BINDURA UNIVERSITY OF SCIENCE EDUCATION

DEPARTMENT OF NATURAL RESOURCES MANAGEMENT

ECOLOGICAL CONSEQUENCES OF SAND AND GRAVELMINING ON VEGETATION DYNAMICS: A CASE STUDY OF WARREN HILLS, HARARE.

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A DISSERTATION SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS OF THE BACHELOR OF SCIENCE (HONOURS') DEGREE IN NATURAL RESOURCES MANAGEMENT

30 MAY 2026

DECLARATION

I, Mupombwa Priveledge Kundai, declare that this project is my piece of work, and I did not use any information from sources without crediting the owner.

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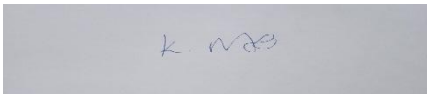
Signature 

DEDICATION

I want to dedicate this project to my mother, Constance Mupombwa, I thank you so much for your constant support in all dynamics of my life, with a special mention to Daniel T Chatendeuka for his unwavering support and guidance through my academic endeavour.

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APPROVAL FORM

The undersigned certify that they have read and recommended to Bindura University of science Education: a dissertation entitled, “Ecological consequences of sand and gravel mining on vegetation dynamics. A case study of warren hills, Harare, Zimbabwe”

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ABSTRACT

Vegetation systems and surface conditions are adversely affected by sand and gravel mining activities, and this is one of the major drivers of environmental degradation in peri-urban areas. The effects of sand and gravel mining on vegetation dynamics was assessed in Warren Hills, Harare, Zimbabwe. The study was designed to evaluate the effects of mining on vegetation cover, density and diversity, to explore community perceptions of mining activities and some of the constraints to good environmental management in mined areas. A Mixed methods research incorporating Geographic Information Systems (GIS), remote sensing techniques, field observations and questionnaire surveys was used. For years 2013, 2018, 2022 and 2025 Landsat 8 satellite data was processed and analysed using QGIS and Google Earth Engine. Indices such as Normalized Difference Vegetation Index (NDVI), Bare Soil Index (BSI), Soil Composition Index (SCI) and Land Use/Land Cover (LULC) classification were generated. Questionnaire surveys were used to gather community perceptions and environmental management insights from Warren Park community and City of Harare officials respectively. Results showed that there were major land use and land cover changes over the study area. The area of mined areas grew significantly from 109.26 ha in 2013 to 437.76 ha in 2025 while the vegetation cover reduced in the same period (Sparse). NDVI analysis showed that there was a decrease in vegetation health and density around active mining sites, supporting the fact that mining leads to vegetation degradation and ecological disturbance. BSI and SCI analyses also demonstrated that a trend of bare surface and disturbed soils as a result of extraction work increased. The issues identified as environmental problems in the community were: vegetation loss, dust pollution, land degradation and rehabilitation problems. The research findings indicate that sand and gravel mining in Warren Hills has significantly impacted vegetation dynamics and ecological conditions and is not sustainable. The research suggests that environmental monitoring systems should be reinforced, sustainable mining operation should be encouraged, rehabilitation programmes should be enhanced after the mining, and community involvement should be encouraged in environmental management. The use of GIS and Remote Sensing techniques proved to be effective in the monitoring of the changes related to the mining activities and in the sustainable environmental management.

Keywords: *Warren Hills, Sand and gravel mining, vegetation dynamics, Normalised Difference Vegetation Index*

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List of Acronyms

COrona Virus Disease	COVID
Environmental Management Agency	(EMA)
Environmental Management Plans	(EMPs)
Geographic Information Systems	(GIS)
Harare City Council	(HCC)
hectares	(ha)
in other words	i.e,
Land Use-Land Cover	(LULC)
near infra-red	(NIR)
Normalized Difference Vegetation Index	(NDVI)
Soil Crust Index	(SCI)
standard deviation	(SD)
The Brightness Index	(BI)
The environmental management unit	(CEMU)
Topsoil Grain Size Index	(TGSI)
United Nation Development Programme	(UNDP)
Zimbabwe Republic Police	(ZRP)

CHAPTER 1: INTRODUCTION

1.1 Background of the Study

Proper environmental management requires a holistic understanding of how natural and anthropogenic activities affect ecosystem variations and the societies around as well as how those could be prevented or adopted to by those affected. Mining has been one of the most devastating source factors causing environmental changes amongst the alternating processes that have altered the functioning of the ecosystem to varying degrees and in most instances, the changes have been irreversible or long lasting.(Bridge 2004; Sonter et al. 2018) Global mining activities leads to significant land use changes, water contamination, and pollution as well as biodiversity loss, making mining activities a major driver of environmental degradation (Bendixen et al. 2023). In recent decades, mining of sand and gravel has actively attracted scholarly attention because of its enormous ecological expansion footprint and its role in economic development. (Bendixen et al. 2023).

Gravel mining also referred to as sand and gravel mining or aggregate mining, is the process of extracting loose materials like sand gravel and clay out of the earth (Kondolf 1997; UNDP 2014). It is mainly done via open pits, hill side quarrying hence it is found in its natural occurrence. This is a process of utmost significance because it provides raw materials which are utilized in construction. It is however mostly identified with environmental degradation through different forms such as, deforestation, soil erosion, water pollution, landscape disturbance and disruption of soil composition (Rentier and Cammeraat 2022) . The sand and gravel aggregates have created an issue of growing interest globally owing to two important aspects; to begin with, the aggregates are being extracted and consumed at a rate faster than it can be replenished therefore posing a risk to the future generations who will have less/no aggregates resources left to work with (Torres et al. 2022; UNDP 2014). Mining has serious negative effects on the environment, which includes great degradation of landscapes and collateral damage (Koehnken .L 2018), which is often exacerbated by inefficient mining practices (Macêdo Coelho et al. 2022) and energy-intensive operations (Tripathi et al. 2025).

Aggregate mining is of paramount importance to this world, it is estimated that 32 to 50 billion tons of sand and gravel is mined in the world yearly, making it the second largest volume of mined raw material after water to be extracted (Gallagher 2019; Leal Filho et al. 2021). The world has been experiencing an ever-increasing demand of sand and gravel aggregates primarily during construction activities. Sub- Saharan African countries such as Zimbabwe use sand and gravel mining to provide urban housing, and development of road projects (Nyame et al. 2009). Even though these benefits are realized when sand and gravel mining is conducted, it only

satisfies the short-term economic objectives at the cost of the long-term ecological benefits. Mining activities are always disruptive to the environment, no matter the scale (Hemmler et al. 2025) The conflicting nature of urbanization and preservation of vegetation therefore becomes an agent issue. Sand and gravel mining in areas such as warren hills have brought about concern on vegetation cover, change of density and diversity. Although management organisations such as Harare City council made efforts to mitigate and control such effects, it is not clear whether the strategies will be effective. The perceptions of the surrounding communities towards the mining activities also should be properly investigated.

This study explores ecological and socio-environmental impacts of sand mining, taking Warren Hill, Zimbabwe, as the case study. Guided by the uncontrolled, fast pace of sand mining in peri-urban Harare, and the lack of any integrated measure to quantify vegetation loss, governance failures, and local resident views. This study uses remote sensing to measure vegetation loss, assess the efficacy of current regulatory structures, and the lived experience of local residents. The subsequent chapters offer a thorough literature review, a mixed-methods research design, the discussion of biophysical and social data, and, lastly, the discussion of the ways to make sand mining more sustainable and inclusive.

1.2 Problem Statement

The continuous increase in demand for construction material such as sand and gravel especially in African cities like Harare have caused significant ecological degradation, including loss of vegetation cover, reduced plant density, and diversity (Mkodzongi and Spiegel 2019; Poonia et al. 2024). This calls for an intensive assessment of challenges that are limiting effective management of mining areas under the jurisdiction of local authorities. Assessment of local communities' perception of the benefits and effects of mining at warren hills mine. This study aims to establish the disturbances of ecological dynamics caused by mining at warren hills, evaluate the effectiveness of Harare city council management measures to combat the challenge as well as identifying opportunities to enhance sustainable management practices on sand and gravel mines.

1.3 Research Objectives

1. To assess the Impact of Sand and gravel Mining on Vegetation Cover, density and diversity in Warren Hills.

2. To assess the perceptions of local communities' views on sand and gravel mining activities in Warren Hills.
3. To identify the challenges that limit effective management of mined areas in Warren Hills.

1.4 Research Questions

1. How do sand and gravel mining impact vegetation cover, diversity and density in Warren Hills.
2. What are the perceptions of local communities on sand and gravel mining activities in Warren Hills.
3. What are the challenges limiting effective management of mined areas in Warren Hills.

1.3 Justification

The study holds paramount importance for stakeholders concerned with environmental management, urban development and utilization of the natural resources in Harare. The research will generate empirical data in relation to the effect of sand and gravel mining on vegetation cover, density and species diversity in Warren Hills for Harare City Council (HCC) and Environmental Management Agency (EMA). This can be used to formulate and apply better environmental management policies, land rehabilitation programme and land monitoring for mined area. The study is significant to surrounding communities in that it raises awareness of local communities to the effects of mining on the environment, peoples' livelihoods, health and safety. Incorporation of community's perception may help to motivate people to participate more in protecting the environment and using it sustainably. Policy makers and urban planners will benefit from the study too because it provides knowledge regarding trade-offs between urban development and environmental sustainability. The results could help in harmonizing the increasing demand for construction materials and a need to preserve existing urban ecosystems and green spaces. The study will be novel to the academic and research community by bringing together the ecological assessment and governance and community perspectives in a single urban case study to contribute to the existing body of knowledge on sand and gravel mining. It will also provide a basis for future research on sustainable aggregate mining and urban environmental management in Zimbabwe and other developing countries.

CHAPTER 2: LITERATURE REVIEW

2.1 Sand Mining Background

Aggregates such as sand and gravel are the most extracted category of solid materials in the world, second only to water in terms of the volume that is consumed by human society (Gallagher 2019; Torres et al. 2022; UNDP 2014). They are the cornerstone of the construction and infrastructure development and land reclamation, and this aspect has made them indispensable in the contemporary economic development.

According to the estimates of the United Nations Environment Programme, 32-50 billion tonnes of sand and gravel are extracted every year around the globe, and it is expected to exceed 60 billion tonnes by 2030 due to a rapid growth of urbanization and population in developing countries (Gavriletea, 2017b; Koehne .L, 2018; UNDP, 2014). About 75 percent of this demand is concentrated in the construction sector alone and this highlights the primary nature of sand and gravel in the current development. This insatiable need has turned aggregate mining into a localized and small-scale industry into an extractive industry in the world with deep and irreversible environmental and social impacts (Tripathi et al. 2025).

Sand and gravel are the most extracted solid materials in the world, second only to water in terms of the volume that is consumed by human society(Gavriletea 2017b; Tripathi et al. 2025). Faced by such strain, the topic of sustainability of existing extraction rates has become a matter of fierce academic attention. As Koehnken .L (2018, 5) notes, "the demand of aggregates in other developing countries in Asia and Africa is also predicted to rise dramatically in the few years to come, although scientific evidence base to comprehend and curb the effects of such extraction has been skewed in favour of temperate rivers of Global North which have largely either stopped mining or are under tight control. Several studies are concerned that extraction of sand in the world has become environmentally unsustainable and is associated with the degradation of the ecosystem, as well as the possibility of the future shortage of sand (Bendixen et al. 2023; Gallagher 2019). By 2060, the natural systems would be under strain because the demand of sand is likely to grow by about 45 percent since the year 2020 (Zhong et al. 2022).

Africa has been listed as one of the most urbanising regions in the world and thus the percentage of the urban population is expected to rise to between 53 and 70 percent between the years 2020 and 2050 respectively (Nakamura et al. 2023). Sand and gravel mining in Africa has become a significant source of informal labour to many people since they would be jobless, but at the cost of devastating the environment (Saviour 2012).

Zimbabwe is the case of such paradox. Despite being landlocked and having no exports sand mining trade dynamics, typical of the global discourse, the country has been experiencing exponential growth in sand mining activities, especially in the peri-urban regions near the major cities, which include Harare, Bulawayo, and Gweru (George and Steven 2022; Mushonga 2022). According to the Environmental Management Agency, sand mining has degraded over 1,594 hectares of land nationally, and Harare alone covers over 721 hectares of that area (Mushonga 2022). These numbers indicate the intensity of the need to know about the ecological impact of this practice especially on the vegetation dynamics, which is the core theme of this dissertation.

2.2 Global Context of Sand and Gravel Mining

2.2.1 The Scale and Extent of Aggregate mining.

The level of sand that is produced today is well beyond sustainable levels of supply because it is a natural resource that is a result of a long process of weathering of rocks (nature geoscience 2024). Overestimating the magnitude of the world aggregate demand is impossible. Tripathi et al. (2025, p. 1) observe that, sand has been rated as one of the most exploited natural resources in the world, after water and other natural resource with construction industry consuming about 75 percent of the total sand. Such demand is directly connected to the urbanization processes which requires construction of new infrastructure such as roads, bridges, hospitals, homes, malls etc.

Sand trade shows some interesting trends in its economic geography. The review of the sand markets worldwide by Gavriletea, (2017) proves that the United States is by far the biggest producer and exporter of sand, followed by Germany, Netherlands, and Belgium. Nevertheless, the consumption trends are having a different narrative: Singapore is the largest importer in the world and has expanded its territories more than 20 percent to date, because of land reclamation projects since 1960 (Koehnken .L 2018). This has created the interaction of transboundary dynamics, as some scholars describe sand wars, as the neighbouring states such as Indonesia, Malaysia and Cambodia have banned exportation of sand due to environmental degradation (Tripathi et al. 2025).

China used more cement during 2011–2013 time frame, than the United States did throughout the whole of the twentieth century (Gavriletea 2017b). The Chinese demand might be taming down but other emerging markets are ready to take the vacuum. The population of India is expected to exceed that of China in the next decade, and in case it adheres to the same pattern under development, its aggregate demand will increase by four times (Koehnken .L 2018).

2.2.3 International Comparisons

The comparison of countries at a global level show that there are similar issues and there are opportunities associated with aggregate extraction. The review of management strategies in India, China, and the United States, by Tripathi et al., (2025) reflects that guidelines have been developed by the Ministry of Environment, Forest and Climate Change in India by using the principles such as prevent uncontrolled sand mining, protect the environment and ensure a clean and safe living environment to the population, promote environmentally sustainable and socially responsible mining practices. These measures also include technological resolutions like night surveillance with the use of night-vision drones, to help in detecting the illegal operations done at night.

Koehnken L., (2018) records the Malaysian practice that focuses on scientific establishment of sustainable extraction rates. Regulations formulated by the Department of Irrigation and Drainage entail estimation of the replenishment rates basing on sediment transportation modelling with licensed volumes extraction being restricted to sustainable quantities. This can be technically complex, but it needs a high degree of site-specific hydrologic, hydraulic and sediment information, which is unlikely to be available in a data-sparse situation such as in Zimbabwe.

The experience of South Africa, in a nutshell as described by Smigaj et al., (2025), demonstrates the difficulties of coordination among agencies. Various government departments such as mining, water, environmental affairs, and traditional authorities usually require various licences and permits. Nonetheless, the government employees would often report that the departments were not communicating with one another, which resulted in delays, enforcement gaps, and the possibility that the illegal operators can use the jurisdictional grey areas.

Active and abandoned mines are not properly assessed by means of effective legislation and reliable tests, which restricts a proper management of the land in many African countries (Smigaj et al. 2025). The intricate combination of geological, ecological, social, and economic conditions cannot be solved unilaterally and thus the concerted efforts of the policy makers, the industry stakeholders and the local communities are necessary to make sand mining sustainable.

2.3 Sand and Gravel Mining in Southern Africa

The development of African cities exerts more pressure on the need on construction materials such as gravel and sand aggregates. Across Africa, sand and gravel extraction is commonly carried out through riverbed dredging, open-pit mining, and hillside quarrying. These methods have positive effects on the short then economies of African cities, but they also have drastic

ones on the ecology and social lives of the local community. A study in Ratnapura district, Sabaragamuwa province of Sri Lanka, Sri Lankan Net water report, (2010) says like many other minerals, sand has become a scare resource due to high demand for constriction and developmental activities. This shows a recurring trend across Africa propelling the need for effective sand and gravel mining management strategies. In countries such as Nigeria, Kenya, South Africa and Zimbabwe, most operations are informal and poorly regulated, resulting in ecological degradation.

2.4 Sand and Gravel Mining in Urban Centres

Most of the available literature about sand and gravel mining has long been rural and riverine based, urban sand mining, hill quarrying and open-pit mining has remained largely unexplored. It is scholarly consensus that the major specific urban environmental challenges include illegal extraction, competition for land use, and loss of green spaces. Mining cities are also often faced with serious environmental issues such as air pollution, water pollution, soil pollution, and deforestation. The increasing need of sand all over the globe can be explained by the fast urbanisation process and the growth of the middle population whose demands in housing, business premises, shopping malls, and infrastructure are ever-increasing (UNDP 2014). Hence the urban cities are also affected by extreme extraction of sand and gravel resources.

The rate of urbanisation is also quite different across Africa, with minimum and maximum rates of 14.8 in Burundi and 91 in Gabon (Hemmler et al. 2025). In some cities like Ouagadougou, the constant urbanization has led to settlement expansion to the peri-urban region at the expense of agricultural land and natural habitats (Hemmler et al. 2025). The same tendencies can be observed in Zimbabwe, where the rural-urban migration has increased urbanization and caused massive construction activity. The extraction of sand takes place both urban and rural including resettlement programs and new agricultural lands to serve the increasing construction needs (George and Steven 2022).

The governance issues especially poor enforcement of laws and poor land-use planning further enhance urban sand and gravel mining crisis. These elements lead to a low-density urban sprawl into peri-urban areas, on the one hand, and overcrowded informal settlements, on the other hand (“Mine Action For Sustainable Development,” UNDP). Even though sand is a highly utilized resource in the construction industry, as well as in the industries like abrasive blasting, its exploitation is consumptive as a resource, which creates adverse as well as beneficial environmental spill overs (Nakamura et al. 2023)

Consequently, Geographic Information Systems (GIS) and remote sensing have gained significant importance as means of monitoring change in the land-use and land-cover in the mining environment. Time series of remotely sensed images can be used to monitor space and time variations in vegetation and is therefore particularly effective regarding monitoring the effects of mining where access to the fields is limited. The free and multi-spectral satellite imagery has lowered the barriers of access to data and has simplified the computation of vegetation, water, and built-up indices. The open-source satellite images have been especially useful in the mining field when access to the field is usually restricted because of the safety as well as the geographical factors.

GIS methods allow appropriate mapping and quantification of environmental degradation without extensive ground-truthing that is typically small because of insufficient funding as well as inaccessibility of the terrain (Loukili et al. 2025). The spatio-temporal land-use dynamics of mining sites should therefore be learnt so that effective mitigation measures may be arrived at.

2.5 Effects of Sand and Gravel Mining on Vegetation Dynamics

2.5.1 Direct Removal and Destruction of Habitats

The most immediate and evident effects of aggregate mining are the total disappearance of the vegetation cover in order to get access to underlying deposits. This clearing of the ground forest on a large-scale result in many land damages.(Fazlioglu et al. 2021). The result of the process is complete destruction of all above ground biomass and the destruction of soil seed bank which is particularly important in natural regeneration. Clearing of the vegetation that occurs during mining destabilises soils, enhancing erosion, and making them less favourable to both flora and fauna.

The sand mining in the Gwadabawa region of Nigeria, studied by (Idris Yusuf Ayab et al., (2024), is quantified in such a stark way: during the period of 25 years, the vegetation cover of the area they examined was reduced by a very large margin, which was 56.25 hectares, to 2.15 hectares specifically, i.e. more than 96% in 25 years. In the meantime, the actively mined area increased to 47.75 hectares, which was 58.7 of the study area. These numbers are eloquent examples of the ability of sand mining to radically change the landscapes.

In a similar manner, Blanche et al., (2024) used remote sensing to monitor the vegetation changes in Mbala locality in Cameroon, and the findings indicated that vegetation cover had reduced by 11.74 percent between 2019 and 2023. Their analysis of the Normalized Difference Vegetation Index (NDVI) demonstrated a progressive degradation in the vegetation health, with

practically no vegetation on the banks of the River Lom, at the N1 national road, and in the villages of Mbala and Bata in 2023, because of the mining and human activity (Blanche et al., 2024, p. 7). This work is especially useful in terms of its methodological rigor, with the classification accuracy over 96% and kappa coefficients indicating the almost complete agreement.

Destruction of vegetation mechanisms are not limited to the direct footprint of the extraction. Stockpile sites and processing sites as well as access roads all occupy the vegetated lands. Idris Yusuf Ayab et al., (2024) mention that many road networks that were built by illegal sand miners and transporters posed a threat to biodiversity as well, as trees and grass were cleared to allow vehicles to pass through it. This disturbance effect further adds to the literal loss of habitat to establish edge effects that change the microclimatic conditions and allow invasion by exotic species. The pit sand mining is especially devastating since it destroys farmlands, reduces land value, and causes soil erosion due to the deforestation of vegetation, loosening of soil, and the formation of empty spaces that facilitate headward erosion (George and Steven 2022). Mining pits lead to loss of substantial vegetation and decrease in the functioning of the ecosystem, whereas heavy machinery used in the mining process compacts the ground killing all possible biological activity in the soil.

2.5.2 Species Composition and Alterations

In addition to the loss of the cover, sand mining has drastic effects on the plant community's structure. Several researchers have used several spectral indices such as SCI, TGSI and BI to describe such changes (Blanche et al. 2024). The use of Soil Crust Index (SCI) demonstrated the general decrease of the soil colour signifying the loss of organic matter and the exposure of parent material. The changing in organic matter and soil cover greatly affects the composition and diversity of plant species. Topsoil Grain Size Index (TGSI) detects the type off plant species that could grow in a certain area. The Brightness Index (BI) was especially educational: the values of BI went up, being 4,578 as a maximum in 2019 to 9,084 in 2023 with a clear indication that the soils are lightened during mining (Blanche et al. 2024, 8).

A study conducted by Poonia et al) in (2014) shows that mining eliminates native plant species adapted to local soils and climates, indigenous shrubs and grasses once common disappear due to habitat destruction. The number of distinct species in the forest are reduced resulting in one or two vegetation species left. Disturbed soils provide niches for invasive plants such as *Lantana camara*, which outcompetes native flora in Zimbabwe (Asabonga et al. 2017). Sand and gravel extraction affects the ecological richness of an area. It alters community composition by

replacing diverse native species with fast-growing pioneers and invasive species, reducing ecological stability (Mkodzongi and Spiegel 2019).

Some international research has reported a significant decline in vegetation and forest cover occurred in mining activities in some countries, which include Australia, Brazil, China, India, Russia, and Ghana(Torres et al. 2022). The growth of quarry has caused a consistent rise in deteriorated land and a reduction in vegetation density to the surrounding cities (Hemmler et al. 2025). Such environmental effects directly impact the lives of human beings, including their health, livelihoods, and quality of life.

2.5.3 Effects of Aggregate Mining on Vegetation Structure, Cover and Geomorphic Changes of the Land

Some of aggregate quarrying most apparent impacts include the physical change in landscapes resulting from excavating and extraction. It has varied effects on the environment and does not solely concentrate on physical land disturbance. One of the main effects is land degradation that occurs in the forms of changes in landforms, a decrease in vegetation cover, the decrease of density, and variations in species composition and species diversity. Deforestation and loss of vegetation cover expose the soil surfaces, enhance the rate of erosion, and reduce the resilience of ecosystems, which eventually impacts the biodiversity and ecosystem services. All these effects have manifested themselves in small-scale and large-scale aggregate extraction projects, with large-scale consequences on the environment and social areas (Macêdo Coelho et al. 2022).

Photogrammetric methods were employed by Blanche et al. (2024) to measure the amount of material mined out of mining pits in Cameroon and estimated a single mining pit at 22,188.7 cubic metres. As they mention, the establishment of pits due to the gold mining poses a literal threat to the security of the local people, their animals, wildlife and even the sound environment. These pits are filled during wet seasons with rainwater, which poses the drowning risks and breeding grounds to the mosquitoes.

Similar effects are reported by George and Steven (2022) in the Gweru District of Zimbabwe, where the key informants found the most common detrimental externality of sand extraction to be abandoned pits. Field surveys identified twenty-two vacant pits whose average depth was 1.5 metres, sixteen of them had water during the survey. The result, among other tragic ones, was the drowning of a primary school student of Mkoba 12 in an uncovered pit on the Macfadden Farm. In addition to actual safety hazards, these pits serve as breeding grounds to mosquitoes that in turn bite the residents in the surrounding.

The effects of geomorphology recorded by Koehnken .L, (2018) are channel incision, bank erosion, and connectivity loss of the floodplain. Floodplain mining in the Paraiba does Sul River, Brazil, between 1985 and 2016 raised the number of lakes (54 to 316), their area (615 to 3876 hectares) and correspondingly decreased agricultural land. This change shows that extraction may permanently change the landscape and, in its place, convert productive land into degraded aquatic environments.

2.6 Socio-economic Drivers and Impacts of Sand Mining

2.6.1 Urbanisation and Demand for Housing

Increasing population of urban areas demands housing that in turn boosts the construction materials. Urban population in Zimbabwe has increased significantly after independence, and the metropolitan population of Harare is greater than two million. This has also been accompanied by the development of informal settlements like the Epworth and Retreat Farm where the inhabitants are busy mining sand not only to build themselves but also to earn some income.

To add, Mushonga (2022) gives a close examination of the effect of the housing demands in the extraction patterns in the Eyrecourt Farm in Harare. The economy was dollarized and the Government of National Unity was established in 2009 after which the construction started again, the land developers in real estate started multiplying, and the reserves of residential housing were on the sale. This boom created subsequent rises in the demand of sand, and this turned small scale illegal activity into a big industry with thousands of employees.

2.6.2 Livelihood and Unemployment Pressures

Sand mining has become an important form of livelihood practice by the unemployed and underemployed in the developing world. A study conducted by Mando, (2023) in Zimbabwe discovered that unemployment was the principal contributor to the present high rate of illegal sand mining with participants indicating clearly that I do sand mining and sell the sand to get some money. The COVID-19 crisis did not help this situation, as lockdowns destroyed other informal sector opportunities and forced a greater number of individuals into extraction. One of the participants shared that she was chased off by the police whenever selling anything, but then proceeded to dig sand and sell near her homestead where the police can hardly reach her (Mando 2023, 130). The same dynamics are reported by Hemmler et al., (2025) in the granite quarries in Burkina Faso, where the workers use sand mining as a one-off reason, which is livelihood. The authors add that almost 98 percent of the respondents lacked any alternative source of income,

and 72 percent of the positive remarks regarding the work were related to the possibility to fulfil the basic needs. But this way of livelihood comes at a price: the income regularly drops below national poverty thresholds, and employees face great seasonal and market volatility, which result in days and weeks of zero earnings.

The study by Smigaj et al., (2025) involves comparative information on the region (Botswana, South Africa and Mozambique) and concludes that despite their not necessarily direct contribution to crime prevention, the formal or informal work offered by the sand harvesting was typically highly appreciated by disenfranchised populations, especially youth and immigrants. This poses a complicated policy dilemma: on one hand, extraction does harm the environment, on the other hand, it is the source of important income in situations, where formal jobs are highly limited.

2.6.3 Social and Community Effects

The social impacts of sand mining go way beyond loss of livelihood due to the poor environments. On one hand, it gives people income, employment opportunities, but, on the other hand, the benefits are unevenly distributed, which strengthens poverty and marginalisation in the circles of people who are affected. It has been reported to cause severe social impacts, such as loss of livelihoods, rise in criminal activity, displacement, and resource distribution conflicts (Marschke and Rousseau 2022), Post-mining open pits are found to be dangerous to the environment and lead to degradation of the land in the long term.

Mando., (2023) records numerous types of social disruption such as community displacement, crime rates, and demolition of heritage sites. In Retreat Farm, illegal mining of sand has left part of the families homeless because of land loss and poor backyard areas and has displaced part of the residents out of their farming fields. One of the residents narrated: The entire agricultural field that I lived in has been excavated by unscrupulous sand miners. I am used to growing vegetables and tomatoes and now there are open pits everywhere.

One of the common themes in the studies is crime and violence. According to Mando (2023), the communities are currently living in fear due to these illegal miners whose groups are on the rise. There are more robbery, theft and violent clash and the illegal sand miners have been involved in crimes committed at night. In South Africa, particularly in the state of KwaZulu-Natal, Smigaj et al., (2025) discovered that organized crime has penetrated the sand mining industry whereby construction mafias were using threats and violence to dominate extraction and sales.

The demolition of heritage sites has a far-reaching cultural implication. Sand mining in cemeteries is reported by Mando., (2023), who states that illegal sand miners discard some of the remains into the adjacent dam that supplies water to the local people to use at home. Such infringement of sacred spaces creates a great deal of resentment in the community and a weak form of social cohesion. According to one of the residents, graves are being exhumed and sand is being extracted in places like Zengeza and Kuwadzana and Waterfalls. And it is also going on in Epworth. They are starved; they do not care provided that they can find sand there.

2.6.3 Health and Safety Concerns

Safety and health in aggregate mining is an area of critical concern. The health effects of sand mining have many pathways which includes respiratory problems eyesight problem, waterborne diseases. Dust-related respiratory disease is a health issue not only to the workers but also communities around them. Hemmler et al., (2025) measured the air quality in the Pissy and Yagma quarries in Burkina Faso, where they found significantly elevated levels of particulate matter which are higher than the limits allowed by the World Health Organization. There were no personal protective gears available to the workers and out of the one hundred interviewed, more than three-quarters (76%) people claimed that they had suffered injuries before. Trauma caused by tools, rock splinters, and accidents were frequent, and only 18% of people came to the hospital with the traumas, as most of them used traditional medicine.

Another major issue is waterborne disease. Un-rehabilitated pits allow stagnant water that carry the mosquitoes, which pose a risk of malaria. Surface runoff and leaching of water sources also contaminate water sources that are utilized by communities that do not treat their water. According to Mando., (2023) the case in question records a situation whereby the wastewater and materials channelled to local dams contaminated water, and this impacted downstream consumers, such as business activities.

2.7 Governance and Regulatory Frameworks

Zimbabwe has a well-developed legislative system that regulates the work of sand mining, but its efficiency is doubted. It has four significant instruments, among them being the Environmental Management Act (Chapter 20:27), the 2013 Constitution of Zimbabwe, the Mines and Minerals Act (Chapter 21:05), and the Urban Councils Act (Chapter 29:15). The most specifications are in the Environmental Management Act that has been administered by the Environmental Management Agency (EMA) through the Statutory Instrument 7 of 2007 that controls the

extraction of clay and sand, requires environmental impact assessment, and specifies the rehabilitation plan. The Mines and Minerals Act classifies sand as an alluvial deposit and it must be extracted using permits. Section 222 explicitly outlines the control measures to people involved or want to be involved in such sand deposits among other alluvial deposits (Mando, 2023, p. 229). The Act, however, does not prioritize on sand as compared to other minerals like diamonds, gold etc., as it did in the past, and this could be attributed to the historical priorities that might not withhold with the current pattern of extraction.

The Urban Councils Act gives the local governments the power to control land use, such as sand mining. Section 18 "outlaws such activities as brick making, extracting and moving sand, quarrying and cutting firewood, grass and brushwood as well without local authority permit (Mando 2023, 235). However, the Act does not impose legal obligation on the local authorities establishing their by-laws, this leaves room to discretion, which can erode uniform enforcement.

2.7.1 The Issues of Unlawful Mining

A substantial percentage of sand mining in the world takes place without any official system of regulation. The problem of illegal sand mining has been reported in more than 70 countries, and the situation is particularly acute in India and China, as well as in Southeast Asia or certain regions of Africa (Gavriletea 2017a; Mando 2023). The extent of such lawlessness is dizzying: whereas it is estimated that some 50 billion tonnes of sand are mined each year, one only estimates 15 billion tonnes to be legally traded (Mando 2023). Lack of good governance, corruption, high demand, and relative ease of extraction compared to other minerals are some of the reasons that drive this shadow economy (Tripathi et al. 2025). The sand business is also lucrative due to the infrastructural development thus making it even more difficult to regulate and enforce (Saviour 2012).

Social implications of the illegal mining of sands are much more than environmental destruction. Sand mining in India has become linked to so-called sand mafias in India, i.e., organized crime gangs that use violence, threats, and fraud to dominate the trade (Mahadevan, 2019, cited by (Mando 2023). According to (Mando 2023), based on the data in December 2020 and March 2022, 418 people were killed and 438 injured due to the incidents related to sand mining in India. This is not only an Asian phenomenon; the same trends have been observed in Kenya, South Africa, and Ghana where the conflict between the miners, communities, and the authorities has led to fatalities and general social unrest (Smigaj et al. 2025).

2.7.3 Trust and Governance

The development of community trust in regulating organizations comes out as the critical consideration influencing the level of perception and behaviour. According to (Mando 2023), disillusionment with government officials is common with residents saying that EMA is not curbing these operations, neither is the Council on land use planning. They are slept in offices. Zimbabwe Republic Police (ZRP) is also not doing its duty. They seem bribed." This institutional failure perception erodes compliance and emboldens communities to undertake matters themselves resulting in vigilante actions that intensify conflict.

On the other hand, with communities that feel heard and secure, their cooperation becomes better. As Smigaj et al., (2025) observe, by granting the local communities more power, this would assist in reducing unlicensed extraction as the more often the river is used by the local communities, the more monitoring would be enhanced inadvertently. This observation makes sense in the context of the stakeholder theory as the framework that many contemporary works on governance support, but it is possible that commonly adopted approaches to governance can be more effective than those based on pure enforcement.

2.7.4 Enforcement Challenges

The disconnection between the law and its implementation comes out as a common thread running through research. George and Steven, (2022, p. 14) observe that the sand mining by EMA is not being vigilantly followed, and the authorities admit that even those who obtain Environmental Management Plans (EMPs) by the Environmental Consultants do not employ them on operational basis. This lack of connection between planning and implementation is inherently destructive of the effectiveness of regulations.

Enforcement problems are enhanced by corruption. According to Mando., (2023, 241), government officials are bribed by illegal sand miners so that they can proceed with mining sand illegally, with no fear. The societies note that these government officials are only bribed with money and the case is sealed. They visit these places but no mining at times, surprisingly. This makes it a cycle of viciousness in which illegality is rewarded, compliance punished and regulatory power increasingly undermined.

The capacity to enforce is also curtailed by resource constraints. According to Mando, (2023), one of the EMA officials has been quoted saying: "The biggest problem that we are facing in ensuring successful programs in relation to the illegal sand mining is the limited funds. Lack of supply of vehicles, equipment and staff implies that the monitoring is not systematic.” This

means that illegal activities can continue to grow in-between enforcement operations and deterrence is compromised.

2.8 Research Gap Identification

Existing studies on sand and gravel mining in Zimbabwe does not integrate quantitative assessment of vegetation change from sand mining with systematic analysis of governance challenges and detailed community perceptions within single research paper. While political ecology studies (Mando, 2023; Mushonga, 2022) focus on governance and conflict without vegetation data, and remote sensing studies (Blanche et al., 2024; Ayab et al., 2024) document ecological change without governance analysis, the specific dynamics of Warren Hill remain entirely unexplored. This study addresses that gap by providing a holistic assessment that links measured vegetation impacts, management failures, and local community perspectives in one cohesive case study.

2.9 Chapter Summary

The chapter has reviewed the global literature on mining of sand and gravel content, and it has been concluded that the pace at which it is being extracted is far out of sustainable rates of supply because of high rate of urbanisation and construction. The loss of vegetation, the lack of species diversity and hydrologic disturbance are being reported repeatedly in the biophysical literature, and the role of unemployment and poor governance was reported in the socio-economic literature to support illegal mining. The regulatory frameworks in Zimbabwe and Africa are not well enforced, and community perceptions are not taken into account even though they are important in ensuring sustainable governance. Four theoretical lenses are used to inform the analysis: political ecology, land resource conflict theory, stakeholder theory, and reflexive governance. The review concludes with a critical gap where no single study in Zimbabwe has combined quantitative evaluation of vegetation, governance and community perceptions in a specific location and this dissertation has been able to fill this gap by using the Warren Hill case study.

CHAPTER 3: METHODOLODY

3.1 Study Area

Warren Hills is in the western part of Harare capital city of Zimbabwe. It is found between Warren Park 1, Warren Park 2, Warren Park D, Westlea, Cold comfort, and Kambuzuma. It is dominated by indigenous tree spices which *includes Brachystegia spiciformis, Julbernardia globiflora and Peltophorum africanum.* There is a suspicion of invasive species intrusion due to the change of the demographic nature of the area. The area used for various purposes which includes cemetery, agriculture, fuelwood, water storage, cultural and religious shrines, and most importantly quarrying. Warren Hills is under the jurisdiction of the Harare City Council (HCC) and the Environmental Management Agency (EMA), both responsible for regulating mining activities and enforcing environmental protection laws. The area has become a hotspot for sand and gravel extraction due to its proximity to the city centre and availability of construction materials. Study Area Map (Figure 3:1)

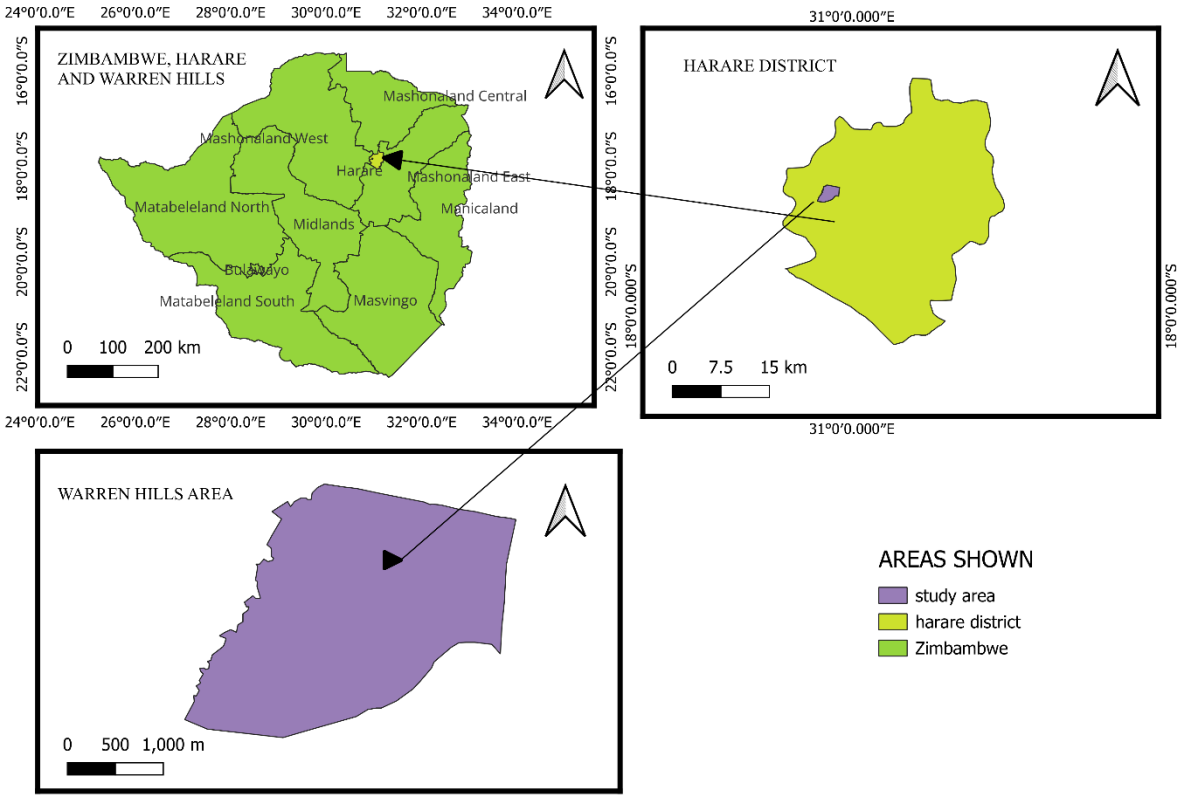


Figure 3:1 Warren hills study area Map, Harare Zimbabwe.

3.2 Data Collection

The data was collected using questionnaires together with GIS and remote sensing free spatial data from USGS Earth Explorer, Copernicus Open Access Hub (sentinel-2), DIVA.com and Google Earth Pro. This provided a comprehensive assessment of the impacts of aggregate mining, community perception and management issues. The data collected included the following variables, vegetation cover, vegetation density, species diversity, Normalised Difference Vegetation Index values (vegetation health index), Soil Composition Index, Bare Soil Index, spatial extent of mined versus unmined areas, soil exposure/bare ground indicators, community perceptions of mining impacts, perceived effectiveness of HCC and EMA management measures, and socio-economic drivers of sand and gravel mining activities.

A total of 35 questionnaires were used to collect data, 15 were directed to the local community surrounding warren hills and the other 20 was directed to HCC. The environmental management unit (CEMU) and the mining unit (Harare quarry, Golden Quarry) were the major recipient of the questionnaires. Multi-temporal satellite imagery was obtained from freely available databases including USGS Earth Explorer land sat 8-9 OLI/TIRS free spatial data, selected for their spatial resolution, how long does it temporal cover, and suitability for vegetation analysis. Images were

selected in both dry and wet season months to minimize weather-based biases such as cloud cover and seasonal vegetation variability.

GIS and ancillary data came from administrative boundaries of HCC, and USGS EarthEplorer, Google Engine Data, ESA World Cover, OpenStreetMap databases were used to support spatial analysis and map production. Social and policy data was primarily collected through household questionnaires administered to residents living near mining sites. Secondary data was collected from environmental policies and regulations at HCC, national legislation associated with mining, environmental management plans and published reports.

3.1.1 Sampling Procedures

Satellites Image Selection- satellite images were selected to represent key temporal intervals before and after intensified mining activities in warren hills. Only images less than 10% cloud cover during dry and wet season each year were prioritized to ensure similar conditions coverage, its spatial resolution and suitability for vegetation analysis were also put into account. Satellites images from 2013,2018, 2022 and 2025 during wet and dry seasons were selected.

Community sampling- A purposive random sampling technique was used to select households located in proximity to both functional and abandoned mining sites.

Harare City Responders Sampling- the sample comprised 20 participants, selected through departmental selection that are relevance to environmental management and mining /gravel extraction. Major respondents were from the environmental and engineering departments.

3.3 Tools, Software and Materials

Several tools and materials were used in the collection and analysis of data for this study. Field observations were conducted using basic equipment including Geographic positioning system (GPS) device to record location coordinates, a phone camera for photographic documentation, and field notebooks for recording environmental observations.

Table 3:1 table showing tools used and what they were used for

TOOL/SOFTWARE/MATERIAL USED	USES
1. Questionnaires	Used to collect primary data from HCC and the community regarding perceptions, expertise and experiences related to sand and gravel mining. Was used to calculate NDVI, BSI and SCI

2. Microsoft Excel	Used for data entry and preprocessing, it was used for preliminary calculations and generation of charts and tables
3. Satellite imagery (sentinel/Landsat)	Used to measure and analyse vegetation changes and trends during the time under study
4. GPS	Used to record geographic coordinates of responders' proximity to mining sites
5. QGIS	Used for image processing, spatial analysis, land use mapping, maps production, vegetation analysis of the study area.
6. SPSS	Used to analyse quantitative data from the questionnaires through descriptive statistics, statistics plots, tables and graphs
7. Phone Camera	Used to take pictures of the state of the mined and unmined areas.
8. Field Notebook	Used for used to record field observation eg species identification, vegetation condition and environmental degradation

3.4 Data Processing and Analysis

Data processing and analysis was conducted in three manners depending on the type of the data, whether it is spatial, quantitative or qualitative data. Spatial data was processed using QGIS application were various maps for 2025, 2020, 2015 and 2010 were generated. QGIS was used to process Landsat 8-9 OLI/TRIS satellite images. Pre-processing measures were such as radiometric correction, atmospheric correction and cutting off images to boundary of the study area were undertaken to enhance consistency and accuracy of muti-temporal datasets. Changes in vegetation cover were quantified using spatial overlay and zonal statistics. Trends in vegetation loss and degradation were analysed in relation to mining expansion patterns.

Normalized Difference vegetation Index (NDVI) was used to measure the vegetation condition that was calculated by the formula: NDVI = (NIR - Red) / (NIR + Red). In which near infra-red (NIR) is the near-infrared band and red is the red band of satellite images. The NDVI values are between -1 and +1 with the positive numbers depicting the dense and health vegetation and the negative numbers depicting sparse or degraded vegetation. The resulting NDVI values were classified using the Supervised Land Use-Land Cover (LULC) Classification into categories representing different vegetation conditions, ranging from low vegetation cover (degraded or bare areas) to high vegetation cover (healthy vegetation). This classification enabled visual and quantitative comparison of vegetation conditions across the study area. Such mining sites post-classification comparison served to identify the changes in the land cover over time.

Analysis of qualitative data in the form of responses to questionnaires was done using thematic analysis. Themes were developed on responses based on:

i. Environmental impacts
ii. Policy effectiveness
iii. Community welfare
iv. Management challenges

These themes were compared with spatial findings to establish linkages between observed environmental changes and governance practices

For statistics questionnaire data collected from community members, miners, and institutional stakeholders were coded and entered into SPSS for analysis. Descriptive statistical methods were used to summarise the data, including:

i. Frequencies
ii. Percentages
iii. Graphical representations such as bar charts and pie charts

These analyses were used to interpret community perceptions regarding vegetation loss, environmental degradation, and management challenges associated with sand and gravel mining. Various analyses were conducted including advanced statistical testing, T-tests, and Correlation analysis.

3.5 Land Use/ Land Cover (LULC) classification

The multi-temporal satellite images were spatially analysed, showing significant land use and land cover changes in Warren Hills during the study period (2013-2025). As sand and gravel mining became increasingly widespread, the amount of bare land surfaces increased significantly while vegetation cover decreased. The fluctuations reflected the increasing and decreasing of anthropogenic disturbance in an area considered as a peri-urban green corridor. Supervised classification was carried out to quantify area in hectares (ha) and percentages of various classes such as dense vegetation, sparse vegetation, bare ground, mined areas that that are/were on the ground. The degree of mining and unmined areas are also considered

Table 3.2: Table showing classification descriptions

LULC CLASSES	**DESCRIPTION**
Dense Vegetation	Lands with vegetation cover closer to 1
Sparse Vegetation	Lands with vegetation cover closer to 0
Mined Area	Excavated Lands and surfaces

Built-up Areas	Lands that contain buildings or manmade structures.
Bare Soil	Lands not constructed and not vegetated.
Water Bodies	Water on land surfaces.

3.6 Rationale for Using QGIS, Thematic Analysis and SPSS for Analysis and Visualisation

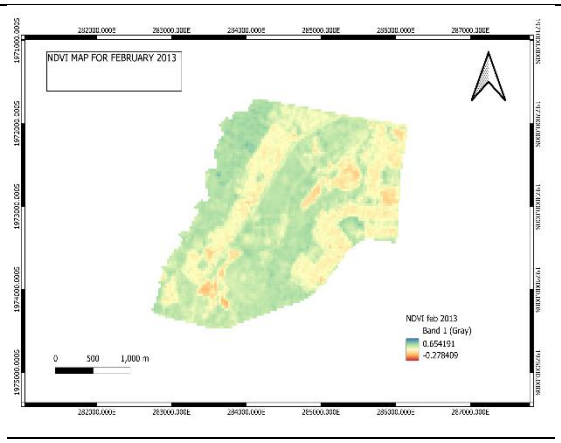
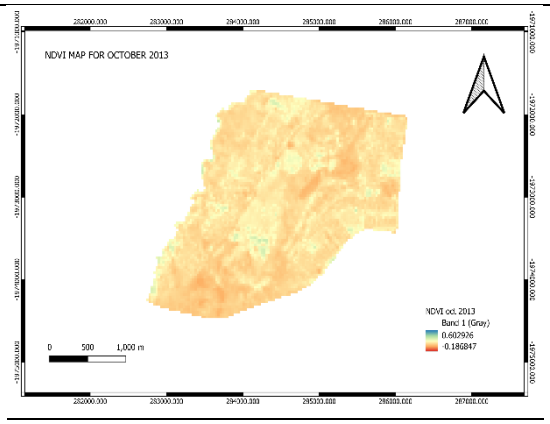
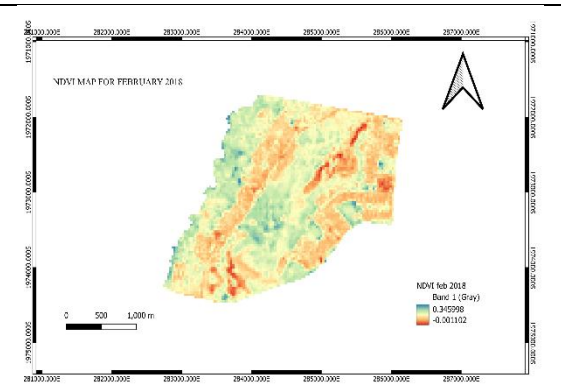
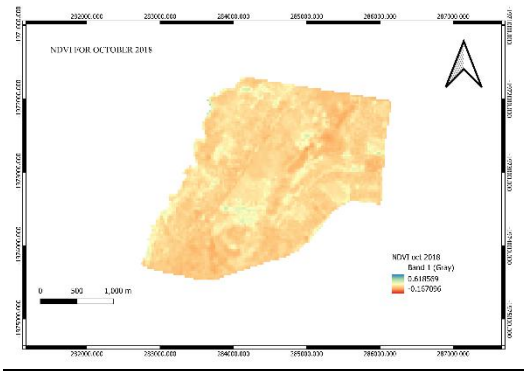
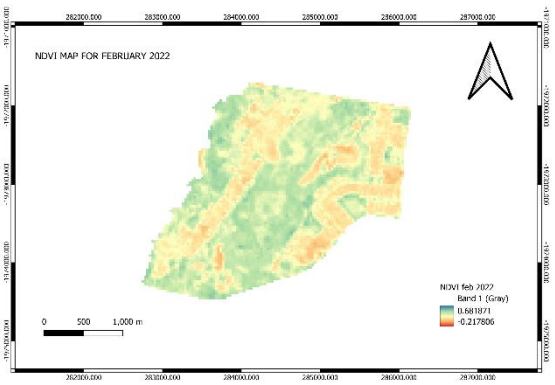
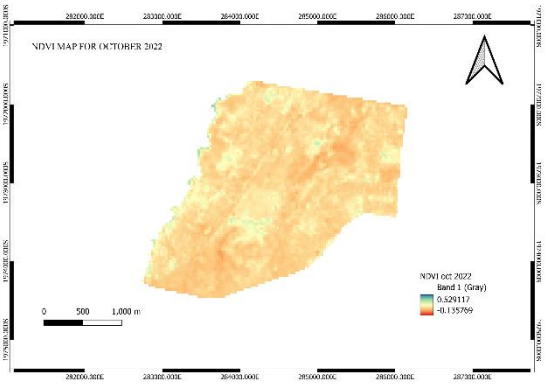
QGIS, thematic analysis and SPSS were used in this study because the three have complementary advantages in the processing of spatial qualitative and statistical data. QGIS was chosen due to its abilities to process and analyse geospatial data, create NDVI maps and visually represent changes in spatial patterns of vegetation over time. It was especially appropriate in measuring the degree and spatial scope of environmental effects caused by sand and gravel mining, because of its capacity to combine satellite images with field-based measurements. The questionnaire data, on the other hand, was thematically analysed to establish the themes, and patterns associated with mining effects and the community's relation to them. The questionnaires were also statistically analysed with SPSS which allowed efficient coding, organisation and interpretation of the responses using such descriptive statistics as frequencies and percentages. It was also useful in the development of the charts and tables to present the data clearly. The combination of these tools led to more accurate, reliable, and visual analysis and the possibility of an overall insight into the ecological changes, as well as the perceptions of the community.

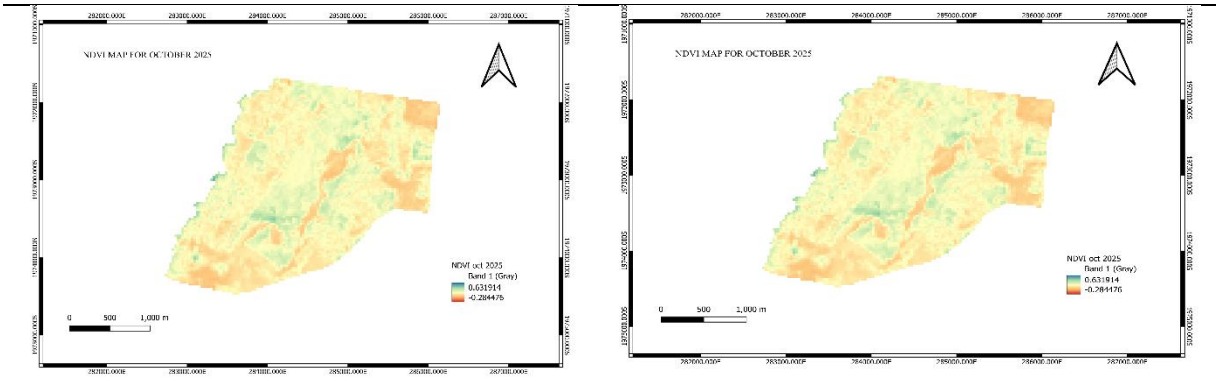
CHAPTER 4 RESULTS

4.1 The Impact of Sand and Gravel Mining on Vegetation Cover, Density and Diversity

Mean NDVI values for warren Hills during 2013-2025 have ranged from 0.14 to 0.36. The findings show that there have been fluctuations over time, which corresponded to changes in the intensity of mining activities and changes in vegetation recovery in line with changes in vegetation cover and health, related to sand gravel mining activities in the period on focus. Spatially disaggregated analysis shows that regions immediately surrounding active mining pits had the lowest 0.15 which shows that areas of near total vegetation removal were present. The spatial dependency of the NDVI values with respect to mining intensity satellite, suggesting a causal relationship between mining activities and vegetation degradation in Warren Hills, which is confirmed by the empirical evidence. (Ranjan et al. 2022a; Yang et al. 2022) also found that the NDVI was reduced by more than 40 percent in 5km radius of active mining sites in west Africa using remote sensing techniques.

Warren Hills Wet and Dry Season NDVI Maps

WET SEASON	DRY SEASON
	
2013	2013
	
2018	2018
	
2022	2022



2025 2025

Figure 4.1 A collection of NDVI maps presenting vegetation health

The mean values of BSI increase from 0.162374 to 0.224883 between October 2013 and October 2025. This is also true of the wet season (mean has gone up from 0.324187 in Feb 2013 to 0.366762 in Feb 2025) where even at the highest moisture there is more land surface disturbance. The land cover during the study period was also quite dynamic, with the highest BSI being 0.681870759 in February 2022, and the lowest BSI being -0.284475565 in October of 2025. The standard deviation also slightly increased from year to year, especially during the rainy seasons, February 2022 had the highest standard deviation (SD) (0.12440822) showing that there was greater variation in bare soil distribution for the month. Furthermore, the percentage of valid data was relatively stable (about 70% per year and season) and ensured consistency and reliability of the data set analysed. Overall, the results depict the general trend of the bare soil exposure and degradation of the land over time in the study area.

Table 4.1. Summaries the NDVI Values Statistics Over the study Time

Year & Season	Minimum	Maximum	Mean	Standard deviation	VALID %
October 2025 (dry)	-0.284	0.632	0.225	0.077	70.8
October 2022 (dry)	-0.136	0.529	0.153	0.046	70.9
October 2018 (dry)	-0.167	0.619	0.170	0.054	70.91
October 2013 (dry)	-0.187	0.603	0.162	0.052	70.96
February 2025 (Wet)	-0.263	0.662	0.367	0.087	70.9
February 2022 (Wet)	-0.218	0.682	0.327	0.124	70.89
June 2018 (Wet)	-0.235	0.593	0.222	0.051	70.9
February 2013 (Wet)	-0.278	0.654	0.324	0.093	70.59

The graph shows vegetation trends using average NDVI results for wet and dry season of the time under study. Wet seasons are consistently higher than dry season. For all wet season except

in 2018, the mean NDVI is higher than 0.3 which shows a positive trend. The dry season ranged from 0.15 to 0.25.

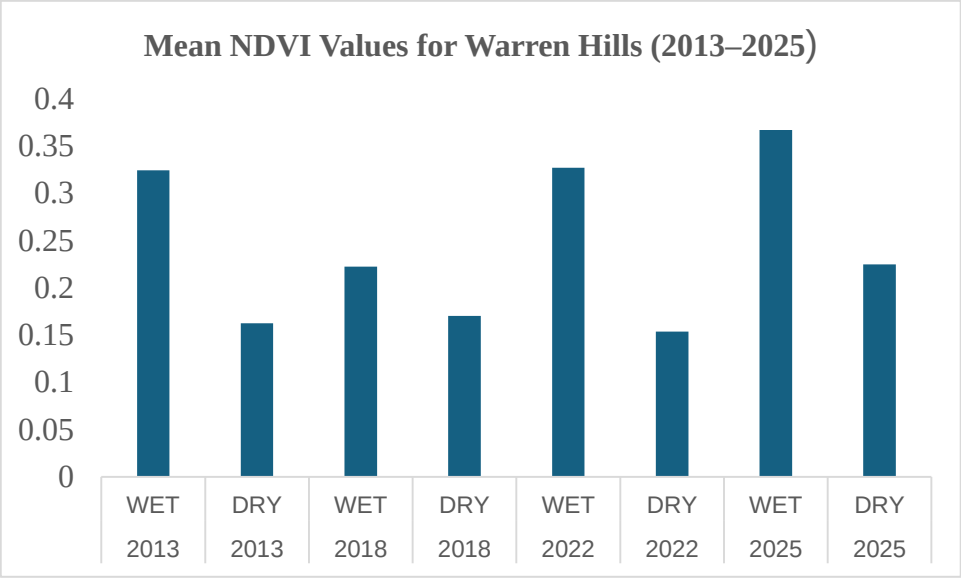


Figure 4.2 graph showing mean vegetation trends

Linear regression was applied to examine the trend in NDVI change over the 12-year (2013-2025) study period. As shown in the table 4.2 there was a positive relationship between the years and NDVI (B = 0.004, p < 0.382). The model shows that 92% of the variation in NDVI (R^2=0.382), indicating fluctuating decreasing and increasing in vegetation cover of Warren Hills.

Table 4.2 Trend Analysis of NDVI from 2013 to 2025

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.618[a]	.382	.072	.030981764

a. Predictors: (Constant), YEAR

The unstandardized coefficients (B) and standard errors (SE) are provided as well as standardized coefficient (Beta), t value (T) and significance level (Sig.). The intercept (B = −7.545) is of high magnitude and has a high standard error (6.952) and it is not statistically significant (Sig. = .391). In this model the YEAR coefficient (B = .004) is strongly predicted by NDVI with a Beta of .618, t value of 1.111 and a lack of significance (Sig. = .382).

Table 4.3 NDVI Coefficients table

Model		Unstandardized Coefficients		Standardized Coefficients	T	Sig.
		B	Std. Error	Beta		
1	(Constant)	-7.545	6.952		-1.085	.391
	YEAR	.004	.003	.618	1.111	.382

a. Dependent Variable: NDVI

4.2. Land use/ Land Cover (LULC)

The change in land use and land cover (LULC) classes between the 2013 and 2025 years as shown for Warren Hills in figure 4.3 indicate that sparse vegetation cover was the predominant land cover type from 2013 to 2022, except for 2025, where there was an appreciable reduction. The situation was different with mined areas growing from 200 to 450 over the study period, including a significant growth in 2025, reflecting the growth of sand and gravel extraction activities in the study area.

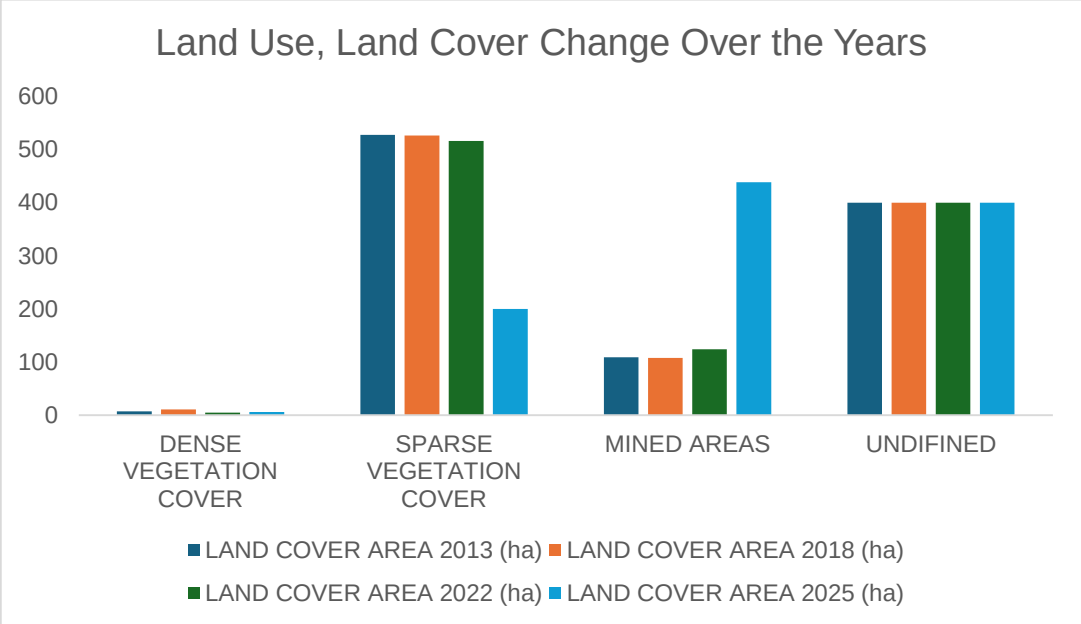


Figure 4.3 Summarises the land use land cover changes that took part from 2013 to 2025 at warren hills.

There was a relatively low level of vegetation cover throughout the study period indicating a continued degradation and disturbance in the vegetation. The undefined class was almost

constant for all years and could be areas in which the spectral characteristics were mixed or unclassified land surfaces. The trends observed overall indicate that there is considerable land cover change and increasing environmental disturbance related to mining activities in Warren Hills.

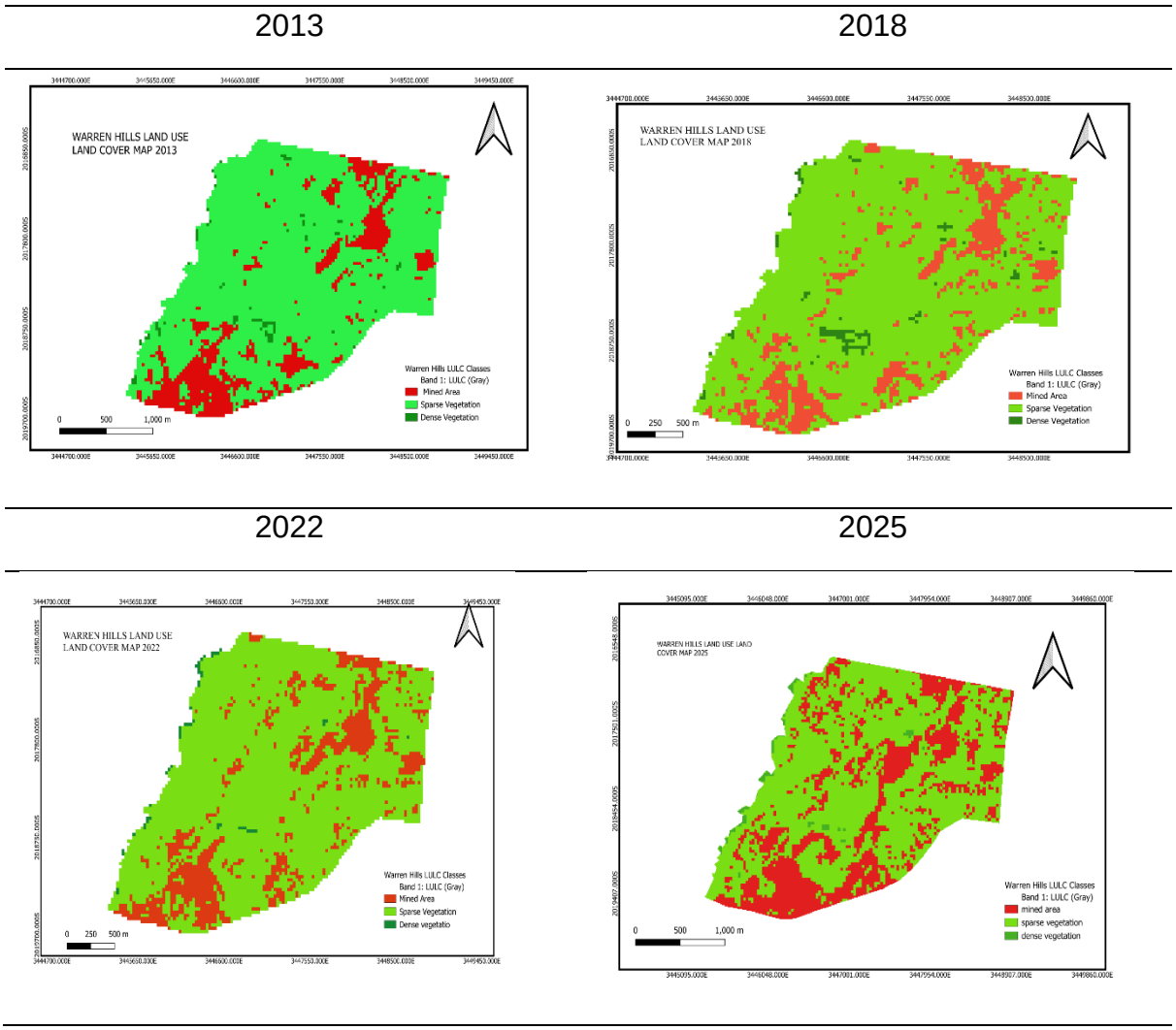


Figure 4.4 shows Land Use Land Cover maps for 2013, 2018, 2022 and 2025

The green cover density begins at a high level (300 ha), increases rapidly to a maximum and decreases with the increase of sparse vegetation, representing an increase in the ratio of dense to sparse green cover. The value of the mined areas category grows rapidly and is at its peak (550 ha) in 2022 and then decreases, and the value of the category of undefined increases over time, indicating more defined land uses will be in this category in the future. The line plot reveals a dynamic change in land use from vegetation to mining and unspecified land use.

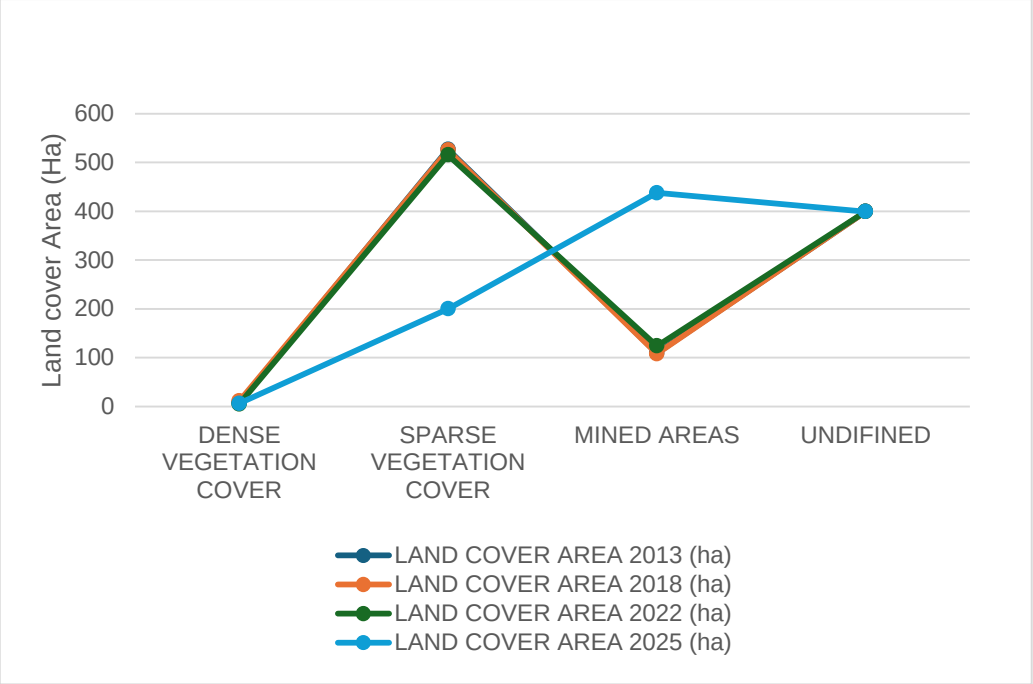


Figure 4.5 shows land to vegetation trends across classes

4.2.1 Soil and Brightness Indices (BSI &SCI)

The 2013 Bare Soil Index (BSI) histogram shows a positive skew of the pixel values and a large number of pixels in the range of 0.10 to 0.22. The primary peak observed on the histogram is at 0.17–0.20, indicating a widespread moderate amount of bare soil in the study area during 2013. The distribution is more moderately peaked than the other distributions indicating comparatively less exposed soil surfaces and comparatively less intense land surface disturbance. This reflects moderate variation in land cover conditions across the study area in the period of study as reflected in the gradual reduction in frequencies away from the peak.

The 2025 Bare Soil Index (BSI) histogram is also skewed in a positive direction, with most of the pixels occurring in the range of about 0.10 to 0.22. The study area was found to be dominated by moderate to high bare soil conditions as reflected in a distinct peak at 0.17–0.20. The overall shape of the histogram is similar to previous observations, but with a higher and more pronounced frequency peak which suggests greater and more concentrated soil surfaces exposed. The increased spread of pixel values is also indicative of greater variability in land surface conditions, possibly related to the variability of land disturbance and exposure to the surface in the study area in 2025.

2013	2025

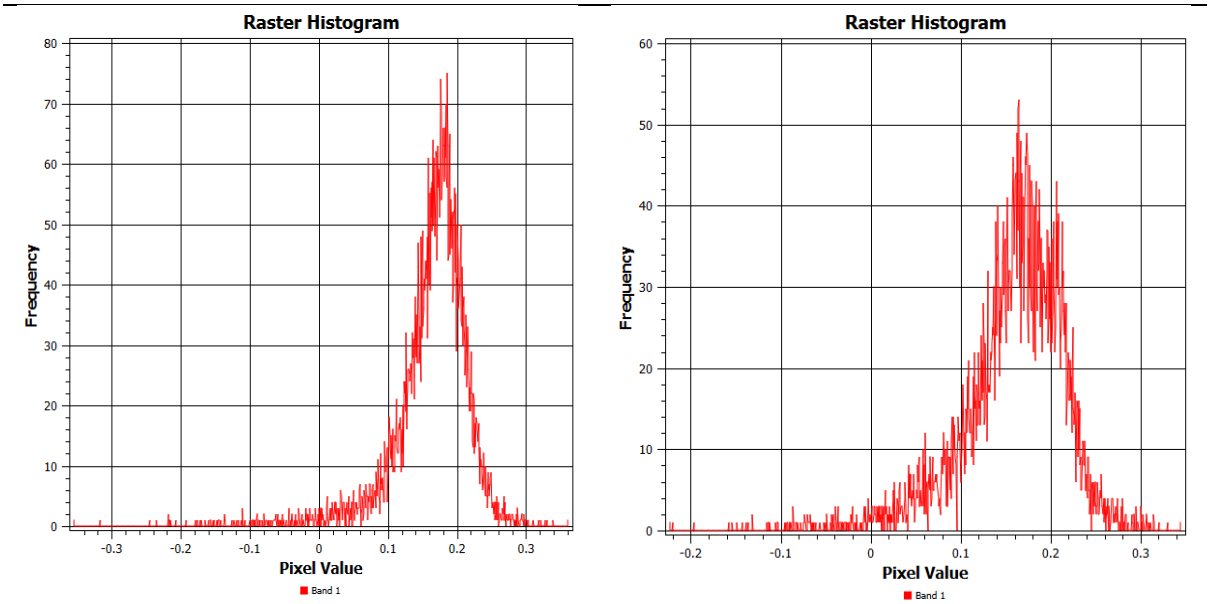


Figure 4.6 Soil and brightness indices for 2013 and 2025

Below are BSI maps for year 2013 and 2025 showing reflectance change between the two.in 2013 the reflectance values ranged from 0.34501 to -0.223872 red gradient indicates low to high reflectance. In 2025 reflectance values ranged from 0.361252 to -0.355484 red gradient indicates low to high reflectance.

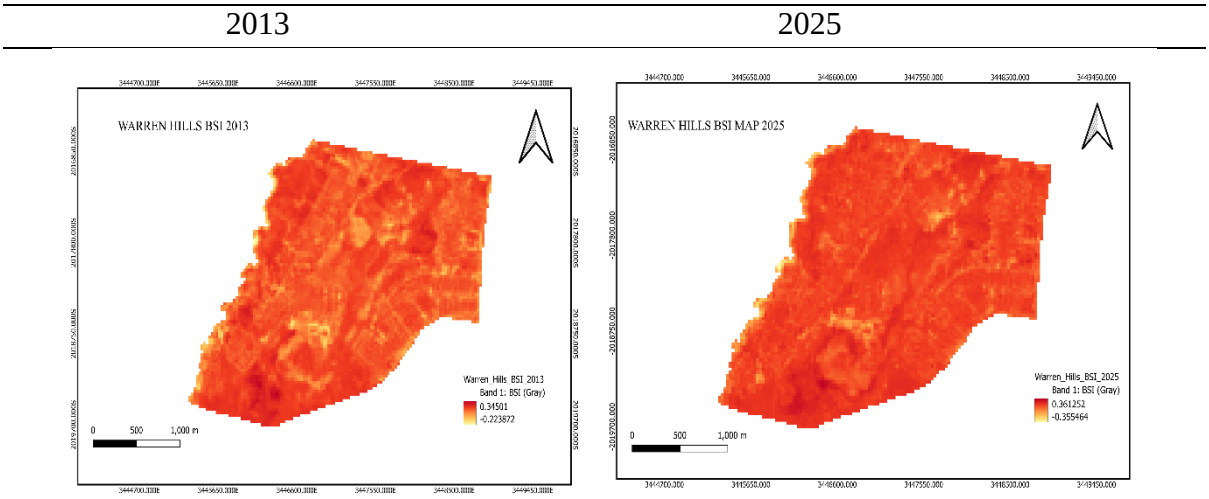


Figure 4.7 shows BSI maps for 2013 and 2025

4.2.2 Spatial Distribution of Mining Activities and Vegetation Loss

The most intensive mining operations were active on the eastern side Warren Hills sections with the lowest vegetation density scores recorded for this section (table 4.4). Moderate degradation was observed in the central zone, through visible bare soils run along the centre of the forest, where fragmented vegetation patches were observed with recently disturbed areas within the matrix. In the southern zone, the situation was very similar to the central zone in that it had fragmented vegetation, but the intensity of mining was lower. Absence of rehabilitation of mined

pits and farming activities poses a greater threat to the buffer zone there. The spatial analysis also shows that there is strong and consistent relationship between ecological degradation and intensity of mining in the study area.

Table 4.4 spatial distribution of mining intensity and vegetation conditions by zones

Zone	Mining Intensity	Vegetation Condition	Primary Concern
Eastern Side Warren Hills	High	Severely Degraded	Proximity to Residential Areas
central Warren Hills	Moderate	Fragmentated Vegetation	Ecological Connectivity Loss
North-West warren Hills	Low	Fragmented vegetation	Buffer zone encroachment

4.3 Community Perceptions of Sand Mining Impacts

4.3.1 Local Community Demographics

A total of thirsty five (35) community members participated in the completing the structured questionnaire survey. Purposive and systematic sampling was employed to representation across different age groups, gender and other categories within the study area. Most responders fell within the 20-30 age range, accounting for 33.33% of the total sample population while the least represented age group was 41-50 and 51-460 range which are both at 20%. (Figure 4.5)

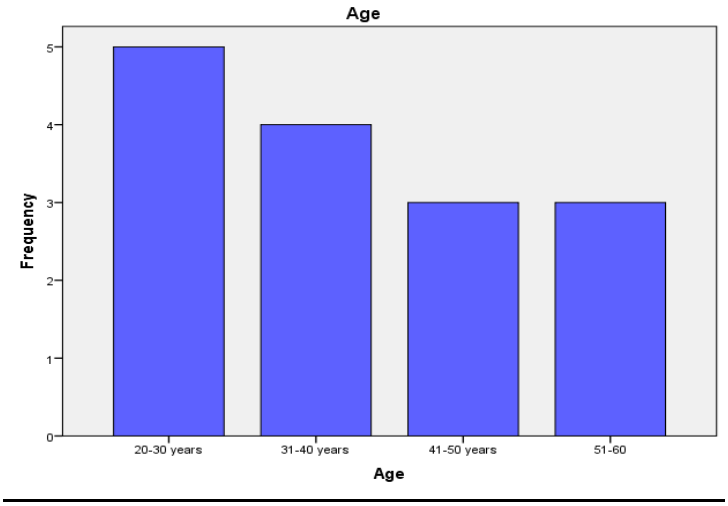


Figure 4.8 shows different Age groups of respondents in the sample

The results on highest educational level show that respondents possessed varying levels of educational attainment. The most participants had attained secondary education, representing 73.33% of respondents, followed by those with tertiary education at 26.66%. There were zero respondents had attained primary education only. (Figure 4.6).

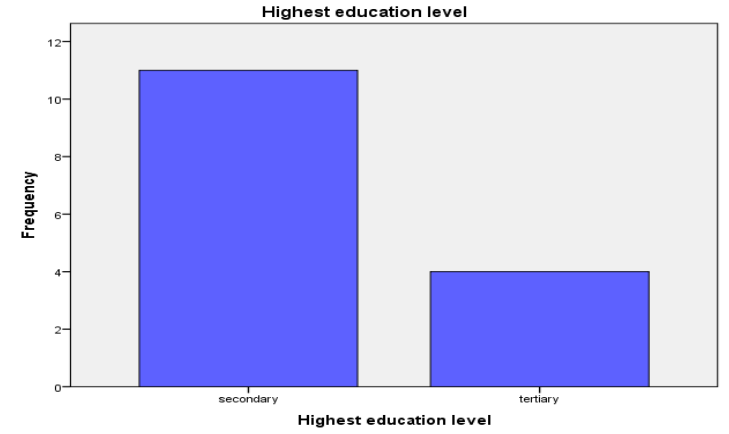


Figure 4.9 shows respondents' highest education level

The results indicate that respondents lived at varying distances from the study area, influencing their level of interaction with sand and gravel mining activities. Most respondents live within 101- 150 meters from the study area, that means they account for 46.66% of the all the sample responders, while fewer respondents lived beyond 151 meters and above from the study area. (Figure 4.10).

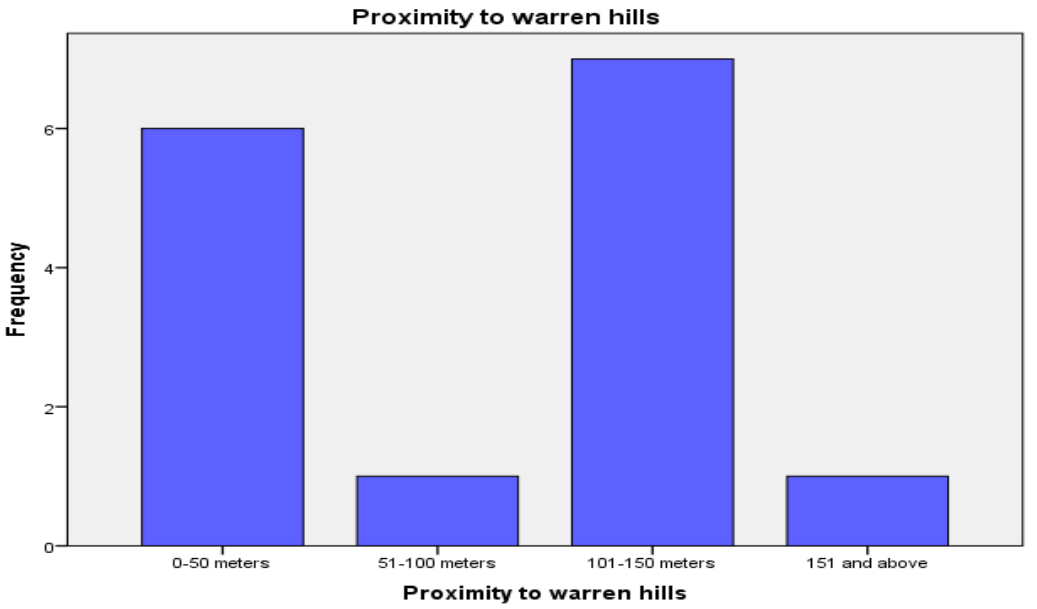


Figure 4.10 Distance of Respondents homes from the Study Area

4.3.2 Environmental Impacts Experienced by the Community

Frequency and percentage of residential reporting on various ecological related impacts such as vegetation loss, dust pollution, water pollution, noise and safety hazards. It reflects that 80% of the respondents have observed the loss of vegetation, 46.7% have reported the loss of non-timber forest products, 100% have reported air and noise pollution, 26.7% have reported conflict between miners and the community, and 46.7% have observed unsafe pits and degraded landscape. (table 4.5). The pie chart below shows the perceived overall impact of mining split into very positive (6.6%), positive (6.6%), negative (33.3%) and very negative (53.3%) categories, suggesting a strong majority opinion that mining has a negative overall impact.

Table 4.5 shows environmental impacts experienced by the community using percentages

VARIABLE	YES (%)	NO (%)
Vegetation loss impact	80	20
Loss of non-timber forest products	46.7	53.3
Air and noise pollution	100	0
Conflict between miner and community	26.7	73.3
Unsafe pits and degraded landscape	46.7	53.3

Respondents were asked to identify environmental problems associated with sand and gravel mining operations in Warren Hills. The results, presented in table 4.5, presents various reporting of adverse ecological consequences of mining. They show that some impacts such as noise and Air pollution were experienced with all people resulting in a 100%. 80 % experienced vegetation loss impacts, 73.3% experienced Conflict between miners and community. Loss of non-timber forest products and unsafe pits and degraded landscape got the lowest experience percentages of 53.3. The various responders gave adverse perception of the overall impact of mining, 26.67% said the impacts were extremely negative, 40% reported the overall impacts as just negative, 20% of the responders said the impacts were positive and lastly 13.33% regarded the impacts as very positive.

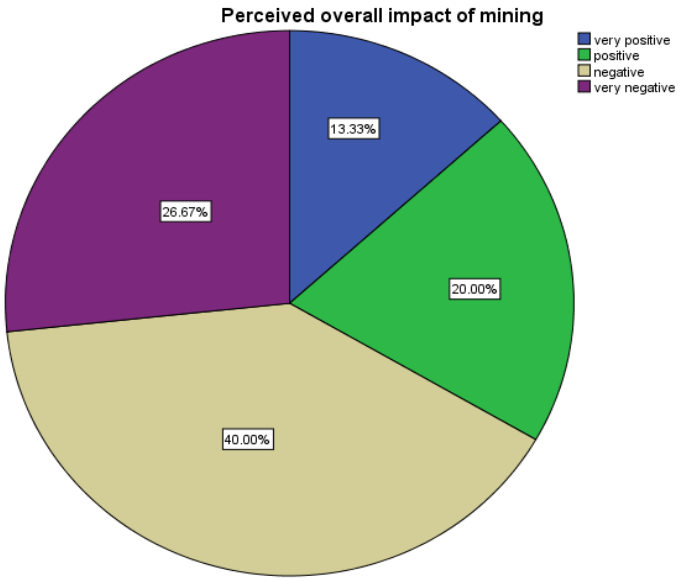


Figure 4.11. Pie chart showing perceived overall impact of mining in percentages

Open ended questions allowed responders to elaborate further their contextualised perceptions. Some long-term community resident contrasted the appearance of warren hills through the years some of their responses included.

"There were trees everywhere and there were no open pits as it is now, the only structures that were here were the cemeteries."

"It was just a jungle filled with trees and wild animals like snakes and birds. Trees were a lot taller than today with traditional shrines within the forest"

"The area was stable with no open spaces and pits it had no erosion gullies. It was filled with trees and wild animals including birds."

"Mining activities is making the area inhabitable especially during rainy seasons when the rain washes down brown/red soil from uphill towards our houses."

Such testimonies underscore the magnitude of ecological change experienced within the community's lived memory and reinforce the quantitative findings presented in this study. Below is a pie chart demonstrating the warren hills resident's preference between economic benefits associated with aggregate mining verses living with the environmental impacts associated with it. A total of 76.92% participants preferred living without environmental impacts.

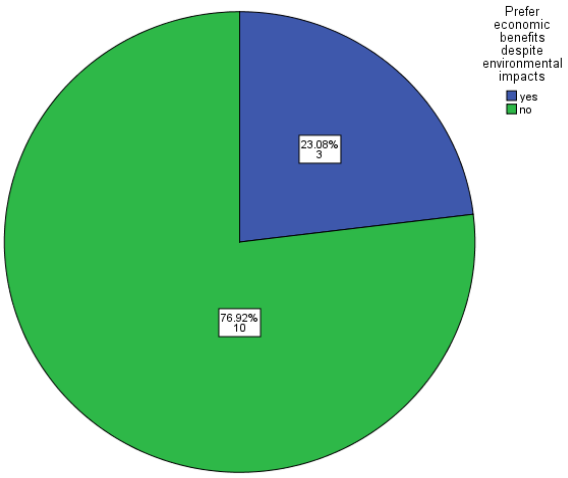


Figure 4.12 Pie chart for Preference of the community

4.3.3 Perceived Socio-economic Impacts of Sand/ Gravel Mining

Even if some of the responders have economic gains from aggregate mining at warren hills, they acknowledge that those gains are short term. Most of the responders expressed the view economic gains are not important when comparing them to long term vegetation/environmental wellbeing. As mining propels challenges such as respiratory issues, malaria risk and increased crime. Respondents' assessments of socio-economic impacts of mining (Table 4.6).

Table 4.6 Dust pollution analysis

		Frequency	Percentage
Valid	not affected	5	33.3
	highly affected	2	13.3
	Very much affected	8	53.3
	Total	15	100.0

Quotes from open ended responses. Questions (3, 12, and 15)

Respondent 3, *In most cases it's especially warren park the mining activities being done are undergoing with the government council also helping to create residential areas. And these hills are associated with very venomous snakes so these hills being used, it kills the area's habitat, and those animals will be transferred to reserve parks.*

Respondent 2, *Children are falling into those pits, thieves are hiding in them, some pets with water are causing mosquitoes*

The data from the questionnaires reveal a stark contrast between the limited economic benefits and the pervasive social costs of mining activity. Although respondents acknowledged that mining created employment, other respondents simultaneously reported increased environmental health risks, others reported damage to roads and community infrastructure and also noted heightened respiratory and other health problems attributable to dust and water contamination. Abandoned mines were consistently cited as a current risk to physical safety, especially for children, with several reports of near incidents of unsupervised access to abandoned mines.

4.4 Challenges That Limit Effective Management

4.4.1 City of Harare Demographics.

City of Harare demographics shows how many employees are in an organisation for each period of service. It displays four tenure categories, 0–5 years, 6–10 years, 11 or more years, and a relatively high number of people at the 0–5 years end of the continuum. This suggests that the majority have served there for less than five years, with diminishing numbers at both ends of the continuum.

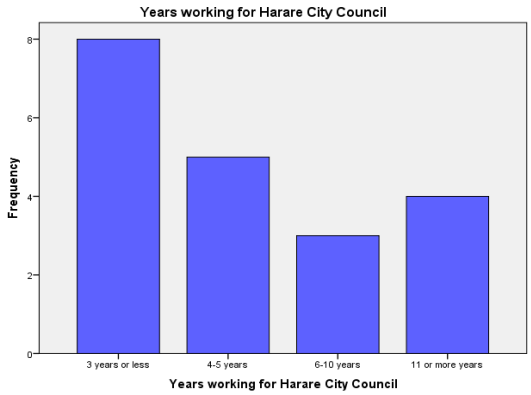


Figure 4.13 Years at which the respondents have been in the organisation.

4.4.2 Laws Governing Sand and Gravel Mining

Sand extraction is regulated by section 140 (k) of the Environmental Management Act (Chapter 20:27) as read with Section 3-7 of Statutory instrument 7 of 2007 Environmental Management (Environmental Impact Assessment and Ecosystem Protection) Regulations [37, 38](“environmental management act,” 2026) (table 4.7). The Water Act chapter 20:24 also touches on river sand extraction. Section 46 of the Water Act Chapter 20:24 details the application for permit to conduct operations in a public stream. However, extraction of sand for desilting purposes is exempted from applying for the permit by Section 46 (5e) of the Act. The

EMA official databases ascribe that Statutory Instrument 3 of 2011 was enacted to cater for the licensing fees and the fine after the dollarization of the economy.

Table 4.7 Legislation Governing Sand and Gravel Mining

Legislation	Section	Provisons
Environmental Management Act (Chapter 20:27)	Section 140 (k)	Provides for the crafting of sand extraction regulations by the Minister
Statutory Instrument 3 of 2011	All sections	Sand extraction licensing fees and fines
Urban Councils Act 29:15	All sections	local government, including the establishment and governance of councils
Statutory instrument 7 of 2007 Environmental Management (Environmental Impact Assessment and Ecosystem Protection) Regulations	Sections 3-7	Provides for the Licensing of sand extraction
Forestry Act	Section 44 &45	falling restrictions in forest land as well as permits to cut trees
Environmental and Climate Policy	All sections	climate adaptions measures related to anthropogenic causes
Mines and Minerals Act chapter 21:05	All sections	granting of special leases and prospecting rights
Ontario Aggregate Resources Act	All sections	extraction limits of aggregates

4.4.3 Challenges preventing Effective Environmental Management of Mining Areas

Limited funds is mentioned most often and given a “Critical” priority; most challenges are given a “High” priority, indicating resource constraints and coordination issues as the top challenges for management.

Table 4.8 Challenges in management and level of priority that should be given to it.

Management challenge	Frequency of Mention	Priority Level
Week Enforcement	17	High

Political Influence	15	High
Poor Coordination	16	High
Limited Funds	19	Critical
Shortage of Personnel	13	Moderate
Corruption	13	Moderate
inadequate Community Participation	16	High
Overwhelming Degradation Rates	16	High

Column1	Strongly	Agree	Neutral	Disagree	Strongly

The responses show the strong agreement (58.82%) to “Limited financial and technical resources” and the strong disagreement (23.53%) to “Shortage of trained environmental enforcement personnel” indicating that these issues are strongly related to environmental issues. (Table 4.9)

Table 4.9 challenges causing ineffective management

	Agree (%)	(%)	(%)	(%)	Disagree (%)
Weak Enforcement of Environmental Laws	29.41	23.53	17.65	17.64	11.76
Political influence	29.41	17.65	23.53	5.88	11.76
Poor coordination among responsible institutions	23.53	11.76	29.41	23.53	5.88
Limited financial and technical resources	58.82	17.65	23.53	11.76	0
Shortage of trained environmental enforcement personnel	5.88	17.65	5.88	11.76	23.53
Corruption or lack of accountability	11.76	29.41	23.53	17.65	0
Inadequate community participation	11.76	35.29	17.65	11.76	17.65
Overwarming land and ecosystem degradation rates	11.76	23.53	23.53	11.76	17.65

The responses showed that financial resources constraints and weak enforcement of environmental laws are the frequent and prominent challenges with each mentioned by 19 and 17 of the 20 HCC officials who responded to the survey questionnaires, respectively. These two factors are closely interrelated: resource constraints limit the Council's capacity for routine inspection and enforcement, thereby creating permissive conditions within which illegal extraction can flourish. Inadequate community participation, overwhelming land and ecosystem degradation rate and poor coordination among responsible institutions were also cited highly by 16 officials, indicating systemic shortfalls in both preventive and remedial environmental management capabilities.

One senior HCC environmental officer elaborated on the operational constraints facing the Council's management function:

"Weak environmental policies and their enforcement is the major challenge because national laws and policies are not being followed since enforcement is weak."

"Poor stakeholder coordination both internal and external. There is need for harmonious approach where all stakeholders will be participating and resource supporting."

A further informant highlighted the fiscal dimensions of the governance gap:

"Inadequate funding, no funds are directed towards rehabilitation. Operators oversee all charges of which their funds are not enough so the government should subsidence the reclamation bills in order to encourage the process."

Rehabilitation and Ecological Restoration Challenges

The results of the field observations and the questionnaire survey confirmed that there was limited systematic ecological restoration in all the already mined sites in Harare. The most significant structural problems in the current regulatory framework were the lack of enforceable post-mining rehabilitation regulations. Warren hills phase 1 and golden quarry

Pictures of Rehabilitated Status of Mined Areas in Harare



Figure 4.14. Status of warren hills (Garusa 2023)

The pictures reveals that most abandoned mining areas had received partial to no rehabilitation whatsoever. Field observation confirmed the prevalence of exposed pits, unstabilised slopes, and bare soil surfaces devoid of any deliberate re-vegetation effort. The near-total absence of effective rehabilitation represents a critical failure in the mining governance lifecycle.

4.4.4 Evaluation of Harare City Council Conservation Policies

Community Awareness of Environmental Regulations

A critical dimension of effective environmental governance is the extent to which regulatory provisions are understood and internalised by the affected community. The study assessed respondents' awareness of the environmental regulations applicable to sand and gravel mining in Warren Hills.

Table 4.10: Community Participation in Environmental Impact Assessment (n = 15)

Response	Frequency	Percentage (%)
Aware of EIA	2	16.67

Not Aware of EIA	13	86.67

The findings shown in Table 4.10 indicate that there is a remarkable lack of awareness about the environment laws and regulations applicable to sand and gravel mining in the area: 86.67 per cent of the respondents said they were not aware of the environment laws and regulations applicable to sand and gravel mining in the area. Just 35% could name a specific provision in the regulations or an enforcement body. This is especially alarming because "community awareness" must precede any form of public involvement in environmental governance and any social accountability of mining companies Proportion of the population who are aware of the mining at Warren hills & the environmental impact of it.

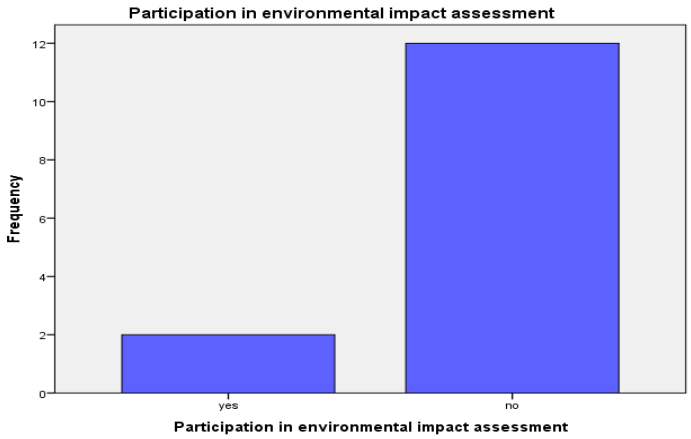


Figure 4.15 showing the number of community member who took part in EIA

The low awareness that was found in this study reflects the wider situation of limited environmental communication in the governance of Zimbabwean municipalities. The EIA provisions of the Environmental Management Act [Chapter 20:27] is complemented by environmental mining regulations that clearly provide for commitments to environmental impact assessment, monitoring during mining, and restoration after mining, but these mechanisms do not seem to be very visible to the public at community level. The lack of information in the community reduces the accountability mechanisms that are key for effective environmental governance (Reed 2008)

4.4.5 Community perceptions on How Effective are Environmental Policies

Beyond awareness, the study also examined respondents' perceptions of the effectiveness of existing HCC environmental policies in managing mining impacts. Results are presented in Table 4.11.

Table 4.11 showing Community perceptions on How Effective are Environmental Policies

Perceived Effectiveness	Frequency	Percentages (%)
Very Strong	0	0%
Fair	6	40%
Weak	5	33.33%
Very weak	4	26.67%

Table 4.12 indicates that 40% of the respondents perceived existing HCC environmental monitoring and control of aggregates extraction policies as fairly effective, while a further 33.33 percent rated them as weak in effectively monitoring and controlling sand and gravel mining. 26.67 percent of respondents considered the policies to be very weak. This largely negative assessment is consistent with the continuing and visible environmental degradation documented throughout the study area, which respondents interpreted as direct evidence of regulatory failure. None of the sample responders said monitoring and control of aggregates extraction of HCC is very effective.

HCC officials who responded to the questionnaires as part of the study seem to largely concur with this assessment, acknowledging that while the formal policy framework was broadly adequate, implementation was severely constrained by limited funding, and weak enforcement as shown below.

Weak enforcement of environmental laws

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	less hindrance	2	10.0	11.8	11.8
	minor hindrance	3	15.0	17.6	29.4
	moderate hindrance	3	15.0	17.6	47.1
	serious hindrance	4	20.0	23.5	70.6
	major hindrance	5	25.0	29.4	100.0
	Total	17	85.0	100.0	
Missing	System	3	15.0		
Total		20	100.0		

Table 4.12 statistical analysis of weak enforcement of environmental laws responses

CHAPTER 5 DISCUSSION

5.1 Land Use and Land cover changes in warren Hills

From a regional perspective, the analyses carried out in Chapter 4 revealed some key changes in LULC between 2013 and 2025 in Warren Hills. The LULC analysis revealed that the most dominant land cover class from 2013–2022 was sparsely vegetated land which decreased drastically in 2025 from 515.34 ha in 2022 to 199.98 ha in 2025. By contrast, the area of mined land rose significantly in 2025 (to 437.76 ha) compared to 2013 (109.26 ha). The results suggest that sand and gravel mining in the study area is fluctuating at a fairly fast rate, with vegetation being lost as a result.

The growing areas of extraction and the decline of green cover in Warren Hills indicates the growing alteration of this green corridor into a landscape of extensive disturbance and extraction. The sharp rise in mined surfaces for 2025 indicates that extraction activity occurred at an even greater rate in the later years of the study. In agreement with this,(Sonter et al. 2018) confirmed that expansions in mining activity play significant role in degrading the vegetation cover and changing the landscape.

The vegetation cover was also found to be very low throughout the study period varying from 4.77 ha to 10.89 ha. This illustrates that natural vegetation recovery within the study area is still restricted with some fluctuations in vegetation conditions. The constant area of the land cover class labelled as “other” (399.24 ha) during the study period may suggest mixed spectral signatures due to disturbed landscapes and the transition of land cover classes. The LULC results indicate that there has been a consistent disturbance and degradation of the environment in the area of sand and gravel extraction activities in Warren Hills.

5.2 Vegetation Dynamics and NDVI Analysis

The NDVI analysis revealed variable vegetation conditions in Warren Hills from 2013 to 2025. The mean NDVI values were between 0.15 and 0.36. With the lowest NDVI values were found within active mining areas with values of about 0.15 at the edges of active pits. The values represent almost complete removal of vegetation and marked disturbance of the ecology.

The NDVI was consistently higher during the wet season than the dry season as a result of higher vegetation productivity during the wet season when there is more rain available. The mean

NDVI rose slightly from 0.324 to 0.366 in February 2013 to February 2025 under wet season conditions. The NDVI during dry season was still relatively low with the October 2022 mean NDVI value of 0.153 being one of the lowest in the last 15 years. This indicates that when conditions are dry, vegetation growing inside the mined areas is more stressed. This possess a threat of vegetation extinction during the dry seasons.

The regression results showed a positive correlation between years under study and the NDVI values the results were ($B = 0.004$; $p = 0.382$; $R^2 = 0.382$). The relationship was not statistically strong however the results show the variable vegetation conditions over the study period. The changes in fluctuations can be correlated to the variation in intensity of mining and sporadic recovery of vegetation in some areas of Warren Hills.

Spatial analysis also revealed that immediately around active mining pits the lowest vegetation density and health were found. The high spatial correlation between mining intensity and NDVI drop indicates that the mining activities have significant impacts on vegetation degradation in the study area. Vegetation indices significantly decreased around active mining areas as a result of excavation, soil disturbance, and the removal of vegetation. (Ranjan et al. 2022b; Yang et al. 2022b)

5.3 Bare soil exposure, land degradation.

Both Bare Soil Index (BSI) and Soil Composition Index (SCI) results illustrate an increase in bare surfaces exposure from 2013 to 2025. The reflectance maps and the raster histograms revealed the increase of reflectance and the extension of the exposed land surfaces in the mining sites. The very high BSI values were grouped around the sites of extraction, confirming that the removal of vegetation and the disturbance of the topsoil has increased with time.

The area of bare soil exposure also increased due to the increase in mined areas in 2025 (437.76 ha) compared with 2013 (109.26 ha). So, more and more vegetated places have been converted into bare and eroded spaces. Within Warren Hills, a high proportion of bare surfaces may lead to higher susceptibility to soil erosion and sediment transport, and to generation of dust.

The results also showed that within abandoned mining areas there were exposed mining pits and unstabilised slopes. Field observations showed there was some rehabilitation, but many areas were where the land surface was degraded with no intentional re-vegetation. These conditions are a sign of an ecological degradation that has persisted over time and is hence less resilient.

The results are consistent with (Liu et al. 2022) who suggested that BSI is a good indicator of soil reflectance variations due to environmental disturbance and soil degradation. The observed bare surfaces, therefore, validate the ecological impacts of unsustainable extraction of sand and gravel in Warren Hills.

5.4 Community Perceptions on Environmental Impacts of Mining

The community views of environmental impacts of the mining activity is also explored. Community perceptions of the environmental impacts of the mining activity are also investigated. Questionnaire survey revealed that local communities strongly felt that sand and gravel mining problem is a significant environmental issue in Warren Hills. The primary environmental impacts of mining activities identified by most of the respondents are vegetation destruction, dust pollution, land degradation and loss of natural aesthetics.

According to the community members, vegetation cover and natural environment have been greatly affected by mining activities. The incidence of destruction of the vegetation was linked with the excavation processes and the widening of the mining pits. The respondents also reported that dust emission from haulage trucks and exposed mining surfaces are a negative impact on air quality and human health.

The results corroborate with those of (Park and Jang 2021) which indicated that the prevalence of respiratory conditions in communities around mining and quarrying activities is high. Mining operations can thus create dust pollution that could be hazardous to the health and environment of nearby communities.

The study also found that certain community members felt there was a lack of environmental management and monitoring within the community. The respondents reported that abandoned pits were rehabilitated somewhat and environmental regulations were enforced poorly. This is a sign of poor environmental governance and institutional monitoring.

Respondents reported insufficient information and low public engagement, which could decrease accountability mechanisms needed for good environmental governance.(Reed 2008) put forward the proposition that the lack of access to environmental information reduces the public's role in and responsibility for environmental management processes.

5.5 Environmental Management and Rehabilitation Practices

The study found that environmental management and rehabilitation is still deficient in Warren Hills. Observations in the field showed evidence of abandoned pit, exposed surfaces and some indication of vegetation restoration in the previously mined areas. To date, there is limited implementation of rehabilitation measures that can be a factor in ecological degradation and loss of ecosystem services in the long term. It is widely recognized globally that post-mining land restoration is an important element of good mining practice (UNDP 2014) Mining can therefore not be expected to be sustainable unless mined areas are rehabilitated and can reduce environmental vulnerability.

Environmental legislation in Zimbabwe mandates environmental effect assessment and rehabilitation for extractive operations, but the results indicate that there is poor compliance and enforcement of the legislation. The Environmental Management Act (Chapter 20:27) and Statutory Instrument 7 of 2007 govern sand extraction activities, but environmental degradation is increasing in the study area. The study also indicates that enhancing the environmental monitoring systems and community participation mechanisms in Warren Hills is needed to enhance environmental governance.

5.6 Chapter Summary

The chapter presented findings of the study in reference to vegetation dynamics, land degradation, perception of the community and environmental management practices relating to the sand and gravel mining operation in Warren Hills. It was determined that sand and gravel extraction activities caused a significant amount of loss of vegetation, more exposure of bare soil, land degradation and environmental disturbance within the study area. The chapter also illustrated how GIS and remote sensing could be applied to the study of changes in the ecological landscape, which are related to the mining activity, such as NDVI, BSI, LULC analysis etc.

The results showed that the locals also consider the negative impacts from the mines as significant causes of environmental degradation, and that they are concerned about poor rehabilitation and environmental monitoring practices. In general, the evaluation indicates that the extraction of sand and gravel in an unsustainable manner has had a detrimental impact on both ecological conditions and vegetation dynamics in Warren hills.

The results of the study were presented in this chapter, which covers aspects of vegetation dynamics, land degradation, community perceptions and practices of environmental management in relation to sand and gravel.

CHAPTER 6 CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

The study was able to successfully measure the effects that the sand and gravel mining had on: Vegetation Cover, density and diversity, and local communities' views, while also identifying many of the challenges to effective sand and gravel mining area management. GIS and remote sensing capabilities and questionnaires based on community and officials facilitated easier acquisition of information.

The multi-temporal satellite imagery and spectral indices were well applied to assess the variation in vegetation cover and exposure of bare soil in the study years. The results showed that the mining activities have contributed greatly to degradation of the environment in the study area. Analysis of Bare Soil Index (BSI) revealed a general trend toward greater bare soil exposure between 2013 and 2025, suggesting a higher level of disturbance to and exposure of the soil surface as time passed. The rise in mean BSI values during both dry and wet seasons showed that the land surface condition has been changed over time in relation to the mining and quarrying activities. The higher and sharper frequency peaks seen in the 2025 image in the histogram also indicated an increase in the amount and area of soil surfaces exposed. The wider range of pixel values in later years was also attributed to the rise in the variability of land cover conditions from stronger human activities.

The first aim aimed to determine the effect of sand and gravel mining on vegetation cover, vegetation density and diversity. The results indicated that sand and gravel mining activities have caused significant degradation of vegetation and disturbance of land over the study area. The Bare Soil Index (BSI) was used to analyse bare soil exposure between 2013 and 2025, revealing some trends of bare soil exposure over time. The surrounding areas of the mining operations showed measurable decreases in vegetation density due to the clearing of vegetation to enable extraction operations, transport and disposal of waste materials. It also showed that there were ecosystem disturbances and alteration in landscape pattern, which was also the case to prove the negative impacts of the mining operations on ecosystem stability and biodiversity.

The second goal was to evaluate the perceptions of the local communities about sand and gravel mining activities. The study found that there were varying perceptions about the mining activities in the area among the local communities. Economic advantages of sand and gravel mining such as employment, income generation and provision of construction materials were recognised by some of the community members. Most of the respondents, however, were concerned about the adverse environmental and social effects of mining operations. These included the destruction of the vegetation, dust pollution, land degradation, noise pollution, road damage and increased health risks, such as respiratory issues resulting from dust emissions. The community members also shared their concerns on the worsening environmental quality resulting from the mining operations and the resulting impact on their livelihoods.

The third goal was to determine the problems that constrain the effective management of mined areas. The study identified a number of problems that could impact the environmental sustainability of mined sites and their rehabilitation. This comprised the weak enforcement of environmental legislation, absence of rehabilitation programmes, poor monitoring of responsible authorities, financial constraints, and low level of community participation in environmental management processes. Abandoned pits and degraded landscapes were left behind in some areas without management following the cessation of extraction activities, thus raising the environmental and safety risks in the surrounding communities.

6.3 Recommendations

The following recommendations are made from the results of the study:

6.3.1 Strengthening Environmental Monitoring

Environmental monitoring and regulatory programme of Government and Environmental management agencies in the study area should be strengthened to monitor and regulate the mining and quarrying activities. Regular environmental checks should be carried out to help ensure adherence to environmental management policies and rehabilitation needs.

6.3.2 Rehabilitate degraded areas.

The rehabilitation and reclamation of the impacted lands should be considered in degraded areas by the mining companies and local authorities. Restoration and prevention of further degradation of the ecosystems should be done through implementation of re-vegetation, afforestation and soil stabilization projects.

6.3.3 Sustainable Mining Practices

The operators of the mining companies are advised to use the environmentally friendly mining methods which minimize the vegetation clearance, soil disturbance and pollution. Environmental impacts of extraction should be minimised through promoting controlled methods of extraction and the development of waste management systems.

6.3.4 Community awareness of and involvement in the conservation efforts.

The local communities should be fully aware and active in conservation of the environment through monitoring and evaluation programmes to foster sustainable management of natural resources.

6.3.5 GIS and Remote Sensing Technologies incorporation in environmental studies

GIS and remote sensing technology should be continued to be used by environmental institutions and researchers for the monitoring of environment and assessment of land degradation. These technologies offer efficient tools for detecting the environmental changes and for supporting decision making process.

6.3.6 Policy Improvement and Enforcement

The environmental laws and policies governing mining operations need to be enforced to a greater degree. Environmental Impact Assessments (EIAs) should be strictly monitored prior to the approval of the mining projects and penalties should be applied to the operators that do not work according to the environment rules.

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APPENDICIES

Appendix 1 Approval Letter

CITY OF HARARE

HUMAN CAPITAL DEPARTMENT
TOWN HOUSE, HARARE, ZIMBABWE
POST OFFICE BOX 990
TELEPHONE 752979/ 753000
EMAIL hrd@hararecity.co.zw
ADDRESS ALL CORRESPONDENCE TO HUMAN CAPITAL DIRECTOR

Bindura University of Science Education
Department of Natural Resources Management
Faculty of Agriculture and Environmental Sciences
P. Bag 1020
Bindura
Zimbabwe

07 January 2026

Dear Sir/Madam

RE: AUTHORITY TO UNDERTAKE RESEARCH KUNDAI P MUPOMBWA

This letter serves as an authority for Kundai P. Mupombwa to undertake a research survey on the topic, "Assessing the Ecological Consequences of Sand and Gravel Mining on Vegetation Dynamics: Case of Warren Hills".

The City of Harare has no financial obligation and neither shall it render any further assistance in the conduct of the research. The researcher is however requested to avail a soft copy and hard copy of the research to the undersigned so that residents of Harare can benefit out of it. The research should not be used for any purposes other than the study purpose specified.

This letter is issued upon payment of US$5.00 administration fee.

Receipt Number: 16143094

Yours faithfully

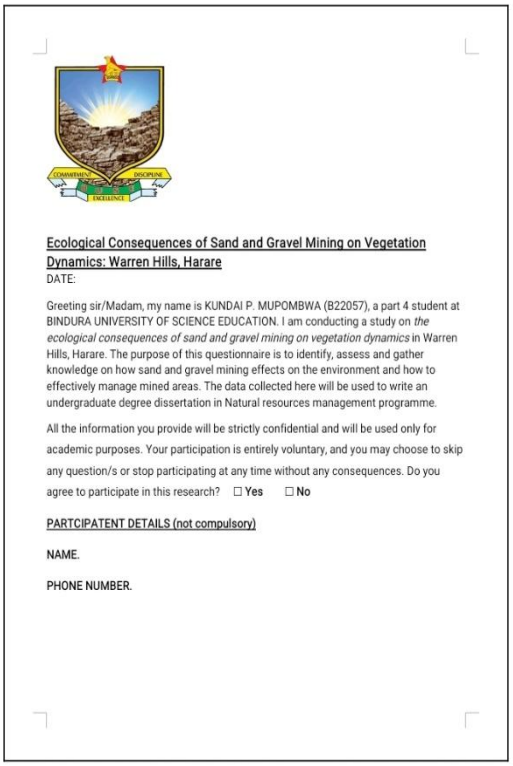
08/01/26

MR J. DUVE

ACTING HUMAN CAPITAL DIRECTOR

CITY OF HARARE
HUMAN CAPITAL DEPT.
12 JAN
P.O. BOX 990, HARARE
TEL 752979

Appendix 2; Household Questionnaire



Ecological Consequences of Sand and Gravel Mining on Vegetation Dynamics: Warren Hills, Harare

DATE:

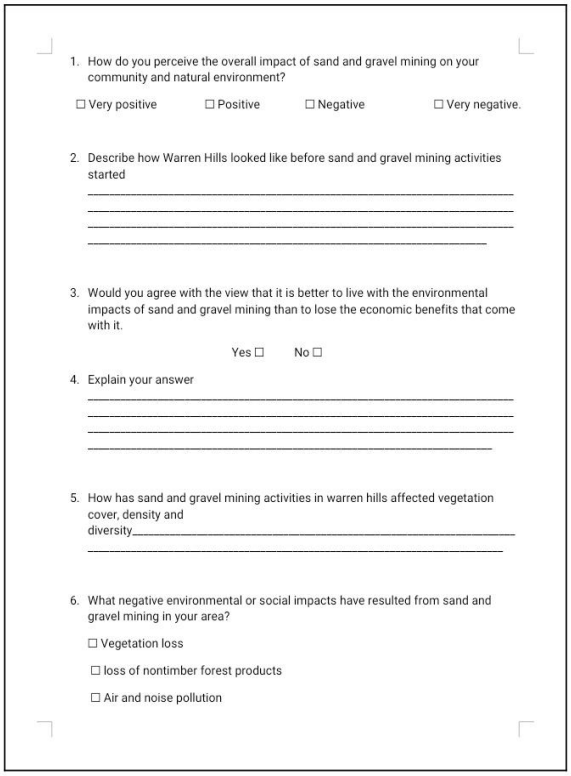
Greeting sir/Madam, my name is KUNDAI P. MUPOMBWA (B22057), a part 4 student at BINDURA UNIVERSITY OF SCIENCE EDUCATION. I am conducting a study on *the ecological consequences of sand and gravel mining on vegetation dynamics* in Warren Hills, Harare. The purpose of this questionnaire is to identify, assess and gather knowledge on how sand and gravel mining effects on the environment and how to effectively manage mined areas. The data collected here will be used to write an undergraduate degree dissertation in Natural resources management programme.

All the information you provide will be strictly confidential and will be used only for academic purposes. Your participation is entirely voluntary, and you may choose to skip any question/s or stop participating at any time without any consequences. Do you agree to participate in this research? ☐ **Yes** ☐ **No**

PARTCIPATENT DETAILS (not compulsory)

NAME.

PHONE NUMBER.



1. How do you perceive the overall impact of sand and gravel mining on your community and natural environment?

   ☐ Very positive ☐ Positive ☐ Negative ☐ Very negative.

2. Describe how Warren Hills looked like before sand and gravel mining activities started

   _____
   _____
   _____
   _____

3. Would you agree with the view that it is better to live with the environmental impacts of sand and gravel mining than to lose the economic benefits that come with it.

   Yes ☐ No ☐

4. Explain your answer

   _____
   _____
   _____
   _____

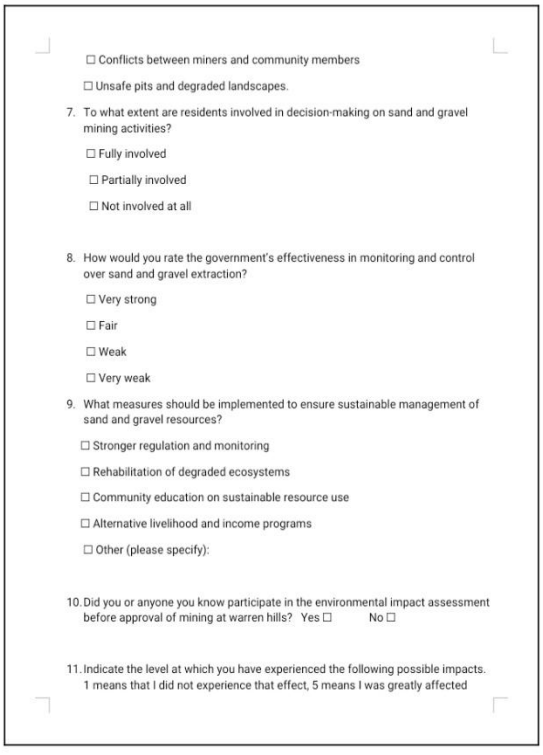
5. How has sand and gravel mining activities in warren hills affected vegetation cover, density and diversity._____
   _____

6. What negative environmental or social impacts have resulted from sand and gravel mining in your area?

   ☐ Vegetation loss

   ☐ loss of nontimber forest products

   ☐ Air and noise pollution



☐ Conflicts between miners and community members

☐ Unsafe pits and degraded landscapes.

7. To what extent are residents involved in decision-making on sand and gravel mining activities?

   ☐ Fully involved

   ☐ Partially involved

   ☐ Not involved at all

8. How would you rate the government's effectiveness in monitoring and control over sand and gravel extraction?

   ☐ Very strong

   ☐ Fair

   ☐ Weak

   ☐ Very weak

9. What measures should be implemented to ensure sustainable management of sand and gravel resources?

   ☐ Stronger regulation and monitoring

   ☐ Rehabilitation of degraded ecosystems

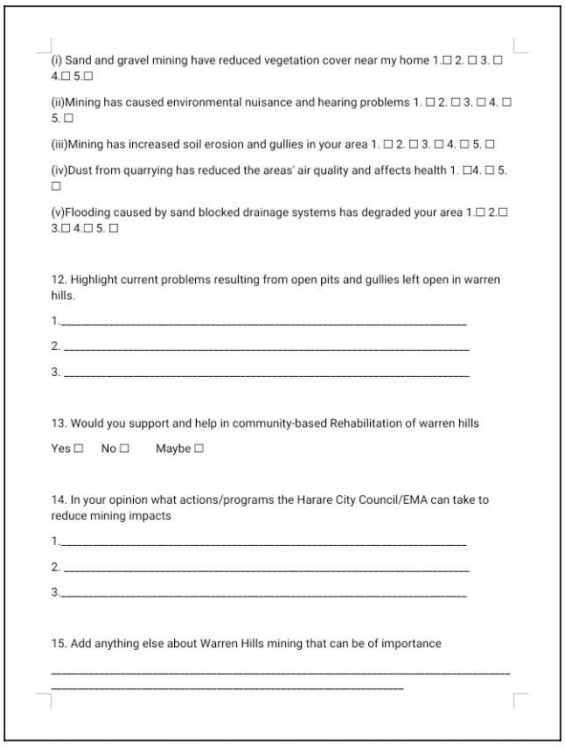
   ☐ Community education on sustainable resource use

   ☐ Alternative livelihood and income programs

   ☐ Other (please specify):

10. Did you or anyone you know participate in the environmental impact assessment before approval of mining at warren hills? Yes ☐ No ☐

11. Indicate the level at which you have experienced the following possible impacts. 1 means that I did not experience that effect, 5 means I was greatly affected



(i) Sand and gravel mining have reduced vegetation cover near my home 1.☐ 2. ☐ 3. ☐ 4.☐ 5.☐

(ii)Mining has caused environmental nuisance and hearing problems 1. ☐ 2. ☐ 3. ☐ 4. ☐ 5. ☐

(iii)Mining has increased soil erosion and gullies in your area 1. ☐ 2. ☐ 3. ☐ 4. ☐ 5. ☐

(iv)Dust from quarrying has reduced the areas' air quality and affects health 1. ☐4. ☐ 5. ☐

(v)Flooding caused by sand blocked drainage systems has degraded your area 1.☐ 2.☐ 3.☐ 4.☐ 5. ☐

12. Highlight current problems resulting from open pits and gullies left open in warren hills.

1._____

2. _____

3. _____

13. Would you support and help in community-based Rehabilitation of warren hills

Yes ☐ No ☐ Maybe ☐

14. In your opinion what actions/programs the Harare City Council/EMA can take to reduce mining impacts

1._____

2. _____

3._____

15. Add anything else about Warren Hills mining that can be of importance

_____
_____

Appendix 3 Key Informant Questionnaire





Ecological Consequences of Sand and Gravel Mining on Vegetation Dynamics: A Case study of Warren Hills, Harare

DATE.....

Greeting sir/Madam, my name is KUNDAI P. MUPOMBWA (B22057), a part 4 student at BINDURA UNIVERSITY OF SCIENCE EDUCATION. I am conducting a study on *the ecological consequences of sand and gravel mining on vegetation dynamics* in Warren Hills, Harare. The purpose of this questionnaire is to identify, assess and gather knowledge on how sand and gravel mining effects on the environment and how to effectively manage mined areas. The data collected here will be used to write an undergraduate degree dissertation in Natural resources management programme.

All the information you provide will be strictly confidential and will be used only for academic purposes. Your participation is entirely voluntary, and you may choose to skip any question/s or stop participating at any time without any consequences. Do you agree to participate in this research? ☐ Yes ☐ No

PARTCIPATENT DETAILS (not compulsory)

NAME.

PHONE NUMBER.

1. How long have you been part of Harare City Council for

☐ 3 or less years

☐ 4-5 years

☐ 6-10 years

☐ 10 or more years

2. Select and rate key factors hindering effective management of mined areas in urban set ups? Rating criteria are 1= less of a hinderance, 5 =major hinderance.

☐ Weak enforcement of Environmental Laws 1. ☐ 2. ☐ 3. ☐ 4. ☐ 5. ☐

☐Political influence 1. ☐ 2. ☐ 3. ☐ 4. ☐ 5. ☐

☐ Poor coordination among responsible institutions *(EMA, ZIMWA, ZIMPARKS ETC)* 1.☐ 2.☐ 3.☐ 4.☐ 5☐

☐ Limited financial and technical resources 1. ☐ 2. ☐ 3. ☐ 4. ☐ 5. ☐

☐ Shortage of trained environmental enforcement personnel 1. ☐ 2. ☐ 3. ☐ 4. ☐ 5. ☐

☐ Corruption or lack of accountability 1. ☐ 2. ☐ 3. ☐ 4☐. 5. ☐

☐ Inadequate community participation 1. ☐ 2. 3. ☐ 4. ☐ 5. ☐

☐ Overwarming land and ecosystem degradation rates 1. ☐ 2. ☐ 3. ☐ 4. ☐ 5. ☐

3. Are site restoration or environmental rehabilitation measures (such as replanting and leveling or pit filling) part of yearly HCC/EMA mandates schedule (a list of targets that should be done yearly without fail.)

Yes ☐ No ☐

4. What major environmental impacts of sand and gravel mining (e.g., vegetation loss, land degradation, safety risks) have been observed by the Council in Warren Hills over recent years?

_____
_____
_____

5. What national laws, by-laws, policies, regulatory frameworks or SI's are you using to control sand and gravel mining activities in warren hills and how effect they are._____
_____
_____
_____
_____
_____
_____

6. What major barriers limit proper land rehabilitation of warren hills?

☐ Inadequate funding and technical capacity

☐ Weak environmental policies and enforcement

☐ Negligence by mining operators

☐ Lack of community awareness and involvement

☐ Other (please specify): _____

7. Pick one answer from the above and explain why it is the major barrier and how to solve it
_____
_____
_____
_____

8. In your own opinion, what strategies can improve the sustainable management of mined areas?

☐ Strengthening policy enforcement and regulation

☐ Enhancing community participation in restoration programs

☐ Increasing government and donor funding for rehabilitation

☐ Promoting environmental education and awareness

☐ Other (please specify):_____

9. Briefly describe any two roles your institution plays in managing sand and gravel mining activities in Harare.
I._____
II._____

10. What are some considerations taken by your organization to enhance sustainable sand and gravel mining practices and restoration of degraded vegetation and biodiversity in warren hills?_____
_____
_____

11. Are there mandated rehabilitation/reclamation requirements for pit in Harare Yes. ☐ No. ☐ Don't know☐. If yes Briefly describe these requirements.
_____
_____
_____

12. Highlight any successful rehabilitation efforts carried out within your organization's jurisdiction.
_____
_____
_____

13. Add any additional information on the consequences of sand and gravel mining on vegetation dynamics that you feel might be necessary.
_____
_____
_____

Kundai mupombwa Mupombwa kundai

KUNDAI P MUPOMBWA (B220577B) DISSERTATION FINAL TC 010626

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