UNITED NATIONS UNIVERSITY

UNU-LRT

Land Restoration Training Programme
Keldnaholt, 112 Reykjavik, Iceland

Final project 2016

SEWAGE SLUDGE AND MUNICIPAL WASTE: POTENTIAL SOURCES OF PHOSPHORUS FOR LAND RESTORATION

Principal Mdolo
Lilongwe University of Agriculture and Natural Resources
NRC Campus, PO Box 143, Lilongwe, Malawi
pmdolo@nrc.luanar.ac.mw

Supervisor
Dr Magnús H. Jóhannsson, PhD
Soil Conservation Service of Iceland
magnus@land.is

ABSTRACT

Waste disposal is one of the environmental challenges facing city authorities. Waste contains nutrients and organic matter required for plant growth that can, in many cases, be recovered and put to use. Quantifying the amount of waste generated and nutrients that can be recovered from it is important. Further, cost of applying the waste on land should be evaluated in order to make wise investment decisions. Globally much of the waste generated is disposed without resource recovery. Therefore, the objectives of this study were to 1) quantify the amount waste generated in the Reykjavík capital area in Iceland, 2) determine the quantity of phosphorus contained in waste and 3) evaluate the cost of transporting the waste to nearby restoration sites and spreading it on the field. Operational data were collected from operators of wastewater and municipal waste treatment in the capital area. The capital area generated 722 tons/year of sewage sludge, 98,890 tons/year of solid waste and 82 million m^3/year of wastewater in 2015. Wastewater treatment and municipal waste contributed 68% and 32% phosphorus, respectively. Phosphorus disposed in waste was 435% higher than the phosphorus used by the Soil Conservation Service in 2015. If all this phosphorus were recovered, it would most likely meet all the phosphorus requirements for land restoration in Iceland. The cost of utilizing phosphorus from waste is higher than using inorganic fertilizers. However, for highly degraded soils, such as those with an erosion scale of 3-5, application of waste would quicken soil recovery as it is rich in organic matter and nutrients. Further, utilizing waste reduces environmental pollution and conserves the non-renewable phosphorus reserves. The study recommends that waste be utilized in restoration as a means of recovering and reusing phosphorus. Legislation should be put in place to encourage waste utilization in land restoration.

This paper should be cited as:
Mdolo P (2016) Sewage sludge and municipal waste: potential sources of phosphorus for land restoration. United Nations University Land Restoration Training Programme [final project]
http://www.unulrt.is/static/fellows/document/Mdolo2016.pdf

TABLE OF CONTENTS

1. INTRODUCTION 1
1.1 The waste management challenge 1
1.2 Application of sewage sludge and organic waste in agriculture and land restoration 1
1.3 Importance of waste as a source of phosphorus 4
2. METHODOLOGY 6
2.1 Description of the study area 6
2.2 Data collection and phosphorus quantification 7
3. RESULTS 9
3.1 Waste generation rates and phosphorus content in sewage sludge, municipal solid waste and wastewater 9
3.2 Cost of utilizing sewage sludge and municipal solid waste in land restoration 10
4. DISCUSSION 10
4.1 Waste generation and phosphorus content 10
4.2 Economic evaluation of transporting and spreading the waste in restoration field 11
4.3 Limitations of the study 12
5. CONCLUSION 12
ACKNOWLEDGEMENTS 13
LITERATURE CITED 14

1. INTRODUCTION

1.1 The waste management challenge

Waste is a man-made resource that is considered of no beneficial use to the owner or is not able to perform with respect to its desired function (Pongrácz & Pohjola 2004). This definition of waste implies that it depends on the functionality of the material, whether it is waste or not. Waste can be categorized based on its origin, i.e. industrial, municipal or agricultural waste. Industrial waste originates from industries and its composition depends on the activities of the industry. Municipal waste includes waste originating from residences and businesses. This waste is highly organic (Hargreaves et al. 2008; Cesaro et al. 2015) due to the nature of activities that lead to its generation. Agricultural waste includes waste originating from agricultural activities such as crop and livestock production and agro-processing (Jana & De 2015). Waste can also be categorized by grouping it according to form, i.e. liquid, gaseous or solid waste. Waste management is the control of waste-related activities with the aim of protecting the environment, public health and resource conservation (Pongrácz & Pohjola 2004). Among other activities, waste management is concerned with the control of waste generation, collection, processing and disposal. Waste management is one of the major environmental challenges facing municipalities (Odlare et al. 2011) but varies with the economy and environmental regulations of the country (Desmidt et al. 2015). Most households in developed countries are connected to the main sewer and dispose of solid waste through landfilling, incineration or composting (Gentil et al. 2009). On the other hand, most countries in Africa do not have adequate waste management infrastructure (Couth & Trois 2010, 2011) such as wastewater treatment systems and solid waste management facilities. Malawi, for example, still disposes of municipal solid waste in uncontrolled open dumps and discharges partially treated wastewater effluent into urban streams (Sajidu et al. 2007; Kumwenda et al. 2012; Wanda et al. 2015; Mdolo 2016). Consequently, untreated or partially treated waste is often discharged into the environment causing environmental pollution such as eutrophication (Wang et al. 2014).

1.2 Application of sewage sludge and organic waste in agriculture and land restoration

Wastewater, sewage sludge and municipal solid waste are among the waste that is generated in urban areas. Such waste has potential application in agriculture and land restoration due to its organic and nutrient content. Wastewater, also known as sewage, is used water collected from residences, institutions, businesses and industrial establishments together with ground water, surface water or storm water, as may be present (Raynolds & Richards 1996; Metcalf & Eddy 2003), and conveyed to a treatment plant for processing (Malawi Government 2008). The main product of wastewater treatment is the treated effluent which is mostly discharged into receiving water bodies. Sewage sludge is a by-product of wastewater treatment (Song & Lee 2010) and is a complex of mixed semisolids comprising organic materials, microorganisms and inorganic materials that settle at the bottom of wastewater treatment ponds/tanks (Tyagi & Lo 2013) while the liquid supernatant proceeds to the next treatment process. Figure 1 shows the layout of a conventional wastewater treatment system.

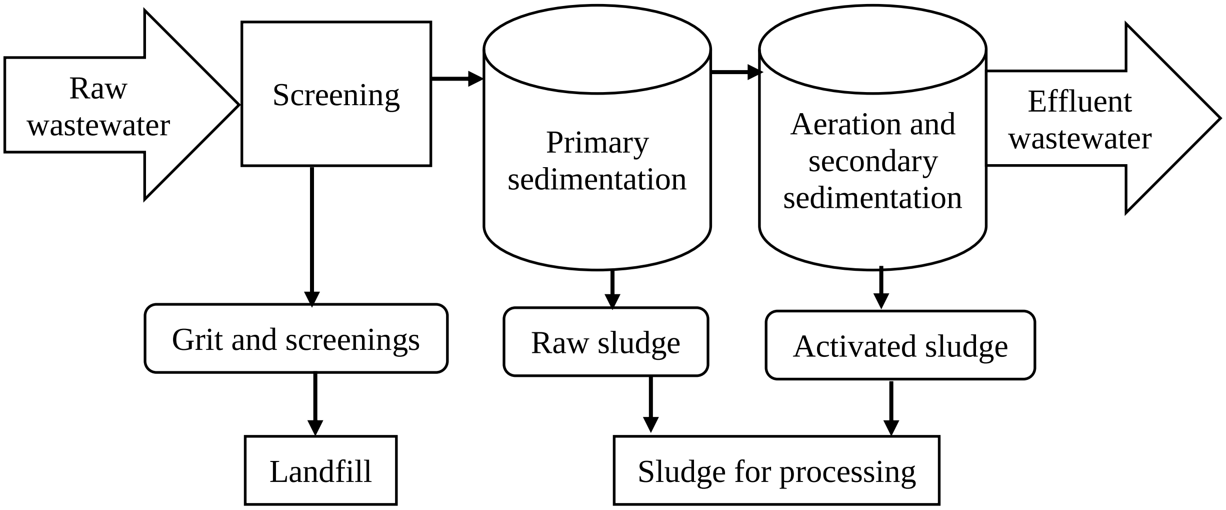

Figure 1. Schematic diagram of a wastewater treatment plant showing stages where sewage sludge is generated (Source: Modified from Water UK 2010).

In such systems, sewage sludge is generated in the primary treatment stage. This stage involves primary sedimentation. It is also generated in the secondary treatment process involving an activated sludge system. Consequently, sewage sludge generated in the primary and secondary stages is known as primary and secondary/activated sludge, respectively. Activated sludge contains active microorganisms utilized in wastewater treatment (Saunders et al. 2016).

Sewage sludge is rich in organic matter, nutrients and other essential elements required for plant growth, hence its potential for soil conditioning and nutrient addition (Antolín et al. 2005; Alvarenga et al. 2015). However, sewage sludge also contains considerable amounts of toxic substances such as heavy metals (Usman et al. 2012; Bruun et al. 2016) which have the potential of causing soil contamination (Bravo-Martín-Consuegra et al. 2016). In addition, heavy metals can be taken up by plants together with nutrients and become available to grazers and human beings. It is, therefore, desirable to properly treat sewage sludge and analyse its chemical composition (Council of the European Communities 1986; Withers et al. 2016) before applying it to land. Treatment of sewage sludge may include digestion, stabilization (liming), dewatering and drying (Water UK 2010) or composting to reduce the risk of heavy metal contamination (Smith 2009). Composting also reduces the volume of waste (Hargreaves et al. 2008) and hence reduces the transportation cost of the product. Sewage sludge can be co-composted with other waste such as municipal waste to improve the quality of compost before application. Composts produced from co-composting of sewage sludge and other waste tend to have higher metal contents (Hargreaves et al. 2008) than composts produced from municipal solid waste alone, due to the high metal content in the sewage sludge. Increasing the maturity period of co-composts increases the humic material in the compost which binds heavy metals (Hargreaves et al. 2008) and hence greatly reduces their bioavailability to plants, animals and human beings. Co-composting of sewage sludge can be advantageous in situations where the final product will be applied on restoration fields and not on fields where food crops will be grown. Composting facilities include windrowing, aerated static piles and horizontal agitated solids beds (Wei et al. 2001). The choice of the composting facility depends on the moisture content of the input raw material (Wei et al. 2001). Compared with the other two composting facilities, aerated static piles and horizontal agitated solid beds, windrowing is economical to build and operate (Wei et al. 2001).

Municipal solid waste, especially food and yard waste, is another potential source of organic matter and nutrients. The need for recycling and re-using municipal solid waste is increasing due to restrictions placed on land disposal of such waste. Restrictions on land disposal of waste could be linked to 1) increasing human populations which lead to less land available for waste disposal and 2) uncertainty with phosphate reserves for the production of inorganic fertilizer (Reijnders 2014). As governments struggle to provide settlements and food for growing populations, more stringent regulations will be placed on waste management practices (Tyagi & Lo 2013; Desmidt et al. 2015). Therefore, the design of future waste treatment facilities should encourage nutrient recovery (Wahlberg 2014), shifting from the current focus of protecting the environment and public health to resource recovery (Pongrácz & Pohjola 2004). Failing to do so will have profound effects on the existence of life (Sverdrup & Ragnarsdottir 2011) if phosphorus reserves are depleted.

Land application of waste adds organic matter to soil, which improves its biological and physicochemical characteristics such as improving aggregate stability and decreasing bulk density (Diacono & Montemurro 2010). Organic matter increases soil organic carbon and nitrogen (Diacono & Montemurro 2010) and can reduce plant parasitic nematodes (Treonis et al. 2010). Higher yields can be realized for crops grown on soils with applied waste (Antolín et al. 2005). However, crops can also accumulate toxic metals if the waste is applied excessively, given that the waste is rich in toxic metals (Antolín et al. 2005). Therefore, use of sewage sludge compost and other composts on non-food plants is a potential alternative. Regulations on land application of sewage sludge and other composts on non-food plants are less restrictive than those regulating application on food crops. For example, land application of sewage sludge in the EU is regulated by the EU sewage sludge directive 86/278/EEC (Council of the European Communities 1986). Within this regulation, grazing animals can be allowed to graze in sewage sludge amended fields after three weeks of application (Council of the European Communities 1986). Iceland has adjusted the directive 86/278/ECC by developing regulation 799/1999 on the handling of sewage sludge (Ministry for the Environment 1999). In accordance with this regulation, untreated sewage can be applied to restoration fields if it is ploughed into the soil (Ministry for the Environment 1999). Further, the Ministry allows a one-year period to elapse after application of treated sewage sludge before the land can be put to beneficial use again (Ministry for the Environment 1999). Therefore, for land restoration purposes, application of sewage sludge and other composts could be ideal and the restored fields could be used for grazing in future. In Malawi, national standards regulating land application of sewage sludge and other composts do not exist. Consequently, untreated sewage sludge is often applied on home gardens and lawns. Members of the public often manually excavate the sludge from wastewater treatment ponds and transport it to their homes or gardens for application. Environmental monitoring is usually not undertaken in areas where the sludge has been applied to assess the environmental risk to public health and the receiving soils. Analysis of the physico-chemical characteristics of sewage sludge is most often not performed by the operators.

In Iceland, land application of sewage sludge and other composts would be ideal and in line with the ongoing land restoration efforts. The practice, if adopted, would reduce the amount of waste landfilled or discharged into the ocean and consequently reduce the use of inorganic fertilizer for restoration. Since Icelandic soils are predominantly basic (Arnalds 2015), application of composted sewage sludge and municipal solid waste is expected to have minimal impact on heavy metal contamination. The pH value plays a major role in the sorption of heavy metals since there is low heavy metal uptake by plants at pH values above 7 (Smith 2009). At such pH values, the soluble form of heavy metals is converted into insoluble metal hydroxides or oxides which cannot be taken up by plants (Brady & Weil 2008). However, in Iceland, as vegetation is established in restored areas, the pH values tend to decrease (Arnalds 2015), which could lead to sorption of heavy metals, making them available to plants and hence grazing animals. Therefore, continued application of compost and sewage sludge should be followed by periodic monitoring of the soils and plants (Singh & Agrawal 2008) for heavy metal toxicity.

1.3 Importance of waste as a source of phosphorus

The cost of inorganic fertilizers is increasing due to increasing production costs (Cordell & White 2011) and uncertainty concerning the size of phosphate reserves (Reijnders 2014). It is argued that the current phosphorus reserves will last for the next 30 to 300 years (Cordell & White 2011). Regardless of when the reserves will be depleted, it is clear that the sustainability of inorganic fertilizers is uncertain. This is compounded by the fact that the accessibility and quality of the reserves is decreasing; hence the high cost of production (Cordell & White 2011; Desmidt et al. 2015). Research has shown that waste contains a considerable amount of organic matter and nutrients (Antolín et al. 2005; Alvarenga et al. 2015). These resources are however often left untapped in landfills and wastewater effluents (Mayer et al. 2016), as illustrated in Figure 2.

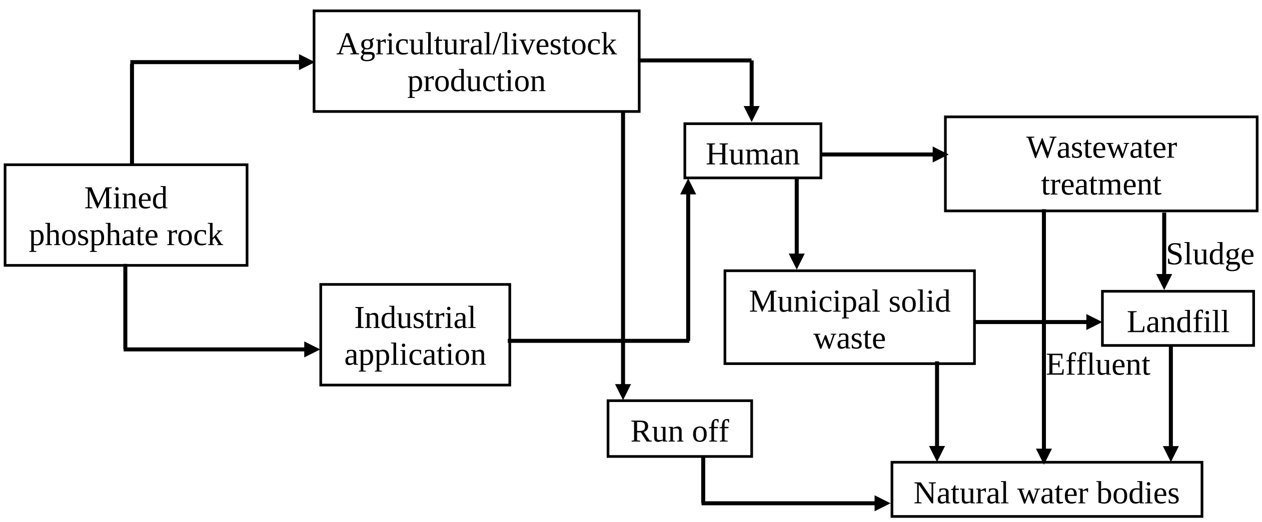

Figure 2. A flow diagram showing how phosphorus is managed from mined phosphate rock to waste after consumption. (Source: Modified from Desmidt 2015).

This practice not only causes eutrophication, as the waste ends up in natural water bodies (Desmidt et al. 2015), but also waste the precious resource needed for plant growth and soil conditioning. The current phosphorus use is, therefore, unsustainable and wasteful (Sverdrup & Ragnarsdottir 2011), especially given that it can be recycled from waste (Fig. 3). Management of phosphorus should be sustainable, with recycling it within the system (Fig. 3) rather than discharging it into the environment (Fig. 2) (Dawson & Hilton 2011).

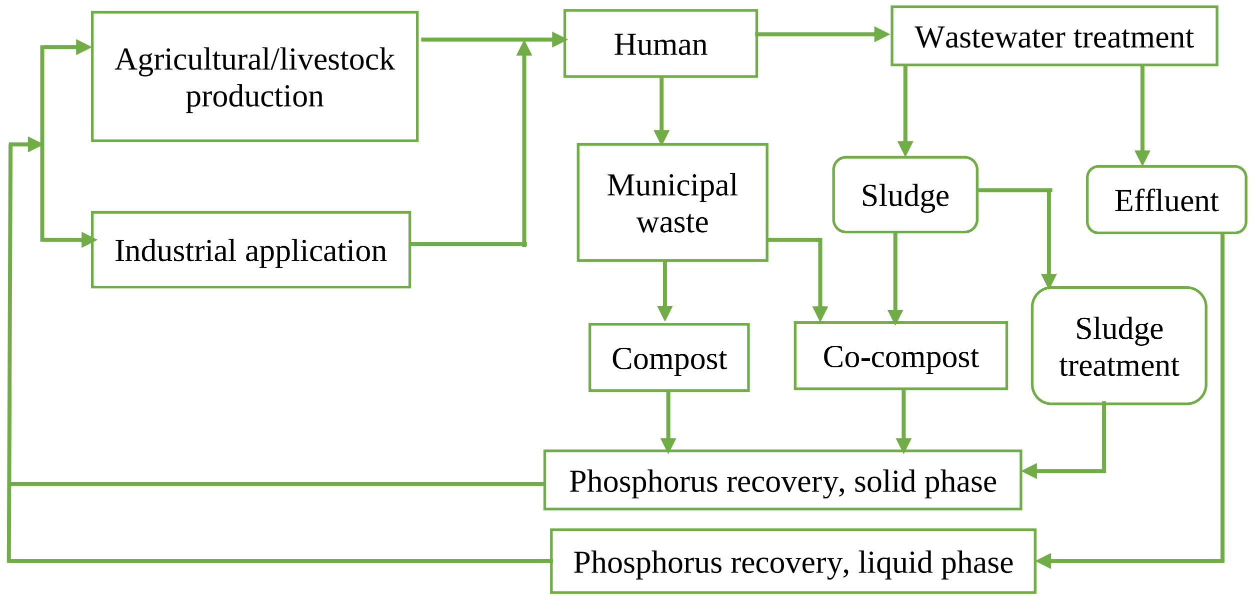

Figure 3. A flow diagram showing how phosphorus should be managed from waste back to agricultural land or industry. (Source: Modified from Desmidt 2015).

It is important to recycle and reuse phosphorus from waste streams (Dawson & Hilton 2011) in order to reduce pressure on the non-renewable reserves. If used in restoration fields, the organic matter and nutrients can improve soil microbial activity (Odlare et al. 2011), soil fertility, soil water retention and soil carbon accumulation (Song & Lee 2010). There has been progress in many parts of the world to recycle waste back into the environment as long as the application rates do not pose a risk to the environment and public health. Consequently, treated and untreated waste has been applied in agriculture, forestry and land restoration. In the European Union, for example, 41% of the sludge produced is used in agriculture (Dawson & Hilton 2011; Kelessidis et al. 2012). On a country basis, Finland reuses almost 100% of its sludge (97% after composting) in agriculture or other land application while Luxembourg, Cyprus and Portugal apply 87% of sludge in agriculture (Kelessidis & Stasinakis 2012), either directly or composted. England, on the other hand, recycles almost 80% of sewage sludge to agriculture (Water UK 2010). Western Australia applies 80% of the sludge generated in agriculture and forestry (Pritchard et al. 2010) while the US applies about 60% of sewage sludge in agriculture, land restoration or other land applications (North East Biosolids and Residuals Association 2007; Lu et al. 2012).

Data on beneficial use of sewage sludge and other organic waste for Iceland are lacking, but small trials are under way (MH Jóhannsson, 12 May 2016, Soil Conservation Service of Iceland, Gunnarsholt, Iceland, personal communication) in which different types of waste are applied in restoration fields and vegetative growth monitored. In Sub-Saharan Africa, especially Malawi, data on waste generation and land application of composts are also lacking. If these data were available, they would form a basis for lobbying governments to invest in construction of composting facilities and land application of composted waste. If waste were collected and properly treated and applied on land, the demand for inorganic fertilizers would considerably decrease and hence conserve the declining non-renewable phosphorus resource.

This study was carried out in the Reykjavík capital area partly because I was in the area at the time and could not get data for such research from Malawi. On the other hand, the study in Iceland could raise awareness on the benefits of utilizing waste in land restoration. While other developed countries are struggling with agricultural application of waste, Iceland could utilize it in restoration work other than mainstream agriculture. The results of this study will help in the design of similar studies in Malawi, profiting from lessons learnt here in Iceland.

The objectives of this research were:

i) To quantify the amount of waste generated in the Reykjavík capital area in 2015, including: wastewater, sewage sludge and municipal waste
ii) To determine the quantity of phosphorus in the amount of waste generated in the capital area for 2015
iii) To evaluate the cost of transporting the waste to nearby restoration sites and spreading it on the field.

2. METHODOLOGY

2.1 Description of the study area

This study was conducted in the Reykjavík capital area in Iceland, which comprises seven municipalities. The population of the capital region in 2015 was 211,282 (Statistics Iceland 2015) which was 64% of the national population. The names and distribution of the population in the seven municipalities making up the capital region are shown in Table 1.

Table 1. Population in the Reykjavík capital region (Statistics Iceland 2015)

Municipality	**Population**
Reykjavík	121,822
Kópavogur	33,205
Hafnarfjörður	27,875
Garðabær	14,453
Mosfellsbær	9,300
Seltjarnarnes	4,411
Kjósarhreppur	216
Total	**211,282**

Waste management regulations in Iceland are based on European Union regulations and each municipality develops its own waste management plans. The Environmental Agency of Iceland (Umhverfisstofnun) is responsible for developing the national waste management plan. Local authorities are supposed to develop their own local waste management plans based on the national waste management plan. In the Reykjavík capital region, solid waste management is coordinated and handled by SORPA, a company jointly owned by municipalities in the area. Wastewater treatment and sewage sludge management is operated by Reykjavík Energy.

2.2 Data collection and phosphorus quantification

This study focused on waste which could be readily composted and utilized in land restoration. Hazardous waste, textiles, metals and plastics were not considered. Timber, wood, packaging waste, paper and cardboard were also not included in the analysis due to their low phosphorus content. Furthermore, these waste fractions are already exported to Sweden for recycling (Saltiola 2014). Therefore, to quantify the amount of phosphorus available in the three major waste streams (wastewater, sewage sludge and municipal solid waste), operational data from wastewater and municipal solid waste operators in the Reykjavík capital region were used. Data collected was on waste generation rates for the year 2015. The operator sampled the effluent wastewater in March, June, September and December 2015 for monitoring nutrient content of the effluent. Phosphorus content in sewage sludge and municipal solid waste was calculated based on phosphorus content values (Table 2) and their moisture content (Table 3) reported in the literature.

Table 2. Typical phosphorus content in different waste fractions.

Item	P content (g P/kg DS)	Source
Organic waste	4	Kalmykova et al. 2012
Sewage sludge (% P_2O_5, TS)	2.5	Metcalf & Eddy 2003
Timber/wood	0.31	Sokka et al. 2004
Paper and cardboard	0.24	Sokka et al. 2004

TS= Total solids, DS= Dry solids, P= phosphorus

The amount of phosphorus in sewage sludge and municipal solid waste was, therefore, calculated from annual data acquired, using typical phosphorus values (Table 2). Calculations of phosphorus content were based on the dry matter of the waste fraction. Moisture content (% wet weight) values for each waste fraction (Table 3) were used to determine the dry matter content of the waste.

Table 3. Moisture content in different waste fractions (Kalmykova et al. 2012)

Waste fraction	Moisture content (% wet weight)
Paper & cardboard	0
Timber/wood	19
Kitchen waste	65
Garden waste	65
Other organic waste	65

Phosphorus content in wastewater was calculated from the wastewater flow rate (*Q*, *L/sec*) and phosphorus concentration (mg/L) data acquired from the operator (Reykjavík Energy), using the following equation;

$$C = \frac{m}{Q}$$

*w*here *C* = concentration of phosphorus (mg/L), m = mass of phosphorus (mg), Q = wastewater flow rate (L/sec).

The amount of waste generated, cost of composting the waste, average distance to nearest restoration sites and recommended application rates formed the basis for calculating the cost of utilizing the waste in restoration. The cost of composting was based on values reported in the literature for such operations. The figures used to calculate the cost of transporting and spreading the waste on the field were acquired from the Soil Conservation Service of Iceland based on typical operational costs for such activities. Figure 4 shows a map of the study area with possible restoration sites within a radius of 30 km to 50 km from the Reykjavík capital area with an erosion scale of 3-5. Erosion severity is based on a scale of 0-5 where point 0 on the scale represents no erosion while 5 indicates extremely severe erosion (Table 4) (Arnalds et al. 2001).

Table 4. Erosion severity scale, colour codes and suggested management actions (Source: Modified from Arnalds et al. 2001)

Erosion scale	Description	Colour code	Suggested management action
0	No erosion	Green	No suggestion
1	Little erosion	Green	No suggestion
2	Slight erosion	Green	Care needed when grazing
3	Considerable erosion	Yellow	Reduce and manage grazing
4	Severe erosion	Orange	Protected (no grazing)
5	Extremely severe erosion	Red	Protected (no grazing)

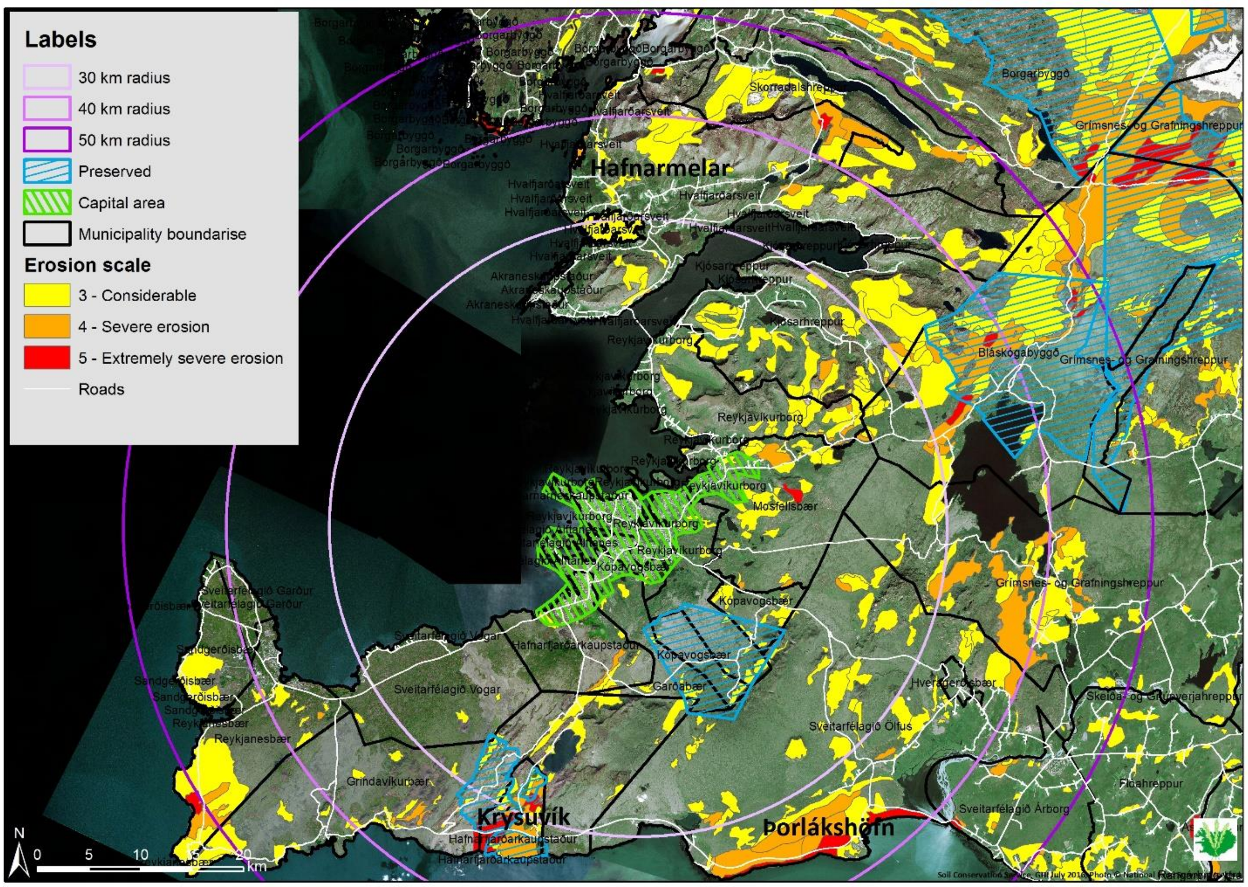

Figure 4. Map showing possible restoration sites within a radius of 30-50 km from the capital area with erosion scale of 3-5 (Source: Guðný H. Indriðadóttir, Soil Conservation Service of Iceland 2016).

3. RESULTS

3.1 Waste generation rates and phosphorus content in sewage sludge, municipal solid waste and wastewater

Results for waste generation rates and associated phosphorus content in each waste fraction of sewage sludge, paper and cardboard, timber/wood, kitchen waste, garden waste, organic waste and wastewater are presented in Table 5. The average wastewater flow rate and phosphorus concentration was 2,601 L/sec and 2.4 mg/L, respectively. The percent phosphorus contribution of each waste fraction is further presented in Figure 5.

Table 5. Amount and different types of waste generated annually in the Reykjavík capital region and their phosphorus content.

Waste fraction	Units/year	Amount	Dry matter (%)	Dry matter (tons)	Total P (tons/year)
Sewage sludge	tons	722	-	-	8
Paper & cardboard	tons	18,852	100	18,852	5
Timber/wood	tons	11,275	81	9,132	3
Kitchen waste	tons	65,721	35	23,000	92
Garden waste	tons	3,015	35	1,055	4
Other organic waste	tons	27	35	9	0.04
Wastewater	m^3	82,249,862	-	-	195
Total					**306**

Wastewater contained the highest phosphorus (Fig. 5) of all waste fractions studied. Kitchen waste was the highest solid waste generated of all the municipal solid waste (Table 5). Despite being about 25 times smaller in the quantity generated for paper and cardboard, sewage sludge contributes 3% phosphorus while paper and cardboard contribute 1%. Timber/wood and garden waste both contribute 1% phosphorus.

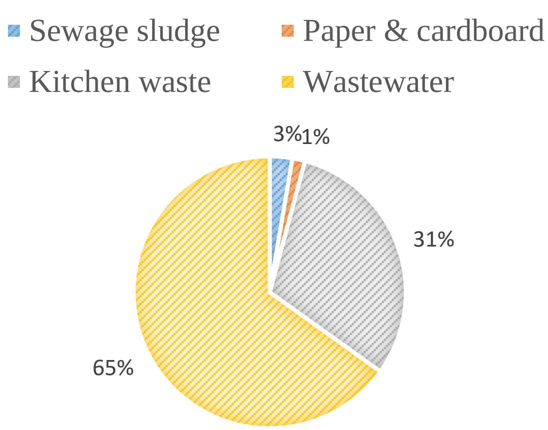

Figure 5. Percent (%) contribution of phosphorus from each waste fraction.

3.2 Cost of utilizing sewage sludge and municipal solid waste in land restoration

The cost of loading, transporting and spreading the waste in land restoration fields is presented in Table 6. Calculations were based on loading the waste in a trailer, transporting it to the nearest restoration field (50 km) and spreading it on the field at an application rate of 30 tons/ha. Therefore, one round trip to the nearest restoration field using a trailer which can take 30 tons of waste would be 100 km.

Table 6. Breakdown of the cost associated with applying 30 tons of waste on a 1 ha of restoration field.

Item	Unit	Quantity	Cost (ISK/unit)	Total Cost (ISK)
Loading	hour	2	5,000	10,000
Transport	km	100	480	48,000
Spreading	hour	2	27,000	54,000
Total				**112,000**

According to these calculations, the cost of utilizing waste on a restoration field would be around 112,000 ISK/ha. With value added tax (VAT) included at 24%, the cost of utilizing waste would be around 140,000 ISK/ha. This is, however, likely to be an upper estimate. The cost of producing 30 tons of compost would be around 60,000 ISK (Wei et al. 2001; Song & Lee 2010).

4. DISCUSSION

4.1 Waste generation and phosphorus content

The contribution of timber, paper and cardboard to phosphorus was almost negligible. Therefore, in cases where the waste management objective is to recover phosphorus from waste, it is important to consider the phosphorus content of the waste fraction rather than the amount of waste generated. It has been shown in this research that sewage sludge contributed more to the amount of phosphorus than paper and cardboard. The amount of paper and cardboard generated was higher than that of sewage sludge. In the Reykjavík capital area, sewage sludge and kitchen waste should be preferred for phosphorus recycling to timber, paper and cardboard.

A little over 82 million m^3/year of wastewater were generated in the Reykjavík capital area in 2015. This wastewater contained 195 tons/year of phosphorus. In comparison, this amount of phosphorus in wastewater effluent was four times higher than the amount in wastewater treatment plants in Gothenburg in Sweden (Kalmykova et al. 2012), a city with a population almost double that of the capital region in Iceland. This observation can be explained by the different treatment systems employed in these two cities. In Gothenburg, advanced wastewater treatment systems are employed to remove phosphorus from effluent before final disposal (Kalmykova et al. 2012; Wu et al. 2016). In the Reykjavík capital area, sewage sludge and wastewater, combined, contributed 67% of the phosphorus. This amount shows that most of the phosphorus in urban areas is contained in wastewater and sewage sludge (Chowdhury et al. 2014; Wu et al. 2016). However, most of this phosphorus is discharged as unproductive outflow into water bodies (Chowdhury et al. 2014) or landfilled (Villarroel et al. 2014).

4.2 Economic evaluation of transporting and spreading the waste in restoration field

There are many sites within a 30-50 km radius from the capital area with erosion levels of 3-5. However, not all of them would be suitable for applying waste. Some of them are grazed and only a few are fenced off from grazing. In addition, there are restrictions on such water protection areas and issues of land ownership that need to be sorted out before restoration activities are undertaken. Also, these sites may be inaccessible due to slope, height and rocks on the surface. Based on the map (Fig. 4), potential sites for waste application might be Krýsuvík in Hafnarfjörður, or Hafnarmelar in Borgarfjörður, all of which are active reclamation sites. If results of a stakeholder analysis were positive (Mackenzie 2011), grazing and fencing were in order and participants agreed on all terms of the operation, these three sites would be ideal for compost and sewage sludge application.

In 2015, about 2,500 tons of chemical fertilizer were used for land restoration with an average phosphorus content (P_2O_5) of 4.5% (MH Jóhannsson, 26 July 2016, Soil Conservation Service of Iceland, Gunnarsholt, Iceland, personal communication). The amount of phosphorus used as P_2O_5 was 113 tons. Since P_2O_5 contains 43.6% P, the amount of phosphorus as P used in 2015 was 49 tons. If sewage sludge generated in the Reykjavík capital area in 2015 was properly treated, the phosphorus it contained would be enough to provide 16% of the phosphorus used for restoration by the Soil Conservation Service of Iceland. If all kitchen waste were composted and applied in land restoration, it would exceed the phosphorus budget for land restoration in 2015. Phosphorus from kitchen waste alone was almost twice (95 tons) the amount of phosphorus used (49 tons) for land restoration by the Soil Conservation Service of Iceland in 2015. If a biological phosphorus removal wastewater treament system was employed (Cornel & Schaum 2009) in the treatment of wastewater generated in the Reykjavík capital area, 98 tons of phosphorus would be recovered in the effluent. Just as was the case with phosphorus in kitchen waste, this amount was almost twice the amount which was used for restoration by the Soil Conservation Service of Iceland. Combining all these phosphorus values, the amount of phosphorus wasted through waste disposal from the Reykjavík capital area alone exceeded the phosphorus used for land restoration by the Soil Conservation Service of Iceland in 2015 by over 435%. On a national scale, the phosphorus contained in waste would have met 18% of the total amount of phosphorus imported into Iceland in 2015. With the ongoing efforts in land restoration in Iceland, application of sewage sludge and municipal waste in land restoration could be a sustainable waste management option. As many other countries are struggling to meet stringent regulations on agricultural use of waste, Iceland could take this as an opportunity since the waste generated would be applied in restoration fields where nonfood plants grow.

Utilizing waste on the nearest restoration field from the Reykjavík capital area would cost around 140,000 ISK/ha, VAT of 24% inclusive. using an application rate of 30 tons/ha (United States Environmental Protection Agency 2007). This application rate is recommended by the United States Environmental Protection Agency (USEPA) on highly degraded land (USEPA 2007) like the ones in the restoration fields nearest to the capital area. The cost of utilizing waste could be higher than using inorganic fertilizer, considering that recovery and reuse of phosphorus from waste is currently expensive (Cornel & Schaum 2009). However, this amount could be reduced, if the service were to be tendered. Again, the cost of electricity in Iceland is comparatively low compared to other European countries, which could further reduce the cost of producing the compost. It is also worth noting that land application of waste not only provides nutrients, but also other benefits such as organic matter and elements required for plant growth (Mayer et al. 2016). On the other hand, other technologies of managing waste such as the scrubbing cost of product gas after incineration, pyrolysis, wet oxidation and gasification are high (Fytili & Zabaniotou 2008) and they emit greenhouse gases, dioxins, fumes and heavy metals. In comparison to such technologies, agricultural application of waste is economical (Lundin et al. 2004). Long term application of waste to agricultural fields can cause heavy metal accumulation in crops. Application of waste in land restoration would be a viable alternative as it could be cheaper and pose a lower public health risk. Composting of the waste would reduce the odour and flies associated with its land application, which could eventually increase its social acceptance. Furthermore, land application of waste is a way of conserving resources, especially phosphorus, which is nonrenewable. In addition, recovery of nutrients from waste reduces the need for importing inorganic fertilizers. Consequently, foreign currency is conserved as a result of reduced importation costs and the country's carbon footprint is reduced.

4.3 Limitations of the study

This study relied on waste generation data collected by operators. It would have been better if the researcher had had enough time to collect and analyse these data. The time for doing this kind of research was enough to collect and analyse the data properly. The phosphorus and moisture content of the waste used in calculations were based on values reported in the literature. These parameters could have been determined for the waste in the study area since they can vary from region to region.

5. CONCLUSION

The results of the study suggest that municipal waste contains enough phosphorus that could definitely meet the phosphorus requirement for restoration works in Iceland. If proper phosphorus recovery treatment systems were employed, the amount recovered could surpass that used for operations like land restoration. Costs associated with composting, transporting and spreading the waste are higher than those associated with inorganic fertilizer use, however. On the other hand, these costs could be reduced if the service were to be tendered. There are other benefits of waste utilization that must be considered, such as pollution control and improvement of soil quality, among others, when evaluating the total value of utilizing waste-produced phosphorus in land restoration.

Proper care should be taken when applying waste to land to minimize the harmful effects that can ensue to soil and plants, especially should the restored land could be used for grazing in future. For example, a detailed physico-chemical analysis of the waste (sewage sludge and municipal waste) and soil where the waste will be applied should be undertaken. Plants and their tendency to heavy metal accumulation should be studied before growing them on waste-amended soils. Therefore, studies are required to understand the waste-soil-plant-metal interaction and nutrient mineralization, especially in Iceland with its unique soils and vegetation.

ACKNOWLEDGEMENTS

I wish to thank the United Nations Land Restoration Training (UNU-LRT) programme for offering the opportunity to participate in the six-month training which led to this research project.

Special thanks also go to my supervisor, Dr Magnús H. Jóhannsson, for guidance throughout the research process. You have really inspired me to take nutrient recycling from sewage sludge wastewater and municipal waste as my main research area! You have taught me to be critical when reviewing literature and think straight when writing. I am also grateful to the UNU-LRT deputy director, Berglind Orradóttir, for the positive comments and guidance on formatting the report to meet set standards for scientific writing. Further, I am grateful to the Soil Conservation Service of Iceland, SORPA, Reykjavík Energy and the local authority in Reykjavík for their support during data collection.

LITERATURE CITED

Alvarenga P, Mourinha C, Farto M, Santos T, Palma P, Sengo J, Morais MC, Cunha-Queda C (2015) Sewage sludge, compost and other representative organic waste as agricultural soil amendments: Benefits versus limiting factors. Waste Management **40**:44–52

Antolín MC, Pascual I, García C, Polo A, Sánchez-Díaz M (2005) Growth, yield and solute content of barley in soils treated with sewage sludge under semiarid Mediterranean conditions. Field Crops Research **94**:224–23

Arnalds O, Arnason A, Thorarinsdottir EF, Metusalemsson S, Jonsson A, Gretarsson E (2001) Soil Erosion in Iceland. Soil Conservation Service of Iceland and Agricultural Research Institute, Reykjavík

Arnalds O (2015) The Soils of Iceland. Springer, New York

Brady NC, Weil RR (2008) The nature and properties of soils. 14th edition. Pearson Education Inc. New Jersey

Bravo-Martín-Consuegra S, García-Navarro FJ, Amorós-Ortíz-Villajos JÁ, Pérez-de-los-Reyes C, Higueras PL (2016) Effect of the addition of sewage sludge as a fertilizer on a sandy vineyard soil. Journal of Soils and Sediments **16**:1360–1365

Bruun S, Yoshida H, Nielsen MP, Jensen LS, Christensen TH, Scheutz C (2015) Estimation of long-term environmental inventory factors associated with land application of sewage sludge. Journal of Cleaner Production **126**:440–450

CEC (Council of the European Communities) (1986) Council directive of 12 June 1986 on the protection of the environment, and in particular of the soil, when sewage sludge is used in agriculture (86/278/EEC). Official Journal of the European Communities. http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:31986L0278&from=EN (accessed 8 August 2016)

Cesaro A, Belgiorno V, Guida M (2015) Compost from organic solid waste: Quality assessment and European regulations for its sustainable use. Resources, Conservation and Recycling **94**:72–79

Chowdhury RB, Moore GA, Weatherley AJ, Arora M (2014) A review of recent substance flow analyses of phosphorus to identify priority management areas at different geographical scales. Resources, Conservation and Recycling **83**:213–228

Cordell D, White S (2011) Peak phosphorus: Clarifying the key issues of a vigorous debate about long-term phosphorus security. Sustainability **3**:2027–2049

Cornel P, Schaum C (2009) Phosphorus recovery from wastewater: Needs, technologies and costs. Water Science and Technology **59**:1069–1076

Couth R, Trois C (2010) Carbon emissions reduction strategies in Africa from improved waste management: A review. Waste Management **30**:2336–2346

Couth R, Trois C (2011) Waste management activities and carbon emissions in Africa. Waste Management **31**:131–137

Dawson CJ, Hilton J (2011) Fertiliser availability in a resource-limited world: Production and recycling of nitrogen and phosphorus. Food Policy **36**:S14–S22

Desmidt E, Ghyselbrecht K, Zhang Y, Pinoy L, Van der Bruggen B, Verstraete W, Rabaey K, Meesschaert B (2015) Global phosphorus scarcity and full-scale P-recovery techniques: A review. Critical Reviews in Environmental Science and Technology **45**:336–384

Diacono M, Montemurro F (2010) Long-term effects of organic amendments on soil fertility. A review. Agronomy for Sustainable Development **30**:401–422

Fytili D, Zabaniotou A (2008) Utilization of sewage sludge in EU application of old and new methods - A review. Renewable and Sustainable Energy Reviews **12**:116–140

Gentil E, Clavreul J, Christensen TH (2009) Global warming factor of municipal solid waste management in Europe. Waste Management and Research **27**:850–860

Hargreaves JC, Adl MS, Warman PR (2008) A review of the use of composted municipal solid waste in agriculture. Agriculture, Ecosystems and Environment **123**:1–14

Jana K, De S (2015) Polygeneration using agricultural waste: Thermodynamic and economic feasibility study. Renewable Energy **74**:648–660

Kalmykova Y, Harder R, Borgestedt H, Svanang I (2012) Pathways and management of phosphorus in urban areas. Journal of Industrial Ecology **16**:928–939

Kelessidis A, Stasinakis AS (2012) Comparative study of methods used for treatment and final disposal of sewage sludge in European countries. Waste Management **32**:1186-1195

Kumwenda S, Tsakama M, Kalulu K, Kambala C (2012) Determination of biological, physical and chemical pollutants in Mudi river. Journal of Basic and Applied Scientific Research **2**:6833–6839

Lu Q, He ZL, Stoffella PJ (2012) Land application of biosolids in the USA: A review. Applied and Environmental Soil Science **2012**:1-12

Lundin M, Olofsson M, Pettersson GJ, and Zetterlund H (2004) Environmental and economic assessment of sewage sludge handling options. Resources, Conservation and Recycling **41**:255–278

Mackenzi DL (2011) Water and wastewater engineering: Design principles and practice. Water and Wastewater Engineering. 1st edition. McGraw Hill, New York

Malawi Government (2008) National sanitation policy. Ministry of Irrigation and Water Development, Lilongwe

Mayer BK, Baker LA, Boyer TH, Drechsel P, Gifford M, Hanjra MA, Parameswaran P, Stoltzfus J, Westerhoff P, Rittmann BE (2016) Total value of phosphorus recovery. Environmental Science and Technology **50**:6606-6620

Mdolo P (2016) Performance evaluation of kauma wastewater treatment works, Lilongwe, Malawi. Master's thesis, University of Malawi, Malawi

Metcalf E, Eddy H (2003) Wastewater engineering: treatment and reuse. Wastewater engineering, treatment, disposal and reuse. 4th edition. McGraw Hill, New York

Ministry of the Environment (1999) Reglugerð um meðhöndlun seyru [Regulations regarding handling of sewage sludge]. Ministry of the Environment, Reykjavík (in Icelandic) http://www.reglugerd.is/reglugerdir/eftir-raduneytum/umhverfisraduneyti/nr/4292 (Accessed 24 August 2016)

NEBRA (North East Biosolids and Residuals Association) (2007) A national biosolids regulation, quality, end use and disposal survey. North East Biosolids and Residuals Association https://static1.squarespace.com/static/54806478e4b0dc44e1698e88/t/5488541fe4b03c0a9b8ee09b/1418220575693/NtlBiosolidsReport-20July07.pdf (Accessed 25 August 2016)

Odlare M, Arthurson V, Pell M, Svensson K, Nehrenheim E, Abubaker J (2011) Land application of organic waste - Effects on the soil ecosystem. Applied Energy **88**:2210–2218

Pongrácz E, Pohjola VJ (2004) Re-defining waste, the concept of ownership and the role of waste management. Resources, Conservation and Recycling **40**:141–153

Pritchard DL, Penny N, McLaughlin MJ, Rigby H, Schwarz K (2010) Land application of sewage sludge (biosolids) in Australia: Risks to the environment and food crops. Water Science and Technology **62**:48-57

Raynolds, T, Richards, P (1996) Unit operations and processes in environmental engineering. 2nd edition. Cengage Learning, New York

Reijnders L (2014) Phosphorus resources, their depletion and conservation, a review. Resources, Conservation and Recycling **93**:32–49

Sajidu SMI, Masamba WRL, Henry EMT, Kuyeli SM (2007) Water quality assessment in streams and wastewater treatment plants of Blantyre, Malawi. Physics and Chemistry of the Earth **32**:1391–1398

Saltiola S (2014) Evaluation of new alternatives to improve landfil waste diversion in Reykjavík, Iceland. Master’s thesis, University of Jyväskylä, Finland

Saunders AM, Albertsen M, Vollesen J, Nielsen PH (2016) The activated sludge ecosystem contains a core community of abundant organisms. International Society of Microbial Ecology **10**:11–20

Singh RP, Agrawal M (2008) Potential benefits and risks of land application of sewage sludge. Waste Management **28**:347–358

Smith SR (2009) A critical review of the bioavailability and impacts of heavy metals in municipal solid waste composts compared to sewage sludge. Environment International **35**:142–156

Sokka L, Antikainen R, Kauppi P (2004) Flow of phosphorus in municipal waste: A substance flow analysis in Finland. Progress in Industrial Ecology **1**:165-184

Song U, Lee EJ (2010) Environmental and economical assessment of sewage sludge compost application on soil and plants in a landfill. Resources, Conservation and Recycling **54**:1109–1116

Statistics Iceland (2015) Statistical year book. Statistics Iceland, Reykjavík http://www.statice.is/media/49296/landshagir2015.pdf (accessed 7 July 2016)

Sverdrup HU, Ragnarsdottir KV (2011) Challenging the planetary boundaries II: Assessing the sustainable global population and phosphate supply, using a systems dynamics assessment model. Applied Geochemistry **26**:S307–S310

Treonis AM, Austin EE, Buyer JS, Maul JE, Spicer L, Zasada IA (2010) Effects of organic amendment and tillage on soil microorganisms and microfauna. Applied Soil Ecology **46**:103–110

Tyagi VK, Lo SL (2013) Sludge: A waste or renewable source for energy and resources recovery? Renewable and Sustainable Energy Reviews **25**:708–728

USEPA (United States Environmental Protection Agency) (2007) The use of soil amendments for remediation, revitalization and reuse. Environmental Protection Agency

Usman K, Khan S, Ghulam S, Khan MU, Khan N, Khan MA, Khalil SK (2012) Sewage sludge: An important biological resource for sustainable agriculture and its environmental implications. American Journal of Plant Sciences **3**:1708–1721

Villarroel WR, Beck MB, Hall JW, Dawson RJ, Heidrich O (2014) The energy-water-food nexus: Strategic analysis of technologies for transforming the urban metabolism. Journal of Environmental Management **141**:104–115

Wahlberg EJ (2014) Nutrient Recovery: Why It is Not an Option Anymore. Pp. 3799–3805. Water Environment Federation Technical Exhibition and Conference

Wanda EMM, Mamba BB, Msagati TAM (2015) Determination of the water quality index ratings of water in the Mpumalanga and north west provinces, South Africa. Physics and Chemistry of the Earth:1–9

Wang H, Wang T, Zhang B, Li F, Toure B, Omosa IB, Chiramba T, Abdel-Monem M, Pradhan M (2014) Water and wastewater treatment in Africa - Current practices and challenges. Clean - Soil, Air, Water **42**:1029–1035

Water UK (2010) Recycling of biosolids to agricultural land. Water UK, London https://dl.dropboxusercontent.com/u/299993612/Publications/Reports/Waste%20recycling/recycling-biosolids-to-agricultural-land--january-2010-final.pdf (accessed 27 July 2016)

Wei YS, Fan YB, Wang MJ (2001) A cost analysis of sewage sludge composting for small and mid-scale municipal wastewater treatment plants. Resources, Conservation and Recycling **33**:203–216

Withers PJA, Flynn NJ, Warren GP, Taylor M, Chambers BJ (2016) Sustainable management of biosolid phosphorus : A field study. Soil Use and Management **32**:54–63

Wu J, Franzén D, Malmström ME (2016) Anthropogenic phosphorus flows under different scenarios for the city of Stockholm, Sweden. Science of the Total Environment **542**:1094–1105