UNITED NATIONS UNIVERSITY

UNU-LRT

Land Restoration Training Programme
Keldnaholt, 112 Reykjavik, Iceland

Final project 2017

ASSESSMENT OF RESTORED/RECLAIMED SITES IN ICELAND TO DETERMINE BEST SUITED AND COST-EFFECTIVE COVER SYSTEM(S) FOR RECLAIMING ARTISANAL AND SMALL-SCALE MINING SITES IN MALAWI

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ABSTRACT

Artisanal and small-scale mining (ASM) presents many environmental challenges, one of the greater being the abandonment of mine pits after the completion of mining activities. The lack of relevant and cost-effective techniques in reclaiming these sites adds to the challenge, as does improper law and regulation enforcement. This study was conducted to assess different land cover systems/techniques used in restoring/reclaiming degraded sites in Iceland to determine suitable and cost-effective cover system(s) to be tailored and used in reclaiming different improperly closed or abandoned ASM sites in Malawi. The study revealed notable differences in how mine sites and general degraded sites are restored/reclaimed. While refilling with materials to cover the excavations and revegetating were the major activities in reclaiming the mine sites, eroded sites on the other hand focussed much on revegetation. A total of five techniques were observed, four of which may be applicable in reclaiming ASM sites in Malawi. However, due to the differences between the type of materials and vegetation used in restoring/reclaiming the studied sites and those that may be found in Malawi, plus the heavy use of machinery, further assessment needs to be done to properly tailor these conditions to those of ASM in Malawi.

This paper should be cited as:
Mwathunga E (2017) Assessment of restored/reclaimed sites in Iceland to determine best suited and cost-effective cover system(s) for reclaiming artisanal and small scale mining sites in Malawi. United Nations University Land Restoration Training Programme [final project]
http://www.unulrt.is/static/fellows/document/mwathunga2017.pdf

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1. INTRODUCTION

Continual growth of the human population coupled with unsustainable agricultural and industrial activities to meet the rapidly growing demands for food, water and energy have globally degraded nearly a billion hectares of land (Wiebe 2000; Scherr & Yadav 2001; Jones & Rowe 2017). This has caused a decline in the quality of ecosystem services provided by the natural landscapes, threatening biodiversity and the habitability of the planet (Walker & Moral 2003; Galatowitsch 2012; Science for Environment Policy 2015). The Convention on Biological Diversity (CBD) adopted at the Rio Earth Summit in 1992 increased global awareness on the importance of biodiversity conservation and sustainable resource use, resulting in countries making firm commitments to develop policies and implement programmes aimed both at conserving and ensuring sustainable use of biological diversity (Van Andel & Aronson 2006). Furthermore, global efforts have also focussed on improving the quality of degraded systems resulting in an increased interest in the field of restoration ecology (Diggelen 2004). The Society for Ecological Restoration International defined ecological restoration as “an intentional activity that initiates or accelerates the recovery of a degraded, damaged, or destroyed ecosystem with respect to its health, integrity, services, and sustainability” (Clewell et al. 2004). Reclamation and rehabilitation are two different actions used in restoration ecology; reclamation is aimed at stabilizing landscapes and increase utility or economic value while rehabilitation is aimed at quickly repairing damaged ecosystem functions, particularly productivity (Walker & Moral 2003).

1.1. Restoration, rehabilitation and reclamation in mining

Mining is known as one of the earliest endeavours of human civilization, and from ancient times to date remains an important activity for human existence (Hartman et al. 2002). Mining has also been a major contributor to the economic stability of many countries around the world through the establishment of manufacturing industries, taxes and jobs (Dorin et al. 2014). However, mining poses serious threats to the environment, for example, through the removal of large quantities of vegetation and soil, the displacement of animal species and the generation of pollutants (ELAW 2014).

Prior to the 20th century, mine sites were usually abandoned without any environmental impact considerations after the cessation of mining activities, but later reclamation/rehabilitation became mandatory because of stricter governmental laws and increased demands for a safe and clean environment (Hartman et al. 2002). Today, the field of mine reclamation/rehabilitation has progressed greatly with the development of new techniques and tools, and companies are working with different stakeholders towards reclaimed/rehabilitated mine sites (Ibarra & De Las Heras 2005). It has also become common to carry out both mining and reclamation/rehabilitation activities simultaneously as this makes the process cheaper, faster and more successful (Australian Government 2006).

1.1.1 Artisanal and Small-Scale Mining (ASM) and reclamation/rehabilitation

Artisanal and small-scale mining (ASM from now on) is a term used to describe a type of mining that is mostly run by local communities, either as individuals or small enterprises, as opposed to medium-scale or large mining operations which are mostly run by large local or multinational companies (African Mining Vision n.d.).

Artisanal mining and small-scale mining are grouped differently in terms of project financing, workforce and equipment used, where both artisanal mining project financing and the work force are relatively low as compared to small-scale mining (African Mining Vision n.d.). Small-scale mining activities can be mechanised, while artisanal mining only involves basic hand tools (African Mining Vision n.d; International Institute for Environment and Development n.d.).

ASM is largely a poverty-driven activity which most local communities engage in to financially support themselves and their families (International Institute for Environment and Development n.d.; Hentschel et al. 2003; Buxton 2013). It is mostly widespread in the developing countries of the world (World Bank 2013; Hilson 2016), where almost 80 to 100 million people depend on it for their livelihoods (Hentschel et al. 2003). The number of people in communities that are involved in ASM fluctuates and depends on which sector is rewarding at a particular period of the year (African Mining Vision n.d.). For example, most farmers switch to mining in periods outside the growing season or when cultivation is not possible due to drought (African Mining Vision n.d.).

Because ASM activities tend to be unregulated (not according to laws and regulations) and focus more on solving immediate financial challenges than long-term impacts (International Institute for Environment and Development n.d.), their activities often have very adverse effects on the environment, ranging from pollution to land degradation with serious health and safety risks (African Mining Vision n.d). Most miners abandon their mining sites when they stop being profitable, or have run out of minerals, without any effort towards reclaiming them. The result is that the area gets covered with unattended pits that pose health and safety risks to the surrounding communities and furthermore, the area further gets degraded, making it unsuitable for any agricultural (Bansah et al. 2016) and economic use.

Success stories of ASM site rehabilitation/reclamation are uncommon, which may be due to the weak enforcement of regulations on the part of enforcement agencies and/or the challenges in finding and using cost-effective methods. Rehabilitation/reclamation attempts have only been successful on a few occasions where the miners have hired machinery to conduct rehabilitation/reclamation activities after having profited from their mineral sales. For example, in Ghana an artisanal and small-scale mine owned by a woman entrepreneur was successfully reclaimed by using machinery and is now used productively for agriculture (Bansah et al. 2016).

ASM and mining in general tend to impact the genders differently. Men are much more likely to receive financial benefits and technical and legal support, whereas women, who are most often in charge of getting water and tending to cultivation, have to deal with the negative consequences of mining, like pollution of water resources and environmental damage (Hinton et al. 2003). This forces women to travel long distances to look for safe water sources and arable land suitable for cultivation.

1.1.2 Reclamation/rehabilitation in artisanal and small-scale mining in Malawi

Like many other developing countries, ASM activities in Malawi are mostly done by poor local people with little or no knowledge of how their activities impact the environment. Frequent droughts and floods caused by climate change, rapid population growth (GoM 2012) and unsustainable land practices by many subsistence farmers have greatly affected agriculture and negatively affected the country’s economic growth (IMF 2017). Consequently, many farmers have been forced to turn to mining as an alternative source of income. This has increased the number of people engaged in ASM and therefore increased environmental challenges caused by ASM activities.

One such challenge is the abandonment of mine sites after mining or when they stop being profitable, and this poses serious land degradation threats. Mine site abandonment in Malawi is not only caused by the ASM sub-sector in Malawi, but also by the large-scale mining (LSM) sector. Recently, Human Rights Watch produced a report on how an abandoned mine site owned by Eland Coal Mine had affected the livelihoods of the surrounding communities (Human Rights Watch 2016). The report noted that the nearby water sources had been polluted, forcing people to travel long distances for clean water, and the arable land which they used for cultivation had also been degraded due to movement of heavy machinery and vegetation clearance.

To date, the ASM subsector in Malawi has never officially recorded any successful site rehabilitation/reclamation. This is attributed to the informal nature of the subsector and to lack of knowledge and skills on how to cost-effectively rehabilitate/reclaim these mining sites.

1.2. Restoration and reclamation in Iceland

Evidence suggests that most parts of Iceland (~60-70%) were covered with vegetation before its settlement in the 9th century (Arnalds 2011), with woodlands and shrubs covering almost 40% (Crofts 2011). However, human settlement and the consequent unsustainable use of land resources for construction, energy and grazing, in addition to unfavourable weather conditions and volcanic activities, dramatically altered the vegetation cover of the country reducing the native birch woodlands to almost 1% (Aradóttir 2003) and subsequently resulted in severe soil erosion (Ágústsdóttir 2004).

Iceland lies on a boundary between two divergent tectonic plates resulting in frequent volcanic eruptions (Camp 1931). Since the first settlement it’s been estimated that 217 eruptions have occurred across Iceland. These volcanic eruptions and other natural catastrophes like floods, harsh climate, fragile soils and storms, along with the subsequent destructive land activities by the early settlers, led to the severe degradation of soils in Iceland (Aradóttir 2003). Consequently, efforts to repair the severely degraded land were initiated with formal land reclamation activities starting in 1907 (Crofts 2011) and the establishment of one of the world’s oldest soil conservation organizations, the Soil Conservation Service of Iceland (SCSI from now on) (Arnalds 2011).

Much of the initial formal reclamation activities were done at Gunnarsholt, a farm owned by SCSI, and mainly focussed at stabilising drifting sands which were threatening agriculture and settlements in the area. These activities, though constrained by lack of resources and manpower, mostly involved the use of stone walls, banks of turf and old hay to act as buffers against the wind-blown sands (Crofts 2011). Later, with advancement in technology, resources, experience and manpower, activities spread widely to other areas and they shifted to revegetating degraded sites and preserving the remaining native woodlands (Ágústsdóttir 2004; Aradottir & Eysteinsson 2005). This was to demonstrate that farming and revegetation could co-exist if managed properly (Crofts 2011).

From the 1940s to the mid-1980s, revegetation of unstable land areas was mainly done by seeding of exotic grass species and fertilization, while relatively stable surfaces were only fertilized. Later, this method of reclamation was later mostly replaced with by introducing (from Alaska) the perennial nitrogen fixating plant, Nootka lupine, (*Lupinus nootkatensis*) (Aradóttir 2003). Since its introduction to date, Nootka lupine has proved to be a very effective method of reclamation, especially for reclaiming frequently degraded areas (Magnusson et al., 2001). However, over the years, reclamation with Nootka lupine has been disputed by different experts due to its invasive nature which outcompetes native plant species (Aradóttir 2003.).

The commitment of the government to comply with international conventions like the United Nations Framework Convention for Climate Change (UNFCCC) and the United Nations Convention on Biological Diversity (UNCBD), plus the urge to restore and preserve native birch woodlands have now shifted the attention and goals for conservation in Iceland from the mere reclamation for productivity to restoring natural ecosystem functions and services (Aradóttir 2003; Aradottir et al. 2013). One hundred years on, SCSI has been restoring, conducting experiments on degraded landscapes and collecting valuable information and data on restoration research in Iceland (Galway & Colloquium 2010; Crofts 2011). Apart from SCSI, other stakeholders like farmers, other landowners, companies, NGO's and interested individuals are also increasingly getting involved in restoration activities (Aradóttir 2003).

1.2.1 Mine reclamation/rehabilitation in Iceland

The mining industry in Iceland does not contribute greatly to the country's economy because few valuable mineral resources are found in the country (Yager 2014). However, gravel and rock mining play a crucial role in the country's construction industry (Haney 2010). Most of the gravel pits and quarries are opened for construction or maintenance of road projects by the Icelandic Road Administration (ICERA from now on) and there are currently over 3000 mines which are registered in the organization's database and this includes both open and reclaimed sites (Geological Department 2008; Haney 2010).

Much of the reclamation of gravel pits and quarries is done by ICERA. In 2010, the organization started a programme to reclaim all of its abandoned mine sites and by 2016 a total of 229 mine sites had been reclaimed (Geological department 2008).

1.3. Objectives

This study was conducted to assess different land cover systems used in restoring/reclaiming degraded sites, particularly mine sites in Iceland, to determine suitable and cost-effective cover system(s) to be tailored and used in reclaiming artisanal and small-scale mine sites in Malawi.

The specific objectives for the study were:

i) To analyse the ability of a cover system to use minimal thickness of top soil but still producing optimum results
ii) To analyse the ability of a cover system to support and sustain a vegetation cover
iii) To analyse the ability of a cover system to resist erosion before vegetation becomes established
iv) To analyse the simplicity of a cover system to construct and its ability to maximise the use of locally available materials
v) To analyse any other cost-effective and relevant aspects of the cover system.

1.4. Research questions

i) What are the different techniques (cover systems) used in restoring/reclaiming the different study sites?
ii) Is there a clear difference in the techniques between how mine sites and general degraded sites are restored/reclaimed?
iii) Which technique(s) can be applied in restoring/reclaiming artisanal and small-scale mines in Malawi?

iv) What can be altered from the suitable technique to make it more applicable to the conditions in the artisanal and small-scale industry in Malawi?

2. METHODOLOGY

Information for the project was collected through the combination of a literature study, meetings with different restoration/reclamation experts and field visits to different sites under reclamation/rehabilitation. The initial idea for the study sites was to exclusively focus on reclaimed mine sites; however because most mine sites employ similar techniques other restored/reclaimed sites were also included in the study. This was done to enhance the scope of the study through assessing a wide variety of techniques to find those which would be suited in reclaiming ASM sites in Malawi. A total of five different sites all located in south-western Iceland (see Fig.1) which also employed five different techniques were visited for the study.

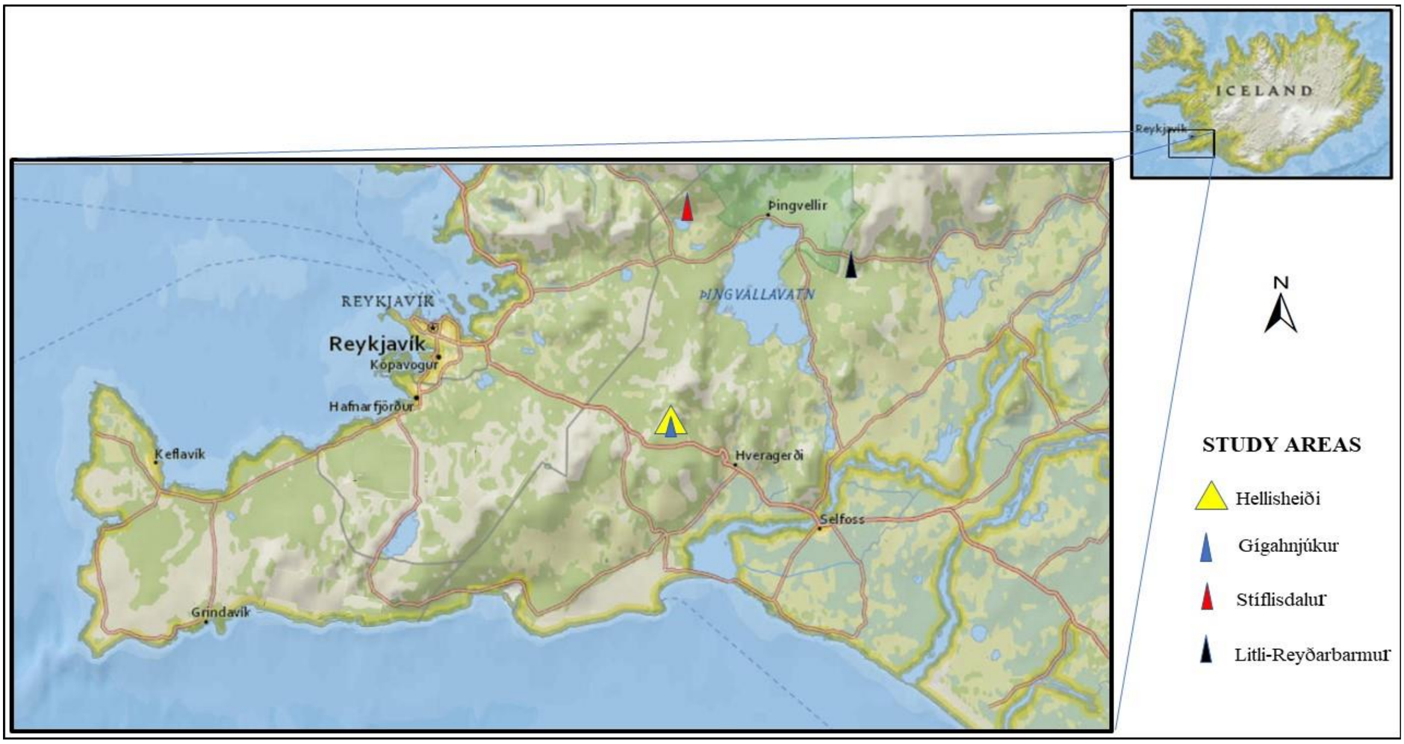

Figure 1. Map of Iceland showing the study areas. The locations of the sites are indicated with coloured triangles. (Source: National Geographic)

Two separate meetings with experts were conducted to gather information on how they conduct their restoration/reclamation activities. Semi-structured interviews were used in both meetings to gather the necessary information. The first meeting with the Environmental and Restoration Manager for Orka náttúrunnar (Reykjavik Energy), was held on the 27th of June in 2017. Three sites on which Orka náttúrunnar had done reclamation/restoration work were visited and all these sites are located in Hellisheiði, an area where the company's geothermal power plant is located. The second meeting held on the 11th of July in 2017 was with the Head of the Geology Department for ICERA. Two mine sites were visited during the course of the meeting, Stíflisdalur and Litli-Reyðarbarmur, which had been reclaimed by ICERA.

ICERA opens most of the gravel mine sites and stone quarries in Iceland and they are also responsible for reclaiming them. A programme that was started in 2010 by the company to reclaim all the abandoned mines in Iceland is still underway and now the company reclaims every opened mine site immediately after activity has ceased at the site. For other sites which are opened or disturbed by other organizations or individuals other than ICERA, the reclamation responsibility lies with those organizations or individuals.

Much of the literature and photos of the reclaimed mine sites were gathered from a website (namur.is) hosted by the ICERA. Some of the literature for the other restored/reclaimed sites other than mine sites was also obtained from the Agricultural University of Iceland**.**

2.1. Study areas

2.1.1 Gígahnjúkur

Gígahnjúkur is located south-east of Reykjavik, the capital city of Iceland, in an area known as Hellisheiði (Fig. 1). This is the area where the second largest geothermal power plant in the world, owned by Reykjavík Energy, was constructed (Resources and Living n.d.).

Figure 2. Construction works at Hellisheiði for the geothermal power plant left a large crater at Gígahnjúkur (Photo: Námur.is, 2017)

Reclamation of the site started in 2007 and ended in 2008. Old aerial photographs were used to create a three-dimensional reclamation model. About 35,000 cubic meters of material were used to fill up the crater (Fig. 2 & 3) and the material was spread in such a manner as to imitate the natural texture and create a favourable condition for vegetation colonization (Fig. 4, Námur.is 2017). The area was ultimately reshaped to mimic the original shape (Fig. 5, Námur.is 2017).

Figure 3. The crater at Gígahnjúkur was first filled with rock and soil materials to replace the rock materials which had been excavated from it (Photo: Námur.is, 2017)

Figure 4. Rock and soil materials at Gígahnjúkur were mixed and spread to imitate the natural texture and create a good condition for vegetation colonization (Photo: Námur.is, 2017)

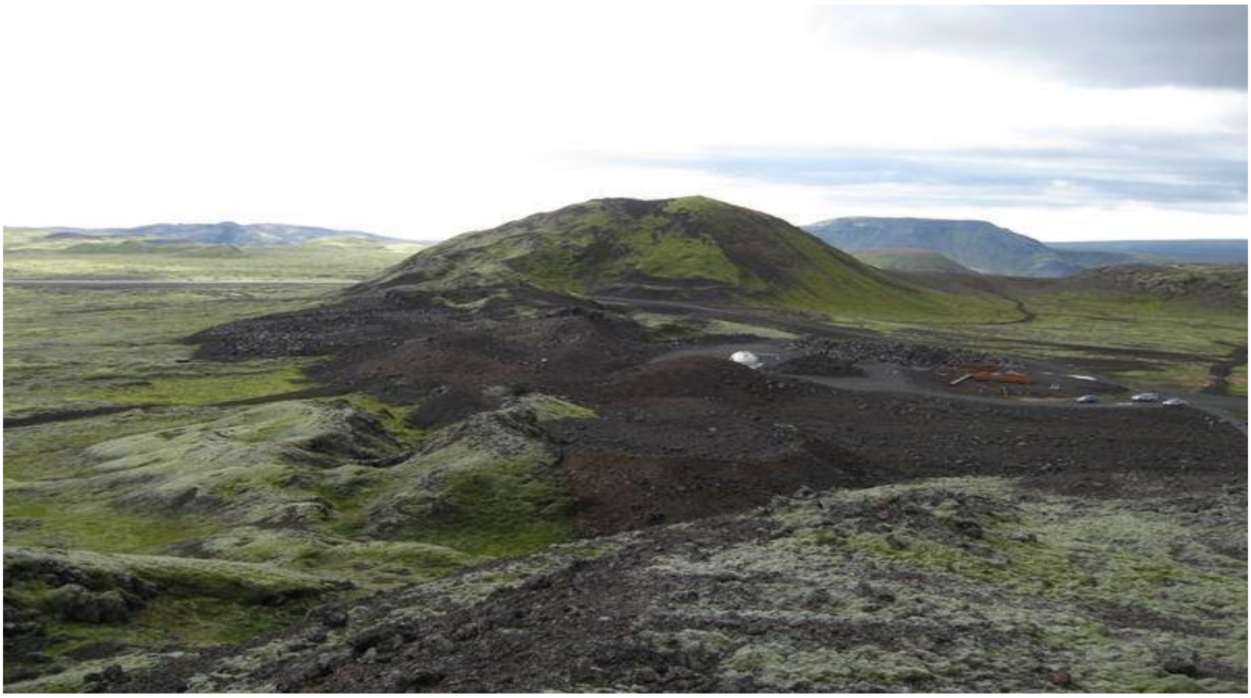

Figure 5. The refilled site at Gígahnjúkur was reshaped to imitate the conditions that existed before the site was mined (Photo: Námur.is, 2017)

Due to the mosses being the prominent native vegetation, a mixture of both grass seeds and mosses were applied on the site (Fig. 6). The moss was extracted from another undisturbed site in the area, and exceptional care was taken when picking the moss to minimize disturbance.

Figure 6. Grass and moss revegetating the final reclaimed site at Gígahnjúkur. Moss from the adjacent sites, where it is dense, is also seen to be colonizing the sparsely vegetated reclaimed site (Photo: Námur.is, 2017)

2.1.2 Hellisheiði

Two additional sites in Hellisheiði were visited, where two different revegetation techniques were used in restoring disturbed sites. For the areas which had been disturbed through the installation of geothermal pipes, turf transplants were used for the restoration, while the degraded site close to the main power plant was restored using fresh seed-containing hay (green hay). Both turf transplants (Fig. 7) and fresh-seed-containing hay (Fig. 8) were collected from undisturbed donor sites. These two restoration techniques had previously been tested in a research project in the same area in 2007 by the Agricultural University of Iceland in cooperation with Reykjavík Energy (Aradóttir & Grétarsdóttir 2011).

Figure 7. A site at Hellisheiði which had been disturbed through installation of thermal pipes. Here turf transplants have been spread to restore the vegetation of the site (Photo: Emmanuel Mwathunga)

Figure 8. A site at Hellisheiði which had been disturbed through construction work. Fresh seed-containing hay was used to restore the site and resulted in good vegetation cover (Photo: Emmanuel Mwathunga)

2.1.3 Stíflisdalur

Stíflisdalur is a quarry that had been abandoned for almost 20 years before being reclaimed by the ICERA. Reclamation of the site did not involve much prior planning and design but rather it involved reshaping the area to match the surrounding landscape through refilling of the site with materials (rock chippings and top soil) from neighbouring areas. During the reshaping of the landscape special care was taken to ensure that the steepness of the slope was at least 1/3 (1cm rise for every 3cm run) and not exceeding 1/2.5 to minimize erosion (Fig. 9). The final stage involved grass seeding and the site is gradually being colonized by native plant species (Fig. 10).

Figure 9. The reclaimed site at Stíflisdalur. Gentle slopes were created which provided good resistance to erosion and favourable conditions for a good vegetation cover (Photo: Emmanuel Mwathunga**)**

Figure 10. Vegetation at a reclaimed site at Stíflisdalur. Apart from the grass which was seeded, native plant species were observed to be colonizing the reclaimed site at Stíflisdalur (Photo: Emmanuel Mwathunga)

2.1.4 Litli-Reyðarbarmur

Litli-Reyðarbarmur is a quarry site recently reclaimed by the ICERA. Excavations for rock material used in road construction were only done on the western side of the ridge and the eastern side was left undisturbed.

The excavated western side of the site was first refilled with tephra (volcanic rock fragments) and then reshaped to look like the undisturbed eastern side of the site (Figs. 11, 12 & 13). Due to cost implications, no top soil was spread on top of the reshaped site and no vegetation was planted but rather left for the native vegetation from the eastern undisturbed site to colonize the area (Fig. 14).

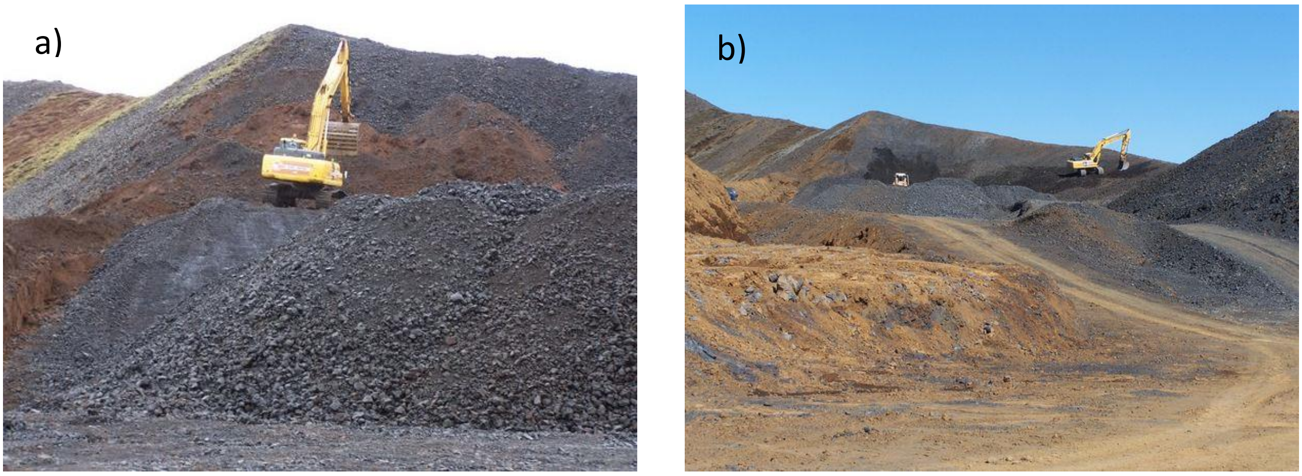

Figure 11**.** The excavated western side of the site at Litli-Reyðarbarmur: a) tephra was first added to fill up the crater; b) an excavator was then used to level the tephra which was used in refilling the crater (Photo**:** Námur.is, 2017)

Figure 12. The refilled and levelled site at Litli-Reyðarbarmur. The western side which was refilled was levelled to resemble the undisturbed eastern side (Photo: Námur.is, 2017)

Figure 13. Litli-Reyðarbarmur after fully being reclaimed. The reclaimed site was shaped to resemble the whole ridge (Photo: Emmanuel Mwathunga)

Figure 14. The colonization of native vegetation in the reclaimed quarry at the ridge Litli-Reyðarbarmur. The ridge was left undisturbed on the eastern side and after the reclamation vegetation from that site stared to colonize the reclaimed western side (Photo: Emmanuel Mwathunga)

3. RESULTS

A total of five sites were visited where different restoration/reclamation techniques were used. In order to observe a wide variety of techniques, a combination of both restored/reclaimed mine and general restoration sites were studied. The sites included three mine sites reclaimed by ICERA and Reykjavik Energy and two general restoration sites restored/reclaimed by Reykjavik Energy. The study revealed five different techniques.

The first technique observed at Gígahnjúkur, a mine site, involved refilling the excavated crater with tephra, rocks and soil and then revegetating the refilled area with grass seeds and moss. The second and third techniques observed at the Hellisheiði sites were used to restore general degraded sites. One involved the use of turfs scattered over the restoration site and the other involved spreading of seed-containing hay (green hay). The fourth technique which was observed at Stíflisdalur, a mine site, involved refilling of the excavated site with rock chippings and soil, making gentle slopes and then seeding with grass. The fifth technique observed at Litli-Reyðarbarmur, another mine site, involved refilling of the excavated site with tephra and reshaping, with no vegetation added on the final area.

Only minor differences were observed within in the techniques used in reclaiming the three different mine sites, whereas substantial differences were observed between the techniques used to restore/reclaim mine sites and general restoration sites. The main difference is that reclamation of mine sites requires usage of materials (rock chippings, tephra and soil) to refill the crater created with excavation activities which then is followed up with either revegetating the area or not. This was not required on the general restoration sites because little or no excavations had been made that extensively disturbed the soil structure so revegetation of the sites was the focus for the restoration/reclamation work. Each of the five different methods was evaluated based on the five objectives of the study (see introduction) and the results of that are presented in Table 1.

Table 1. Results from literature study and field visits with respect to the specific objectives of the study. Five different sites were visited in south-west Iceland and five different sites were observed. There was a difference in how mine sites and eroded/degraded sites were restored/reclaimed. Mine sites involved the use of different rock and soil materials to refill the craters and then vegetating, while degraded sites focussed mainly on establishing a vegetation cover.

Study site	Cover system/technique used	Objectives	Observations/Results
a) Gígahnjúkur	Refiling with materials (tephra, rock chippings and soil) and revegetating	i) Use of minimal thickness of top soil and still producing optimum results	The system used minimal amount of top soil which was mixed with tephra and rocks to imitate a natural texture and create favourable conditions for vegetation colonization.
		ii) Ability to support and sustain a vegetation cover	The system sustained the moss vegetation cover better than the grass vegetation cover.
		iii) Ability to resist erosion before vegetation becomes established	The system showed good resistance to erosion.
		iv) Simplicity to construct and ability to maximise the use of locally available materials	Except the grass seeds, the system used locally available tephra, rock chippings, soil and moss and was easy to construct.
		v) Other cost-effective and relevant aspects	The system used some tephra and rock chippings from demolition/construction sites which could otherwise be discarded.

Study sites	Cover systems/techniques used	Objectives	Observations/Results
b) Hellisheiði - Geothermal pipe installation sites	Use of turf transplants	i) Use of minimal thickness of top soil and still producing optimum results	Since grass turfs already have a minimal thickness of top soil no additional top soil was applied.
		ii) Ability to support and sustain a vegetation cover	Vegetation cover was well supported and sustained in this system.
		iii) Ability to resist erosion before vegetation becomes established	There was good ability to resist both wind and water erosion.
		iv) Simplicity to construct and ability to maximise the use of locally available materials	The system was simple to construct and used locally available turf transplants.
		v) Other cost-effective and relevant aspects	The system used some grass turfs from construction sites which could otherwise be discarded.
c) Hellisheiði - Site close to the main power plant	Use of green hay	i) Use of minimal thickness of top soil and still producing optimum results	The system did not use any quantity of top soil since it is used in areas which already have some top soil.
		ii) Ability to support and sustain a vegetation cover	The system had very good results in terms of supporting and sustaining a vegetation cover.
		iii) Ability to resist erosion before vegetation becomes established	The application of the green provided a perfect cover for both wind and water erosion.
		iv) Simplicity to construct and ability to maximise the use of locally available materials	The method used locally available hay and was easy to construct.
		v) Other cost-effective and relevant aspects	None

Study sites	Cover systems/techniques used	Objectives	Observations/Results
d) Stíflisdalur	Refiling with materials (rock chippings and soil), making gentle slopes and seeding with grass	i) Use of minimal thickness of top soil and still producing optimum results	The system used a minimal thickness top soil taken from the surrounding area even though the actual thickness was not measured during the application of the top soil.
		ii) Ability to support and sustain a vegetation cover	The system had very good results in terms of supporting and sustaining the grass vegetation cover plus native plant species were observed to be colonizing the area.
		iii) Ability to resist erosion before vegetation becomes established	The gentle slopes constructed provided a good environment for erosion resistance before the grass became fully established.
		iv) Simplicity to construct and ability to maximise the use of locally available materials	Though the system involved the use of machinery and purchased grass seeds, the construction was fairly simple and involved the use of locally available rock chippings and soil.
		v) Other cost-effective and relevant aspects	None
e) Litli-Reyðarbarmur	Refiling with tephra without revegetating	i) Use of minimal thickness of top soil and still producing optimum results	No top soil was added
		ii) Ability to support and sustain a vegetation cover	No vegetation was planted but rather left for native vegetation to colonize. Colonization of native vegetation was observed to be rather slow.
		iii) Ability to resist erosion before vegetation becomes established	Due to the steepness of the ridge erosion was observed on the site and demonstrated through the accumulation of soils at the bottom of the ridge.
		iv) Simplicity to construct and ability to maximise the use of locally available materials	Though the system used locally available tephra, the heavy use of machinery to level the site in accordance with the shape of the ridge made it complex.
		v) Other cost-effective and relevant aspects	None

4. DISCUSSION

Since early civilization to the present, mining has played a crucial part in human existence (Hartman et al. 2002). It used to be common to abandon mine sites after mining (Zyl et al. 2002) but during the late 19th and early 20th centuries formal reclamation/rehabilitation of mine sites became mandatory due to improved regulations on safety and protection of the environment (Hockley & Hockley 2015). Today, the field of mine reclamation/rehabilitation has progressed greatly with development of new techniques and tools (Ibarra & De Las Heras 2005). However, in the informal mining industry (ASM), abandonment of mine sites after mining, or when the sites have stopped being productive, is still very common (Zyl et al. 2002). Abandoned mine sites present a lot of safety, health and environmental challenges, for example, the pits create a threat to both people and animals that may fall into them and get injured, and mining activities degrade the land to such a level that cultivation is impossible, causing food insecurity in the surrounding communities.

Abandonment of artisanal and small-scale mines is a big problem in many countries, for example Malawi which is the focus of this study, and information on cost-efficient restoration methods is needed. Iceland has a relatively long history of reclaiming/restoring its severely degraded landscapes (Aradóttir 2003; Crofts 2011) and much emphasis has been on developing different techniques for restoration/reclamation. Here an assessment has been made of five different restoration techniques with the aim of determining the best techniques suited for ASM restoration in Malawi and recommendations are made.

4.1. Techniques used for restoration/reclamation

4.1.1 Refilling with materials (tephra, rock chippings and soil) and revegetating with grass seeds and moss

The technique involved filling the crater with a combination of tephra, rock chippings and soil and later vegetating with grass seeds and moss.

Top soil is an important aspect of restoration/reclamation of degraded sites as growth rate, health and visual appearance of plants on such sites are all directly linked to richness in organic matter (Koenig & Isaman 2002). In this technique, a minimal quantity of top soil was used but still showed optimal results in terms of supporting a good vegetation cover, making this technique especially suitable for ASM in Malawi because lack of top soil due to mismanagement is common. The grass and moss created a good vegetation cover on the site which protected the soil surface from both wind and water erosion. An established vegetation cover is also important in restoration/reclamation because it increases soil organic matter, moderates soil pH and brings mineral nutrients to the surface for accumulation (Koenig & Isaman 2002). Almost all the material used in reclaiming the site was obtained locally, reducing the costs that could be incurred if these materials were sourced elsewhere. This is also an advantage for ASM as finances are always limited in this subsector (Hentschel et al. 2003).

The cost of using machinery and exotic grass seeds in this technique affects its suitability in the ASM in Malawi, where it is important to keep cost at a minimum. Likewise, the unavailability of materials like tephra and moss in Malawi can make this technique not directly applicable in Malawi. However, tailoring these conditions to those found in ASM may make it applicable.

4.1.2 Use of turf transplants

This technique uses whole turfs which are taken from an undisturbed donor site and then applied to the site to be restored/reclaimed (recipient site). As observed by Aradóttir and Grétarsdóttir (2011), transferring of turfs onto a recipient site results in the quick colonization of vegetation making this an ideal technique for restoration/reclamation. However, harvesting turf from an undisturbed site causes disturbance of the donor site, so to minimize disturbance caused by this technique would be to collect turfs from an area which is already undergoing construction (when situations allow such).

The use of locally available turf transplants in this technique reduces the costs that could be incurred if these were sourced elsewhere. Turf transplanting introduces a variety of native plant species onto the recipient site, including moss and lichens, which are often left out in revegetation projects, but research has shown that survival composition of native species diverges from the donor site (Bullock 1998) with transplant survival ranging from 50 to 100% of species at the donor sites (Kiehl et al. 2010). The usage of native plant communities usually results in more biodiversity as compared to seeding with fast-growing plant species which result in homogenous plant communities (Aradottir & Oskarsdottir 2013). The success of this technique in restoration/reclamation depends on several factors such as the size of the turfs, growth form and conditions at the recipient site (Aradottir 2012).

This technique is very applicable to conditions in ASM in Malawi because it is low-cost and uses locally sourced material which does not require heavy machinery. Exceptions to this might be if turfs are not locally available. Another advantage of this technique is that the revegetation process is short, making it a good option for ASM in Malawi. The major activity before using this technique would be to refill mine pits with other rock or soil materials first.

4.1.3 Use of green hay

This technique uses seed-containing green hay which is harvested from a species-rich donor site and is spread on the recipient site (Magnificent Meadows 2016). The seeds from the hay colonize and revegetate the area.

Green hay is collected when seeds are being shed and still green as opposed to conventional dry hay. The use of green hay in restoration is preferred over dry hay because it contains a higher proportion and diversity of seeds, whereas a big proportion of seeds in dry hay are shed in the processes of drying and collecting, and what remains mostly are grass seeds resulting in less plant diversity (Peel et al. 2010). This technique of collecting green hay protects the seeds, holds moisture, adds organic material to the soil and enhances colonization of plants. The fresh hay adheres to the soil surface when it is drying (Magnificent Meadows 2016) which reduces the probability of soil erosion, making it a very useful option in land restoration. Furthermore, the technique makes use of locally available seed-containing green hay which makes it a better option over buying commercial seeds. The harvesting of seed-containing hay causes vegetation disturbance from the donation site but this is not significant because of subsequence regrowth (Aradóttir and Grétarsdóttir 2011). However, this method has the disadvantages of transferring seeds of weeds and problematic species along with the desirable species. Also, there is a probability that only seeds from plants that are about to shed seeds are collected, leaving out those from plants that shed seeds before or after collection (Magnificent Meadows n.d.).

The successful implementation of this technique requires careful planning and organization of actions for two reasons. Firstly, the recipient site which is meant to be restored must have its surface properly levelled before the hay is applied because spreading of hay onto an unprepared site is very unlikely to yield positive results. Secondly, the green hay must be immediately spread onto the reception site after it is cut as any delay can cause heating which can threaten the survival of the seeds (Peel et al. 2010).

This technique can be applied in ASM in Malawi but it requires mine pits to be refilled with rock or soil materials and a substantial amount of top soil to support the vegetation colonization. The use of machinery to harvest the seed-containing hay may have minor cost implications but cheaper methods for harvesting the hay can be used, e.g. using a sickle/scythe.

4.1.4 Refilling with materials (rock chippings and soil), making gentle slopes and seeding

This technique involved the refilling of the crater with rock chippings, making gentle slopes, spreading top soil and then seeding with fast-growing grass seeds. The heavy use of machinery in this technique for reshaping of the area to create gentle slopes, seeding of grass and fertilizing has high cost implications. However, the local sourcing of materials (rock chippings and top soil) used in refilling the crater might reduce the cost.

No significant indications of soil erosion were observed on the site which most likely can be attributed to the gentle slopes and usage of fast-growing grass seed, which together ensured a quick establishment of vegetation cover. Both gentle slopes and a solid vegetation cover reduce the speed of water to break off and carry soil particles, which is important during the restoration process (Queensland Government 2015).

This technique has a lot of cost involved because it requires extensive usage of heavy machinery. For that reason it is not a preferred option, and the applicability of this technique in ASM in Malawi would require the substitution of heavy use of machinery with affordable local techniques. The availability and cost of grass seeds in Malawi may also have implications on whether this technique would be suitable and needs further observation before implementation.

4.1.5 Refilling with tephra without revegetating

This technique involved the refilling of the excavation with tephra. No vegetation was added onto the site but rather was left for the colonization of native plant species. In comparison to the other techniques that similarly use machinery and materials to refill the crater, this technique is regarded as the most cost-effective due to its non-use of externally sourced top soil and plant seeds. Natural regeneration defined as the natural regrowth of native plant communities from self-sown seeds or vegetation sources in cleared or disturbed areas (Land for Wildlife 2001) is the preferred way of establishing vegetation on the site. Plants establish at a most suitable time when soil conditions are favourable for them, i.e. when the right nutrient levels are present and right soil structure has been formed (Magnificent Meadows n.d.). However, this presents a challenge because it takes a long time for vegetation to establish, which may make this technique inapplicable in areas where quick recovery of vegetation is required. Soil was observed to be accumulating at the bottom of the reclaimed ridge indicating an occurrence of soil erosion. This could be attributed to the steep ridges created and the absence of vegetation cover which in turn can affect the success of using the technique.

This technique is not very suitable for ASM in Malawi because of how long the restoration/reclamation takes. Because the technique does not add any top soil or encourage revegetation, colonization of native vegetation happens after a long period of time and additionally it has cost implications for it requires usage of heavy machinery.

5. CONCLUSION

Experience from the study has revealed that several things need to be considered before employing the restoration/reclamation techniques observed in this study. These include the intentions for restoring/reclaiming the area, availability of resources and materials, and the status or condition of the site to be restored/reclaimed. Consequently, there is still a need to do more research on the studied techniques with regard to the conditions in ASM in Malawi and find more cost-effective, socially-acceptable, and practical ways to restore/reclaim ASM sites. This would solve mine abandonment challenges causing land degradation and threatening livelihoods in Malawi.

6. RECOMMENDATIONS

Abandonment of mine pits after cessation of activities has been, and remains, one of the serious challenges in the ASM subsector in Malawi. Both the Mines and Minerals Policy (2007) and Artisanal and Small-scale Mining Policy (draft) have highlighted this as one of the major factors contributing to environmental degradation in Malawi. Strategies for tackling this challenge have focused on enforcement of relevant laws and regulations, rather than supporting the sub-sector through research of the underlying causes of this challenge and finding appropriate solutions. This research project is the first step in bridging that gap by assessing five different techniques used in restoring/reclaiming degraded sites in Iceland, four of which have the possibility of being suitable to use in ASM in Malawi. These techniques are:

1. Refilling with materials and revegetating
2. Use of turf transplants
3. Use of green hay
4. Refilling with materials, making gentle slopes and seeding with grass

However, to successfully implement these techniques the following are suggested:

1) Because of the differences between the conditions and materials available in the study areas in Iceland and the ASM sites in Malawi, further studies of local conditions are needed to assess the possibility of using the techniques.

2) In ASM areas where mine pits are too extensive to be filled up using hand-tools financial support is necessary to pay for the use of heavy machinery.

3) In ASM areas where disturbances from people or animals is inevitable, the use of fast growing grass seeds is recommended to successfully establish vegetation cover even though this may have cost implications.

4) Because of the importance of water for revegetation and growth of plants, it is recommended that reclamation activities be performed at the start of or during the rainy season.

ACKNOWLEDGEMENTS

This has really been an exciting and great learning experience for me getting to learn both in theory and practice all aspects of land restoration and to successfully conduct this research project which I believe if properly implemented will change the face of artisanal and small-scale mining in Malawi in terms of mine reclamation/rehabilitation. All this would not be possible had it not been the contribution of several great minds to whom I also owe sincere gratitude. First and foremost, I would like to thank The Almighty God, the source of all wisdom, knowledge and grace. My sincere gratitude should go to the UNU Land Restoration Training Programme (and management team - Hafdis Hanna, Berglind, Halldóra and Azfar) and the Icelandic Government for this opportunity and of course this well managed, structured and practical training programme. To my two supervisors Lilja Jóhannesdóttir and Tómas Grétar Gunnarsson who have greatly helped in shaping this research project using their vast knowledge and experience, I say thank you very much. To Magnea Magnúsdóttir, Gunnar Bjarnason and Járngerður Grétarsdóttir, thank you for providing me with the necessary information and permission to use your materials. Last but not least, I would to thank all friends and family who have provided me with different types of support.

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