studies have been done on quarry rehabilitation, which looks for the ultimate and most suitable methodologies. Rehabilitation is the methodology used in alleviating the negative impact of quarried land by converting it to more economical use

(Milgrom, 2008). There are many successful rehabilitated quarries in different regions of the world which utilised different rehabilitation methods. Examples include: Milton quarry rehabilitation into a recreational park in Ontario Canada (CSI Quarry Rehabilitation Guidelines, 2011); Haller park land reclamation using vegetation into a recreational site in Kenya (Siachoono, 2010); and Serra da Arrábida quarry in Portugal rehabilitated through revegetation (Werner *et al.,* 2001).

2.2 History of quarrying in Kenya

In Kenya, quarrying is a lucrative business both at small- and large-scale exploitation due to the widely available market resulting from continuous urban and rural development (Shadmon & Gakunga, 1999; K'Akumu, 2010). In the 1960s and 70s, the demand for quarry stones was low, and quarrying was done at a small scale, but this changed from the 1980s when the demand for quarry stones increased, facilitating increased quarrying activities (Wells & Wall, 2003). The soft volcanic rocks are available in the different parts of the country, especially the Rift valley of Kenya, that are suited for construction (Fairburn, 1963; Wells & Wall, 2003). Consequently, the availability of the rock deposits has facilitated increased stone quarrying in different parts of the country, causing quarry landscapes to increase each passing day. In most quarried areas, miners neglect the law and do not rehabilitate the land for better use, thus leaving it as a wasteland (K'Akumu, 2013).

Artisanal quarrying is the major form of stone mining in Kenya and a vital source of employment opportunity for people (Wells, 2000). Various stakeholders benefit from artisanal quarrying, including landowners who lease out their land for quarrying by quarrying firms, concessional owners, quarry owners, quarry workers, and government organisations. Artisanal quarrying is still developing. For instance, the quarries in Juja are now well mechanised (Shadmon & Gakunga, 1999). There are various limitations to quarrying in Kenya. Therefore, these include poor quarrying practices, lack of marketing strategies, poor management, and lack of essential equipment. Consequently, this results in the loss of resources, exploitation of workers and quarry land owners, and reduced benefits from quarrying activities (Shadmon & Gakunga, 1999; K'Akumu, 2010; K'Akumu, 2015).

2.3 Impact of quarrying

2.3.1 Quarrying and the environment

Quarrying activities have both short- and long-term impacts on the environment (Berry & Pistocchi, 2003; Darwish *et al.,* 2011; Lameed & Ayodele, 2011). Quarrying is among the leading anthropogenic activities that alter the landscape (Dentoni *et al.,* 2006; Flavenot *et al.,* 2014). The quarrying process entails the removal of the top soil that includes the destruction of terrestrial and aquatic habitat and plant and animal species that thrive in the area (Kumar *et al.,* 1998). Excavation, waste dumps, and linear disturbances such as a road that has a serious impact on the visual quality of the landscape (Dentoni & Massacci, 2007). The dust produced from the quarry sites settles on the nearby trees and shrubs, thus reducing growth rate of plants as well as their aesthetic appeal in the landscape (Nartey *et al.,* 2012). Construction of the road, clearing of working sites, and transportation of quarry stones and other materials result in loosening up of soil, leading to increased erosion (Chigonda, 2010). Furthermore, the quarrying noise disturbs the wild animals and leads to forceful migration that leads to alteration in the biodiversity balance (Angotzi *et al.,* 2005; Darwish *et al.,* 2011).

2.3.2 Social-economic impact of quarrying

Quarrying plays a major role in social-economic development in various parts of the world (Chigonda, 2010). The society perceived benefits from quarrying included creating employment, increasing household income, and enhanced infrastructure development based on questionnaire surveys (Weston *et al.,* 1999; Chigonda, 2010). For instance, Chigonda (2010) undertook a questionnaire survey of 400 quarry workers in the Mutoko area in Zimbabwe. The worker perceived that the impact of quarrying included biophysical costs associated with the destruction of organism habitats such as those of hyenas and leopards, especially in mountainous regions. Other biophysical cost includes lowering water table leading to drying of marshes that supported various life forms. Poor disposal of waste that includes oil in quarry sites was perceived to lead to soil and underground water pollution, an important source of economic activities (Chigonda, 2010). The study also identified positive social and cultural benefits that included construction of infrastructure and social amenities such as schools and cattle dipping facilities important for social development in the quarried region (Chigonda, 2010).

Quarrying has also negatively impacted society through dust pollution, water pollution, and quarry pits (Saliu *et al.,* 2014). Subsequently, this has affected human health due to diseases such as Pneumonia and lung diseases associated with the dust and fumes from the quarrying process. Besides, it has led to increased school dropout, illegal quarrying, and increased conflicts in society (Chigonda, 2010; Nartey *et al.,* 2012). Madhavan and Raj (2005) undertook a result on the impact of quarrying in India and found that quarrying converts agricultural land to quarry landscape, impacting the agriculture-dependent economies. In addition, the research identified that quarrying changes society's dependence on quarry activities compared to other economic activities (Madhavan & Raj, 2005). Asante *et al.* (2014) undertook a study on the socio-economic benefit of stone quarry in Ghana through a survey of key stakeholders. The study identified that although quarrying was the main economic activity within the study area, the stakeholders had low perceived social-economic benefits (Asante *et al.,* 2014). There is evidence that quarrying socio-economic benefits differ based on the reviewed articles.

İlseven and Kaşot (2020) evaluated people's perception of the impact of quarrying in Kyrenia mountains in Cyprus towards human and natural environment through a questionnaire survey. Some of the perceived impacts included hazardous fumes, dust, and blast noise that leads to health issues among the people. The quarries were also perceived to impact animals' natural habitat and destroy vegetation in the quarry region. The people also perceived lack of legislation towards quarries to reduce quarry impact

(İlseven & Kaşot, 2020). The research recognized that people perceived the need for legislation to control quarrying impact and the need for quarry rehabilitation. Mabey *et al.*(2020) surveyed 360 people from mining edge communities in Sierra Leone to assess their perceptions. The community perceived quarrying led to noise pollution, inadequate availability of clean water, and destruction of forest that led to loss of ecosystem services. The community also perceived need for strategies to restore ecological function to favor the edge communities (Mabey *et al.,* 2020). The perception of people can therefore be crucial in influencing mining sites restoration.

2.4 Quarrying rehabilitation and Management

Quarry management can influence quarry rehabilitation and plant composition in the sites. Legwaila *et al.* (2020) evaluated the different quarry treatment options on the reclamation of limestone quarries. The treatment methods included backfilling, bench planting, restoration blasting, and natural recovery. The management method combined with different post quarry land use such as agriculture and nature conservation were identified to have different impacts on the plant composition and visually appealing of the quarried sites. Even so, restoration blasting and woodland planting were the most preferred quarry management by respondents. Purwanto and Mujiyo (2018), in their study, identified that the use of fast-growing species in quarry restoration leads to an increase in quicker quarry revegetation. Even so, the plants used are supposed to be suitable for the land area. Moreover, Carabassa et al. (2018) undertook a study on the use of digested sewage as an amendment for quarry restoration. The study identified that sludge application in the quarry improves the soil's organic matter, which in turn can support plant colonization in the quarried sites. The addition of organic matter in quarried sites, therefore, accelerates quarried sites colonization. Zucca *et al.* (2013) also identified that the restoration method adopted in quarry rehabilitation influences the plant composition in quarried sites. Furthermore, Zhao *et al.* (2020) reported that the management type adopted is crucial in retaining resources and subsequent development of the quarried site. Apart from the management method adopted. Tomlinson *et al.*

(2008) reported that age plays an important role in plant composition and quarried site colonisation and recovery. The vegetation composition of quarried site was identified to increase over time.

2.4.1 Natural colonisation

Plant colonisation of degraded land is of importance in restoration process of quarry sites (Box, 1999). The early stages of plant colonisation are critical for successful restoration of the quarry site. Plants colonisation of bare soil depends on various factors. These include the edaphic factors of the quarry site (Zhang & Chu, 2011); the surrounding environment, age of the site, the size of area to be colonised; and phytogeographical position of the site (Sumina, 1998; Radu, 2012). Natural colonisation is a spontaneous process that involves various stages of vegetation succession (Zhao *et al.,* 2014). The initial stages comprise primary vegetation mainly annual plants that improve the edaphic factors and form a conducive environment for secondary vegetation. Secondary vegetation also involves different plant species that are mainly perennial. As the quarry site characteristics improve, the primary vegetation is worn out, and the secondary vegetation dominates (Novák & Prach, 2003). Primary vegetation takes 1 to 4 years before perennial grasses, and other secondary vegetation starts to grow (Novák & Prach, 2003). Although Natural colonisation of abandoned quarry can result in land restoration, it takes a long time, and the restoration may not be achieved (Imboden *et al.,* 2010).

2.4.2 Human-assisted colonisation

Assisted colonisation has been used to enhance rehabilitation of the different environments as it assists in overcoming various barriers such as environmental barriers (Seddon, 2010). Even so, plant-assisted colonisation has become conventional among biologists, especially when exotic species are utilised (Ricciardi & Simberloff, 2009). Mining and quarrying result in creation of a new environment that alters the capability of indigenous species colonising the site. Assisting colonisation enhances the development of local plant communities or planting of fast-growing species in the quarry site (Tischew *et al.,* 2014). Some of the interventions in assisted colonisation include planting seeds and seedlings; erosion control; and soil amendments that enable plants to grow in quarry dust (Tischew *et al.,* 2014). The human-assisted quarry site restoration and plant colonisation facilitate the identification of suitable plants that can perform better in the quarried site (Omoti & Kitetu, 2016).

2.4.3 Rehabilitation process assessment methods

Ecological system and landscape rehabilitation are influenced by processes that regulate resources such as nutrients and water. Understanding the ecosystem processes is critical for ecosystem conservation (Siroosi *et al.,* 2012). Monitoring processes involved in the rehabilitation of disturbed land are majorly based on visual assessment. Consequently, this has led to demand for objective, rigorous and fast methods for assessing the landscape (Randall, 2004). There are various methods formulated that meet these objectives. Ecosystem function analysis (EFA), developed by Commonwealth Scientific and Industrial Research Organization (CSIRO) is one of the methods that objectively assess the ecosystem development using simple indicators (Tongway & Ludwig, 2011). EFA can be used to monitor all types of ecosystems (Ludwig & Tongway, 1995; Tongway & Hindley, 2004; Ludwig *et al.,* 2004). The core of EFA is landscape functional analysis (LFA) (Randall, 2004). LFA is a set of monitoring procedures that utilizes simple, easy, and quickly determined field indicators to assess the state of functionality of biophysical processes in the landscape (Tongway & Hindley, 2004; Tongway & Ludwig, 2011). Integrated Biodiversity Assessment Tool (IBAT) is another tool used in monitoring quarried land and evaluating restoration process as it facilitates global and national data for biodiversity indices and protected zones. Integrated assessment models for ecologists are also used to monitor the present state of the landscape and project the future development of the landscape (Baral *et al.,* 2014; Harfoot *et al.,* 2014).

2.4.4 Soil development and macro fauna in quarried land

The efficient operation of an ecosystem depends on the various components that make up the ecosystem (Lawrence, 1984). Soil development is a vital component of the terrestrial ecosystem as it supports vegetation growth. Soil development takes place over time (Reintam *et al.,* 2002). Quarrying impacts soil characteristics such as chemical, soil structure, organic carbon and nitrogen, and organic matter (Jim, 2001; Rani *et al.,* 2017). Soil formation process can be gauged through assessing changes occurring in the initial soil of the quarry (Pietrzykowski & Krzaklewski, 2007). The ability of quarry soil to support plants depends on its organic content, depth of soils, texture, and ability to retain water (Jim & Liu, 2001). Various factors enhance soil formation and development, including human influence such as fertiliser application, ploughing, and soil treatment; vegetation colonisation, and soil macro and microfauna composition (Reintam *et al.*, 2002; Pietrzykowski & Krzaklewski, 2007; Sheoran *et al.,* 2010). In the quarried site, the overburden and quarry dust are usually considered the substrate on which the plant can colonize. The edaphic factors of the quarried sites sometimes are not favourable for plant growth and development. Thus, they require modification or amendment to support a variety of plant species (Ojeda *et al.,* 2015; Luna *et al.,* 2018).

Ludwig and Tongway (1995) reported that the substrate component of the quarried site influences its ability to support plant composition and quarried site ecosystem. Tongway and Hindley (2004) recognised that evaluating soil surface characteristics through the LFA method could enable one to understand landscape soil development and its influence on resource accumulation. Nichols and Toro (2011) identify that soil stability was crucial in disturbed land as it plays a crucial role in increasing resistance to soil erosion and subsequent recovery of the landscape. On the other hand, Huang *et al.* (2015) identified that the quarried surface characteristics influence the infiltration process in evaluating quarry surfaces. On the other hand, Meadows et al. (2008) reported that infiltration in the landscape increases with the age of the landscape. Older landscapes are identified to be well developed to reduce runoff and increase infiltration.

Macro fauna forms part of the ecosystem and plays various roles (Wall & Virginia, 1999). Soil organisms play an important role in stabilizing soil by enhancing vegetation establishment, thus very critical for soil rehabilitation (Doran & Zeiss, 2000; De Deyn *et al.,* 2003; Wang & D'Odorico, 2008). Soil macrofauna diversity and composition vary from one ecosystem to the other and are influenced by various factors. These include human activity, climatic conditions, type of litter accumulation, and plant composition (Mitchell *et al.,* 2012). The more the diversity of litter, the more the fauna diversity as the fauna coexist with minimal competition (Schultz *et al.,* 2014; Gholami *et al.,* 2016; Kamau *et al.,* 2017). The macro fauna availability and diversity vary across plant succession stages (De Deyn *et al.,* 2003).

The macro fauna plays other roles in soil, including improving soil aeration and water infiltration through burrowing in soil; facilitating fungal growth through transferring of spores (Lawrence, 1984; Bottinelli *et al.,* 2015); suppressing pathogenic and noxious organisms; and detoxification of toxicants (Doran & Zeiss, 2000). Disturbed landscapes are characterised by low macro fauna diversity, but in restoration, the soil is colonised by macro fauna progressively. The macro fauna can be assessed through soil core analysis as well as emergence traps placed in the study area (Smith *et al.,* 2008; Riutta *et al.,* 2012). Some of the macrofauna found in disturbed sites such as ants, termites, and earthworms play an important role in ecosystem restoration over time. They influence soil structure and improve soil characteristics over time-related to their activities (Arnold & Williams, 2016).

Further studies can be undertaken evaluating the performance of different crops and trees species growing on the quarry dust that occupy most of the quarried land after quarrying ceases. Utilisation of LFA method in quarry restoration and soil development is yet to be utilised and understood.

CHAPTER THREE

QUARRY PROFILING AND LANDOWNERS' PERCEPTION OF STONE QUARRYING ACTIVITIES AND POST QUARRY USE

3.1 Introduction

Quarrying is among the leading anthropogenic activities that alter the landscape (Dentoni *et al.,* 2006; Flavenot *et al.,* 2014). It has been on the rise due to increased demand for building material for agricultural, domestic, industrial, and other uses as a result of rapid urbanization and population growth (Dong-dong *et al.,* 2009; Olusegun *et al.,* 2009; Unde *et al.,* 2010; Lad & Samant, 2014). Stone quarrying operations involve removing the overburden, drilling and stone cutting, and sometimes blasting and crushing rocks. The quarrying operations and the quarry landscape scars left behind impact the environment and the social-economic well-being of the people living around quarried lands (Chatterjee, 2010; Bamgbose *et al.,* 2014; Lad & Samant, 2014).

The negative impacts of quarrying on the environment include loss of biodiversity (Unde *et al.,* 2010; Darwish *et al.,* 2011), dust pollution, water pollution, landscape aesthetic disruption (Dentoni *et al.,* 2006; Dentoni & Massacci, 2007), underground water pollution, lowered water table, land degradation, increase soil erosion and landslides, destruction of habitats and air pollution from fumes, smoke and noxious gases (Weston *et al.,* 1999; Jim, 2001; Kaliampakos & Mavrikos, 2006; Dong-dong *et al.,* 2009; Chatterjee, 2010). Quarrying significantly alters the ecosystems and ecological relationships that are irreversible (Milgrom, 2008). Quarrying has negative impacts on the aesthetic and visual values of the landscape as it leaves behind quarry scars that require to be rehabilitated (Menegaki & Kaliampakos, 2006; Dong-dong *et al.,* 2009; Misthos *et al.,* 2018). However, abandoned quarries have some positive impacts on the environment, including acting as a water reservoir when well maintained and providing habitat refuge for valuable flora and fauna (Jefferson, 1984; Flavenot *et al.,* 2014).

The communities have different perceptions of the quarrying and mining activities and the post-quarried land use. Wanjiku *et al.* (2014), in a study on occupation health of quarrying, reported that the quarry workers and quarry owners perceived the quarrying activities as the source of poor health conditions. Olusegun *et al.* (2009) also reported that communities around the quarrying zone were aware of the risks associated with their quarrying activities. Kaliampakos and Menegaki (2001) found that people's perception of quarrying impact could influence stopping quarrying activities as it occurred in Attica basin, Greece. Perceptions of post quarry land use from the communities around the quarry areas are usually related to beneficial use to individuals and the community (Ambrose-oji *et al.,* 2009; Kryzia & Kryzia, 2017).

Quarrying activities impact the life of the communities living around the quarry zones and those working in the quarry (Nartey *et al.,* 2012). The negative impacts on the socioeconomic status include an increase in health complications and diseases such as pneumonia, eyes and ears infections, and other respiratory illnesses associated with the dust, smoke, fumes, and noise emitted in the quarrying operations; accidents and health hazards due to existence of quarry pits (Olusegun *et al.,* 2009; Nartey *et al.*, 2012; Saliu *et al.,* 2014; Wanjiku *et al.,* 2014); increase in conflict in the society; water source pollution; loss of productive agricultural land and illegal stone extraction (Lad & Samant, 2014). The vibration from rock blasting and moving machinery damage houses, roof tops and catalyses landslides that cause fatal accidents and losses to the surrounding communities (Bamgbose *et al.,* 2014). The increase in the number of abandoned quarries provides an area for water accumulation, a breeding site for mosquitoes and freshwater snails that further spread diseases to the surrounding population if the water is not treated (Hilson, 2002). Mining also destroys traditional cultural sites, which are of intangible value to the communities. Post quarry land use has also not considered the traditional cultures destroyed during the mining activities and thus total loss of such cultures (Svobodova & Hajek, 2017). Quarrying impacts society positively in various ways, such as employment creation (Weston *et al.,* 1999; Chigonda, 2010).

Sustainable development in the twenty-first century aims at conserving the environment and maximizing benefits from natural resources. Quarry re-greening and rehabilitation focus on reducing the impact of quarrying, enhancement of sustainable development, and increasing economic gains from the abandoned quarries (Dong-dong *et al.,* 2009; Mendes *et al.,* 2014). Many environmental repair approaches are geared towards quarried land to enhance its economic value (Dal Sasso *et al.,* 2012). Different quarry sites had different degree of disturbance. Thus priorities in rehabilitation should focus on the hierarchy of impacts (Mhlongo & Amponsah-Dacosta, 2015; Mavrommatis & Menegaki, 2017). The environmental and socioeconomic negative impacts of quarrying are the main source of conflicts between quarrying firms and the communities living around the quarrying zones (Lad & Samant, 2014). Understanding the perceptions of the communities around the quarry area on issues related to quarrying and post-quarried land status is crucial in quarried area rehabilitation (Lad & Samant, 2014).

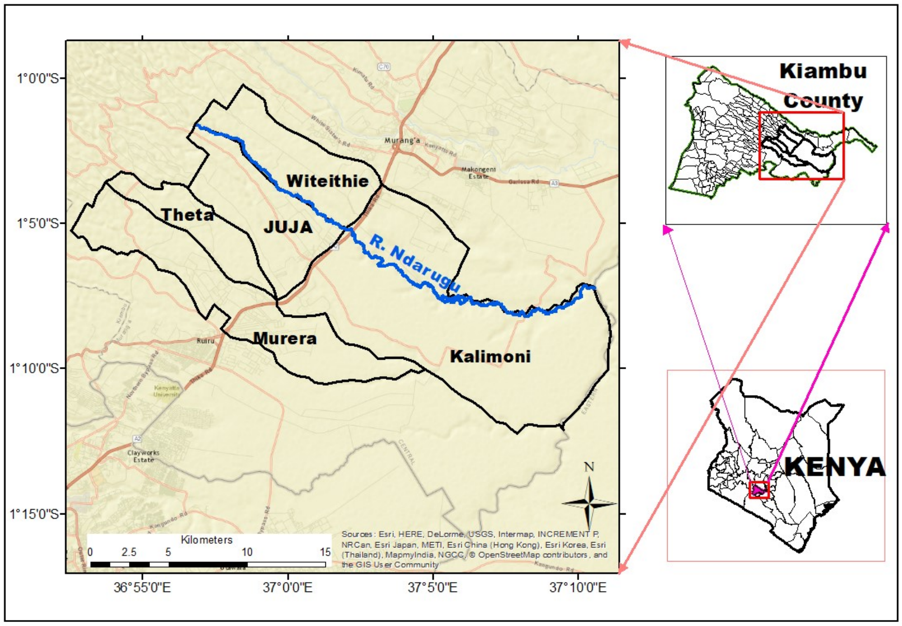
Quarrying activities in Kenya have increased in the recent past due to increased demand for quarrying material for urban development (Shadmon & Gakunga, 1999; K'Akumu, 2010). There is, however, less research on the impacts of quarrying activities within the Kenya context. The profiling of quarried land within the different quarry zones has also not been fully documented. The aim of the current research thus was to assess the perception of quarry landowners on positive and negative impacts of quarrying, post quarry land uses, the limiting factors to quarry rehabilitation, and profiling of quarried land on status and time since quarried.

3.2 Materials and Methods

3.2.1 Description of Study Area

The study site is located in Ndarugu area Juja Sub-county of Kiambu county 36 km north east of Nairobi and about 12 km from Thika town (Figure 3.1). The quarries are embedded in agricultural and natural fields within a region experiencing an increasing density of settlements. The quarry zone strip is subdivided into two sections by the

Thika super highway, eastern and western sides, which enhance transportation of the quarry products. The area gets its name from river Ndarugu whose ridges have an outcrop of soft volcanic rock that is easy to shape, providing a favourable site for quarrying. The abundance of soft volcanic rock is responsible for the presence of many quarrying companies in the area



Sources: Esri, HERE, DeLorme, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), MapmyIndia, NGCC, © OpenStreetMap contributors, and the GIS User Community

Figure 3.1: Map of study area (Source: Authors developed using ArcMap 10.5, and ILRI datasets)

The site is in a semi-humid agro-climatic zone with bimodal rainfall with long rains experienced between March and May while the short rains experienced between October and December. The driest month is usually July, with an average temperature of 17.3 °C, while the hottest is March, with an average temperature of 21.0°C. The predominant basement rock in the area is a soft volcanic and granitic rock that is quarried as building stones (Ndegwa *et al.,* 2007). The area is composed of tertiary volcanic and sediments on sub-Miocene peneplain. The area has basaltic agglomerates layer, but it is very unevenly distributed. The Grey pumiceous tuff bed underlay the Laikipian basaltic layer is the youngest pyroclastic bed in the region.

Moreover, the region has a massive layer of fined grained tuffs, pale bluish and easy to shape, used as a building stone (Fairburn, 1963). There are two layers of the building stone, the upper building stone layer that is about 15 feet thick and the lower layer that reaches 30 feet thick, both of which outcrops in valley bottoms. The building stones are part of the Thika building stone layers that outcrop in the region's various valleys, including Thika, Komo, Ngenia, Samuru, Kabuku, and Ndarugu valleys. The building stone consists mainly of glass, and sometimes it contains crystals of orthoclase (Fairburn, 1963).

Juja has a population of 117,138, according to the Kenya National Bureau of Statistics (KNBS, 2013), with a population density of 652.04 Km^{-2} according to Kenya open data survey (Ngure *et al.,* 2015). The area was initially a coffee plantation zone, and the area's main economic activity was quarrying and small-scale farming. Stone quarrying has been going on for the last 60 years and remains the main economic activity.

3.2.2 Sampling and data collection

The business of quarrying in the study site’s locality usually involves two parties, the land owner and the quarrying company. Often the landowner is also the quarry operator. Because the owner determines land usage, the target respondents in this study were quarried landowners who have settled on the land. Data was collected through interviews guided by a semi-structured questionnaire. From the reconnaissance and site observations, most of the homes consisted of more than one household, and they constituted a homestead of several households of related family members. Therefore, sampling was done for homesteads by following a selected road transect parallel to river Ndarugu ridge where quarrying activities were concentrated and homes set to maximise respondents' number. Systematic sampling was applied to identify the home steads surveyed by selecting every other homestead and interviewing the head of the homestead or the land owner. This was considered random sampling as no prior ordering or criteria was ever used in locating the homesteads during member settlement on the land

The semi-structured questionnaire schedule addressed issues of quarrying impact, post quarried land use preference, expected rehabilitation benefits, current quarry status, and limiting factors for rehabilitation. The interviews were conducted face to face by the lead author assisted by a local in both English and the local language, Kikuyu. Before the actual survey, a pilot survey was undertaken to test the validity and reliability of the information collected by the data collecting tools. The pre-test was done by administering the questionnaire to the JKUAT community. The community is more informed and exposed and would help bring out the necessary critique for further refining the questionnaire. Ndarugu was not used in the pilot test not to lead to repeated surveying.

The final questionnaire response format was either open, ranked in scale, or closed. A total of 10 questions were used to assess the land-use status, impacts of quarrying, and land owner's perception on the management of post-quarried land. Demographic information of the respondents was collected that included name, gender, age, homestead and household sizes, education, means of livelihood, and income level. The respondents were also required to identify the number of stone quarries in their land and the time quarrying started and stopped or if it was going. The total number of quarries in the study area was based on this information.

In each visit to a homestead, consent was first sought to participate in the survey from the respondents and then explained the purpose of the survey. After developing a rapport with the respondent, each interview took about 12 minutes to complete allowing for ample time to express their true experience. The face-to-face interviews were undertaken between February to May 2015 and between March to April 2016. Visits were done during the day, but when the selected landowners were away on other duties, arrangements were made to meet at their convenient times. A total of 36 interviews were conducted on landowners, of which 34 were for homesteads, and 2 were companies. Systematic sampling was used where every other house was surveyed, targeting 50% of the quarry land owners in the Ndarugu region.

3.2.3 Data analysis

The data from the questionnaires were checked to ensure completeness, then coded and entered on a spreadsheet of SPSS software. Qualitative data analysis and interpretation of perceptions were carried out. Principal component analysis (PCA) was carried out to remove redundant variables from both the dependent and independent variables before further data analysis was undertaken. These were then associated with group independent variables (gender, age, education, livelihood means, and income). Kruskal Wallis and Mann Whitney U tests were used to examining the relationships between variables. Kruskal Wallis was used to test whether there was a significant difference between categories. Mann Whitney U test were used to test whether two sample means for a given category were equal or not.

3.3 Results

3.3.1 Sociodemographic characteristics of Landowners

A total of 34 homesteads and 2 companies were issued with semi-structured questionnaire during the survey where the homestead head or company managers were interviewed. The majority (66.7%; n=24) of the landowners were male. Moreover, about 35.3% of landowners were between 36 to 55 years old, followed by the age group above 65 years old (29.4%; n=10), as shown in table 3.1. Majority (97.1%; n=33) of the respondents were married. The greatest number (67.6%; n=23) of the homesteads surveyed had one or two households, followed by those with three or four households (17.6%, n=6). The homestead size is attributed to parents and their children's families living within one compound.

Majority of households surveyed (41.2%) had between 1 and 3 persons, followed by the 4 to 6 persons category (32.4%). The majority of the respondents (47.1%) had primary education, while 29.4 % had secondary education. Most (44.4%) of the respondents were small-scale farmers, while 22.2% were quarry stone dealers. Farming was the area's main economic activity before start of quarrying activities that can explain why most of the respondents were small-scale farmers. The majority of the respondents (48.5%) earned an average monthly salary of between KSh. 10000 ($100) to 30000 ($300) followed by the less than KSh.10000 ($100) monthly salary category (30.3%). Table 3.1 presents the summary of socio-demographic characteristics of quarry landowners. The evaluation of the landowner profile recognizes the diversity in socio-demographic characteristics of the landowners.

Table 3.1: Socio-demographic characteristics of the sampled quarry land owners (n=36)

Variable	Frequency	Percent	Variable	Frequency	Percent
Gender			**Marital status**		
male	24	66.7%	single	1	2.9%
female	12	33.3%	Married	33	97.1%
Age			**level of education**		
18-25	1	2.9%	Primary school	16	47.1%
26-35	8	23.5%	Secondary school	10	29.4%
36-55	12	35.3%	College certificate	3	8.8%
56-65	3	8.8%	Diploma	3	8.8%
> 65	10	29.4%	Degree	2	5.9%
Homestead size			**House hold size**		
1-2	23	67.6%	1-3	14	41.2%
3-4	6	17.6%	4-6	11	32.4%
4-5	2	5.9%	7-9	2	5.9%
> 5	3	8.8%	>9	7	20.6%
Occupation			**Average monthly income**		
Small-scale farmer	16	44.4%	<10, 000	10	30.3%
Quarry stone dealers	8	22.2%	10,000-30,000	16	48.5%
Small scale business	3	8.3%	30,000-50,000	5	15.2%
Contractor	2	5.6%	50,000-100,000	2	6.1%
Stay at home (no occupation)	2	5.6%			
company Manager	2	5.6%			
Transportation sector	1	2.8%			
marketing	1	2.8%			
Masonry	1	2.8%			

From the principal component analysis of the socio-demographic characteristics, 3 principal components were extracted with an eigen value of greater than one that explained 67.3% of the respondents' variation in the various issues covered in the survey. The factors with the highest loading in the first three components were age, homestead size, and occupation, which were then used for further analysis.

3.3.2 Land ownership and land use

On land ownership, 55.6% of the respondents' land was family-owned (two or more related nuclear families), while 44.4% was privately owned (one nuclear family, single individual, or company). The family land type of ownership was high, which could be attributed to the majority of the landowners having inherited from the parents. Most of the homesteads thus had more than one person to be consulted on issues relating to quarrying, as the land was majorly managed at a family level. A larger percentage of respondents in >65yrs, 56-65yrs, and 26-35yrs categories headed family-owned land (Table 3.2).

Most of the small-scale farmers (56.3%) and companies (100%) had privately-owned land, while a large proportion of members of the other occupation categories had family-owned land. This could be attributed to privately owned land being large enough for an individual to decide to farm compared to family land where the large percentage of land is covered by homesteads and less or no portion is left for farming. There was no statistically significant difference in land ownership amongst the occupation categories (X2 (1) = 6.44, p =0.375). About 52.2% of the homesteads with less than 2 households and those with 4-5 households had family-owned land.

Table 3.2: The relationship between social demographic characteristics with land ownership and land size

Social demographic factors		Land ownership (in % frequency) a		Land size (in % frequency)			
		Private	Family	<1 acres	1-<4 acres	4-5acres	>5acres
Age	18-25 (n=1)	100(1)				100(1)	
	26-35(n=8)	25(2)	75(6)		50(4)	50(4)	
	36-55(n=12)	50(6)	50(6)	8.3(1)	66.7(8)	25(3)	
	56-65(n=3)	33.3(1)	66.7(2)	66.7(2)		33.3(1)	
	> 65(n=10)	40(4)	60(6)	20(2)	80(8)		
	Total	14	20	5	20	9	0
Homestead size	1-2 (n=23)	47.8(11)	52.2(12)	13(3)	56.5(13)	26.1(6)	4.3(1)
	3-4(n=6)	33.3(2)	66.7(4)	16.7(1)	66.7(4)	16.7(1)	
	4-5(n=2)		100(2)	50(1)		50(1)	
	> 5(n=3)	33.3(1)	66.7(2)		100(3)		
	Total	14	20	5	20	9	0
Occupation	Transportation sector(n=1)		100(1)			100(1)	
	Contractor(n=2)	50(1)	50(1)		50(1)	50(1)	
	Farmer(n=16)	56.3(9)	43.8(7)	18.8(3)	68.8(11)	12.5(2)	
	Quarry stone dealers(n=8)	50(4)	50(4)		50(4)	50(4)	
	Small scale business(n=3)		100(3)	33.3(1)	33.3(1)		
	Stay at home(n=2)		100(2)	50(1)	50(1)		
	marketing(n=1)		100(1)		100(1)		
	Masonry(n=1)		100(1)				100(1)
	company Manager(n=2)	100(2)			50(1)		50(1)
	Total	16	20	5	20	8	2

The number in brackets represent the number of respondents in that social economic category or group.

About 58.3% of the landowners had a land size of between 1 and 3 acres, 22.2% had 4-5 acres, while 13.9% had <1acres. About sixty-nine percent of those who consider their occupation as farming had 1-3 acres, while only one of the companies had more than 5 acres. No significant variation was found between the occupation categories for the land size owned (x^2 (1) = 10.52, p =0.105.

A large percentage of the older generation (>65years) had between 1-3 acres of land, similar to the 36-55 years category. From the results, the older generation in the quarried area had small sizes of land as compared to the younger generation. This may be due to land subdivision by the parents to their children where they end up with smaller lots. This concurs with Ogechi and Odera (2015), who identified that land subdivision in Kiambu has increased. Therefore, the land sizes owned are expected to decrease in the future due to an increase in the subdivision. Most extended families constituted a homestead in the study area, with more than 50% of the homesteads having two or more households.

The majority (97.2%) of the landowners had a portion of their land quarried, and only one respondent (2.8%) had land that had been cleared ready for quarrying. About 52.8% (n=19) of the respondents practiced crop farming while 58.3% (n=21) practiced poultry farming. Apart from quarrying, agricultural activities were the other main economic activities undertaken by the quarried land owners. Most of the respondents (52.8%; n=19) had their permanent residence in the same land being quarried. A large percentage of quarried land owners lived close to the quarry zones, thus being exposed to the impacts of quarrying activities. Even so, a good percentage of the quarry land owners had alternative homes far from the quarry zone, which may be crucial in avoiding exposure to the negative impacts related to quarrying. Other land uses identified as shown in figure 3.2.

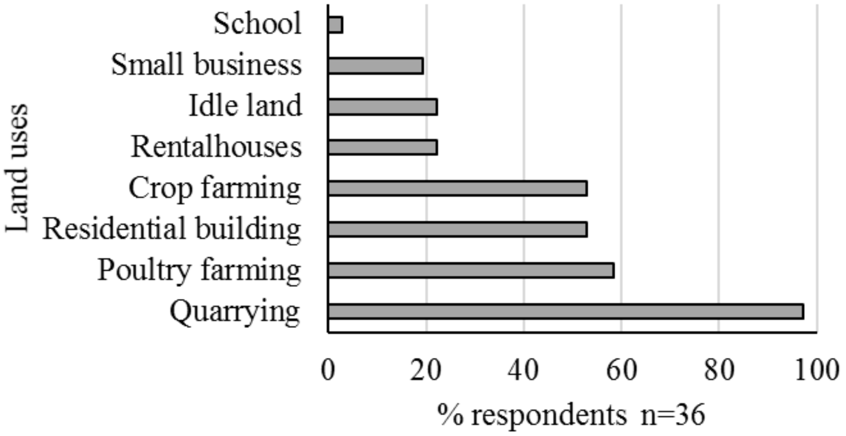


Figure 3.2: Types of land use and level of occurrence among the surveyed respondents

3.3.3 Stone quarrying activities

The survey assessed the stone quarrying activities within the study area. A total of 60 quarry sites were identified from the survey. The oldest quarry site was first quarried in 1989, while the earliest closed quarry was first quarried in 1995. The year 2014 and 2015 recorded the highest number of quarry sites started, 15% (n=9) in each of the years (figure 3.3). The year 2014 recorded the highest percentage of sites that quarrying had stopped per year (16.67%; n=10). About 30 % (n=18) of the quarries identified were still being quarried at the time of the study. The research identified a high number of new quarrying sites in 2014 and 2015, attributed to the increased demand for quarrying materials. The finding concurs with those of Wanjiku *et al.* (2014) and Wells (2000) who pointed out that quarrying activities in Kenya are on the rise. Quarrying in the area was identified to have been undertaken for more three decades as the first case reported was in 1989. Consequently, this point to the importance of the activity over the period supporting the communities and economy in the area

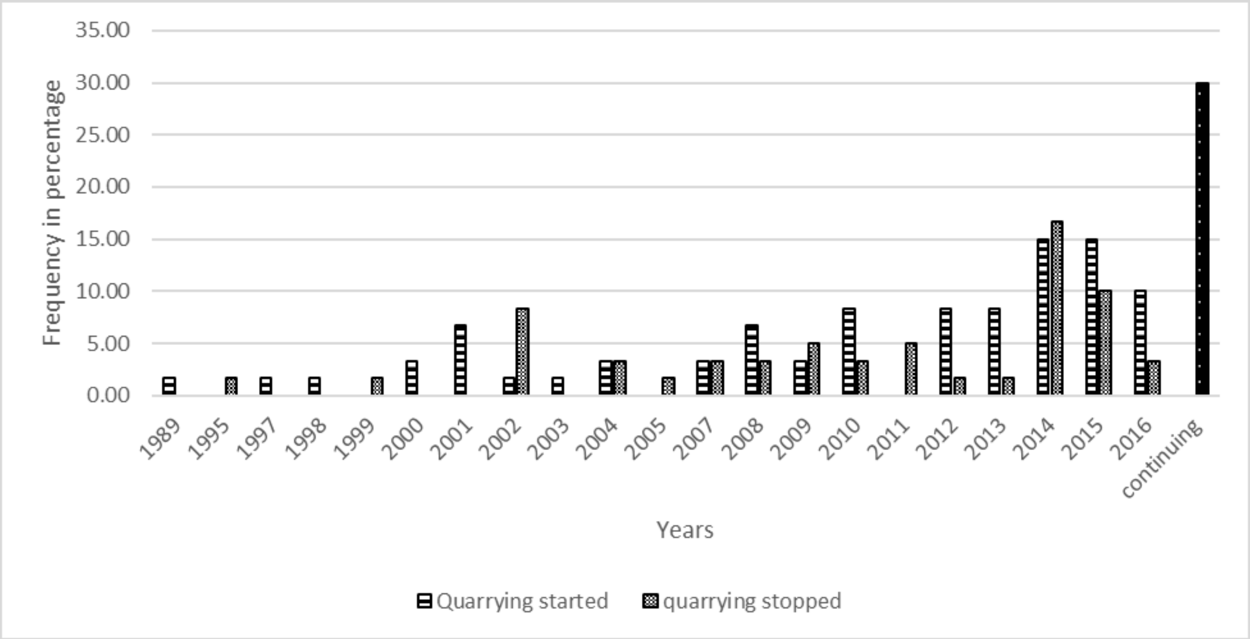


Figure 3.3: Characteristics of the quarry sites mapped from the landowners in terms of proportion that opened or closed in each year. (n=60)

Table 3.3 shows the association between quarrying activities and socio-demographic factors. The greatest number (75%; n=27) of the respondents rented their land out to quarrying firms, while 22.2% (n=8) undertook quarrying by themselves (Table 3.3). Renting out is attributed to the majority of the landowner not having the capital and machines required to do the quarrying. Moreover, it can be attributed to being cost-effective to rent out instead of quarry independently. Half (50%; n=4) of those who quarry by themselves were quarry stone dealers as they had the required expertise.

Sixty-six percent of the respondents (n=24) had less than 50% of their land being quarried. The lower percentage of land being quarried can be attributed to the majority of the land owners living on the land hence their homestead and other activities within the land have to be spared Quarrying in many of the homesteads (80.6%; n=29) was undertaken in 1-2 sections, 13.9% (n=5) done in 3-4 sections while 2.8% (n=1) was done in more than 6 sections. The highest number of sections per land owner was 6 sections which were in land owned by a company. Quarrying was done within defined sections of the land as it was being done in small scale. In addition, the quarried sections served as the receiving areas for overburden while quarrying was on going on the other newer sections. Landowners with larger land sizes were therefore able to have more quarried sections in their land

Table 3.3: Status of quarrying activities categorized based on socio-demographic factors of landowners in Ndarugu area

Social demographic factors		Portion of land under quarrying (in % frequency)		Who did quarrying (in % frequency)[a]		No of quarry sections (in % frequency)			Quarrying duration in years				
		<50%	≥50%	Owner	rented out	1-2 sections	3-4 sections	>6 sections	<1	1-2	3-4	5-6	>6
Age	18-25 (n=1)	100(1)	0	100(1)	0	100(1)	0	0	0	100(1)	0	0	0
	26-35(n=8)	37.5(3)	62.5(5)	37.50(3)	62.5(5)	62.5(5)	37.5(3)	0	13(1)	63(5)	13(1)	0	13(1)
	36-55(n=12)	66.7(8)	33.3(4)	16.67(2)	83.3(10)	83.3(10)	16.7(2)	0	0	50(6)	33(4)	8(1)	8(1)
	56-65(n=3)	100(2)	0	50(1)	50(1)	100(2)	0	0	0	100(2)	0	0	0
	> 65(n=10)	80(8)	20(2)	0	100(10)	100(10)	0	0	30(3)	40(4)	20(2)	0	10(1)
	N	**22**	**11**	**7**	**26**	**28**	**5**		**4**	**18**	**7**	**1**	**3**
Homestead size	1-2 (n=23)	60.9(14)	39.1(9)	21.74(5)	78.3(18)	82.6(19)	17.4(4)	0	13(3)	57(13)	22(5)	4(1)	4(1)
	3-4(n=6)	66.7(4)	33.3(2)	33.33(2)	66.7(4)	83.3(5)	16.7(1)	0	0	67(4)	17(1)	0	17(1)
	4-5(n=2)	100(1)	0	0	100(1)	100(1)	0	0	0	0	100(1)	0	0
	> 5(n=3)	100(3)	0	0	100(3)	100(3)	0	0	33(1)	33(1)	0	0	33(1)
	N	**22**	**11**	**7**	**26**	**28**	**5**		**4**	**18**	**7**	**1**	**3**
Occupation	Transportation sector(n=1)	100(1)	0	0	100(1)	0	100(1)	0	0	0	0	0	100(1)
	Contractor(n=2)	50(1)	50(1)	0	100(2)	100(2)	0	0	0	50(1)	50(1)	0	0
	Farmer(n=16)	86.7(13)	13.3(2)	20(3)	80(12)	93.3(14)	6.7(1)	0	20(3)	53(8)	13(2)	7(1)	7(1)
	Quarry stone dealers(n=8)	25(2)	75(6)	50(4)	50(4)	62.5(5)	37.5(3)	0	0	75(6)	25(2)	0	0
	Small scale business(n=3)	100(3)	0	0	100(3)	100(3)	0	0	33(1)	33(1)	0	0	33(1)
	Stay at home(n=2)	50(1)	50(1)	0	100(2)	100(2)	0	0	0	50(1)	50(1)	0	0
	Marketing(n=1)	0	100(1)	0	100(1)	100(1)	0	0	0	0	100(1)	0	0
	Masonry(n=1)	100(1)	0	0	100(1)	100(1)	0	0	0	100(1)	0	0	0
	Company Manager(n=2)	100(2)	0	50.00(1)	50.0(1)	50(1)	0	50(1)	0	50(1)	0	0	50(1)
Total		**24**	**11**	**8**	**27**	**29**	**5**	**1**	**4**	**19**	**7**	**1**	**3**

The number in brackets represent the number of respondents who are in that category.

Homesteads with 1-3 households had the highest number of land owners (60.9%; n=16), with less than 50% occupied by a quarry. A large proportion of the members in all the homesteads categories had less than 50% of land occupied by quarrying. Only 1-2 and 3-4 categories had some land with greater than 50% under quarrying. Most of the landowners in majority of the homestead categories had their land rented out for quarrying. Homesteads with 1-2 households had the highest number of landowners who had either rented out or did quarrying by themselves. In all the homestead categories, majority of the quarried land was done in 1-2 sections. A large percentage of respondents in the different homestead categories had their land quarried for 1-2 years except for the 4-5 homestead category which had one respondent whose land was quarried for 3-4 years. About 52.8% (n=19) of the respondents had their land quarried for 1-2 years followed by 3-4 years (19.4%; n=7), <1 year (11.1%; n= 4), >6 years (11.1%; n=4) and 5-6 years (2.8%; n=1). The short duration for quarrying activity within a farm is related to majority of the landowners having small land sizes and thus few quarry sections that could last more than 2 years.

A large percentage of respondents in the different age categories had less than 50% of their land under quarrying except for the 26-35-year category. In all the age categories, the majority of the land owners rented out their lands, which were quarried in one or two sections. In all the different age categories, many of the respondents' land was quarried for two to three years. Only three respondents had their land quarried for more than six years. About 45.5% (n=5) of the homestead with greater than 50% of land under quarry was headed by respondents between 26-35 years while 36-55 and >65 years' age groups headed the majority of homesteads with less than 50% of land under quarry. A large percentage of land with 3-4 quarry sections belonged to land owners of 26-35-years category, while most of those with 1-2 quarry sections belonged to owners over 35 years old, as shown in table 3.3. Age influences the number of quarry sections per land. The older generation only allowed few quarry sections while the younger generation allowed for many quarry sections.

In all the occupation categories, most landowners had quarrying occupying less than 50% of land except for those in the quarry stone dealer's category and marketing category. About 54.2% of the land with <50% quarried section belonged to small-scale farmers, while most (54.5%; n=6) of those with >50% quarried area belonged to quarry stone dealers. Consequently, this could be attributed to part of the land being set aside for farming practices; hence less than 50% of the land area being quarried. All respondents who had <1 acre of land and 66.6% of farmers with 1-3 acres of land had <50% of their land being quarried, while 50% of those with 4-5 acres having more than 50% of their land under quarrying. There was strong evidence of association (X2 (1) = 18.854, p =.026) between the size of land owned and the proportion of the land under quarrying. This could be attributed to a larger portion of land remaining even after quarrying is undertaken in over 50% for those who own a large quarry section. In comparison, those with small land have to retain a larger portion for homestead areas and other economic activities. The land size thus determines the portion of land dedicated to stone quarrying by the land owners. The larger the land size owned, the larger the portion of land that is dedicated to stone quarrying.

Half of quarry stone dealers and companies and 20% of farmers did quarrying by themselves. All the other categories rented out their land for quarrying. Majorities of the respondent in all the occupation categories had their land quarried in 1-2 sections except for the company category where one had >6 sections and transportation where one had 3-4 quarry sections. A large proportion of quarried pieces of land with 3-4 sections were managed by stone quarry dealers, while most of those with 1-2 sections belonged to small-scale farmers. The land owners' occupation influenced the number of quarry sections. An occupation related to the use of quarry product influenced the increase in the number of quarry sections, while occupation that depends on land productions influenced a smaller number of quarry sections in their lands.

The main land use in the study area was quarrying, followed by small-scale farming. A large percentage of the homesteads had a land size of between 1-3 acres which was used for various purposes such as quarrying, farming, and building residential areas. Quarrying was done in sections, with most land having one or two quarry sections the same as finding made by K'Akumu (2013). Therefore, the quarrying activities were undertaken in a small scale in the area. The quarrying activities are expected to continue transforming the area, as depicted by Asante *et al.* (2014). As the quarrying activities increases in Ndarugu area, the associated positive and negative impacts are also expected to continue to be experienced in the area (Kuzu & Ergin, 2005; Ndegwa *et al.,* 2007)

3.3.4 Respondents' perception on the environmental and livelihood impacts of quarrying

The respondents identified quarrying activities to have positive and negative impacts to the environment and their socioeconomic status. The positive impact of quarrying and their mean score out of 5 included employment (3.8), opening interior for commercial activities (3.7), increase in income (3.4), social harmony (3.3), improved infrastructure (2.9), easy access to financial loans (2.8) and access to social services (2.6). All the impacts had a score of greater than 2.5, which means at least the majority of the respondents agree that the factors positively impact quarrying. The advantages and positive impact could be attributed to their direct and indirect involvement in quarrying as quarried land owners.

PCA was undertaken to identify the most perceived positive impact of quarrying on society. The communalities revealed that an increase in infrastructure explained the highest variance while the increase in household income had the least. From the PCA, two Principal components (PC) that had Eigen value greater than 1 and explained 59% of the variation of respondents' perception on the positive impact of quarrying were extracted as shown in table 3.4. Two factors that contributed most to the variation for each of the principal components were selected. They included access to financial loans, employment, better access to social services, and improved infrastructure, as shown in table 3.5.

Table 3.4: Principal component analysis output of impacts of quarrying

Total Variance Explained									
Component	Positive impact of quarrying			Environmental negative impact			socio-economic negative impact		
	Total	% of Variance	Cumulative %	Eigenvalues	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	2.743	39.189	39.189	2.272	56.804	56.804	3.180	39.753	39.753
2	1.397	19.959	59.148				1.555	19.436	59.189
3							1.010	12.627	71.816

Table 3.5: Factor scores for the different principal components on impact of quarrying

Positive impact of quarrying			Negative impact					
			Socioeconomic				Environmental impact	
variables	Component		variables	Component			variables	Component
	1	2		1	2	3		1
easy access to financial loans	0.781	0.111	Mismanagement of money leading to poverty	0.768	0.341	-0.248	Water pollution	.670
Source of employment	0.722	-0.27	Increased rate of communal disharmony	0.866	0.269	-0.049	Noise pollution	.808
Better access to social services	0.651	0.555	Influx of new people	-0.195	0.093	0.799	Increased dust pollution	.817
Increase in household income	0.631	-0.066	Change in social ethic	0.226	0.319	0.775	Biodiversity loss	.708
Opening up interior for commercial activities	0.616	-0.546	Domestic violence	0.739	-0.037	0.444		
Better social harmony	0.572	-0.167	Agricultural land Destruction	0.187	0.742	0.075		
Improved infrastructure	0.288	0.807	Insecurity	0.257	0.788	0.295		
			Health and safety hazards	0.065	0.769	0.095		

There was no significant difference in the degree of agreement of the four factors as a positive impact of quarrying between male and female respondents at $p<0.05$. However, there was a statistically significant difference in the degree of agreement of Easy access to the financial loan as a positive quarrying impact between the different age categories of respondents ($p=0.036$) as shown in table 3.6. There was also statistically significant difference in degree of agreement of source of employment as a positive impact of quarrying between the respondents in the different occupation categories ($p=0.012$).

Quarrying activities were perceived to have positive socioeconomic impacts on landowners, whereas creating employment was the most positive impact as presented in Table 3.6. The finding concurs with those of Chigonda (2010) and Weston *et al.* (1999), who found that quarrying activities improved people's livelihood by creating job opportunities and improving infrastructure. Quarrying was also identified to influence easy access to a financial loan that owner could utilise in other activities. Landowners in Ndarugu could therefore be able to access financial support to improve their livelihood. The findings concur with that of Okoyan *et al.* (2021), which identified quarrying and mining as the basis on which loans can be granted.

The social-economic negative impact of quarrying included influx of new people (4.1) and change in social ethics (3.5) (Table 3.6). The negative impact of quarrying to the environment included dust pollution (3.9) and noise pollution (3.2) (Table 3.6). The perception could be attributed to the majority of the landowners living near the quarried site experiencing the negative impact first-hand. Dust and noise pollution that arises from the quarry is linked to health issues among the residents and plants around the quarry sites that include crops hence perception of being a negative impact.

Table 3.6: Perceived negative impact on the environment and social economy

	Score out of 5		
Negative impact	**Mean**	**Median**	**Mode**
Increased rate of communal disharmony	2.0	1.0	1.0
Insecurity	2.0	1.0	1.0
Domestic violence	2.1	1.0	1.0
Water pollution	2.5	2.0	1.0
Health and safety hazards	2.7	3.0	1.0
Mismanagement of money	2.9	3.0	1.0
Destruction of productive agricultural land	2.9	3.0	1.0
Loss of biodiversity	3.1	3.0	5.0
Noise pollution	3.2	3.0	5.0
Change in social ethic	3.5	4.0	5.0
Increased dust pollution	3.9	4.5	5.0
Influx of new people	4.1	5.0	5.0

PCA was undertaken for variables on negative socioeconomic impacts and environmental impacts separately with the output shown on table 3.4 and 3.5. From the PCA, three PC component with Eigen value greater than one and explained 71.82% of the variation was extracted (Table 3.4). Three factors that explain most variation in the perceived negative impact of quarrying was selected. These were domestic violence, insecurity and influx of new people (Table 3.5).

From the PCA, only one PC component with Eigen value greater than one and explained 56.8% was extracted. Three factors that explain most variation in the perceived negative impact of quarrying on environment was selected. The factors are loss of biodiversity, dust pollution and noise pollution. All the six impacts were not significant different in mean score for degree of agreement between male and female respondents except dust pollution at $p< 0.05$. There was also no statistical significance difference in the degree of agreement of the factors as negative impact of quarrying between the different categories of age, homestead size, and occupation as shown in table 3.7

The quarrying activities were perceived to have negative impacts such as destruction of agricultural land and health and safety hazards. Various studies have reported on similar negative socio-economic impacts of quarrying, such as reduction of crop production and impact on the well-being of people (Nartey *et al.* 2012). Quarrying was found to contribute to dust and noise pollution that affects the health of the population living around quarry zone that concurs with Bamgbose *et al.*, (2014) and also caused loss of biodiversity due to the destruction of large areas of forest and productive land as concurred with the reporting of Darwish *et al.* (2011).

The loss of biodiversity in the study area is crucial as it affects the riparian region of River Ndarugu. The findings also concur with Darwish *et al.* (2011) findings where quarrying was identified to destroy a large area of forest and productive land leading to loss of the existing animal and plant species richness in the quarry zone. The loss of trees and quarrying close to the river have increased water pollution, as perceived by the respondents. Stone quarrying activities increased scars of land not repaired in the quarry zone, similar to the findings of Wells (2000), who identified that the artisanal quarrying in Kenya has been on the rise, resulting in an increase in the quarried land has not been fully rehabilitated.

Table 3.7: The negative and positive impact of quarry categorized based on the socio-demographic factors.

Social demographic factors		Socio-economic negative impacts (mean score)			Environment negative impacts (mean score)			Positive impacts (mean score)			
		Domestic violence	Insecurity	influx of new people	Loss of biodiversity	Noise pollution	Dust pollution	Easy access to financial loan	source of employment	Better access to social services	Improved infrastructure
Age	18-25 (n=1)	3	5	5	5	5	5	5	5	1	3
	26-35(n=8)	1	1	4.6	2.9	3.1	3.4	3.8	4.5	3.4	3.5
	36-55(n=12)	2.8	2.5	4.6	3	3.3	3.8	3	4.3	3.0	3.3
	56-65(n=3)	3	1	3.7	3	1	4.3	3.7	3	3	1.7
	> 65(n=10)	2	2.2	3.5	3.4	3.8	4.2	1.4	2.9	1.7	2.7
	P (Kruskal Wallis)	0.061	0.26	0.212	0.799	0.088	0.74	0.036	0.105	0.223	0.514
Homestead size	1-2 (n=23)	1.9	2.1	4.3	3.3	3.4	4	2.7	4.0	2.4	2.7
	3-4(n=6)	2.3	1.3	4	2.5	2.5	3.2	3	3	3.1	3.3
	4-5(n=2)	4	2	3	2	1	3.5	1	2	4	4
	> 5(n=3)	2.3	2.7	5	4	4.7	4.7	2.7	4	2.3	2.7
	P (Kruskal Wallis)	0.256	0.561	0.448	0.421	0.065	0.394	0.755	0.561	0.545	0.365
Occupation	Transportation sector(n=1)	1	1	5	1	1	2	5	5	5	1
	Contractor(n=2)	1.5	2	4.5	1.5	3.5	4	1	4.5	2.5	2.5
	Farmer(n=16)	2.7	2.2	3.9	3.3	3.3	4.2	2.7	3.7	2.7	2.9
	Quarry stone dealers(n=8)	1.3	1.8	4.9	3	3	3.1	3.6	5	2.9	3.3
	Small scale business(n=3)	1.5	2.3	4	4.7	4.7	4.7	2.3	1.7	2.3	4.7
	Stay at home(n=2)	3.5	3.5	3	4	3	4.5	1	1	1	3
	marketing(n=1)	5	2	5	5	2	3	3	5	1	3
	Masonry(n=1)	1	1	5	1	1	4	5	5	5	1
	company Manager(n=2)	1	1	1	1	1	5	1	4	1	1
	P (Kruskal Wallis)	0.239	0.841	0.516	0.359	0.472	0.481	0.24	0.012	0.538	0.53

The score of quarrying impacts are between 1 and 5 where 5 represents a strongly agree and 1 disagree. The number in brackets represent the number of respondents who identifies the factor as an impact. * p<0.05, **p<0.01.

3.3.5 Quarry rehabilitation, limiting factors to rehabilitation and post quarry use

Eight rehabilitation status of quarried land were identified from the survey. Backfilling with local soil and not levelled was the most common rehabilitation status followed by quarried land abandonment for natural rehabilitation as presented in (Figure 3.4). Only 3.4 % of post quarried land, had been rehabilitated to economic use, one planted with trees and one had buildings established. The rest of the land had been left to rehabilitate naturally through colonisation by plants. About The quarrying firm rehabilitated 67.6% of the quarries while the quarried landowner rehabilitated 32.4%. Backfilling with local soil and not levelled was common as it involved dumping the quarry dust and overburden of new section to quarried section that had been completed. Quarry dust was easily accessible hence widely used. Levelling using machine is costly hence was avoided in grading of sites.

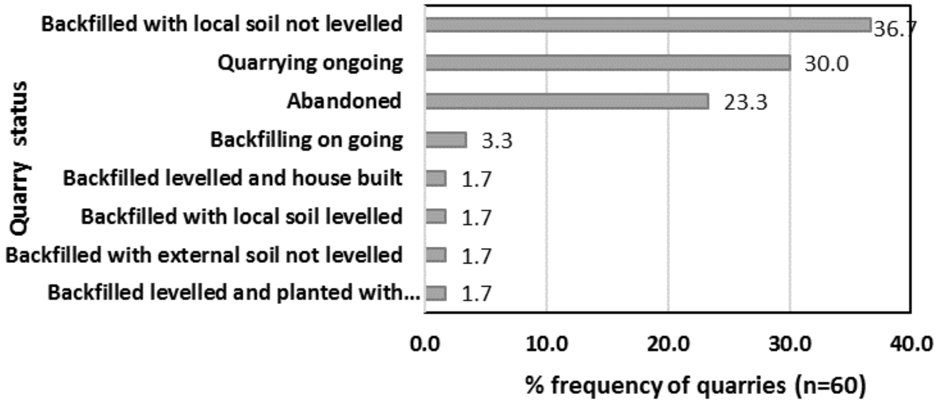


Figure 3.4: Quarry status of quarried land and rehabilitation method used.

The quarry firm and the landowners were the responsible parties that were supposed to rehabilitate the quarried land. One of the limitations to rehabilitation was the responsible parties not taking responsibility towards post quarry improvement of land. This could be attributed to no follow-ups by authority for those who had not honoured their obligation of rehabilitating sections that had been quarried. Consequently, this could explain the large proportion of the quarried land is not rehabilitated as it is left as quarry pits. The responsible parties thus do not accomplish their obligation which results to lose of valuable land that could be put into other economic use. There is a need for action to be undertaken in the quarry zone to enhance accountability of the responsible parties.

Knowledge on quarry rehabilitation plays an important role in enabling quarried land rehabilitation (Kumar *et al.,* 1998; Rushworth & Budnik, 2012). The majority of the landowners were informed about land rehabilitation, which means they can effectively utilise their land the post quarry phase. The finding concurs with those of Barbour (1992) that emphasized on importance pre-planned rehabilitation knowledge for successful quarry rehabilitation. Even so, a good percentage of the landowners were not informed about post quarry land use which points to the need for more awareness and training to equip the landowners with knowledge and skills on quarry rehabilitation. This concurs with Wbcsd (2011) recommendation that pointed to the importance of informed stakeholders for improved post quarry use.

3.3.6 Limiting factors and preferred post quarry land use

Table 3.8 shows the limiting factors to quarry rehabilitation and the land owners' preferred post quarry land use. Lack of financial support (median score 5) and rehabilitation parties not undertaking their responsibility (median score 5), were identified as the main limiting factors to quarry rehabilitation. Other limiting factors included lack of technical support (median score 5) poor body health (especially elderly land owners) (median score 3) and legal barriers (median score 2). Financial constrain can be associated with the process of rehabilitation being labour intensive and costly for the small-scale landowners. In addition, the agreed parties of quarry rehabilitation do not honor their responsibility to leave the quarry site unsuitable for post quarry use. Lack of technical support can be attributed to most landowners not having the rehabilitation experience and easy access to information that can guide cost-effective and economical post quarry use of quarried sites. Statistically, (Kruskal wallis test), there was no significant difference in perception of the limiting factors among the different categories of age, homestead size, and occupation. The result points to the surveyed population having a similar perception of the limiting factors to quarry rehabilitation irrespective of their differences in social and economic characteristics. The findings concur with that of K'Akumu (2013) who identified hostile policy environment as one of the main factors hindering small-scale artisanal stone quarry industry in Kenya to develop and be managed effectively. The findings also agree with those of Kaliampakos and Mavrikos (2006), who identified that legislation for quarry rehabilitation does not effectively work to facilitate rehabilitation.

Table 3.8: Quarry rehabilitation and post quarry factors categorized based on socio-demographic factors.

		Party responsible for rehabilitation (in % frequency)		Limiting factors to rehabilitation (in mean score) ^{a}					Knowledge on post quarry use (in % frequency)		Preferred post quarry land use (in mean score) ^{b}			
Social demographic factors		Owner	quarrying firm	Technical support	Financial constrains	Law and regulation not followed	Irresponsible rehabilitation party	poor body health	Yes	NO	Crop farming	Dairy farming	Creation of dam/ water reservoir	Hotel development
Age	18-25 (n=1)	100	0	1	1	5	5	1	0	100	3	3	3	3
	26-35(n=8)	62.5	37.5	3.9	4	2.4	2.5	2.8	87.5	12.5	2.8	3	2.6	2.4
	36-55(n=12)	16.7	83.3	3.3	4.3	3.7	4	2.9	91.7	8.3	2.6	2.6	2.6	1.8
	56-65(n=3)	0	100	2.7	5	2	3.7	4.3	100	0	3	3	2	3
	> 65(n=10)	20	80	3.5	4.8	2	4.3	3	60	40	2.7	2.3	2	2.1
	P (Kruskal Wallis)	1	1	0.672	0.256	0.114	0.173	0.525	1	1	0.915	0.398	0.227	0.277
Homestead size	1-2 (n=23)	30.4	69.6	3.2	4.4	2.7	4	3	78.3	21.7	2.7	2.5	2.4	2
	3-4(n=6)	33.3	66.7	3.7	3.5	2.2	2.8	2.8	83.3	16.7	2.8	3	2.5	3
	4-5(n=2)	0	100	3.5	5	4.5	3	4	100	0	1	3	3	1
	> 5(n=3)	33.3	66.7	3.7	5	3.7	3.7	2.5	66.7	33.3	3	3	2	1.3
	P (Kruskal Wallis)	1	1	0.895	0.229	0.403	0.484	0.862	1	1	0.131	0.357	0.671	0.025
Occupation	Transportation sector(n=1)	0	100	5	5	1	1		100	0	3	3	3	3
	Contractor(n=2)	0	100	4.5	5	1	2.5	2.5	100	0	2	2	3	3
	Farmer(n=16)	12.5	87.5	3.3	4.4	2.6	3.9	3.4	68.8	31.3	2.6	2.7	2.1	2.1
	Quarry stone dealers(n=8)	87.5	12.5	3.9	3.5	3.2	3.4	2.4	87.5	12.5	3	2.8	2.6	2.1
	Small-scale business(n=3)	0	100	1	5	4	3.7	5	100	0	2.7	3	2.3	1
	Stay at home(n=2)	50	50	3.5	4.5	3	5	2	50	50	3	2	3	2
	marketing(n=1)	0	100	5	5	4	5	1	100	0	2	2	3	2
	Masonry(n=1)	0	100	1	5	1	5	5	100	0	3	3	2	3
	company Manager(n=2)	50	50	1	1	1	1	1	0	100	1	1	1	1
	P (Kruskal Wallis)	1	1	0.333	0.681	0.489	0.339	0.338	1	1	0.299	0.376	0.413	0.315

The score of limiting factors is out of five where 5 represents an extreme limiting factor and 1 not a limiting factor. Preferred post quarry use is scored out of 3 where 3 represents most preferred and 1 being least preferred. The number in brackets represent the number of respondents who identifies the factor or in that group. * $p<0.05$, ** $p<0.01$.

Overall, quarry rehabilitation was perceived to impact the environment and socio-economic wellbeing of the people positively. The most perceived quarry rehabilitation benefits were a reduction of health and safety hazards (score of 4.7 out of 5), increase in household income (4.6), improved land productivity (4.5), biodiversity restoration (4.5), and job creation (4.4). The perceived positive impact of rehabilitation may be attributed to the few natural rehabilitating quarry sites within the study area. The finding concurs with those of Mabey et al. (2020), who identified that the community around the mining site perceives the importance of rehabilitation and requires it to be undertaken.

On preferred post quarry land uses, planting of trees, crop farming, and dairy farming were the most preferred post quarry land use, while natural vegetation colonisation, hotel development, and building rentals or estates were the least preferred post quarry land use as shown in Figure 3.5. The post quarry land use perception related to what the stone quarry landowners associated as economic development initiatives such as farming, which was one of most homesteads' main economic activities. The preferred post quarry land use can be attributed to providing the respondent with the identified quarry rehabilitation benefits.

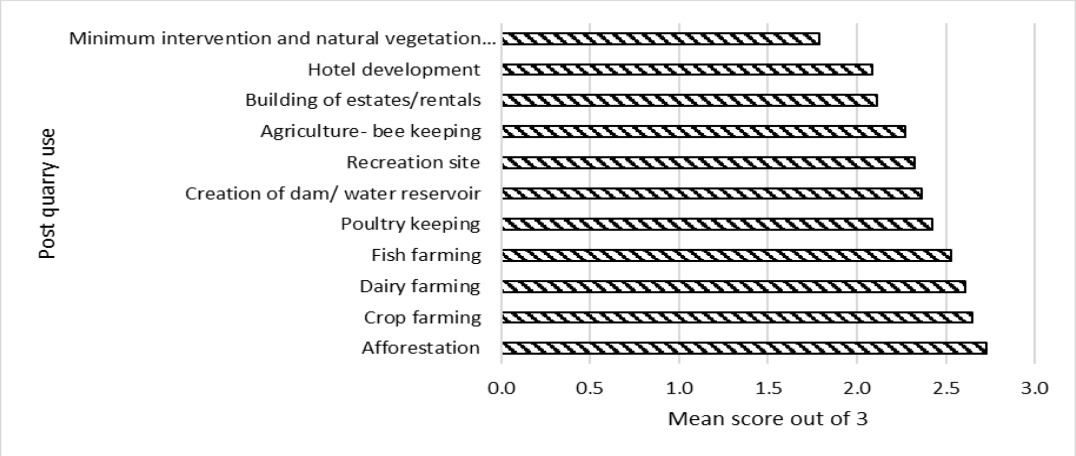


Figure 3.5: The acceptability means score of the identified possible post quarry uses as given by the respondents.

NB: A score of 1 refers to least preferred while three is the most preferred

From the PCA of mean scores for the various preferred land uses four principal components with an eigenvalue of greater than one and explained more than 67% of the variation in respondent perception were extracted as shown in table 3.9. The post quarry land use with the highest loading in each principal component was considered which were, dairy farming, hotel development, the creation of dam/water reservoir and crop farming for principal components 1, 2 3, and 4, respectively, which can potentially increase profitability and sustainable use of post quarried land. Trees planting can be very significant in a stone quarried landscape as it enhances species biodiversity, soil development, reduction of soil erosion, and provision of other economic benefits to the landowners such as wood and firewood (Gathuru, 2011).

Table 3.9:Principal component analysis (PCA) of post quarry land use

Total Variance Explained			
Component	Initial Eigenvalues		
	Total	% of Variance	Cumulative %
1	3.421	31.103	31.103
2	1.504	13.669	44.772
3	1.394	12.677	57.449
4	1.072	9.744	67.193

From Principal component analysis (PCA) of post quarry land use to identify variables that explained most variation in post quarry land, four principal components (PC) that had Eigenvalue of greater than one that explained 67.193% of the variation of respondent perception on post quarry use was used as shown in table 3.9. PC1 alone explained 31.103% of the variation of the respondents. The highest loading of PC1 was dairy farming, while the least was building estates and rentals, as shown in table 3.10. Increase in any of the loadings positively impacted PC1. PC1 was a gradient from dairy farming to building of estates/rentals. PC 2 had highest negative contribution from Agricultural beekeeping and the highest positive of hotel development. PC2 had hotel development to beekeeping gradient. The major positive loading of PC2 was hotel development and building estates/rentals while the major negative component was bee keeping and creating a dam or water reservoir. PC3 major positive loadings were creating a water dam or reservoir, fish farming and bee keeping, while the major negative loading included minimum intervention and natural vegetation colonization, and dairy farming. PC4 had reforestation/ planting of trees to fish farming gradient. The major factor loadings were reforestation/planting of trees, fish farming, and crop farming. Decrease in the perception of Fish farming and crop farming would increase PC4.

From the PCA analysis, variables with a factor loading of greater than 0.64 were selected (Table 3.10). Five-post quarry use was identified that explained the main variation in respondents' perception of post quarry use. The five-post quarry use included crop farming, Dairy farming, Afforestation, creation of dam/water reservoir, and recreational site development. The perception of the five-post quarry uses was not significantly different in the different categories of age, occupation, marital status, level of education, monthly income, and household (Table 3.8). Therefore, the respondents have the same perception towards the most important post quarry land use that can benefit them. The choice for post quarry land use can be associated with the quarry land owners' economic activities before quarrying activities on their land and surrounding environs.

Table 3.10: Factor loading of component for post quarry land use.

Component Matrix

	Component			
	1	2	3	4
Dairy farming	.867	.043	-.300	.054
Reforestation/planting of trees	.678	.020	-.145	.410
Crop farming	.661	-.050	-.077	-.628
Recreation site	.649	.223	-.140	.027
Poultry keeping	.569	-.246	-.286	.103
Minimum intervention and natural vegetation colonization	.498	-.276	-.320	-.028
Hotel development	.454	.639	.186	.238
Agriculture- bee keeping	.426	-.631	.423	.116
Building of estates/rentals	.279	.621	.366	.066
Creation of dam/ water reservoir	.368	-.331	.724	.273
Fish farming	.423	.101	.449	-.588

Extraction Method: Principal Component Analysis.
a. 4 components extracted.

3.4 Conclusion

The survey of the quarry landowners in Ndarugu quarry zone aimed to assess the perception of stone quarry landowners on economic and social impacts of stone quarrying, to determine the status of post-quarry land and factors influencing rehabilitation efforts. Quarrying activities were perceived to have positive and negative impacts on the environment and the socio-economic wellbeing of the people. Most of the landowners were informed about quarry rehabilitation. Even so, a large percentage of quarried land in the area was not rehabilitated, which increased the quarry scarred landscape. Lack of financial support services was perceived as the main limitation to land rehabilitation.

CHAPTER FOUR

MICRO-SITE PLANT COLONIZATION AND ORGANIZATION IN POST STONE QUARRIED SITES IN NDARUGU, KENYA

4.1 Introduction

As the demand for building materials such as sand, gravel, building stones, and cement continues to increase, the presence of quarried landscape has also grown within our environment (Dong-dong *et al.,* 2009; Lad & Samant, 2014). Removal of soil, plants, and other material during the quarrying process has been identified as one of the most critical anthropogenic land use land cover change drivers since the landscape left behind has many negative impacts on the community and the environment (Milgrom, 2008). The negative impacts include loss of biodiversity, health and safety risks, loss of visual aesthetic value of the landscape, and reduction of quarried land productivity (Ramos & Panagopoulos, 2006; Ozean *et al.,* 2012). To mitigate the impacts of quarrying on the landscape and communities, various approaches are employed which includes natural rehabilitation with spontaneous succession, re-vegetation with fast growing plant species after site amelioration, and assisted site rehabilitation using native species (Tischew *et al.,* 2014). The site amelioration determines the quality of the site substrate, which determines the plant species that will acclimatize to the edaphic factor of the site (Tischew *et al.,* 2014).

Understanding the ecological restoration process requires evaluating the processes of resource regulation, such as water and nutrients, vital for plant species colonization of quarried landscapes (Siroosi *et al.,* 2012). The landscape with a high capability of retaining resources leads to improved recovery and improved spatial landscape organization (Ludwig and Tongway, 1995; Randall, 2004). The microsites are considered important in resource accumulation and influence plant recruitment in the landscape (Owens et al., 1995; Haugland & Beatty, 2005; Maher & Germino, 2006). Therefore, understanding the microsite organisation and plant colonisation of quarried land will be crucial in understanding the post quarry land use and effective rehabilitation. The landscape patch is considered an area for resource accumulation. Plant colonisation of landscape form plant patches that play a role in retaining or resources in the landscape and ultimately influences the landscape organisation development. Joining of plant patches leads to an increase in the area of resource accumulation and further leads to landscape restoration in the case of quarried land sites (Humphries & Consultants, 2016). In addition, Zhang and Chu (2011) reported that the plant structure and composition in quarries improve with the sites' age, which further improves the landscape.

With respect to Kenya, quarrying activities have increased in recent years. It is common in areas with soft volcanic rock to meet the growing demand for building material such as cement and building stones. some of the quarried sites have been rehabilitated such as Haller park in Mombasa (Siachoono, 2010). Most of the small-scale quarries have been semi-rehabilitated or abandoned to rehabilitate naturally. Although legally, the Environmental Management and Coordination Act, 1999 requires that quarried land be rehabilitated, compliance has been minimal, attributed to enforcement challenges and lack of adequate research to inform policy and actions (Gathuru, 2011). Knowledge of microsite organisation and plant colonisation of quarried land can enhance rehabilitation and post quarry land use. Even so, assessment of micro landscape organisation of quarried land in Kenya has not been documented. Therefore, the objective of this study was to determine the type and organization of micro-site land surfaces of post-quarried land and type of colonising plant species.

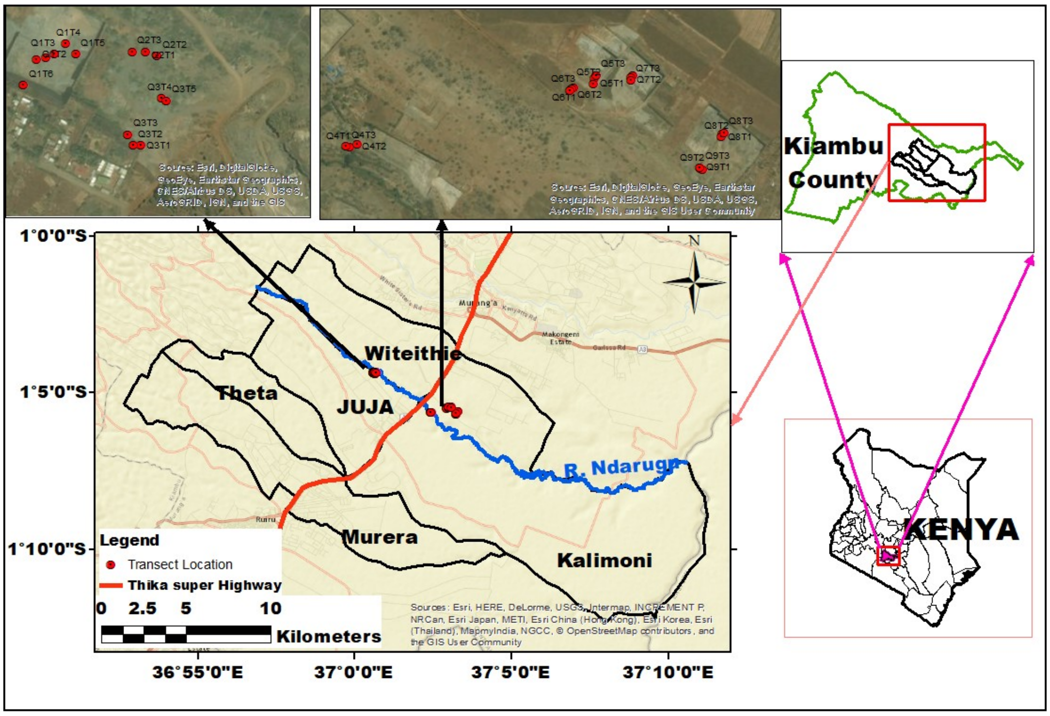
4.2 Materials and Methods

4.2.1 Study site

The description of the study site is presented in section 3.2.1

4.2.2 Sampling and data collection

The study was undertaken in nine sites sampled from sixty quarry sites that were initially identified through a questionnaire survey of landowners along the Ndarugu quarry zone, as shown in figure 4.1. The sites were selected because quarrying activities had ceased, they covered large area of quarried land, and the owners gave consent for them to be utilised in the study.



Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Sources: Esri, HERE, DeLorme, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), MapmyIndia, NGCC, © OpenStreetMap contributors, and the GIS User Community

Figure 4.1: The map represents the study area with the locations where the transects survey was undertaken.

The selected sites were within the same geographical region. The sites were characterised by different rehabilitation and age group since last quarried (Table 4.1). The substrate in the different quarry sites differed depending on the soil dumping or rehabilitation method used, with the majority of the sites having quarry dust as substrate. Table 4.1 shows the nature of the study sites.

Table 4.1: Characteristics of the different quarry sites that were sampled during the study

Quarry site	Years elapsed since last quarrying	Rehabilitation method	Area (Ha)	Number of Transects
Q1	1-5 years	Backfilled with local soil not levelled	1.9	6
Q2	6-10 years	Backfilled with local soil levelled	1.0	3
Q3	11-15 years	Backfilled with local soil not levelled	1.0	5
Q4	16-20 years	Backfilled levelled planted with trees	1.9	3
Q5	1-5 years	Backfilled with local soil not levelled	1.0	3
Q6	16-20 years	Backfilled with local soil not levelled	2.1	3
Q7	6-10 years	Backfilled with external soil levelled	1.5	3
Q8	1-5 years	Backfilled with local soil not levelled	0.9	3
Q9	11-15 years	Backfilled with local soil not levelled	1.0	3

4.2.3 Micro-site features and vegetation assessment

Field inspection for each of the nine quarries was done to delineate the basic landscape functional types. For each of these landscape functional types, three transects were laid down, 10 meters apart. The transects length was between 35 and 85 meters depending on the size of the site. Transects were set down-slope using a tape measure and marked with pegs and coloured line markers for identity purposes and ease of tracking. The landscape functional analysis (LFA) method was used to quantify features along each transect as detailed in the LFA manual (Randall, 2004; Tongway & Hindley, 2004). The starting point of the transect was at the boundary between a patch and inter-patch. Micro-landscape features of concern along the transect were either a patch or inter-patch. The patch is defined as the area of resource accumulation while the inter-patch acts as the source of resources found between two patches. Along the transect, for each patch encountered, the patch type, patch width, and patch length were measured, and photos of the same were taken. For the inter-patch area, the type and length were recorded (Figure 4.2).

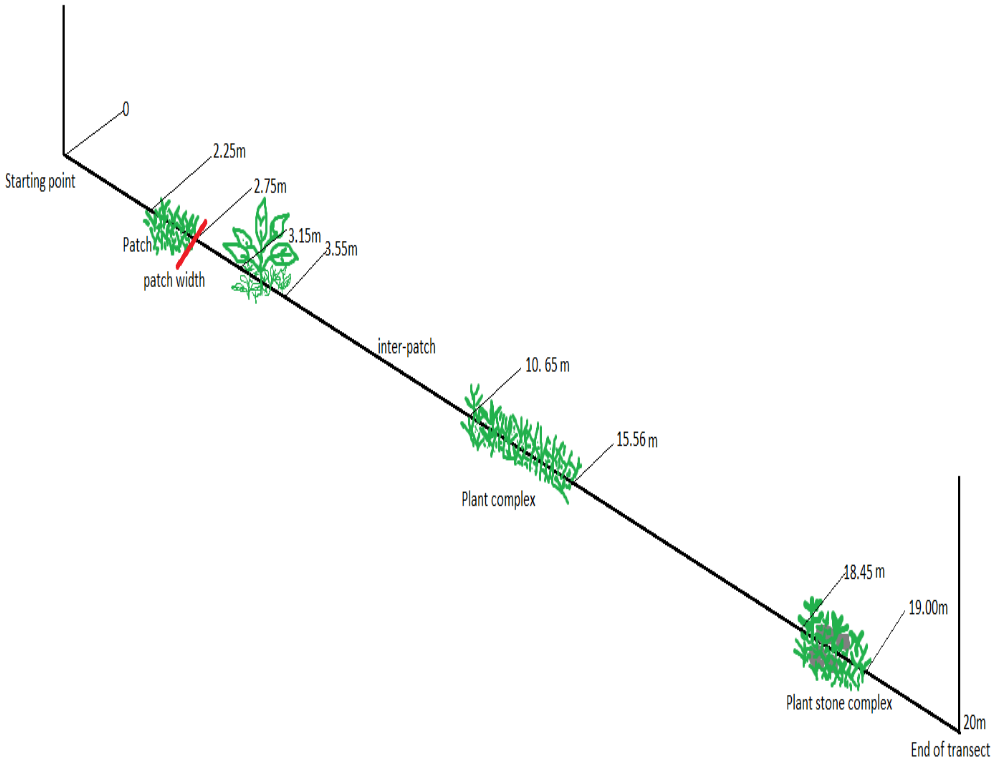


Figure 4.2: Diagrammatic representation of the transect line and the features of patch and inter-patch as encountered along the transect.

Further, the type of plant species present in a patch along the transect were identified with the help of plant identification books (Blundell, 1994; Ivens, 2012; Terry & Michieka, 1987) to species level. The study was carried out between June to August 2015 and June to August 2016 (dry season) and repeated in December 2015 to February 2016 and November to December 2016 (wet season). Plate 4.1 summarizes the steps followed in the data collection in patch-interpatch analysis.

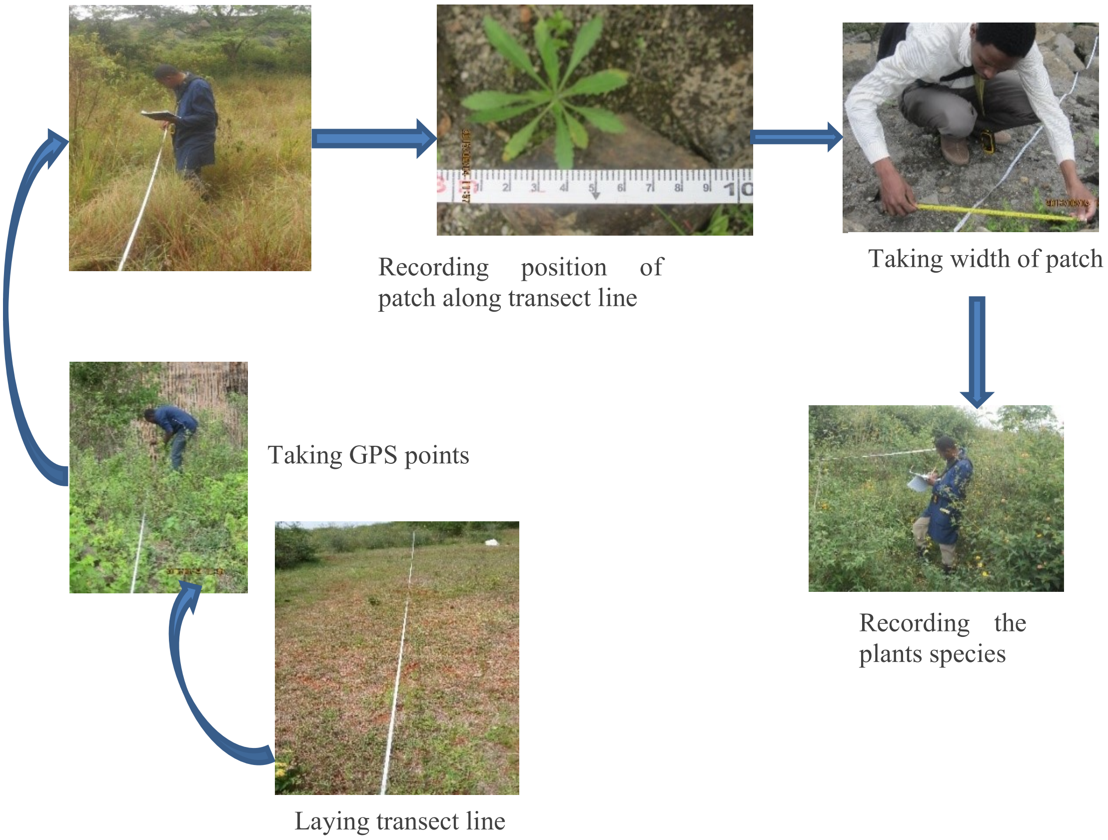


Plate 4.1: The steps followed in collecting the patch and interpatch data.

4.2.4 Data analysis

4.2.4.1 Patch inter-patch analysis

The patch and inter-patch types recorded in each transect were identified for both the wet and dry seasons. For each patch type, the total number, the average length and width, percentage length along the transect, and number per 10 m of the transect (density) were computed for each transect. For inter-patch, the number of inter-patch types and percentage cover along the transect were computed. The patch organization pattern for each transect was then calculated using the relationship below as;

Patch organization index = Sum of all individual patch length / total length of transect

Patch and inter-patch variables were analysed for individual transects and averaged for the whole quarry scale and expressed as; the mean patch number per ten meters, average patch width per 10 m along the transect, average of inter-patch number per 10 m, mean percentage cover for each patch type and mean patch organization pattern. These variables were computed for both dry and wet seasons. The influence of quarry site age (time elapsed since the last quarrying) and substrate type and surface characteristics (rehabilitation method) were then tested against the measured patch attributes. The Kruskal-Wallis test and Mann-Whitney test at $p < 0.05$ were applied to test for statistical significance between seasons, rehabilitation methods, and time duration elapsed since the last quarrying.

4.2.4.2 Plant composition

The plant species identified in each transect were counted to give the richness of the plant species for both dry and wet seasons and the mean value derived for the whole quarry site. The plant identification was undertaken through the help of a taxonomist and botanical books. Photos of plants were also taken, which was analysed by a taxonomist who helped identify the plant. For each species, its family and origin (native or exotic) was determined, and the number of families identified per transect and the whole quarry was noted. The plant species density (number of plants species per 10m along the transect) was computed for each of the transects and whole quarry sites for both wet and dry seasons.

The plant species data were further analysed to identify the effect of time elapsed since end of quarrying, rehabilitation method, and season. This involved determining the species number per ten meters for each category, the frequency of plant families, and plant origin. The data was subjected to Kruskal-Wallis test and Mann-Whitney test at $p <0.05$ to test for statistical significance difference between seasons, rehabilitation methods, and time duration since last quarrying.

4.3 Results and discussion

4.3.1 Characteristics of surveyed transects and resource zone types

A total of 32 transects were surveyed twice in the wet and dry seasons. Based on the LFA criteria on the process of resources generation and movement during initial stages of seedling setting and soil development in disturbed soils, the dominant zones of resource origin and accumulation in the microsites surveyed in the study were identified; (i) for resource origin, one inter- patch type, bare soil (BS); then (ii) for resource accumulation, identified zones were four patch types; plant stone complex (PSC), plant complex (PC), single plant (SP) and stone complex (SC), (Plate 4.2).

Plate 4.2: Different patch and inter-patch types. Bare soil (BS), plant stone complex (PSC), plant complex (PC), single plant (SP) and stone complex (SC).

Plant stone complex (PSC) presence was due to the quarry site having a stony surface where plants find refuge to set and grow to form a combination of stone and plant patch. The stone complex patch (SC) on the other hand was found present as the building stone quarry had been backfilled partly or wholly by quarry dust and stone, hence having a section with stone patch that resources can accumulate. Plant complex presence is an indication of plants growing together in same place, forming a continuous plant cover patch which is good representation of quarry site recovery. Single plants (SP) are an indication of new plants colonising the quarry site and the initial stage of formation of a plant complex patch. The only area of the source of resource was the bare soil. Before the plant colonises the quarry site, the land is usually bare and forms the source of resources. The existence of the area of resources is an indication that the quarry site is not fully restored.

4.3.1.1 Patch density

Table 4.2 shows the overall patch and inter-patch density (number of patches per 10 meters) for all nine sites during the wet and dry seasons. The average patch number per 10m was highest during the dry season as compared to the wet season except for Q7 and Q8 where the wet season had higher values. The highest average patch density was 6.96 in Q1 during the dry season, and the lowest was 0.2 patch no per 10m of transect length recorded in dry and wet seasons (Table 4.2). The inter-patch and patch number per 10m were higher during the dry season as compared to the wet season. Even so, there was no statistical significance difference ($p>0.05$) in the number of patches per 10m between the wet and dry season for all the patch and inter-patch types except for SP (single plant) patch type ($x^2= 9.871$; $p= 0.002$) (Table 4.2).

The low density of patch and interpatch during the wet season is associated with more vegetation growth due to water availability. The small patches join together to form larger patches. In addition, wet season is characterised by seasonal or biannual plant growth that colonises quarry sites, facilitating coalescing of patches reducing the number of patches. During the dry season, seasonal plants dry up, and large patches break down to smaller patches that result in increased patch and interpatch density during the dry season. For SP, during the wet season, the number is low as single plants joined to form plant complex, but in the dry season, plant complex breaks to single plants and small PC and reason for significant difference between wet and dry season for SP.

However, the Kruskal Wallis test for patch and inter-patch density between the different quarry sites showed that there was a significant difference between the nine quarry sites as shown in table 4.2. The difference could be associated with the unique characteristic of the different quarried sites associated with age and substrate characteristics. Older quarries such as quarry 6 and 4 had established bigger patches due to large percentage of perennial plants hence low density compared to young quarry such as quarry 1 that had new patches forming that had not started coalescing. The finding agrees with those of Humphries and Consultants (2016) who identified that increase of age of quarry leads to joining of small patches to form large patches, with young quarry having higher density of patches.

Table 4.2: The patch and inter-patch density and spatial metrics for the dry and wet seasons for the nine sampled quarry sites

Quarry	Number of transect	Mean of individual patch no. /10m					Overall patch characteristics			
		BS (Interpatch)	SC	PC	SP	PSC	mean patch no /10m	Mean landscape organisation index	Patch width(m)/10m	Patch coverage (%)
							Dry season			
Q1	6	7.66	2.71	0.58	1.62	2.57	6.96	0.55	6.26	51.7
Q2	3	4.46	0.20	2.72	0.85	0.94	5.47	0.72	14.22	78.2
Q3	5	2.90	0.08	1.79	0.36	1.14	3.38	0.86	15.45	85.5
Q4	3	0.27	0.00	0.27	0.00	0.27	0.53	0.98	28.61	98.5
Q5	3	4.00	1.00	0.67	0.47	2.00	4.13	0.59	10.92	59.0
Q6	3	0.07	0.00	0.00	0.00	0.20	0.20	0.99	16.00	99.1
Q7	3	0.07	0.00	0.20	0.00	0.07	0.27	0.99	26.67	99.3
Q8	3	0.00	0.13	0.00	0.00	0.20	0.20	1.00	25.00	100.0
Q9	3	0.07	0.33	0.00	0.00	0.60	0.93	0.98	64.00	98.5
P-value		0.001	0.001	0.002	0.001	0.000	0.001	0.001	0.002	0.001
							Wet season			
Q1	6	2.69	0.72	0.88	0.33	2.16	6.79	0.80	16.10	79.8
Q2	3	2.22	0.09	1.75	0.05	0.76	4.88	0.83	20.03	83.2
Q3	5	0.45	0.08	0.73	0.00	0.61	1.88	0.95	28.73	95.3
Q4	3	0.00	0.00	0.00	0.00	0.20	0.20	1.00	24.00	100.0
Q5	3	2.53	0.67	0.67	0.00	1.80	3.13	0.70	9.53	70.4
Q6	3	0.00	0.00	0.00	0.00	0.20	0.20	1.00	13.33	100.0
Q7	3	0.13	0.00	0.13	0.00	0.20	0.33	0.99	33.33	99.0
Q8	3	0.00	0.13	0.00	0.00	0.27	0.40	1.00	31.67	100.0

Q9	3	0.07	0.33	0.07	0.00	0.27	0.67	0.98	31.03	98.0
P-value		0.001	0.006	0.001	0.158	0.002	0.000	0.001	0.026	0.001
	Comparison density across wet and dry season									
Kruskal-Wallis H		3.344836	0.7657	0.24454	9.615	0.5054				
df		1	1	1	1	1				
P-value		0.067416	0.3816	0.62095	0.002	0.4771				

The computed patch and inter-patch density for the years elapsed since stoppage of quarrying and for the different substrate conditions (rehabilitation methods) for dry and wet seasons is listed in Table 4.3. For the time elapsed since the last quarrying, the youngest quarry category (1-5 years) showed a high patch and inter-patch density value compared to the rest except for plant complex (PC), which was lower in the 5-10-year period category. The older quarry category (16-20 years) recorded the least mean patch and inter-patch density value. Except for the plant complex (PC) patch type, patch and inter-patch density decreased with the increase in the period of years elapsed since the last quarrying for all patch types. The mean number of inter-patches per 10 m decreased with an increase in the time elapsed since the last quarrying.

From the Kruskal Wallis test, the difference in density of all the patch and inter-patch types between age categories since the last quarrying was found to be highly significant at 95% confidence limit. The decrease in patch density is associated with small patch joining over time to form large patches. Therefore, the young quarry will have a very high number of patch and interpatch types, which is different from the old stone quarry with a very small number. Hence, the mean density of the different categories differs. The findings agree with those of Humphries and Consultants (2016), who pointed out that as the age of site increases, the small patch joins to create a larger patch, hence reducing patch density. Zucca *et al.* (2013) explain that determining the patchiness of the site can be used to evaluate its functionalities. The reduction of patch density can therefore reflect the improvement of the quarry functionality and colonisation over time.

Table 4.3:The mean patch density (patch and inter-patch number per 10 m) for different patch types recorded for the different periods elapsed since stoppage of quarrying and for the different substrate conditions (rehabilitation methods) for both the dry (D) and wet (W) seasons

Quarry Site categories	Inter-patch (BS) and patch number per 10 metres									
Years elapse since last quarrying	DBS	WBS	DSC	WSC	DPC	WPC	DSP	WSP	DPSC	WPSC
1-5 years	22.78a	10.17a	7.44a	2.83a	2.33a	3.00a	4.39a	0.78a	9.00a	8.17a
6-10 years	10.00a	4.78a	1.00ab	0.78b	5.89b	3.78a	1.89a	0.11a	3.44ab	2.44ab
11-15 years	7.87b	1.53b	0.20bc	0.20b	5.20ca	2.23a	1.00b	0.00a	3.50bc	2.43b
16-20 years	0.67b	0.00c	0.33c	0.33b	0.67c	0.00b	0.00b	0.00a	1.17c	1.17c
Rehabilitation methods										
Backfilled with local soil levelled	29.33a	14.00a	1.33a	0.67a	17.67a	11.00a	5.67a	0.33a	6.33a	5.00a
Backfilled with local soil not levelled	14.07a	5.54a	4.07a	1.76a	2.73b	2.19a	2.53a	0.39a	6.17ab	3.20ab
Backfilled levelled planted with tree saplings	1.33b	0.00b	0.00b	0.00b	1.33c	0.00b	0.00b	0.00a	1.33c	1.00bc
Backfilled with external soil levelled	0.33b	0.67b	0.00b	0.00b	1.00c	0.67b	0.00b	0.00a	1.00c	9.00c

DBS, bare soil dry season; WBS, bares soil wet season; DSC, Stone complex dry season; WSC, Stone complex wet season; DPC, plant complex dry season; WPC, plant complex wet season; DSP, single plant dry season; WSP, single plant wet season; DPSC, plant stone complex dry season; WPSC, plant stone complex wet season. The mean value of patch or inter-patch no per 10m followed by same letter within a column are not significantly different at p=0.05.

Based on substrate condition of quarried sites, backfilled with local soil and levelled (BFLSL) recorded the highest mean patch density for BS, PSC, and PC types of patches both in dry and wet seasons, and SP patch type during the dry season (Table 4.3). In both dry and wet seasons, SC recorded the highest patch number per 10m in the backfilled with local soil and not levelled (BFLSN) rehabilitation category. Backfilled with external soil and levelled (BFES) recorded the least patch and inter-patch density in all the patch and interpatch type for wet and dry seasons except for PSC, BS, and PC type of patches in the wet seasons where patch density was slightly higher than in the backfilled planted with tree saplings rehabilitation (BFPT) category. Backfilled planted with tree saplings recorded no patch for all the patch types for both the dry and wet season except for PSC. There was no inter-patch recorded in BFPT rehabilitation method during wet season indicating a full patch cover of the sites under this type of rehabilitation.

From the Kruskal Wallis test, all the patch and inter-patch types were found to be significantly different in number between the four rehabilitation categories (Table 4.3). The results point that the substrate or rehabilitation type considered had a significant influence on the patch density of the quarried landscape. Consequently, this can be explained by backfilled level planted with trees and backfilled with external soil levelled supporting faster plant establishment that result in formation of larger patches leading to very low patch and interpatch density compared to backfilled with local soil levelled and backfilled with local soil not levelled. For SC, the high number in backfilled with local soil levelled and backfilled with local soil not levelled is because local soil is composed of stones increasing the possibility of having high SC density. SC was not recorded in backfilled level planted with trees as the stones patch were colonised by plants to form PSC, while for backfilled with external soil levelled the substrate had little stones that resulted in absence of SC patch.

The findings agree with those reported by Zucca *et al.* (2013), who identified that the rehabilitation method adopted in the mine influences the soil and landscape functions. The study identified that sites with plantations of shrubs performed better than those that did not have shrubs. Consequently, this can explain the low patch density for the stone quarry backfilled and planted with trees species compared to the other methods.

4.3.1.2 Patch width

The patch width represented how the patch had spread out from the transects line. Quarry 9 (Q9) recorded the highest mean patch width per 10 m of transect length of 64 m during the dry season while Q1 recorded the lowest value of 6.2 m per 10m in same season (Table 4.2). There was no significant difference between the wet and dry season for SC, PC, and PSC patch types in width per 10 m ($P > 0.05$), but there was a significant difference between the wet and dry season for SP patch type width per 10m ($x^2 = 10.724$; $p = 0.001$). The wet season had a higher patch width per 10m for PC and PSC as compared to the dry season due to an increase in vegetation, although the increase was not significant as larger patches were formed by joining the existing smaller patches. For SP, the significant difference could be due to many single plants during the dry season and low number during the wet season, resulting in higher patch width in the dry season than the wet season.

During the wet season, the plant stone complex had the highest average patch width per 10m in all age categories except for 11-15 years. The plant complex recorded the highest average width (Table 4.4). PSC recorded the highest patch width of 28.52 m during the dry season of 6-10 years category and 27.20 m in the wet season of 16-20 years category and plant complex (PC) type of patch, recorded the next highest patch width. The rest of the patch types (SC and SP) recorded mean patch widths of less than 2 m in wet and dry seasons.

From Kruskal Wallis test, there was significance difference in patch width between the four age categories of the quarries for SP ($x^2 = 15.268$; $p = 0.002$), SC ($x^2 = 26.728$; $p = 0.000$), PC ($x^2 = 16.479$; $p = 0.001$) and PSC ($x^2 = 10.835$; $p = 0.013$) patch types. SC width decreased with an increase in the age of quarried sites as, over time, it was colonised by plants to change to PSC patch. SP also decreased over time as the single plant joined with other plants to form a plant complex, reducing SP. PC and

PSC increased over time due to the joining of smaller PC and SP and SC in the case of PSC to form larger patches as the stone quarry site is restored. Therefore, the quarry's age has a significant effect on the patch width in quarried sites. The finding concurs with those of Humphries and Consultants (2016), who identified that overtime patches joined creating larger patches and subsequently increasing the landscape functionality. Similar findings were reported by Tomlinson *et al.* (2008) who identified that the physical characteristic of the quarry floor is influenced with age. Therefore, it is expected that older quarries will have larger patch width as compared to the young quarried sites.

Table 4.4: Mean patch width (patch width per 10 m length of transect) of the different patch types recorded for different time elapsed since stoppage of quarrying and for the different substrate conditions (rehabilitation methods) for both the dry and wet seasons

Quarries categories	Average patch type width in meters per 10M along the transect							
	Dry season				Wet season			
Years since quarried	SC	PC	SP	PSC	SC	PC	SP	PSC
1-5years	1.91	0.62	0.13	11.43	1.22	1.77	0.01	16.08
5 - 10 years	0.4	2.52	0.01	28.52	0.31	4.67	0	16.49
10 -15years	0.02	13.9	0.02	7.28	0.19	15.54	0	15.3
15 -20 years	0.38	4.64	0	21.79	0.63	0	0	27.2
Rehabilitation methods (Substrate condition)								
Backfilled with local soil levelled (BFLSL)	0.07	7.55	0.04	6.69	0.37	13.64	0	6.02
Backfilled with local soil not levelled (BFLSN)	0.05	7.79	0.04	7.89	0.38	17.74	0	10.61
Backfilled levelled planted with tree saplings (BFPT)	0	9.28	0	19.33	0	0	0	24
Backfilled with external soil levelled (BFES)	3.57	1.67	0.08	5.59	1.49	1.12	0	6.91

N.B: 0 value means that the patch zone type was absent.

The PSC patch type recorded the highest mean patch width in the BFPT rehabilitation method, but higher in wet than dry season (Table 4.4). Overall the next highest patch width in rehabilitation category was PC with higher values in wet season than in dry season except for the BFPT method. Single plant patch width was lowest among all rehabilitation methods, showing these patch types' rarity in the land surfaces. There was statistically significant difference at p-value of 0.05 in patch width per 10m between the rehabilitation methods for SC (x^2= 12.312; p= 0.006), PC (x^2= 8.272; p= 0.041) and PSC (x^2= 10.557; p= 0.014) type of patches except for SP type (x^2= 7.606; p= 0.055).

The difference can be associated with the different substrate and rehabilitation having an impact on the different patches and interpatch. BFPT supported PC and PSC patch establishment that recorded high patch width. Similarly, BFLSN facilitated the establishment of plants in the wet season, resulting in a large average patch width per 10 m for PSC and PSC. Therefore, the rehabilitation method is considered to influence the patch width in a quarried landscape significantly. Similar findings were reported by Tomlinson *et al.* (2008) who pointed that the land composition influences functional traits of vegetation communities. Zucca *et al.* (2013) also reported a similar finding in which the rehabilitation method influenced the size of the patch width. Therefore, it is expected that the different rehabilitation or substrate composition will have different influences on the presence and width of the different patch types in a stone quarry.

4.3.1.3 Micro site landscape organisation

The calculated landscape organisation index (LOI) for the different sites ranged between 0.55 and 1.00. Site Q1 had the least LOI of 0.55 during the dry season, while Q5 had the least during the wet season with LOI of 0.70 (Table 4.2). One site, Q8 had the highest LOI of 1.0 during the dry season while three sites, Q4, Q6, and Q8, recorded the highest LOI of 1.0 during the wet season, indicating almost complete coverage of the transects with either of the patch types (resource accumulating zones). Although Q8 was a young site (1-5years), the high LOI was due to a large portion of the site being colonized by a single plant species, *Rumex Usambarensis*.

Sites that had LOI of 1 point to all transect being covered by patch type with no or minimal patch type. Q4 and Q6 had higher LOI as they were old quarry and had established plant patches. The LOI for poorly restored quarries is less than 1, such as in Q1, which was a young quarry with patch type not yet established. Even though the difference between the wet and dry season for the LOI was not significant at p value of 0.05 ($x^2 = 1.984$; p= 0.164). The lack of significant difference between wet and dry seasons could be attributed to some of the quarry sites such as Q6, Q7, Q8, and Q9 having almost similar LOI in both seasons as the site had established perennial vegetations.

The LOI increased with increase in years lapsed since the last quarrying. The older quarries (15-20yrs) recorded the highest mean LOI both during the wet and dry season of 1.0 and 0.99, respectively, while the young quarries (1-5yrs) recorded the least LOI during both the wet and dry season of 0.83 and 0.71, respectively (Table 4.5). The difference in mean LOI between the four categories of age since last quarrying were significant at p-value of 0.05, (x^2= 24.506; p= 0.000). The results show that the percentage area of the quarry site that acts as resource sink increases with an increase in years elapsed since last quarrying. The patch area increased with increase in age, as quarry sites were more colonised by plants overtime improving the landscape organisation. Ludwig and Tongway (1995) report that LOI increases due to an increase in the patch number and structure of landscape. The findings agree with Tabeni et al. (2016), who identified that landscape organisation and function improved with age as more vegetated patches were recorded in older landscapes. Consequently, quarry landscape functionality improved over time.

Table 4.5: The mean landscape organization index (LOI) for years elapsed since last quarrying and rehabilitation method category for the wet and dry seasons.

Quarry categories	Mean landscape organization index Wet season	 dry season
Years elapsed since last quarrying		
1-5 years	0.83	0.71
6-10 years	0.91	0.86
11-15 years	0.97	0.92
16-20 years	1.00	0.99
Rehabilitation methods		
Backfilled with local soil levelled	0.83	0.72
Backfilled with local soil not levelled	0.91	0.83
Backfilled levelled planted with trees saplings	1.00	0.98
Backfilled with external soil levelled	0.99	0.99

Among the different surface substrates (rehabilitation method), the highest mean LOI was recorded under the rehabilitation method of backfilled planted with trees at 1.0 during the wet season while backfilled with external soil and levelled recorded the highest LOI of 0.99 during the dry season. Backfilled with local soil and levelled recorded the lowest average LOI of 0.83 and 0.72 during the wet and dry seasons, respectively (Table 4.5). The mean LOI differences among the rehabilitation method categories were found to be significantly different at p value of 0.05, (x^2= 12.84; p= 0.005). The difference in the LOI is associated with the difference in the ability of patch development under the different substrate in the quarry. For Backfilled levelled and planted with tree saplings, it facilitated faster vegetation establishment in the site hence more established patches increasing the landscape organisation and structure development as compared to other substrate types. Backfilled with external soil and levelled also support plant establishment that influence faster establishment of PSC and PC patch types that influences landscape structure development as compared to back filled with local soil levelled and not levelled.

Backfilled levelled and planted with tree saplings, and backfilled with external soil and levelled were identified as the best rehabilitation method supporting quarry site recovery as it ensures high coverage of the quarry surface leading to increased resource accumulation within the quarry site. Backfilled with local soil and levelled had the least influence on the quarry site recovery after quarrying ceased. The findings agree with those of Ludwig and Tongway (1995) who reported that the substrate characteristic influenced the spatial landscape organisation. Similar finding were found by Zhao *et al.* (2020) who reported that the management type adopted in a landscape influences the landscape organisation through its role in retaining of resources in the landscape. Therefore, it is expected the different substrate and rehabilitation methods used in quarried landscape to have different influence on the landscape organisation and subsequently on the landscape function.

4.3.2 Plant composition

A total of 178 plant species number belonging to 41 plant families were identified in the wet and dry seasons in the quarry sites of which 163 were identified to species level. Of the plants identified to species level, 95 were native while 68 were exotic. Based on growth cycle, 116 plant species identified were perennial while 62 were annual. Of the 178 species identified, 71 were herbs, 38 shrubs, 25 trees, 23 grasses, 17 vines, 3 sedges and 1 fern. Fabaceae, Asteraceae and Poaceae were the families with the highest number of plant species identified in the quarried sites with 26, 24, and 23 species, respectively. The diverse plant species type identification can be because the quarried sites provided refuge for diverse plants adopted to the quarry environment. Consequently, means that various plant species colonise quarry sites.

In all the quarry sites studied, 163 and 173 plant species were found during the dry and wet seasons respectively. *Achyranthes aspera, Bromus sp. and Rhynchelytrum repens* were the most common plant species during the dry season each occurring in 31 out of 32 transects that were surveyed (Table 4.6). *Tagetes minuta, Bidens pilosa* and *Lantana camara* were the top three most common species in the wet season occurring in 30, 29, and 29 out of 32 transect that were surveyed, respectively. All the top three species identified during the dry season were native, two of which were perennial grasses in the Poaceae family. Being native makes them acclimatized to the local conditions. The top three species identified during the wet season were exotic species, two of which were annual herbs belonging in the Asteraceae family (Table 4.6). The wet season has a higher number than the dry season because of the seasonal plant species that grows during wet season and dry up during dry season. *Tagetes minuta* and Bidens Pilosa were common during the wet season as they were seasonal.

Table 4.6:Top ten and bottom ten plant species in wet and dry season

Plant Species	Plant Family	Plant type	Growth cycle	Frequency	Plant Species	Plant Family	Plant type	Growth cycle	Frequency
	Dry season					Wet season			
	Top ten species					Top ten species			
Achyranthes aspera	Amaranthaceae	herb	annual	31	Tagetes minuta	Asteraceae	herb	annual	30
Bromus sp	Poaceae	grass	perennial	31	Bidens pilosa	Asteraceae	herb	annual	29
Rhynchelytrum repens	Poaceae	grass	perennial	31	Lantana camara	Verbenaceae	shrub	perennial	29
Bidens pilosa	Asteraceae	herb	annual	30	vernonia lasiopus	Asteraceae	shrub	perennial	28
Tagetes minuta	Asteraceae	herb	annual	30	Tridax procumbens	Asteraceae	herb	perennial	28
Lantana camara	Verbenaceae	shrub	perennial	29	Sida acuta	Malvaceae	shrub	perennial	28
vernonia lasiopus	Asteraceae	shrub	perennial	29	Bromus sp	poaceae	grass	perennial	27
Nicotiana glauca	Solanaceae	shrub	perennial	28	Neonotonia wightii	Fabaceae	vine	perennial	27
Conyza bonariensis	Asteraceae	herb	annual	27	Euphorbia hirta	Euphorbiaceae	herb	annual	27
Alternanthera pungens	Amaranthaceae	herb	perennial	25	Rhynchelytrum repens	Poaceae	grass	perennial	26
	Bottom ten species					Bottom ten species			
Ipomoea kituiensis	Convolvulaceae	vine	perennial	1	Mirabilis jalapa	Nyctaginaceae	herb	perennial	1
Ipomoea sp2	Convolvulaceae	vine	perennial	1	Persea americana	Lauraceae	Tree	perennial	1
Ipomoea sp4	Convolvulaceae	vine	perennial	1	Polygonum capitatum	Polygonaceae	herb	annual	1
ipomoea sp5	Convolvulaceae	vine	perennial	1	Cyperus sp2	Cyperaceae	sedge	perennial	1
Leonotis nepetifolia	Lamiaceae	herb	perennial	1	Alternanthera sp2	Amaranthaceae	herb	perennial	1
Mirabilis jalapa	Nyctaginaceae	herb	perennial	1	Carica papaya	Caricaceae	tree	perennial	1
Pennisetum sp	Poaceae	grass	perennial	1	Crotalaria sp6	Fabaceae	herb	annual	1
Persea americana	Lauraceae	Tree	perennial	1	Eriobotrya japonica	Rosaceae	Tree	perennial	1
Polygonum capitatum	Polygonaceae	herb	annual	1	Ficus sp	Moraceae	Tree	perennial	1
Sida sp	Malvaceae	shrub	perennial	1	Zea mays	Poaceae	grass	annual	1

Fabaceae was the most common tree family with six tree species followed by Bignoniaceae and Myrtaceae each with four species. *Grevillea robusta* and *Acacia senegal* were the most common tree species in dry season, occurring in 10 and 9 transects, respectively out of the 32 surveyed, while *Accacia sp. (14/32), Croton megalocarpus (10/32)* and *Grevillea robusta* (10/32) were the most common plant species during the wet season (Table 4.7). The tree species in the quarry sites could have originated from the surrounding area of the quarries where there were farms with various vegetations, including those found in the quarry. Consequently, this means that quarry sites can be colonised by tree species and become more established.

Table 4.7: Plant families for tree species identified in the study sites

Tree species	Family	Frequency	
		Dry season	Wet season
Acacia sp2	Fabaceae	8	14
Croton macrostachyus	Euphorbiaceae	8	10
Grevillea robusta	Proteaceae	10	10
Jacaranda mimosifolia	Bignoniaceae	5	7
Acacia Senegal	Fabaceae	9	7
Markhamia lutea	Bignoniaceae	2	6
Acacia kirkii	Fabaceae	1	6
Trema orientalis	Ulmaceae	5	6
Spathodea nilotica	Bignoniaceae	0	4
leucaena leucocephala	Fabaceae	0	4
Acrocarpus fraxinifolius	Fabaceae	2	3
Ficus sp2	Moraceae	0	3
Eucalyptus saligna	myrtacea	2	3
Eucalyptus sp1	myrtacea	2	3
Eucalyptus sp2	myrtacea	2	3
Croton megalocarpus	Euphorbiaceae	1	2
Ficus sycomorus	Moraceae	1	2
Psidium guajava	Myrtacea	2	2
Grewia similis	Tiliaceae	3	2
Ehretia Cymosa	Boraginaceae	1	1
Carica papaya	Caricaceae	0	1
Persea americana	Lauraceae	1	1
Ficus sp	Moraceae	0	1
Eriobotrya japonica	Rosaceae	0	1
Cassia spectabilis	Fabaceae	2	0

The mean plants species number per 10 metres (species richness) was highest in Q6 both in wet and dry season. Apart from Q3 mean plants species number per 10 m was higher during wet season in all the other quarry sites (Table 4.8). Soil moisture availability could have contributed to an increase in the number of plant species identified during the survey in the wet season. However, there was no statistically significant difference in the mean number of plant species per 10m between the dry and wet season at p-value of 0.05 (x^2= 39.333; p= 0.545).

Table 4.8: Mean plant species number per 10 m along the transect for the nine-quarry site for wet and dry

Quarry site	Mean plants species richness /10m of transect	
	Dry season	Wet season
Q1	4.59± 1.66	7.61± 2.12
Q2	6.71± 1.2	6.93± 0.75
Q3	9.07± 1.18	7.58± 1.36
Q4	9.20± 1.91	9.93± 1.42
Q5	6.47± 2.61	7.00± 1.91
Q6	11.33± 0.21	12.87± 1.79
Q7	8.60± 1.91	11.07± 1.4
Q8	9.53± 1.42	10.07± 1.80
Q9	7.47± 1.33	7.60± 1.31

4.3.2.1 Plant species composition across quarry age category

In the 1-5 years’ category, 109 plant species were identified during the dry season belonging to 20 plant families, while 128 plant species belonging to 35 plant families were identified during the wet season. *Achyranthes aspera, Conyza bonariensis* and *Nicotiana glauca*, were the most common plant species during the dry season, and *Sida acuta, Nicotiana glauca,* and *Conyza bonariensis* were the most common species in the wet season for the 1-5years category (Appendix III). Asteraceae and Fabaceae were the common plant families in both seasons (Appendix II.)

A total of 89 plant species belonging to 27 plant families and 106 plant species belonging to 26 families were identified in the dry and wet season, respectively of 6-10 years stone quarry category. Asteraceae and Fabaceae were the most common families in this category for both wet and dry seasons. *Achyranthes aspera, Nicotiana glauca, Bromus sp, Rhynchelytrum repens, Tagetes minuta, Bidens pilosa, vernonia lasiopus, Cynodon nlemfuensis, Lantana camara, Tridax procumbens and Launaea cornuta* were the most common plant species in dry season while *Bromus sp, Tagetes minuta, Tridax procumbens, Lantana camara, Cynodon nlemfuensis, Vernonia lasiopus, Asystasia Schimperi and Conyza bonariensis* were the common plant species in the wet season occurring in all the six transects in the 6-10 years category (Appendix III).

In the 11-15 age category, 98 and 94 plants species belonging to 29 families were identified in the dry and wet seasons, respectively. Asteraceae was the most common plant family with 21 and 18 plant species in the dry and wet season. The *Achyranthes aspera, Bromus sp, Rhynchelytrum repens, Tagetes minuta, Bidens pilosa, vernonia lasiopus, Lantana camara, Neonotonia wightii, Triumfetta sp, Ageratum conyzoides and Plenctranthus sp* were the most common plant species in the dry season while *Bromus sp, Tagetes minuta, vernonia lasiopus, Indigofera erecta, Triumfetta sp and Sida acuta* were the most common plant species in the wet season in the 11-15 years quarried land age category (Appendix III).

In the 16-20 years' category, 107 and 125 plant species were identified in the dry and wet seasons, respectively belonging to 30 and 32 plant families, respectively. Asteraceae and Poaceae with 18 and 17 plant species respectively were the most common plant families in the dry season while Fabaceae and Poaceae with 19 and 18 plant species were the most common plant families in the wet season. *Bromus sp, Rhynchelytrum repens, Bidens pilosa, Lantana camara, Indigofera erecta, Leonotis mollissima, Aspilia mossambicensis, acacia Senegal, Schkuhria pinnata, and Eragrostis tenuifolia* were the most common plant species in the dry season while *Lantana camara, Bidens pilosa, Panicum maxima, Schkuhria pinnata, Acacia sp2* *and Pennisetum purpureum* were the most common plant species in the wet season occurring in all the six transect in the 16-20 years' category (Appendix III).

Table 4.9: Mean plant species richness per 10 m of transect classified by years elapsed since last quarried.

	Dry season		Wet season	
Years since quarried	Plant species richness	STDV	Plant species richness	STDV
1-5 years	6.862	2.498	8.227	1.623
6 - 10 years	8.503	2.480	9.131	3.253
11 -15 years	8.837	0.335	9.323	2.465
16 -20 years	9.367	0.236	10.000	0.094

The 16-20 years' category had the highest mean plant species richness per 10m along the transect while 1-5years category had the least both in the dry and wet season (Table 4.9). This portrays increase in number of plant species as the quarried land ages. The diversity of the plants that colonizes the quarried land improves with age since last quarried. The difference in species richness between the different age categories was statistically significant (x^2= 19.583; p= 0.000).

From the findings the number of species per 10 m increased with increase in the age of the quarry. This is associated with increase in vegetation colonisation of quarry site over time as the environment improve to be more conducive for plants growth. In addition, the wet season had higher plant species richness as compared to the dry season as wet season more plant grows due moisture availability increase the species richness. The finding agrees with those of Antwi, *et al.* (2008) who identified that the age of post mining influence plant diversity and richness in which they increase with age. Similar finding were also reported by Zhang and Chu (2011) who reported that the plant structure and composition in quarries improves with the age of the sites. The increase was associated with soil development. Therefore, it is expected that older quarries to have more plant richness as compared to the younger quarries due to vegetation structure development.

4.3.2.2 Common and unique plant species

Plant species composition across the different age categories were found to differ. In dry season, 52 plant species were found to be common in all the age categories while 58 were found in the wet season. The existence of common plants in all the age categories of quarried land points to the existence of some plant species that colonises the quarry sites throughout without being substituted by secondary plant species during successive plant colonization.

In the 1-5 years' category, 19 plant species and 15 plant species unique to the category were identified in the wet and dry season respectively (Table 4.10). When considering both seasons, only 7 species were found to be unique to quarried land of between 1-5 years both during the dry and wet season and 27 total plant species unique to the age category when considering either wet or dry season. In the 6-10 years' category, 3 and 4 species were found to be unique to the quarry category in the wet and dry seasons, respectively. Only one species, *Acrocarpus fraxinifolius* was found to be unique to the 6-10 years' category in both the dry and wet season and 6 plant species were unique to the category. In the 11-15 years' category, 7 and 10 plant species were found to be unique to the quarry category in wet and dry seasons respectively. Only five plant species were found to be unique in both the dry and wet season of the 11-15 years age category hence the category had 12 plant species unique to the category. In the 16-20 years' age category, 18 plant species and 20 plant species were found to be unique to the age category in the wet and dry seasons respectively. On considering both season, 8 plant species were found to be unique to the quarry site in both seasons with the majority being trees and grasses. The category had 30 unique species in total.

Table 4.10: Number unique plant in each category of quarry age for both wet and dry season

Age category	Wet season	Dry season
1-5 years	19	15
6-10 years	3	4
11-15 years	7	10
16-20 years	18	20

The plant species unique to specific age category of the quarry site play an important role in the evolution of colonisation of the disturbed or quarried sites. The unique plants in the young quarries (1-5 years) are the primary coloniser of the quarried land. They are important as they assist in developing the soil structure of the quarry site and modifying the site to be habitable by secondary and tertiary colonizer. As colonisation is a process, the unique plant species identified in subsequent age category represents the different generations of secondary colonizer plants of the moving towards wood and grass plant species as evident in the older quarry sites (16-20 years). Every plant species that colonize the quarry sites is thus important in restoration of the quarried sites.

Similar findings were reported by Zhang, *et al.* (2013) who identified that quarried sites recruit different plant species during its rehabilitation. Similar finding on plant colonisation was reported by Novák and Prach (2003) who reported spatio-temporal variation of vegetation exists in quarried sites that are recovering. It is there expected that over time, the plant composition of the disturbed landscape to change as the plant diversity increase. This further concurs with the findings of Fujiki *et al.* (2017) who identified that for disturbed land, there is plant community shift due to plant success.

4.3.2.3 Plant species composition across media substrate (rehabilitation methods) categories

Backfilled with local soil and not levelled rehabilitation category recorded the highest number of plant species of 146 and 158 during the dry and wet season, respectively. *Achyranthes aspera, Bromus sp, Conyza bonariensis, Rhynchelytrum repens, Tagetes minuta, Bidens pilosa, Nicotiana glauca* and *Vernonia lasiopus* were the most common plant species in the dry season while *Sida acuta, Tagetes minuta, Bidens pilosa, Nicotiana glauca, Lantana camara, Vernonia lasiopus, Tridax procumbens, Neonotonia wightii, Euphorbia hirta and Conyza bonariensis* were the most common plant species during the wet season. Many species in the category could be associated with the ridges on the unlevelled surface forming important refuge for resources that support plant growth. Moreover, most of the sites incorporated in the study belonged to the category that could have resulted in a higher number of plant species recorded. The findings agree with Owens et al. (1995) who reported that the areas that support resource accumulation influence plant recruitment in the landscape.

Backfilled with local soil levelled recorded 69 plant species during the dry season and 68 species during the wet season. *Achyranthes aspera, Bromus sp, Conyza bonariensis, Rhynchelytrum repens, Tagetes minuta, Bidens pilosa, Nicotiana glauca, vernonia lasiopus and Lantana camara* were among the most common plant species in the dry season of the Backfilled with local soil levelled rehabilitation method while *Sida acuta, Tagetes minuta, Bidens pilosa, Lantana camara, vernonia lasiopus, Tridax procumbens, Neonotonia wightii, Euphorbia hirta and Conyza bonariensis* were the most common plant species in the wet season.

Backfilled levelled planted with tree saplings (BFPT) recorded 77 plant species during the dry season and 84 during the wet season. *Bromus sp, Rhynchelytrum repens, Bidens pilosa, Lantana camara, Leonotis mollissima, Panicum maxima, Indigofera erecta and Aspilia mossambicensis* were the most common plant species in the dry season while *Lantana camara, Rhynchelytrum repens, Panicum maxima, Aspilia mossambicensis, Schkuhria pinnata, Acacia sp2, Bidens pilosa, ipomoea sp, Acacia Senegal, and Pennisetum purpureum* the most common in the wet season for the BFPT rehabilitation method.

Backfilled with external soil levelled recorded 65 plant species during the dry season and 84 during the wet season. *Bromus sp, Rhynchelytrum repens, Bidens pilosa, Lantana camara, Leonotis mollissima, Panicum maxima and Achyranthes aspera* were the most common plant species in the dry season while *Lantana camara, Rhynchelytrum repens, Panicum maxima, Aspilia mossambicensis, Schkuhria pinnata, Acacia sp2, Tagetes minuta, vernonia lasiopus, Tridax procumbens and Bromus sp* were among the most common plant species during the wet season.

BFPT had the highest plant species per 10m during the dry season of 9.2 while Backfilled with external soil and levelled recorded the highest during the wet season of 11.07 plant species per 10m along the transect (Table 4.11). From Kruskal Wallis test, there was a statistically significance difference in plant species per ten meters between the different rehabilitation categories (x^2=7.954; p= 0.047).

Table 4.11: Mean plant species richness per 10 m for the rehabilitation method categories

	Plant species richness	
Rehabilitation methods	Dry season	Wet season
Backfilled with local soil levelled	6.71	6.93
Backfilled with local soil not levelled	8.08	8.79
Backfilled levelled planted with tree saplings	9.20	9.93
Backfilled with external soil levelled	8.60	11.07

The significance difference could be attributed to the different substrate providing different degree of conducive environment for plant recruitment and colonisation. Backfilled levelled planted with trees and back filled with external soil levelled provided the most conducive environment for plants in the wet and dry season that increased species richness. The rehabilitation and substrate methods thus significantly influence plant colonisation of disturbed land site. This has direct influence on the recovery of quarried site and the diversity and abundance of the plant species in the disturbed landscapes.

The findings agrees with those of Middleton (2010) who identified that the restoration method that is adopted in the landscape impact the resulting plant community over a period of time. Moreover, similar findings were reported by Gentili *et al.* (2020) who reported that the backfilling material used in rehabilitation influences the vegetation cover and diversity. The stoniness of the soil was identified to have significant influence of plant richness (Gentili *et al.,* 2020). The finding therefore supports the finding of the current research that the type of substrate that is considered during the rehabilitation management is crucial as it significantly influences the plant species recruited in the stone quarries and the subsequent vegetation succession. Backfilled with local soil and planted with trees, and back filling with external soil levelled had the highest influence on plant species richness hence the most effective in improving species colonisation in post quarried sites. Furthermore, the quarry dust use as a substrate whether levelled or not levelled supported quarried land revegetation and subsequent restoration of the landscape.

4.4 Conclusion

Age, season and rehabilitation method impact the density of zones of resource accumulation and zone of material sources. Increase in age result to decrease in patch density due to merging of the expanding patches. Overall, plant complex (PC) type of patch, recorded the next highest patch width followed by PSC which varied slightly between the year categories, rehabilitation methods and seasons. The increase in micro site landscape organisation was positively related to quarry age.

Season, rehabilitation methods and age of land disturbed by quarrying, influence plant species colonization and successive quarry site regeneration. The density of inter-patch and patch (number per 10m) decreased with increase in number of years elapse since last quarrying. Backfilled planted with tree saplings recorded the lowest patch number per 10m implying increased quarry recovery. The majority (95 out of 178, 53%) of plants that colonized quarried sites were native plant species. The plants species composition in quarried land per unit section increases with increase in time elapsed since last quarried. Backfilled levelled and planted with tree saplings and backfilled with external soil levelled rehabilitation categories were the top two best rehabilitation methods in plant species richness.

CHAPTER FIVE

SOIL DEVELOPMENT OF STONE QUARRIED SITE

5.1 Introduction

The quarrying process results in the soil's destruction, which affects its ability to support vegetation growth (Jim, 2001; Zucca *et al.,* 2013; Costantini *et al.,* 2016). The degraded quarry habitat is a challenge for quarry rehabilitation as it limits the number of plants that can colonize it increasing the risk of soil erosion due to lack of plant cover and steep slopes. Many research studies have evaluated the influence of quarry edaphic factors on plant colonisation of quarried land in different parts (Tongway and Hindley, 2004; Randall, 2004; Johansen *et al.,* 2019). Efforts to reclaim the quarried sites require undertaking biological, chemical and physical soil characteristics management (Sheoran *et al.,* 2010), aimed at enabling vegetation growth and reducing degradation (Lal, 2015).

Soil development takes a long time and is affected by various processes such as resource movement, organic matter accumulation, and erosion (Biddoccu *et al.*, 2016). The substrate available on the quarried site can influence the plant characteristics and the speed at which the quarried site is rehabilitated. Understanding the various components of the soil could help understand the quarried sites colonisation and the process of soil development and landscape sustainability. The importance of plants in the soil is improve soil stability, provide organic matter through leaf litter and create a conducive environment for secondary and tertiary plant colonisation (An et al., 2010). The present research study aimed at evaluating the soil development of stone quarried site and the different processes that affect it.

5.2 Material and methods

5.2.1 Site descriptions

The study description is presented in section 3.2.1. The soil surface assessment (SSA) was done in nine quarried sites during the dry and wet season. Eight of the sites (Q1, Q2, Q3, Q4, Q5, Q6, Q8, and Q9) had been backfilled with local soil that refers to quarry dust, or a mixture of quarry dust with other underlying soil layers. The local soil refers to a crushed tuff rock, which is the main basement rock in this region (Fairburn, 1963). Site, Q7 was backfilled with external soil that is red soil. Table 4.1 summarizes the study sites description.

5.2.2 Sampling and data collection

Each of the nine quarry sites was sub-divided into sections based on the identified landscape functional types. Following the method used for the plant colonization survey, the resource accumulation zones (patches) and resource mobilization zones (inter-patch) along each of the three transects set for each quarry site were the sampling units for soil surface assessment. Along each transect, systematic sampling was used to select at least five sample points per patch and inter-patch type following the LFA manual (Tongway & Hindley, 2004; Randall, 2004). Eleven soil surface indicators were used to assess each patch or inter-patch microsite on the site. For each microsite, soil was then collected, packed in sampling bags, and labelled for laboratory analysis. The soil was collected when it was intact up to 10cm depth using a shovel. In the lab, the soil aggregate stability test (ASWAT) was done to examine soil stability in water (Tongway & Hindley, 2004). Both the field and laboratory soil analyses were done during dry and wet seasons as presented in plate 5.1.

Plate 5.1: Steps followed for soil surface and stability assessment from the field to laboratory.

5.2.2.1 Soil surface assessment indicators

a) Rain splash protection

The assessment entailed assessing the combined percentage cover of perennial vegetation to a height of 0.5 m, woody material, rocks of greater than 2 cm, as well as other long-lasting immovable materials on the soil surface as detailed in the LFA manual. Classification categories were 5 ;1% or less cover, 1 to 15%, 15 to 30%, 30 to 50%, and more than 50% respectively.

b) Perennial vegetation

The perennial grass cover was assessed by summing the butt diameters of the grasses in the query zone while the trees and shrubs were assessed by the canopy cover and density that is above the query zone. The classes were; percentage cover of basal or canopy of 1% or less as class 1; 1 to 10% class two; 10 to 20% class three and more than 20% class four.

c) Litter

Litter cover. The area covered by litter within the query zone was assigned to one of the 10 classes based on percentage cover of <10, 10-25, 25-50, 50-75, 75-100, 100 % 20mm thick, 100 % 21- 70 mm thick, 100 % 70- 120 mm thick, 100 % 120-170 mm thick, and 100 % >170 mm thick.

Litter origin classes. Classified as litter from local origin that originates from same patch (L) or transported to the patch (T).

Degree of litter decomposition. This indicator had four classes. The classes were nil decomposition (n), slight decomposition (s), moderate decomposition (m), extensive decomposition (e).

d) Biological soil crust cover

The biological soil crust on the surface including the cryptogam such as algae that covers the soil was assessed and soil surface categorised in one of five classes. The biological soil crust cover classes were; not applicable-class (class 0); 1 % or < 1 (class 1); 1 to 10 % (class 2); 10 to 50 % (class 3); > 50 % (class 4).

e) Physical crust brokenness.

The extent of the physical crust brokenness was assessed through evaluating the extent of availability of material that can be carried away by erosion. The classes were: class 0 for no surface crust present; class 1 for crust present but extensively broken; class 2 for crust present moderately broken, class 3 for crust present slightly broken and class 4 for crust present intact and smooth.

f) Soil erosion type severity

Erosion resulting from management practice, human factors and climate were assessed in each of the fields. The five major forms of erosion classes assessed were sheeting erosion, pedestalling, rill and gullies, terracettes and scalding.

g) Deposited material.

This was the amount of alluvium deposited in each of the patch type selected as the query zone. The class type considered was: Extensive material present covering > 50% and several cm deep as class 1; 20-50% cover with significant depth as class 2; 5-20% cover as class 3; and 0-5% cover or none at all as class 4.

h) Surface roughness

This was analysis of the ground surface cover as well as the presence of depression on the surface that will hold materials. The classes used were: Depression on the surface less than 3mm as class 1; 3 – 8 mm relief- low but visible retention class 2; 8-25 mm or cover plants growing close together class 3; Deep depression with visible detention as class 4; and Very deep depression or cracks with width greater than 1000 mm high retention as class 5.

I) Surface dry coherence

The indicator is used to assess ease with which the surface can be disturbed to remove or release material. The test was undertaken on dry soil only. The classes considered were: loose sandy surface class 1; easily broken surface as class 2; moderately hard surface class 3; crust very hard and brittle class 4; and non-brittle surface as class 5.

J) Slake test

This is test for surface coherence of the soil when wet. The test was done by gently immersing a dry soil fragment about 1 cm cube into a petri dish containing distilled water or rainfall water. The response was observed for the first two minutes. The soil fragment that floats was classified as class four due to high organic matter content. The classes were: class 0 where soil fragment to test could not be extracted, class 1 fragment start slumping in less than 5 seconds; class 2 fragment slumps within 5-10 seconds; class 3 surface crust remains intact with less than 50 % of the sub-crust volume slakes; and class 4 the whole fragment remains intact with no swelling and include fragments that floats which point to high organic matter content.

K) Soil surface texture

The soil surface texture assessment procedure involves taking a soil sample from a depth of 1-5 cm and placing on the palm. Water is added in small amount at a time and knead the soil to form a soil bolus. This was done until the soil ball just stopped sticking on the hand, that is, it reaches the field capacity. The kneading is done until no change is observed on the soil ball. The characteristic of the soil bolus and the soil ribbon formed when the bolus was pressed between the first finger and the thumb determined the soil texture class. The classes were; Class 1 was either silty clay, medium and heavy clay or light clay; class 2 was silt loam, clay loam, sandy clay or sandy clay loam; class 3 was silty clay loam, loam or fine sandy loam; while class 4 was loamy sand and clayey sand.

L) ASWAT test

ASWAT refers to soil aggregate stability test in which soil aggregate stability in water is assessed by immersing a soil aggregate in water and evaluating milkiness that arise after 10 minutes. For no milkness score was 0, slight milkness was 1, moderate scored 2, obvious milkiness score 3, and total dispersion 4. The scoring was repeated after two hours. For those that scored zero, the solid sample was taken, wetted, moulded into a bolus, placed in water in the petri dishes and milkiness scored for both 10 minutes and 2 hours.

5.2.3 Data analysis

Using the score values from the assessed indicators, three indices were calculated through the weighted average procedure that represented measures of (i) stability (equation 1), (ii) infiltration / runoff (equation 2) and (iii) nutrient cycling (equation 3) according to Tongway and Hindley (2004). Table 5.1 presents the factors considered under each of the index.

Table 5.1: Indicators used to determine the different indices

Indicator	Class range	Indicator	Class range
Infiltration index		**Stability index**	
Perennial basal, shrub and tree canopy cover	1-4	Crust broken-ness	1-4
Surface rough-ness	1-5	Surface resistance	1-5
Slake test	1-4	Slake test	1-4
Litter cover, origin and decomposition	1-30	Erosion type and severity	1-4
Surface resistance to disturbance	1-10	Deposited materials	1-4
Soil texture	1-4	Cryptogam cover	1-4
Nutrient cycling Index		Soil cover (rain)	1-5
Perennial basal, shrub and tree canopy cover	1-4	Litter cover	1-10
Litter cover, origin and decomposition	1-30		
Cryptogam cover	1-4		
Surface roughness	1-5		

Each of scores for the variable assessed in the field were assigned a weighted factor based on importance as per LFA methodology. For example, in litter, the different scores were weighted as transported and nil score was multiplied by 1, local origin by 1.5, slight incorporation (S) by 1.3, moderate incorporation by 1.7 and extensive incorporation by 2. The overall score for litter was thus obtained by multiplying the score with the weighted factors. The final transformed score ranged between 1 and 30 for each microsite evaluated. For infiltration index, surface resistance to disturbance indicator was revalued as follows, class 5 and 2 scored 6.6, class 4 score 1, class 3 scored 3.3, and class 1 scored 10. The final contribution of each indices was determined by adding the final score for each of the variable considered and then converted to percentage as presented in the equations below.

Equation 1:

Stability index = crust broken-ness + surface resistance + slake test + erosion type and severity + deposited materials + cryptogam cover + soil cover (rain) + litter cover (litter cover only category).

Equation 2:

Infiltration/Runoff = perennial basal, shrub and tree canopy cover + surface rough-ness + slake test + litter (litter cover + origin (transported (T) litter and nil (N) incorporation of litter, multiply cover value by 1, local (L) origin, multiply by 1.5.) + decomposition (slight (S) incorporation multiply by 1.3, moderate (M) incorporation of litter by 1.7. and extensive (E) incorporation of litter by 2.0)) + surface resistance to disturbance (Class 5 given a score of 6.6, Class 4 scored 1, Class 3 → 3.3, Class 2 → 6.6, and Class 1 → 10) + soil texture

Equation 3:

Nutrient cycling status = perennial basal, shrub and tree canopy cover + litter cover, origin and decomposition (litter cover + origin (transported (T) litter and nil (N) incorporation of litter, multiply cover value by 1, local (L) origin, multiply by 1.5.) + cryptogam cover + surface roughness

The indices were determined for each of the query sites, and mean score for transect, quarry site, age elapsed since quarried category and substrate type (rehabilitation method) for both wet and dry season were calculated. The mean of the indices for the wet and dry season were compared through the non-parametric Mann-Whitney U test. At the microsite level, the non-parametric Kruskal Wallis test was used to compare the Stability index (IS), Infiltration/runoff index (IR) and nutrient-cycling index (NC) of the different patch types, different quarry rehabilitation method (substrate types) and time elapsed since stoppage of quarrying.

For the ASWAT test, the result was calculated to determine a total score of each soil assessed on a scale of 0-16. In determining the total score, the sum of the score for the first 10 minutes and 2 hours' assessment in water was added to 8 giving a score of 1-16; while for the one that scored zero, the sum of their remoulded scores for 10 minutes and 2 hrs together in the second step were added, giving a score between 0 and 8. The results were then analysed using Kruskal Wallis test to compare differences between quarry rehabilitation method (substrate types) and time elapsed since stoppage of quarrying in SPSS version 23.

5.3 Results and discussion

5.3.1 Overall variation of soil surface indicators

A total of 696 microsites from the nine quarry sites were assessed for soil stability, infiltration and nutrient cycling, based on soil surface indicators and ASWAT test in the laboratory described in the LFA methodology. During the wet season, only seven sites were assessed as quarry activities in Q2, and Q3 sites were being used a quarry dust dumpsite; hence data could not be collected for soil surface assessment (SSA).

Of the 696 microsites assessed, 291, 151, 132, 62 and 60 were plant stone complex (PSC), plant complex (PC), bare soil (BS), single plant (SP) and stone complex (SC), respectively. There were 429 sites sampled during the dry season and 267 sampled during the wet season. The difference in sampled microsites between seasons was expected as patchiness would change with moisture content of media substrate. Table 5.2 shows the number of different types of patch and inter-patches sampled during the wet and dry season.

Table 5.2: Number of patch (plant complex (PC), plant stone complex (PSC), stone complex (SC), and single plant (SP)) and inter-patch types (bare soil (BS)) assessed for soil surface characteristics for the nine quarry sites during the wet and dry season.

Quarry site	Dry season						Wet season						
	BS	PC	PSC	SC	SP	Season Total	BS	PC	PSC	SC	SP	Season Total	Total
Q1	30	17	35	31	27	140	32	32	40	18	18	140	280
Q2	16	15	19		11	61						0	61
Q3	26	33	26		6	91						0	91
Q4		6	16			22			16			16	38
Q5	14	11	19	5		49	14	7	17	3		41	90
Q6		15				15			18			18	33
Q7		15				15			18			18	33
Q8			17			17			17			17	34
Q9			16	3		19			17			17	36
Total	86	112	148	39	44	429	46	39	143	21	18	267	696

5.3.1.1 Infiltration index

Infiltration index evaluates water that is retained in the soil for plant utilisation after rain and runoff (Costantini *et al.,* 2016). Quarry site 4 recorded the highest infiltration index of 49.3% and 51.8% for the dry and wet seasons, respectively (Table 5.3). The infiltration index was higher in the wet season as compared to dry season. From Mann-Whitney test, there was significant difference in infiltration index between the wet and the dry season (p= 0.001). During the wet season, the higher infiltration index could be associated with an increase in vegetation cover that reduces run-off. Quarry 4 had the highest infiltration as it had established perennial plants that facilitate infiltration during the wet and dry seasons.

PSC recorded the highest infiltration in all the quarry sites where it was present during the dry and wet seasons except for quarry 4 in the dry season and quarry site 5 in wet season where PC recorded the highest infiltration index. The high infiltration index points that PSC and PC were the microsites that played a crucial role in facilitating water infiltration in the quarried sites as there is also high density of root system that allows water infiltration in the soil (Yang & Zhang, 2011). The plant species in the microsite, therefore, play an important role in facilitating infiltration, making it higher. High infiltration index during the wet season as compared to the dry season recognizes that in wet season, there is more surface and canopy cover that confer more surface resistance to disturbance. Soil that has good infiltration retains resources that are crucial for landscape restoration. Therefore, a well-developed soil is expected to have a higher infiltration rate. Consequently, Q4 having the highest infiltration could be considered to have a more developed soil than the other quarry sites.

Table 5.3: The soil indices for the different quarry sites for wet and dry season determined under bare soil (BS), plant complex (PC), plant stone complex (PSC), Stone complex (SC), and single plant (SP).

	% stability					% infiltration					%Nutrient cycle					ASWAT				
											Dry Season									
Quarry	BS	PC	PSC	SC	SP	BS	PC	PSC	SC	SP	BS	PC	PSC	SC	SP	BS	PC	PSC	SC	SP
Q1	38.0	45.1	51.9	39.2	42.9	20.9	26.1	29.3	20.2	24.7	8.7	17.1	23.2	9.4	15.2	5.2	5.1	4.8	3.8	6.3
Q2	40.9	52.5	53.2		40.9	20.4	26.4	30.9		18.1	8.8	17.5	23.2		9.6	4.6	3.9	3.3		5.3
Q3	41.2	49.1	52.7		45.4	19.8	26.4	28.9		19.8	10.0	18.8	23.3		11.6	5.1	3.5	2.8		3.8
Q4		61.7	63.1				49.3	45.5				41.6	36.6			0.7	0.4	1.9		
Q5	35.7	44.0	46.2	39.0		17.9	24.8	25.1	16.5		8.0	20.3	20.7	9.9		10.0	10.1	10.0	10.0	
Q6			61.8					34.4					33.5					4.4		
Q7		61.7					48.3					40.6					2.2			
Q8			56.6					36.7					35.5					7.8		
Q9			59.3	40.8				45.2	26.8				42.7	20.4				5.9	9.7	
											Wet season									
	BS	PC	PSC	SC	SP	BS	PC	PSC	SC	SP	BS	PC	PSC	SC	SP	BS	PC	PSC	SC	SP
Q1	41.6	53.9	55.3	44.0	38.7	21.2	33.7	34.0	25.0	18.5	10.7	30.7	31.8	16.3	13.9	4.9	5.5	3.7	6.0	5.2
Q4			65.8					51.8					45.2					1.9		
Q5	35.2	49.0	48.2	39.2		19.4	32.5	27.7	12.4		9.6	29.1	25.2	11.8		9.5	8.1	9.3	10.0	
Q6			63.9					39.6					40.7					5.4		
Q7			66.1					45.5					44.5					6.6		
Q8			61.0					42.7					38.4					6.4		
Q9			62.9					43.7					41.6					8.1		

5.3.1.2 Nutrient cycle index

Nutrient cycle index evaluates the in-situ recycling of organic matter in the soil (Costantini *et al.*, 2016). Nutrient cycling is associated with the process of nutrient cycle in the landscape that is related to perennial vegetation, litter cover and decomposition, cryptogram cover, and surface roughness. It involves the litter from vegetation, its decomposition, being retained in the soils, and subsequent utilisation by other plants(Tongway & Ludwig, 2011).

The PSC patch type recorded the highest nutrient cycle indices for all the quarry sites where it occurred during the wet and dry season except for Q4 during the dry season and Q5 during the wet season. In all sites where BS was evaluated, it recorded the lowest nutrient cycle index as compared to patch types. The nutrient cycle was higher during the wet season as compared to the dry season except for Q9. From Mann-Whitney test, there was statistically significant difference between the dry and wet season (p=0.001). The wet season having the highest nutrient cycle could be associated with perennial vegetation growth due to availability of water and increase in litter trapped within the different patch types especially PSC and PC that had highest score. High nutrient cycling index means that soil nutrient is retained more in the soil. Nutrient cycling of quarried land enables how the substrate is recovering and its influence on colonisation of quarried site.

From Kruskal Wallis test, there was a statistically significant difference in mean nutrient cycling percentage between the different quarry sites (x^2 (8) = 91.837; p= 0.001) with mean ranking scores for nutrient cycle index of 286, 256, 288, 525, 274, 555, 588, 531, and 556 for Q1, Q2, Q3, Q4, Q5, Q6, Q7, Q8, and Q9, respectively. Q7 had the highest mean rank, which points to it retaining a lot of soil nutrients and resources while Q2 had the lowest nutrient retention potential. Q7 having a high nutrient cycle could be associated with the externally obtained soil containing minimal quarry dust and supporting plant growth. This points to nutrient cycling processes in the site and the substrate having developed more than those of other sites. The findings agree with those of Zucca et al. 2013), who pointed that the high nutrient cycle is associated with processes that occur in the landscape that facilitate recycling of nutrients in the soil and make them available to the plants (Zucca et al., 2013). Moreover, Lal (2015) points out that overcoming soil degradation leads to availability of nutrients and organic content crucial in plants growth and ecosystem development. It is therefore expected that soil that are developed to have higher nutrients cycle.

5.3.1.3 Stability index

Stability index evaluates the soil vulnerability to erosion and its capability to recover after exposure to stress (Costantini *et al.,* 2016). During the dry and wet seasons, PSC recorded the highest average soil stability percentage in all the nine quarry sites where it was present. In sites with BS (inter-patch), the stability index recorded the lowest as compared to other patch types. From Mann-Whitney test, there was statistically significant difference in soil stability between the wet and the dry season in the sites evaluated (p=0.000). Kruskal Wallis test showed that there was significance difference in mean stability index between patch types (x^2 (4) = 291.8; P=0.001) with mean ranks of 159.5, 410.3, 463.1, 184.1, and 220.9 for BS, PC, PSC, SC, and SP, respectively. PSC and PC had the highest stability index while BS had the lowest mean rank. From evaluating the quarry sites, there was statistically significant difference in mean stability index between the quarry site (x^2 (8) = 219.4; P=0.001) with mean rank percentage stability of 287.5, 325.4, 327, 538.9, 217.2, 576.83, 566.4, 487.2, and 502.1 for Q1, Q2, Q3, Q4, Q5, Q6, Q7, Q8, and Q9 respectively. Quarry site characteristics thus impact the stability of quarry sites.

On the other hand, wet season was identified to have higher soil stability as compared to the dry season that can be associated with the presence of plants due to water availability irrespective of the substrate type. The substrate in the quarry site is considered to be of importance in the recovery of the site through its ability to support plants colonisation and survival. The soil stability is one of the aspects of the substrate that ensures its ability of retaining of soil. From the study, the wet season recorded the higher soil stability as compared to the wet season which points to the ability of the quarry site having higher protection to erosion as compared to dry season. The findings concur with Nichols and Toro (2011) who identify that soil stability was crucial in disturbed land as it plays a crucial role in increasing resistance to soil erosion.

The soil stability was also identified to vary across the different patch and interpatch types. PSC that consisted of plants and stones as a patch had highest stability followed by PC which SP and BS had the lowest soil stability. PC and PSC had the highest stability index which can be associated with the presence of plants that supports soil stability. BS recorded lowest soil stability due to lack of plants and other material that could support the soil. The composition of the patch was therefore important in enhancing the soil stability. The finding concurs with those of Liu *et al.* (2018) that identified the patch plant characteristics and structure was crucial in enhancing the stability of soil and preventing soil erosion in the landscape. Moreover, the findings concurs with An et al. (2010) who reported that plants facilitate remediation of eroded soil through improving the stability of the soil that is also associated with increased organic content of the soil. Therefore, improving the patch characteristics of quarried landscape can play an important role in enhancing the soil stability and in turn influence the quarried landscape recovery.

5.3.1.4 Soil aggregate stability

Soil aggregate stability is considered as a measure of soil quality (Nichols & Toro, 2011). The Soil aggregate stability of quarried landscape was evaluated in the study. From the research findings, the highest average of Aggregate Stability in WATer (ASWAT) score was 10.1 and 10 during the dry and wet season, respectively both recorded in Q5 (Table 5.3). The lowest soil aggregate stability was recorded in Q4 in both dry and wet season, respectively. Mann Whitney test revealed that there was statistically significant difference between the wet and dry season (p=0.07). Between the different patch types, Kruskal Wallis test revealed that there was no statistically significant difference between the different patch types (x^2 (4) = 8.416; P=0.077). The patch types impact on the soil aggregate stability was not different

ASWAT test evaluates soil stability in water. Quarry sites with a high ASWAT score mean that the soil stability in water is low and could easily erode. Q4 low ASWAT score could be associated with plants that increase organic matter in the soil, making it stable in water and less risk of erosion. In evaluating the difference in soil stability between quarry sites, it was found that there was a significant difference between the quarry sites (x^2 (8) = 179.6; P=0.001) with mean rank in ASWAT score of 326.8, 309.2, 286.3, 125.8, 557.4, 329.4, 293.8, 437.6, and 436.9 for Q1, Q2, Q3, Q4, Q5, Q6, Q7, Q8, and Q9, respectively. The difference in the ASWAT score for the different quarry sites points to the existence of different levels of substrate developed due to differences in vegetation cover and age.

5.3.2 Effect of time lapse and substrate type on soil surface indicators

5.3.2.1 Time lapse

During the dry season, infiltration percentage was highest in the older quarry categories (Table 5.4). The highest score was 45.3, while the lowest was 19.8. BS infiltration index was almost the same in all the quarry categories in the dry and wet seasons. For 1-5 category, SP recorded the lowest infiltration index while PSC recorded the highest in the wet and dry season. In all the quarry age categories, PSC had the highest water infiltration percentage as compared to the other patch types. PC patch type had the next highest infiltration index among the patch and interpatch type. SP had the lowest infiltration index that can be due to its inability to effective reduce runoff as compared to PSC and PC that can reduce runoff while facilitating infiltration. It is evident that the surface characteristics of the quarry site influenced the infiltration of water as the surface characteristic influences water flow. The findings agrees with those reported by Huang *et al.* (2015) who found that in refuse dumps in mine, the surface characteristics influenced the infiltration. More vegetated surfaces were considered to have higher infiltration, and surface vegetation increase with age. Therefore, it is expected that infiltration in a quarried site will differ depending on the surface characteristic of the surface. Even so, with time, the surface of the substrate is expected to improve and in turn improve the infiltration process.

From the Kruskal Wallis test, there was statistical significance difference in the average infiltration index among the four-age category (x^2 (3) = 91.837; p= 0.000). From the Mean rank (Table 5.5), the infiltration index of quarried sites increases with the age of the quarried sites. The finding can be due to the older quarries having a better landscape organization index than the young quarries. The presence of plants and other material on the soil surface reduces surface runoff and enhances infiltration. Moreover, soil organic matter and aeration improved over time due to plant roots that are crucial in supporting infiltration. This points to the older quarried having more effective infiltration of water as compared to the young quarried site. Consequently, the runoff of the older quarries is less as compared to the young quarries.

A study by Huang *et al.*(2015) got similar findings that the age of the landscape influences infiltration rate due to better plant establishment. Report by Meadows et al. (2008) also reported a similar finding in which water infiltration evolved with the age of the soil surfaces. The reason was associated with the young surface not being developed enough to facilitate water infiltration and low water holding capacity (Meadows, et al.,2008). Therefore, older quarried sites are expected to have higher water infiltration that supports vegetation in successful colonisation and recovery.

Table 5.4: Soil functionality indices measured for the different patch types presented for the different quarry age categories for the wet and dry season.

	Infiltration index					Stability index					Nutrient Cycle index					Aswat Test Score				
Dry season																				
Age	BS	PC	PSC	SC	SP	BS	PC	PSC	SC	SP	BS	PC	PSC	SC	SP	BS	PC	PSC	SC	SP
1-5	20	26	30	20	25	37	46	51	39	43	8.5	19	25	9.4	15	6.5	7.1	6.9	4.6	6.1
6-10	20	26	32		18	41	53	53		41	8.7	18	24		9.6	4.6	3.9	3.1		5.3
11-15	20	33	36	27	20	41	53	56	41	45	9.9	26	31	20	12	5.1	3.2	3.9	9.7	3.8
16-20		39	45				62	63				36	37				3.3	1.5		
Wet season																				
1-5	21	33	36	21	18	40	53	55	43	38	10	30	33	14	13	6.2	5.8	5.5	6.6	5.6
6-10			48					67					47					5.5		
11-15			43					63					41					8.2		
16-20			42					62					39					3.6		

As presented in table 5.4, the stability index in all the quarry ages was highest in PSC both in the wet and dry season. The stability index under each of the patch types was identified to increase with quarry age. PSC has high stability due to the presence of stones and plants in the microsite, which is crucial in ensuring surface stability. Therefore, the substrate's surface characteristics are an important component of soil stability, which improves over time. Liu et al. (2018) made a similar finding in which the soil surface characteristics are important for soil stability. The research finding are also supported by the report of Sheoran et al. (2010) who concluded that revegetation can be used to improve the soil surface stability during reclamation. Therefore, it is expected that improvement of the substrate stability will be dependent on the surface characteristic in terms of the patch and interpatch type.

Table 5.5: The mean rank score of soil indices for the different age categories of the quarried sites from results of Kruskal Wallis tests

		Mean rank			
Age since quarried	N	% infiltration	% stability	% Nutrients Cycle	ASWAT
1-5years	404	300.27	288.73	304.39	387.51
6-10years	79	358.10	388.37	335.82	328.88
11-15years	142	385.18	392.36	385.59	312.44
16-20years	71	538.91	556.54	539.40	220.49

From table 5.5, soil stability of the quarry sites increases with an increase in age. Young quarry sites recorded lower stability as compared to the older quarry. From the Kruskal Wallis test, there was statistically significant difference in stability index mean between the quarry age categories ($x^2(3) = 122.137$; p= 0.000). The mean ranks showed that the stability index of quarried sites increased over time. The finding can be associated with the surface characteristic as presented in table 5.4. The older quarries had more PSC patch types, especially during the wet season while younger quarried had different patch types that include single plants and bare soil interpatch type. From the finding, age is considered a significant factor that influences soil stability. In addition, improvement in soil stability point to soil development in the quarried sites that occurs over time. Similar findings were reported by Abakumov (2008) that soil stabilities in quarried sites improve over age and associating the change by increase in organic matter concentration in the soil.

Similarly, the nutrient cycle index increased with age of the quarry site, as presented in table 5.5. The highest index was 37 and 47 during the dry and wet seasons, respectively as presented in table 5.4. The lowest nutrient cycle indices in both the dry and wet season were recorded in the 1-5 years category. The Kruskal Wallis test revealed that there was statistically significant difference in mean nutrient cycle index between the four age categories of quarried site (x^2 (3) = 88.734; p= 0.000). The mean rank of the analysis revealed that the nutrients cycle index of the quarried sites increased over time elapsed since last quarried. Therefore, the quarry's age is considered an important factor of quarry site recovery with respect to nutrient cycle. Evaluating the surface characteristics of the quarry, PSC and PC recorded the highest nutrient cycle and were more pronounced in the older quarries that were evaluated. The two-patch type are associated to provide more cover for the substrate surface and act as a better sink or resources in the landscape that can explain the high nutrients cycle.

Increase in nutrient cycle over time may be associated with the increase in PSC and PC, which supports substrate cover and facilitate infiltration. The nutrient cycle is therefore expected to increase as the soil develops. Substrates with high nutrient cycle, therefore, are considered to be developed. Similar findings were reported by Randall (2004) who identified the soil nutrient cycle increased with increase in the in age of habitat that is disturbed. Kumar et al. (2015) also reported similar findings that rehabilitation age contributed to soil development due to accumulation of organic matter and vegetation succession. The improvement of the indices of the stone quarries can thus be associated with vegetation growth and deposition of organic materials on soil substrate. Therefore, it is expected that for stone quarried land, nutrients accumulation including organic matter will increase over time that will enable it to support plant colonisation.

The ASWAT test recorded the highest index of 9.7 and 8.2 during the dry and wet seasons, respectively. During the dry and wet season, the ASWAT test score for all the patch and inter-patch types except for SC decreased with an increase in the time since last quarried. The Kruskal Wallis test showed a statistically significant difference in mean ASWAT score between the different age categories ($x^2 = 50.769$; p= 0.000). The mean rank showed that the ASWAT score of quarried sites decreased with an increase in the time since last quarried (Table 5.5). Decrease in the score points to the soil having less dispersion and increasing its stability in water. Consequently, this lowers the vulnerability of the soil to soil erosion. Therefore, the younger quarry's soil is more vulnerable to dispersion and erosion than the older stone quarry. The stability of the older quarry sites can be associated with plant patch development that increases soil organic components and roots holding the soil particles together. Abiven et al. (2009) made similar conclusions who pointed that soil aggregate stability improves over time due to an increase in the organic matter that prevents the aggregate breakdown and subsequent dispersion.

5.3.2.2 Rehabilitation methods (Substrate type)

Backfilled with local soil levelled was not assessed for soil surface indicators during the wet season thus, there was no data that was available. Based on the type of surface substrate (rehabilitation method), the highest score for infiltration was 49% and 48.4% during the dry and wet season, respectively (Table 5.6). Backfilled levelled planted with trees saplings had the highest score during the dry season while the backfilled with external soil levelled had the highest score during the wet season. Backfilled with local soil levelled recorded the lowest infiltration index of 18% during the dry season, while backfilled with local soil not levelled recorded the lowest index during the wet season. From the Kruskal Wallis test, there was a significant difference in mean infiltration indices between the different categories of rehabilitation method ($x^2(3) = 113.419$; p= 0.000).

Backfilled with external soil and levelled improved the infiltration rate more than the other substrate types. This could be attributed to the higher proportion of organic matter in externally sourced soil material compared to the locally available, quarry dust material. On the other hand, backfilled levelled planted with trees saplings high infiltration could be attributed to the established perennial plants and established undergrowth that improves infiltration through reducing runoff. Consequently, the substrate and rehabilitation method adopted in stone quarry restoration is an important determinant of the degree of infiltration. The findings agree with those of Sheoran et al. (2010), and Yang and Zhang (2011), who recognised vegetation's role in soil improvement to support infiltration and soil retaining and availing water to plants. Therefore, an increase in infiltration points to soil development and is dependent on substrate and rehabilitation method utilised.

Table 5.6: The soil indices for the different patch and inter-patch types categorized by rehabilitation methods for the dry and wet seasons.

	Infiltration index					Stability index					Nutrient Cycle index					Aswat Test Score				
Rehabilitation method	BS	PC	PSC	SC	SP	BS	PC	PSC	SC	SP	BS	PC	PSC	SC	SP	BS	PC	PSC	SC	SP
Dry season																				
Backfilled with local soil not levelled	20	28	32	20	24	39	50	53	39	43	9	22	27	10	14.6	6	5	5.8	5	6
Backfilled with local soil levelled	20	26	32		18	41	53	53		41	9	18	24		9.6	4.6	3.9	3.1		5
Backfilled levelled planted with trees saplings		49	45				62	63				42	37				0.7	1.5		
Backfilled with external soil levelled		48					62					41					2.2			
Wet season																				
Backfilled with local soil not levelled	21	33	38	21	18	40	53	58	8	38	10	30	35	14	13.4	6.2	5.8	5.9	4	6
Backfilled with local soil levelled																				
Backfilled levelled planted with trees saplings			46					61					37					1.5		
Backfilled with external soil levelled			48					67					47					5.5		

Stability indices of soil were higher in quarries that were backfilled levelled and planted with trees saplings during the dry season and backfilled with external soil and levelled during the wet season scoring 63 and 67 respectively. BS and SC of the backfilled with local soil not levelled recorded the lowest soil stability of 39 and 8 during the wet and dry seasons, respectively (Table 5.6). From the Kruskal Wallis test, a significant difference in soil stability (x^2 (3) = 81.459; p= 0.000) was found to exist between the different substrate types (rehabilitation methods) of the quarried sites. Table 5.7 reflects the same trends in the mean ranking scores for the rehabilitation categories.

Backfilled levelled and planted with trees saplings and backfilled with external soil and levelled recording of high stability index could be attributed to their ability to their ability to recruit plant plants that contribute to increase in organic matter and root holding soil particles together. Backfilled with local soil levelled and not levelled recorded low soil stability that could be attributed to local soil being quarry dust that has low claim content and a large percentage of course sand like particles. Therefore, the substrate and rehabilitation type utilised in quarry rehabilitation influences quarry site soil stability.

Table 5.7:The mean rank scores of soil indices for the age category of the quarried sites from Kruskal Wallis tests

Age since quarried	N	Infiltration	Stability	Nutrients Cycle	ASWAT
		Mean rank			
Backfilled with local soil not levelled	564	325.68	325.42	332.53	370.94
Backfilled with local soil levelled	61	283.07	325.42	256.32	309.29
Backfilled levelled planted with trees saplings	38	568.03	538.92	525.41	125.87
Backfilled with external soil levelled	33	606.62	566.42	588.11	293.80

The nutrients cycle index was highest in the backfilled levelled planted with trees saplings and backfilled with external soil levelled during the dry and wet season at 42% and 47%, respectively. Backfilled with local soil levelled recorded the lowest nutrient cycle index during the dry season, and Backfilled with local soil not levelled during the wet season. The Kruskal Wallis test showed a statistically significant difference between the four-rehabilitation categories in the mean nutrient cycle indices (x^2 =92.809; p= 0.000). The mean rank of the nutrient cycle indices shows the same trend, (Table 5.7).

The highest score of nutrients cycle in backfilled levelled and planted with trees saplings and backfilled with external soil and levelled could be attributed to the vegetation cover that were recorded in the PSC and PC patch types. The main factors of nutrient cycles included perennial vegetation cover and litter which were high in the two rehabilitation methods resulting in high nutrient cycle. Consequently, backfilled levelled and planted with tree saplings and backfilled with external soil and levelled methods is crucial in rehabilitating quarry sites and supporting vegetation. The finding is in agreement with those of Ayusa et al. (2020) who recognised the importance of organic matter and nutrients in quarry substrate in supporting plant growth.

The highest mean ASWAT test score was 6 and 6.2 in BS of the backfilled with local soil not levelled for dry and wet seasons, respectively. PC and PSC of backfilled levelled planted with trees recorded the lowest ASWAT test index during dry and wet seasons. From the mean ranks (Table 5.7), backfilled levelled planted with trees saplings recorded the lowest mean ASWAT index while backfilled with local soil not levelled recorded the highest mean ASWAT test score. The Kruskal Wallis test revealed that there was statistically significant difference in ASWAT test score between the different rehabilitation categories of the quarried sites (x^2 =60.111; p= 0.001).

Backfilled levelled and planted with trees saplings recorded the lowest ASWAT test score that could be attributed to organic matter due to established perennial vegetation as a result of the planted trees. The soil therefore is less prone to dispersion in water and subsequently lower risk to erosion. On the other hand, backfilled with local soil not levelled had a high ASWAT test score that could be attributed to the soil being quarry dust that has high sand content, which disperses easily in water, hence prone to erosion. Therefore, the substrate and rehabilitation method adopted in quarry restoration impacts the soil stability in water and the risk of erosion. Well-developed soil is expected to have low ASWAT test score, which make them have less risk of erosion. The finding agrees with the findings of Nichols and Toro (2011) who identified that soil aggregate stability determines the quality of soil with those that have high stability in water being better for vegetation growth.

5.4 Conclusion

Infiltration, nutrient cycle and stability indices of soil are higher in the patch compared to interpatch sections. Plant stone complex and plant complex had more influence on soil development as compared to the other patch types. The age of quarried site and substrate type (rehabilitation method) significantly influence the soil development of stone quarried sites as it affects the soil indices. Season (wet and dry) was also found to affect the soil stability, infiltration, and nutrient cycle.

CHAPTER SIX

SOIL MACRO FAUNA COMPOSITION IN QUARRIED SITES

6.1 Introduction

Soil macrofauna contributes to the accumulation of organic matter in the litter layer of the soil due to litter fragmentation by saprophagous microorganisms. The macro organisms also facilitates mixing of the soil which increases soil physical properties such as water holding capacity of poor soils in mined sites (Frouz *et al.*, 2006). In a study done by Frouz *et al.* (2007), soil macrofauna including earthworms facilitate development of top soil through soil component mixing, organic matter accumulation and humus creation through faecal matter and macrofauna fragmentation. Earthworms are considered important to ecosystem development through improving soil structure, pollution remediation, nutrient recycling, water regulations, and pedogenesis (Blouin *et al.*, 2013). The accumulation of humus was found to be higher in reclaimed land as compared to unclaimed mined land (Frouz *et al.*, 2007). The soil macrofauna in post-mined sites is considered as one of the methods that can be used to assess quality of soil (Venuste *et al.*, 2018).

The composition of the soil macrofauna in the landscape is dependent on the soil and the overlaying materials characteristics. According to Frouz (2008), the quality of the litter that are found on the soil surface influence the presence and diversity of soil organisms. Barros *et al.* (2002) evaluated the land-use practices impact on soil microorganism in western Brazilian Amazonia. The study recognised that the type of land use had an impact on the soil parameter and the presence and diversity of soil microorganisms. Fallow, agroforestry system, and annual crop recorded very high density on invertebrate communities while pastures and forest recorded the highest density (Barros *et al.,* 2002). Agroforestry and forest macrofauna communities were similar, although they had high density of social insects. Sayad *et al.* (2012) also evaluate soil macrofauna in reclaimed sites where the tree species was identified to have a significant influence on the composition of soil macrofauna. The age of landscape is considered to influence soil macrofauna activities in quarried sites. Domínguez-Haydar *et al.* (2018) reported that in early age of mined sites, the macrofauna activities are low but the activities were found to increase with the age of the site. Older sites are there expected to have higher soil macrofauna activities as compared to the young quarry sites. The objective of the study was to assess soil macro fauna found on quarried land under different management regimes and different periods of post-quarry activities

6.2 Material and methods

6.2.1 Sampling method

Out of the 60 quarry sites accessed, nine quarry sites in which quarrying had ceased and landowners gave consent were included in the study survey (Table 4.1). Random sampling was used to select sampling points within the quarry site for survey of soil macro fauna. For each of the quarry zone in the study sites, five quadrats of 25 cm by 25cm were set. Within each quadrat, soil was excavated to a depth of 15 cm using a shovel and trowel and put on a dry nylon sheet. The soil was gently sorted and any macro fauna observed was picked out and put on a tray. For each organism, the species name and numbers were recorded in a data sheet and then given an identification code. The macrofauna samples were put in sampling bottle for laboratory identification and characterisation. Survey was done during both the dry and the wet seasons. In the lab at National Museums of Kenya, the sampled fauna was pinned on the board except for mollusc that were retained in ethanol for preservation. After pinning the insects on the board and allowed to dry, dichotomous key was utilised to identify the animal to their order, family, genus and some to species level. Larvae and maggots were only identified to the order of family level because of lack of distinguishing features. The identification key was used together with reference books such as Schabel (2005) and Nair (2007). Plate 6.1 presents a summary of the data collection of macrofauna during the research undertaking.

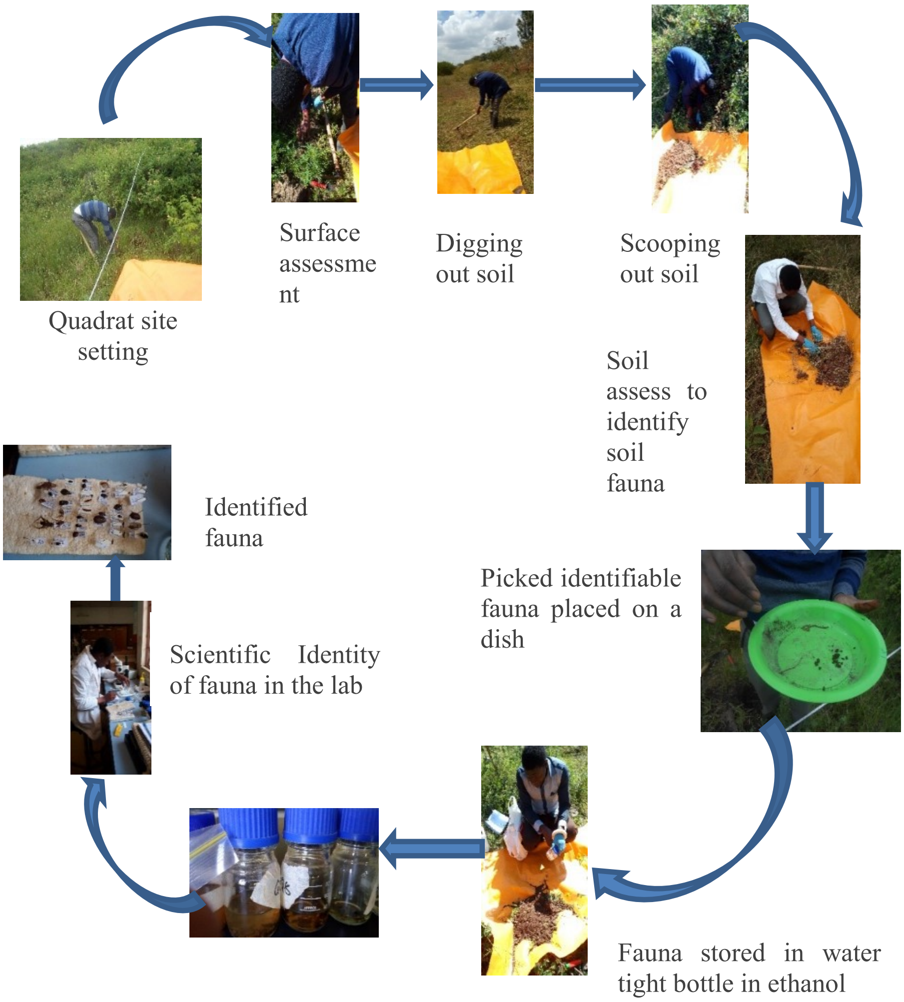


Plate 6.1. Summary of data collection procedure of macrofauna

Data analysis

Data for macrofauna was aggregated and assessed for species richness, abundance of individual species and diversity of species starting at the sampling scale of the quadrat which was pooled for whole quarry site. For species diversity the following formula was applied to give the Shannon index of diversity.

$$\mathbf{H'= -\sum pi\ ln\ pi}$$

H= Shannon index of diversity

Pi= is the proportion contribution of i species. It is calculated by ni/N where ni is the total number of I species while N is the total number of individuals identified

In= is the natural log

The effect of the independent variables of substrate (rehabilitation method) and time lapse since last quarrying on the macrofauna composition was compared using the Mann-Whitney U test and Kruskal Wallis test for both the wet and dry season.

6.3 Results and discussion

6.3.1 Macrofauna composition

A total of 100 quadrats were surveyed during the wet and dry season in the 9 quarry study sites. A total of 72 macro fauna species were identified belonging to 15 faunal orders. Coleoptera was the most common order with 25 fauna species followed by Hemiptera with 9 macrofauna species (Table 6.1). Of the 72 species, 18 were identified to order level, 17 to family level, 19 to genus level and 18 were identified to species level. The reason for not identifying all the macrofauna was because some were recorded while young with no fully developed body parts that could have helped in full identification. A total of 26 fauna families were identified which were for 54 species that were identified to the family level and below. A total (abundance) of 5901 macrofauna were sampled in both the dry and wet season of the quarried sites.

The soil macrofauna identified in the quarry sites could be attributed to water availability, especially during the wet season, and plants that offer food and a conducive habitat. For instance, earthworms were recorded during the wet season as small ponds of water in the quarried site provided them with their required habitat. The identification of diversity points to the quarried sites forming important habitat of soil macrofauna (Arnold & Williams, 2016; Frouz *et al.,* 2006). In addition, the presence of macrofauna in quarried sites, recognises that macrofauna can recolonised quarried sites with Coleoptera being the most adapted to the environment as evidence by large no of species types identified. Even so, Frouz (2008) recognises that the rate of colonisation and macrofauna's diversity depends on the substrate and the litter type available. This is also supported by Mitchell *et al.* (2012) who recognised the importance of quarry condition on the macrofauna composition.

Table 6.1:The number of macrofauna species identified per order

Order	No of species	relative %	Order	No of species	relative %
Coleoptera	25	34.72	Isoptera	2	2.78
Hemiptera	9	12.50	Mollusca	2	2.78
Lepidoptera	8	11.11	Orthoptera	2	2.78
Araneae	6	8.33	Acari	1	1.39
Hymenoptera	6	8.33	Diplopoda	1	1.39
Blattodea	3	4.17	Isopoda	1	1.39
Chilopoda	3	4.17	Oligochaeta	1	1.39
Dermaptera	2	2.78			

Table 6.2 presents summary of soil macrofauna population in the quarried sites. The mean species number per quadrat was highest in quarry 9 and 4 during dry and wet seasons. Quarry 5 and 6 had the least species number per quadrat during the dry season while Q3 recorded the least during the wet season. The difference in species no per quadrats of the different quarry sites can be attributed to the difference in site characteristics. For instance, Q4 high number of species could be attributed to established perennial plants and undergrowth that has enhanced soil characteristics to support diverse soil macrofauna.

The species richness for the dry season was 56 while that of the wet season was 59. *Pheidole crassinoda, Caponia sp* and *Pheidole sp1* were the most common macrofauna both in the wet and dry season, having a frequency of 18, 14 and 13 out of 18 total surveys respectively. Quarry 9 ,8 and 1 had the highest species of 31, 21 and 21 respectively during the dry season while Q1 and Q4 had the highest richness species richness of 26 and 20 during the wet season respectively.

The macrofauna species richness being high in the wet season as compared to the dry season can be attributed to some of them only being recorded during the wet season when the environment is conducive. For instance, earthworms that require moist environment were only found during the wet season. In addition, wet season is associated with an increase in litter and vegetation cover that improved the soil condition and makes it more habitable by soil macrofauna. The Macrofauna species richness therefore is influenced by the weather season in the different quarried sites. The difference in the composition of the macrofauna in the different quarries can explain different in the site condition and soil composition. More developed soil is expected to be more colonised by soil macrofauna as compared to the developing soil. The findings agree with those of Venuste et al. (2018) who recognised that the composition of the soil macrofauna can be utilised to evaluate soil quality.

Table 6.2: The mean species richness for the surveyed quadrats during the dry and wet season.

Quarry site	Species richness	Quadrats no	Species no/quadrat	Species richness	Quadrats no	Species no/quadrat
		Dry season			Wet season	
Q1	21	9	2.3	26	10	2.6
Q2	14	5	2.8	15	5	3
Q3	8	6	1.3	7	5	1.4
Q4	18	5	3.6	20	5	4
Q5	5	5	1.0	12	5	2.4
Q6	5	5	1.0	12	5	2.4
Q7	13	5	2.6	12	5	2.4
Q8	21	5	4.2	17	5	3.4
Q9	31	5	6.2	18	5	3.6

6.3.2 Rehabilitation methods

The macrofauna diversity index was found to be highest in post quarried sites rehabilitated through planting of trees. Macrofauna diversity index was lowest was recorded in sites that was backfilled with external soil and levelled. The high diversity in the post-quarried sites planted with trees can be explained by the increase in the amount of litter, which provides a good habitat for the soil macrofauna through shelter and food. The findings agree with those of Frouz (2008), who identified that litter's quality and presence influences the soil organism biodiversity with reclaimed sites having more macrofauna.

Table 6.3: Soil macrofauna characteristics categorized based on substrate type (rehabilitation method)

Rehabilitation method	Species richness	Mean species no/quadrat (abundance)	N	Shannon diversity index (H)	Total no of quadrats
Dry season					
Backfilled with local soil not levelled	49	1.4	1564	0.69	35
Backfilled with local soil levelled	14	2.8	84	0.66	5
Backfilled levelled planted with trees saplings	18	3.6	246	0.77	5
Backfilled with external soil levelled	13	2.6	325	0.41	5
Wet season					
Backfilled with local soil not levelled	55	1.57	1520	0.79	35
Backfilled with local soil levelled	15	3	1196	0.60	5
Backfilled levelled planted with trees saplings	20	4	365	0.89	5
Backfilled with external soil levelled	12	2.4	603	0.39	5

Sayad *et al.* (2012) also identified that the tree species found in the reclaimed sites determines the richness and abundance of macrofauna as it affect availability of organic matter through littering. Difference in macrofauna diversity across the different rehabilitation method can be due to differences in quality of the substrate and the subsequent vegetation recruitment and colonisation. Barros *et al.* (2002) identified that the different land uses impact the occurrence and diversity of macrofauna and this could explain the difference in diversity difference in the case of post stone quarried sites in Ndarugu area. The type of post quarry rehabilitation system of stone quarry sites thus impacts on the soil macrofauna diversity.

6.3.3 Age categories of quarried sites

Table 6.4 presents the soil macrofauna categorized based on the age category. The 1-5 years category had the highest species richness both in the wet and dry seasons of 41 and 34 species respectively. The macrofauna species abundance was generally higher during the wet season as compared to the dry season except for the 11-15 category. During the wet season, the species number per quadrat, which was the measure of abundance, increased with the quarry age since last quarried. The same was in the dry season except for the 16-20-year category where the abundance decreased. There was a significant difference in mean species number per quadrat between the different age categories (p-value <0.05).

The diversity index assesses the possibility of two randomly selected individuals coming from different macrofauna species. From the Simpson's index of diversity, the macrofauna diversity was higher during the wet season as compared to the dry season for all the quarried sites. Quarry category of 1-5 years during the dry season had the lowest diversity index of 0.46 which points to a higher probability of two randomly selected individuals coming from the same species. The older quarries had a higher diversity as compared to the younger quarries both for the wet and dry seasons. The high species diversity index in older quarry can be attributed to developed soil that form conducive habitat for diverse macrofauna. The old quarry is attributed to established vegetation cover and increase in litter cover that are crucial in supporting soil macrofauna activities increasing their diversity and population. Over time, soil becomes more and more habitable for more macrofauna, resulting in increased soil macrofauna diversity over the years. The diversity indices point to the fact that the macrofauna in the post-quarried site vary depending on the season, with their population being higher during the wet season and with age of the site.

Table 6.4: Soil macrofauna characteristics categorized based on quarry age category

Quarry age	Species richness	Mean species no/quadrat (abundance)	N	Shannon diversity index (H)
		Dry season		
1-5	34	1.79	689	0.46
6-10	22	2.2	409	0.59
11-15	33	3	809	0.69
16-20	20	2	312	0.68
		Wet season		
1-5	41	2.05	460	0.84
6-10	23	2.3	1799	0.63
11-15	23	2.3	905	0.61
16-20	25	2.5	520	0.90

A study by Holecová et al. (2005) got similar findings that the age of the habitat influences the occurrence and richness of the soil macrofauna. Moreover, the findings agree with those of Domínguez-Haydar et al. (2018), who reported that the biological activities of soil macrofauna in the mined site are minimal during the early stages of reclamation but increase with time. Hence more activities witnessed in sites that were 20 years old since last disturbed. The finding concurs with the finding from Ndarugu quarry sites as more soil macrofauna densities were found in the older quarries as compared to the younger quarries. The finding points to the existence of significant influence of age since quarried on the abundance of soil macrofauna in post-quarried sites.

The diversity of soil macrofauna thus is expected to increase with the age of quarried sites if the site is not disturbed. The finding is supported by Frouz et al.(2006) that reported macrofauna influence the development of the soil through the different activities that they undertake. Therefore, quarried whose substrate were older are expected to have mode soil macrofauna diversity. Moreover, the research finding is supported by Venuste et al. (2018) who identified that the quality of the soil can be determined the quality of the soil macrofauna composition in post mined sites. The increase of the macrofauna in the stone quarried sites can be associated with improvement of the site’s substrate and the vegetation diversity that developed in the sites. The increase in the soil fauna abundance and diversity can be crucial for improvement of the quarried sites over time.

6.4 Conclusion

The quarried site was identified to be an important refuge for diverse soil macrofauna, as evidenced by the diverse soil macrofauna that were identified in the quarried sites. Coleoptera was the most common order. Total of 26 macrofauna families were identified to reside in the quarried sites. Rehabilitation methods and age since last quarried were identified to influence soil macrofauna diversity. The season was also identified to influence abundance and richness of soil macrofauna in stone quarried sites. The macrofauna diversity can contribute to soil development in the quarried sites making them more habitable by flora and fauna.

CHAPTER SEVEN

CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

The assessment of perception of quarry landowners on quarrying identified that stone quarrying activities have positive and negative impacts to the socioeconomic characteristic of the community who live around the quarry zone as well as to the environment. There were more negative impacts of quarrying as compared to positive impacts. A large percentage (66.6%, n= 60) of the surveyed stone quarries were not rehabilitated to any extent. Lack of financial support services and lack of a compulsive legal framework were perceived as main limitations to quarry rehabilitation.

Age, season and rehabilitation methods impacted the density of zones of resource accumulation and sources. Increase in age resulted in decrease in patch density due to coalescing of the patches. Wet season had higher patch density as compared to the dry season. Overall, plant complex (PC) type of patch, recorded the next highest patch width after PSC which varied slightly between the year categories, rehabilitation methods and seasons. Micro site landscape organisation was found to increase with quarry age and was higher during the wet season. Plants species richness increased with increase in the age since stoppage of quarring of stone quarried sites. Quarried sites form an important habitat of unique plants species.

For soil development, age, season (Wet or Dry) and rehabilitation method significantly influenced infiltration, nutrient cycle, and stability of quarried site soils. Plant stone complex and plant complex had more influence on soil development as compared to single plant and stone complex zones of resource accumulation. The quarried sites were identified to be an important refuge for diverse soil macrofauna.. The order coleoptera had the most common macro fauna in stone quarried sites. Rehabilitation method, season and age elapsed since last quarried were identified to significantly influence soil macrofauna diversity in quarried sites.

7.2 Recommendations

The study was carried out along River Ndarugu through surveying of land owners on impact of quarrying, and undertaking soil, macrofauna and plant study of nine quarried sites with different age and substrate characteristics in wet and dry season. From the study, the following recommendations were made:

1. Quarry land owners, quarrying firms and concerned regulatory bodies need to improve the management of quarrying activities to lower the negative impacts of quarrying to the community and the environment.
2. Improvement of the legal framework on stone quarry rehabilitation by government and policy makers to facilitate implementation of cost-effective methods of quarry rehabilitation.
3. Adopt the use of identified pioneer plant species in quarry rehabilitation to facilitate fast and successful re-vegetation and vegetation succession of the quarry sites.
4. Naturally evolved post-quarry sites create habitat for plants and soil macrofauna. Human interventions to rehabilitate should consider this ecological role.

The following are suggestion of areas for further research:

a) Undertaking a survey of non-quarry landowners to assess their perception on quarrying activities.
b) Experimental studies on plant growth performance under quarry environmental conditions.
c) Assessment of historical trends of quarrying activities along the Ndarugu quarry zone.

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APPENDICES

Appendix I: Questionnaire survey

RESEARCH QUESTIONNAIRE

JOMO KENYATTA UNIVERSITY OF AGRICULTURE AND TECHNOLOGY

FACULTY OF AGRICULTURE.

Questionnaire for a Study on quarry rehabilitation along river Ndarugu in Kiambu County

Introduction: This is an academic research being conducted by a research scientist who is a member of Jomo Kenyatta University of Agriculture Technology (JKUAT) in the Department of Horticulture. The researcher invites you to participate in this exercise, whose objective is to assess post-quarry rehabilitation methods, factors influencing the choices and perception of post-quarried environments along river Ndarugu. The questionnaire will take at most 20 minutes. Fill the questionnaire to your knowledge best as your response is key to the research.

Informed consent: As a good gesture to research ethics I find it prudent that I ask for your consent to participate in the survey. If you accept to participate, sign in space provided below. Consequently, I am bound by the following:

- Your responses will be treated with **CONFIDENTIALITY.**
- The study **DOES NOT** intend to associate any of the responses in this questionnaire with you, your associates or any other party.

Participant signature ………………………… Date…………………………

SECTION A: RESPONDENT PERSONAL DETAILS

1. Name…………………………………………………………………………
   …..
2. Gender.
   a. Male [ ] b. Female [ ].
3. Age bracket in years.
   a. 18-25 [ ] b.26-35 [ ] c.36-55 [ ] d. 56-65 [ ]e. >65
4. Marital status.
   a. Single [ ] b. Married [ ] c. any other…………………..
5. Homestead size.(number of households)
   a. [1-2] b. [3-4] c. [4-5] d. [>5]
6. Household (number of family members)
   a. [1-3] b. [4-6] c. [7-9] d. [>9]
7. Highest completed level of education
   a. Primary level [ ] b. Secondary level [ ] c. Certificate [ ] d. Diploma [ ]
   e. Degree [ ] f. Any other (specify)……………….
8. Among the following, select the ones that best explain your main occupation(s).
   a. Transportation (bodaboda, lorry) [ ] b. Contractor [ ] c. Farmer [ ]
   d. Quarry stone dealers [ ] e. Small-scale business [ ] f. Estate management [ ] g. Shop/restaurant [ ] f. Any other ……………
9. What is your average monthly household income in KSH?
   a. <10, 000 [ ] b. 10,000-30,000[ ] c. 30,000-50,000 [ ] d. 50,000- 100,000 [ ].
   e. > 100,000 [ ].
10. Location of the homestead (GPS readings).
   Latitude …………………………Longitude………………………..

SECTION B

1. Status of land ownership
   a. Private [ ] b. Community owned [ ] c. Family [ ]
2. Tick the check box that best explain the size of your land in acres.
   a. Less than 1 [ ] b. 1-3[ ] c. 4-5 [ ] d. Greater than 5[ ]

3. The list below represents land use/ land cover activities. Identify/select the activity (ies)that best identify your land use and rank them by income and the land area on a scale of 1to 3. For income 1 being low income and 3 the highest income. For land cover 1 being an activity that covers a small area while 3 covers the largest segment.

Land use activity	Income	land coverage
Quarrying		
Rental houses		
Crop farming		
Dairy and poultry farming		
Small business example		
Idle land		
Residential building		
Any other specify		

4. If your land has been quarried;

I. What portion of the land is under quarrying?

a. < 25% [ ] b. 25-50 [ ] c. 50-75 [ ] d. 75-100 [ ]

II. Who did the quarrying?

a. Owner [ ] rented out [ ]

III. For how long has/was your land been quarried?

a. < 1yr [ ]b. 1-2yr [ ]c. 3-4 [ ]d. 5-6[ ] e. >6yr[ ]

IV. How many sections has your quarried land area been subdivided into for quarrying purposes?

a. 1-2[ ] b. 3-4[ ] c. 5-6 [ ] d. 6-7 [ ] e. >7[ ]

V. Please indicate the time quarrying started and stopped for each quarry section in the table below.

Sections	1	2	3	4	5	7	8
Year started							
Year stopped							
Continuing							

VI. Before quarrying; there is always a documented agreement between the land owner and the quarrying firm that stipulates the terms of quarrying. In your quarrying agreement, was there stated a post quarrying handing over procedure?

a. Yes [ ] b. No [ ]

VII. Please indicate from the list below, the party identified in the agreement as responsible for quarry rehabilitation?

a. Owner [] b. Quarrying firm [ ] c. County Council [ ] d. NEMA [ ]e. Not Mentioned []

VIII. Below is a list of methods through which quarry site can be rehabilitated, choose the set that best describe how your land was/ will be rehabilitated.

a. Backfilling with imported topsoil levelled and planted [ ]
b. Backfilling with imported topsoil levelled and not planted [ ]
c. Backfilling with local soil levelled and planted [ ]
d. Backfilling with local soil levelled and not planted [ ]
e. Backfilling with imported topsoil levelled and built up[ ]
f. Backfilling with local soil levelled and built up [ ]
g. Backfilling with no levelling [ ]
h. No backfilling and quarry used as water reservoir [ ]
i. Abandoned quarry [ ]

5. Quarrying activities affect the social, economic status of the community and the environment. Below is a list of some of the impacts of quarrying to the society. Rank them on a scale of 1 to 5 based on your preferred level of importance.1 being the least important and 5 being the most important

	Impacts of Quarrying on the social economy	1	2	3	4	5
	Increase in household income					
	Source of employment					
	Opening up the interior for commercial activities.					
	Improved infrastructure such as roads, infrastructure, and water					
	Better social harmony					
	Better access to services such as health and education					
	Having more access to financial loans					
	Health and safety hazards such as diseases.					
	Water pollution					
	Noise pollution					
	Increased dust pollution					
	Destruction of productive agricultural land.					
	Insecurity					
	Lose of biodiversity (plants, animals, and microorganism)					
	Mismanagement of money leading to poverty					
	Increased rate of communal disharmony.					
	The influx of new people.					
	Change in social ethic (change in people behaviour such alcoholism,)					

	Domestic violence					
	Any other specify…					

6. I. Do you have any knowledge pertaining post quarry use?

a. Yes [ ] b. No [ ]

ii. If yes, how did you first learn about post quarry use?

a. Short course study and seminars [ ]
b. Past Experience in post quarry use [ ]
c. Social media (TV, Radio, Facebook, etc.)
d. The quarrying company
e. The government
f. Other people in the village
g. Any other specify……………………………………………………………

7. After quarrying is done, the quarried land can be put into different economic use. From the list of post quarry use below, identify and rank your preferred post quarry use on a scale of 1 to 3.1 being least preferred and 3 most preferred.

Post quarry use	**1**	**2**	**3**
Minimum intervention and develop to natural vegetation			
Agriculture- beekeeping			
Crop farming			
Dairy farming			
Poultry keeping			
Fish farming			
Building of estates/rentals			
Recreation site e.g. parks, children playing ground.			
Reforestation/planting of trees.			
Hotel development			
Creation of dam/ water reservoir			
Any other specify			

8. In quarry rehabilitation, there might be limiting factors encountered. Below is a list of some of the possible limiting factor. Select the ones that you identify as the limiting factors and rank them in a scale of 1 to 5; 1 being the least limiting factor and 5 the highest limiting factor.

	Limiting factors in quarry rehabilitation	1	2	3	4	5
a.	Lack of technical support.					
b.	Lack of financial support.					
c.	Legal barriers (laws and regulation not being followed to the later.no clear law framework for rehabilitation)					

d.	Responsible party for quarry rehabilitation is not fulfilling responsibility.					
e.	Poor body health					
f.	Any other specify					
g.						
h.						

9. Quarry rehabilitation have many benefits to the social, economic status of the community and the environment. The list below represents some of the possible benefits of quarry rehabilitation. Identify the significant benefit according to you and rate them on a scale of 1 to 5; 1 being least significant and 5 being the most significant.

Benefit	1	2	3	4	5
a. Increase in income					
b. Reduced health and safety hazard					
c. Job creation					
d. Biodiversity restoration					
e. Improved productivity of land					
F. Any other specify					

10. Quarrying rehabilitation requires studying the land area to identify the most appropriator rehabilitation method and post quarry use. Can you allow your quarried land to be used for studies purposes?

a. Yes [ ] b. No [ ]

THANK YOU FOR YOUR PARTICIPATION.

Appendix II. Transect plant families

Family	Species number	Family	Species number
Fabaceae	26	Verbenaceae	2
Asteraceae	24	Caesalpiniaceae	1
Poacea	23	Cannabaceae	1
Malvaceae	10	Caricaceae	1
Solanaceae	8	Chenopodiaceae	1
Amaranthaceae	7	Combretaceae	1
Bignoniaceae	7	Flacourtiaceae	1
Convolvulaceae	7	Lauraceae	1
Lamiaceae	7	Osmundaceae	1
Cucurbitaceae	6	Oxalidaceae	1
Euphorbiaceae	5	Papaveraceae	1
Myrtacea	4	phytolaccaceae	1
Polygonaceae	4	Proteaceae	1
Cyperaceae	3	Pteridaceae	1
Moraceae	3	Rosaceae	1
Nyctaginaceae	3	Rubiaceae	1
Acanthaceae	2	Tiliaceae	1
Asclepiadaceae	2	Ulmaceae	1
Commelinaceae	2	Vitaceae	1
Passifloraceae	2	Zygophyllaceae	1
Sterculiaceae	2		

Appendix III. Top ten most common plant species in wet and dry season for the different age categories

Plant species			
Wet season	**Dry season**	**Wet season**	**Dry season**
1-5 years		11-15 years	
Sida acuta	*Achyranthes aspera*	*Bromus sp*	*Achyranthes aspera*
Nicotiana glauca	*Conyza bonariensis*	*Tagetes minuta*	*Bromus sp*
Conyza bonariensis	*Nicotiana glauca*	*vernonia lasiopus*	*Rhynchelytrum repens*
Bromus sp	*Bromus sp*	*Indigofera erecta*	*Tagetes minuta*
Rhynchelytrum repen	*Rhynchelytrum repens*	*Triumfetta sp*	*Bidens pilosa*
Bidens pilosa	*Tagetes minuta*	*Sida acuta*	*vernonia lasiopus*
Tagetes minuta	*Ageratum conyzoides*	*Lantana camara*	*Lantana camara*
Tridax procumbens	*Alternanthera pungens*	*Conyza bonariensis*	*Neonotonia wightii*
Euphorbia hirta	*Bidens pilosa*	*Bidens pilosa*	*Triumfetta sp*
Phytolacca octandra	*Sonchus oleraceus*	*Neonotonia wightii*	*Ageratum conyzoides*
6-10 years		*16-20 years*	
Bromus sp	*Achyranthes aspera*	*Lantana camara*	*Bromus sp*
Tagetes minuta	*Nicotiana glauca*	*Bidens pilosa*	*Rhynchelytrum repens*
Tridax procumbens	*Bromus sp*	*Panicum maxima*	*Bidens pilosa*
Lantana camara	*Rhynchelytrum repens*	*Schkuhria pinnata*	*Lantana camara*
Cynodon nlemfuensis	*Tagetes minuta*	*Acacia sp2*	*Indigofera erecta*
vernonia lasiopus	*Bidens pilosa*	*Pennisetum purpureum*	*Leonotis mollissima*
Asystasia Schimperi	*vernonia lasiopus*	*Tagetes minuta*	*Aspilia mossambicensi*
Conyza bonariensis	*Cynodon nlemfuensis*	*vernonia lasiopus*	*acacia senegal*
Rhynchelytrum repen	*Lantana camara*	*Neonotonia wightii*	*Schkuhria pinnata*
Bidens pilosa	*Tridax procumbens*	*Tridax procumbens*	*Eragrostis tenuifolia*

Appendix IV. List of publications

Waweru, S.W., Njoroge, J.B. and Adimo, A.O., 2018. Management status and perception of post quarried sites in Ndarugu Kiambu, Kenya. African Journal of Environmental Science and, p.268.

Waweru, S.W., Mukundi, J.B. and Adimo, A.O., 2016, November. Plant composition and micro-landscape organization of post-quarried land in Ndarugu area, Kiambu county. *In the 11th JKUAT scientific, technological and industrialization conference and exhibitions conference proceedings*

Waweru, S.W. and Mukundi, J.B., 2015 Perception on quarrying activities and post quarried land use along river Ndarugu, Kiambu county. *In the 11th JKUAT scientific, technological and industrialization conference and exhibitions conference proceedings.*