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Water hyacinths (*Eichhornia crassipes*) and their presence in Shire River, Malawi

Problems caused by them and ways to utilize them elsewhere

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Abstract

Malawi is one of many countries throughout the world struggling with massive amounts of water hyacinths (*Eichhornia crassipes*) in the country's fresh water resources. In nutrient-rich ecosystems where the aquatic weed has no natural enemies it will reproduce very rapidly. With the result that lakes become overgrown, water flow in rivers is reduced and other water organisms becomes excluded. At the same time, the plants form a good breeding place for species carrying tropical diseases for example malaria and bilharzia. Water hyacinths are usually more of a problem for tropical countries with less financial strength. Besides that, there are often great economic losses caused by the weed and to control the plants relative abundance is costly.

In Malawi, 99 % of the produced electricity is based on water resources. Most of it through hydropower turbines in the main river, named Shire River. Water hyacinths aggregated as islands, floats along the river and clog the turbines which cause repeated electricity black-outs. Approximately 140 megawatt power is lost every day. To counter the weeds interference with the electricity supply, there are great amounts of water hyacinths harvested every day. These plants are dumped along the road with no further disposal plan. In this report, soil from one local dump area is analysed to determine if such places are leaching nutrients or metals to the surrounding environment.

Water hyacinths consist of naturally high nutrient (N and P) and crude-protein values. Farmers use the harvested plants as a green manure to improve soil properties on agricultural land. This study aims to examine levels of metal ions in water hyacinths used as green manure. This is of interest since water hyacinths have the ability to effectively absorb substances from the water body. This capacity could pose a risk for potentially toxic elements (PTEs) to accumulate in the agricultural soil and cultivated crops.

Sampling and analyses were carried out with standard methods. Metal ions and nutrient levels in the analysed samples were obtained through detection with atomic absorption spectrophotometry (AAS), ion chromatograph (IC) and UV/Vis spectrophotometry at the Department of Chemistry on Chancellor College in Zomba, Malawi.

None of the more harmful investigated metal ions (Cr^{3+}, Pb^{2+}, Cd^{2+}) were found in the analysed water hyacinths. Relatively high amounts of total phosphorus were found in the plants. Soil sampling was carried out during the dry season so this study cannot determine if the dumping areas are leaching nutrients or metal ions. Overall, the conclusion is that there is no risk of using water hyacinths harvested in Shire River as a green manure on agricultural land.

Keywords; water hyacinths, *Eichhornia crassipes*, green manure, Malawi

Preface

This study was partly performed during two months, 8th of June to 1th of August 2012, at the chemistry department of Chancellor College, University of Malawi in Zomba, Malawi, and partly during the autumn/winter 2012 at Uppsala University, Sweden.

The project was possible to carry out thanks to a minor field study (MFS) scholarship, founded by the Swedish International Development Agency (Sida) through the Committee of Tropical Ecology (ATE) at Uppsala University.

The supervisors of the thesis were Dr Jonas F Mwatseteza at the Department of Chemistry at Chancellor College, University of Malawi and also Professor Ingmar Persson and Daniel Lundberg at the Department of Chemistry, Inorganic and Physical Chemistry at Swedish University of Agricultural Sciences.

During the laboratory work I gathered much help from Mr.Chikumbusho Masutano Harrison Kayira and Mr. Charles Nkukumira as well from Upile Chitete, Timothy Mguntha and from my study colleagues and friends Agnes Forsberg and Sandra Lundgren.

This study will examine the levels of metal ions in water hyacinths (*Eichhornia crassipes*) harvested from Shire River, close to Liwonde Town, which are used as natural fertilisers (green manure) on local crop fields.

I would very much like to thank the above mentioned people for all help and the warm welcome my friends and I received during the time in Malawi, summer 2012. During this MFS-study I learnt a lot of the Malawian country and culture and that people of Malawi are very warm and welcoming. I am very thankful that I had the opportunity to go to Malawi and gathered all this new friends and knowledge. During our stay we had many interesting lunch discussions about anything from current political situation to how wonderful the nature of Malawi is.

Acronyms

AOAC	Americas Official Analytical Chemists
APHA	American Public Health Association
ESCOM	Electricity Supply Commission of Malawi
GNI	Gross National Income
MECCM	Ministry of Environment and Climate Change Management
MGDS	Malawi Growth and Development Strategy
PTE	Potentially Toxic Elements
SADC	Southern African Development Communities
UNDP	United Nation Development Program
USDA	United States Department of Agricultural
VY	Vanadomolybdophosphoric yellow calorimetric method
WHO	World Health Organisation

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1. Introduction

Malawi is a small country located in the southeast part of Africa; it is landlocked with borders to Zambia, Mozambique and Tanzania. Total area is about 118 500 km^2, 20 % is covered by surface water mainly consisting of Lake Malawi, Lake Malombe, Lake Chilwa and Shire River, Figure 1, and one third is covered by cultivated areas (AQUASTAT, 2006). Approximately 50 % of Malawi's population, of just over 15 million people, lives below the national poverty line with a GNI per capita much below the average sub-Saharan countries (World Bank, 2011). According to UNDP, Malawi is one of the poorest countries in the world, and is ranked as 171 out of the 187 countries studied in the Human Development Index (UNDP, 2011). However, since 2006 Malawi's economic growth rate has increased with 7,5 percentage and The Malawi Growth and Development Strategy (MGDS, 2006-2011) visualized that the economic situation is to be improved with trade-led growth. Malawi is one of the most densely populated countries in Southern African Development Communities (SADC) region which creates a great pressure on both land and water resources.

Figure 1. Map of Malawi (Google maps, 2013)

The majority of Malawi's population has agriculture as their main source of livelihood, most as smallholder farmers. This sector generates over 90 % of the export earnings for the country (UN, 2011). Since many people are dependent on agriculture, years with climate changes and increased climate variations such as flooding, unpredictable precipitations, droughts and temperature variability, all with crop failure as a result, has struck hard on the population. Several times the country has suffered from mass starvation. The Malawian government has identified a rising agriculture as the key factor in decreasing poverty and developing the country. A factor that led to reduced fallow periods as well as an expansion of cultivation to less fertile woodland areas. The percentage of forest covering the country has decreased with 6 percentage points from 1990 to 2008 (UNDAF, 2012). This leads to more erosion and decreased water quality in Malawi's main river, which due to the countries landlocked location, serves as a vital organ in its society structure.

The soils in Malawi has generally low fertility, the range for nitrogen levels differs greatly throughout the country and phosphorous alternates between sufficient to low levels (Snapp et al., 2002). Malawi's dense population requires efficiency in crop production and soil fertility is one of the big problems for Malawian farmers (CARE International, 1998).

1.1 Problem description

In Malawi, water is a prime natural resource. There is high potential for hydropower generation and 99 % of the produced electricity is based on water resources (Kawejere, 2009). Mostly from Shire River and dams along the mountain area and plateau. Most power is generated and distributed by the Electricity Supply Commission of Malawi (ESCOM). In recent years, there have been problems with the generation of electricity from Shire River both due to a massive invasion of water hyacinths and due to increased siltation caused by deforestation. The invasion is likely to be caused by interactions between an increased eutrophication of Lake Malawi and the fact that water hyacinths have no natural enemy in African fauna. Water hyacinths grow very rapidly, especially in Shire River's inlet Lake Malombe, Figure 2, and then float along the river alone or aggregated as islands. This is causing a problem to Malawi's electricity supply as power-generating turbines become clogged by the aquatic weeds. The blocking is causing repeated electricity interruptions, affecting population and industries. Great amount of water hyacinths are also slowing down the flow of Shire River potentially changing the ecosystem in the river (Poff et al., 1997).

Figure 2. Southern region of Malawi, red ring around problem area at Liwonde barrage, black arrow mark Lake Malombe and black ring point out where we were stationed (nationonline, 2013).

To prevent water hyacinths from clogging power turbines approximately 15 tons of weed are harvested at Liwonde Barrage every day. This harvested plants are later dumped on the riverbank or along the road in large piles and there seem to be no disposal plan (Mwatseteza pers.com., 2012). The plants have natural high levels of nutrients (N and P) and dumping areas will therefore have a potential leaching risk. Nitrogen and phosphorous are the two nutrient elements most often associated with eutrophication and an escape of these substances will further contribute to an increased growth in already nutritious Shire River. Some of the harvested plants are later used by farmers in Malawi as a green manure to improve soil features on their crop fields (Mwatseteza pers.com, 2012). Since the plants are used on local crop fields there is important to secure that there is no harmful levels of potentially toxic elements (PTE´s), such as the trace elements; Cu, Cd, Pb and Zn, in the plants. These elements could accumulate in soil and the cultivated crops and in the long term affect human beings in a negative way.

1.2 Aim

The aim of this study is to examine levels of metal ions in water hyacinths (*Eichhornia crassipes*) harvested from Shire River, just upstream Liwonde Town. The water hyacinths are later used as natural fertilisers on local crop fields. The reason for investigating this is to ensure that these weeds do not pose a risk that potential harmful metals accumulate on the fields.

As an additional task, soil analyses are carried out on soils from a local dumping site of harvested water hyacinths with the intention to investigate if there is any leakage of nutrients or metal ions from such areas.

Since water hyacinths are present in great amounts in Malawi I also discuss different harvesting techniques and ways to utilize the plants.

In order to fulfil the aim some outlining questions are to be answered:

- How can Malawi control the number of water hyacinths? How to use harvested plants in an efficient way? (Literature study, 2.1.1 and 2.1.2)
- What is the status of the soil in Malawi, with respect to nutrients and minerals? (Literature study, 2.2)
- What are the limit values for metal compounds in green manure and food? (Literature study, 2.3.2)
- Have the harvested water hyacinths from Liwonde Barrier a high content of metals? (Analysis)
- Are the dumping areas leaching nutrient or metal ions? (Analysis)

1.3.1 Delimitations

Since there was no knowledge of which farmers that collected green manure from the sampling site, no soil analyses were carried out on any agricultural soil in order to determine the specific need for addition of nutrients.

Due to a lack of time, exact location of the dumpsites and access to transportation water hyacinths from only one dumping area were collected for analyses.

2. Background

In this section some background facts about water hyacinths in general, ways of controlling their abundance and different utilisation areas is presented. This section also addresses the current status within Malawi with respect to both the invasion of water hyacinths and the soil status and need of fertilisers.

2.1 Water hyacinths

Water hyacinth (*Eichhornia crassipes)* is a free floating perennial plant with thick dark green leaves, circular to oval in their shape and attached to the plant by a spongy inflated petiole, Figure 3. Underneath the water it has numerous dark fibrous roots. The size of the plant varies between a few centimeters up to a meter and it has light blue to violet flowers in a loose terminal spike.

Figure 3. Image of a water hyacinth (SFRC, 2013).

The water hyacinth is originally from South America where it is kept under control by natural predators (Lee, 1979). In many countries with a tropical or sub-tropical climate water hyacinths have been introduced and become an invasive weed taking over lakes and rivers. Water hyacinths are considered to be one of the world's worst fresh water plants due to their very rapid growth rate, especially in waters with high nutrient levels. It has been reported that, under optimal conditions, a plant community can double in area in as little as 6-20 days (Msningeni, 1995). Usually the plants start growing at the edges of rivers and lakes and when they reach a large enough quantity they detach and float like islands along the stream. These islands, or dense mats of plants, are not only a problem due to the fact that they slow down the water flow and interfere with navigation and power generation. These mats of water hyacinths also exclude other submersed and floating-leaved plants and create good breeding conditions for mosquitoes and snails that carrying bilharzia. Making the presence of water hyacinths to a contributing factor to the spread of tropical diseases. Due to their high abundance they will also increase evapotranspiration from the water and can contribute to water losses in areas already suffering from poor water resources (Malik, 2007).

Water hyacinths consist of more than 95 % water but despite this they have high nutrient (N and P) and crude-protein content and very fibrous tissue (Gunnarsson and Mattsson, 1997). They also have an ability of absorbing both trace element ions (Cu^{2+}, Pb^{2+}, Cd^{2+} and Zn^{2+}) as well as minor element ions (Ca^{2+}, Mg^{2+}, Na^{+} and K^{+}) from water bodies (Msningeni, 1995). These properties can make them potentially useful in many different application areas. In Table 1 the general levels of some nutrient and minor elements in water hyacinths are summarised (Gunnarsson and Mattsson, 1997).

Table 1. Nutrient and minor element levels in water hyacinths, summarised by Gunnarson and Mattsson (1997). DW in the second column stands for the plants dry weight

Parameters	**mg / g plant (DW)**
Phosphorus, Tot-P	5,3
Nitrogen, Tot-N	27,6
Magnesium, Mg^{2+}	1,7
Calcium, Ca^{2+}	5,8 – 22,9
Potassium, K^{+}	24,4

2.1.1 Controlling methods

Since water hyacinths cause big problems, methods of controlling their reproduction and abundance in lakes and rivers must be in effect.

2.1.1.1 Mechanical methods

Harvesting the plant is an effective way of reducing biomass from rivers and lakes with an immediate effect. This is done in order to control the weeds propagation and its interference with power generation and fishing opportunities. There are several different harvesting techniques, ranging from fishermen working with rakes to machines operating both from shore, Figure 4, and floating on water. Removing plant biomass with this technique has the advantage of also removing some of the nutrients causing eutrophication. This might slow down the reproduction rate. Harvesting is also providing the

Figure 4. Picture showing a similar harvesting technique as that one used in Liwonde Barrier (Photo: FAO of UN)

possibility of using water hyacinths in other ways, e.g. in agriculture or biogas production. A difficulty with harvesting is the great disposal problem. There are several different attempts to solve the logistics by burning, deposit or compost the plants. Other negative aspects with harvesting are the facts that it is time consuming, in relation to the effect it gives, and also expensive (Verbrandt, 1990).

It is also common to build physical barriers to prevent the plants to access an area where they cause problems. This can be done for example in harbours, streams with power generating turbines or dams.

2.1.1.2 Biological methods

In biological weed control a natural enemy is introduced to the problem area. The organism starts feeding and reproducing on the plant resulting in progressive decrease of plant biomass over time. If the plant biomass has been allowed to increase in an uncontrollable way, biological control is often too slow to reduce the amount of plants at an acceptable rate (Hill et al., 1999). However, this method is a good way of reducing the problem in the long-term.

2.1.1.3 Chemical methods

There are three main chemicals in use controlling the growth of water hyacinths; Diquat, Glyphosate and 2,4-D (Calvert, 2002) which all are herbicides affecting the weed directly. All three substances strongly bind to soil particles (WHO, 2004a), which results in little risk of contaminating groundwater. However, there is a risk that these chemicals end up in drinking water if surface water represents the local water supply. For 2,4-D there is a suspicion of interference with other hormones (PAN, 2011) and a recent study revealed that Glyphosate in drinking water may contribute to promotion of tumors (Ji, 2013).

When using chemicals as a controller of water hyacinths the dead plants remain in the water releasing nutrients during the decomposing process. This results in an instant re-growth of new plants and instead of reducing plant growth it contributes to an increased eutrophication in the water. However, if the dead plants are removed, none of the chemicals are shown to affect fishes in a negative way. Rather a slightly greater fish biomass is obtained due to the re-growth of algae (Petr, 2000). Positive aspects of chemical control are its rapid effects on fresh plant biomass in connection with low costs.

Figure 5. Water hyacinths on a farmer's backyard aimed to be used as green manure, Liwonde (photo: J. Mwatseteza).

2.1.2 Utilisation

Water hyacinths represent a great problem in many regions and large quantities of plants are harvested every day throughout the world. Many studies have been carried out on the weeds different application and utilization areas (Gunnarsson and Mattsson, 1997, Elserafy et.al, 1980, Höglöv, 2000 and Msningeni, 1995). Due to their fast growth and relatively high nutrient and crude protein levels they could be used as natural fertilisers and soil improvers, Figure 5, as well as a potential raw material for producing biogas or in the paper industry. Their ability to absorb and concentrate nutrients from a water body makes them feasible as a step in wastewater treatment. They could also be used as one component in domestic animal fodder.

2.1.2.1 Fertiliser, soil improver and compost

Composting water hyacinths is a good and feasible way of using harvested plants, especially in developing countries. Composting is a well-known low budget option for improving crop yields and can be carried out by mixing dried water hyacinths with soil, ash and organic municipal waste (PACE, 2013). This is also an advantageous way of disposing water hyacinths because the ability to reproduce is lost as it passes the stomach of earthworms (Malik, 2007). Most important nutrients (N, P and K) are retained during the process and tolerable compost can be reached during the relatively short time period of 30 days (Polpraset et al., 1998). A study in India showed that decomposition of water hyacinths resulted in an increased mineralisation of nutrients in the soil and as a result enhanced grain yield. This was when partly decomposed water hyacinths were applied to a sandy clay loam in a pot experiment with rice (Gunnarsson & Mattsson, 1997).

When used as a green manure the plants can either be ploughed into the soil or used as mulch, Figure 5. Utilizing water hyacinths as green manure on fields of potatoes, tomatoes and lady's fingers has shown an increased crop yield (Malik, 2007). The addition of organic carbon helps improving the soil structure which decreases the leaching of nutrients.

The fact that water hyacinth are good at absorbing substances from water bodies must be taken into consideration when applying harvested plants to a crop field. Mulching with plants that have absorbed herbicides is instead decreasing the crop production. There is also a risk that undesirable compounds accumulate in the soil and eventually in the harvests.

2.1.2.2 Wastewater treatment

Because of high photosynthetic efficiency water hyacinths absorb and concentrate compounds from the water body very effectively. Not only excess nitrogen and phosphorus are removed but also potentially toxic metal ions and some organic chemicals (Zaranyika & Ndapwadza, 1995). Phytoremediation is the process where a plant has the ability to mitigate or eliminate an environmental problem without the need to excavate and dispose the contaminated material elsewhere. Water hyacinths capacity to accumulate metal ions together with their ability to grow in polluted waters has made them world-wide accepted in waste water treatment (Malik, 2007). Water hyacinths seem to have a wide range of pollutants which can be absorbed and thereby decontaminate waters from toxic metals, inorganic nutrients and also from persistent organic pollutants (Malik, 2007). There are well documented effects of using water hyacinths for treating wastewater (e.g. domestic wastewater and agricultural runoff) both with respect to high nutrient contents and biological oxygen demand- (BOD) levels (Malik, 2007). Also industrial wastewater containing metals and some organic chemicals, such as herbicides, could be treated with water hyacinths.

2.1.2.3 Producing biogas and ethanol fuel

With an increased demand for renewable energy sources converting water hyacinths to biogas is a field of great interest these days. Water hyacinths can be used to produce biogas trough an anaerobic process, although in small scale the weed need to be mixed with other substrates (Höglöv, 2000). On a larger scale water hyacinths can be used alone. Some problems with digestion of water hyacinths are primarily low efficiency due to the plants very large water content and costly pre-treatment processes of plant tissue in order to reduce entrapped air (Malik, 2007). To circumvent these problems multi-phasic reactors are developed instead of the traditional single stage reactor.

On paper, water hyacinths can be considered as feasible substrate to produce ethanol fuel due to their amount of crude protein and hemicellulose (Gunnarsson & Mattsson, 1997). Unfortunately the process of fermenting the sugars to alcohol is not as effective as initially hoped when using water hyacinths and this utilization area is only recommended when there is high demand for ethanol as liquid fuel (Malik, 2007).

2.1.2.4 Animal fodder / other

Another application area for the harvested plants is by using them as fodder for domestic animals. Höglöv (2000) reached the conclusion that water hyacinths alone are a poor animal feed mostly due to their high content of water and the fact that their proteins are difficult for animals to assimilate.

It is possible to process the petioles into paper, rope and fiber boards. Other future applications are the production of biodegradable feminine protections and charcoal briquetting (Calvert, 2002).

2.1.3 Water hyacinths in Malawi

Water hyacinths were first observed by fishermen in southern Malawi during the 1960's. During the following decades they spread north along Shire River. Nowadays, the species is widely spread across the whole of Malawi (Juien et al., 2001). Under periods with more water hyacinths water upstream Liwonde Barrier, Figure 6 and 7, is completely covered by the invasive weeds. Areas completely colonised by water hyacinths suffer from great environmental challenges and many water animals are forced to relocate or in cases were that is not possible they will die (Kawejere, 2009). Water hyacinths are causing a great loss in biodiversity and an increased siltation in the lakes of Malawi because the weed harvesting is

Figure 6. Area around Liwonde Barrier. Red dot mark where Liwonde barrier is situated, red arrow mark Malosa Forest Reserve and the pin show local dumping area along the main road (Google maps, 2012).

Figure 7. Liwonde Barrier completely covered by water hyacinths (photo: J. Mwatseteza).

often performed near river banks which affect the littoral vegetation that binds soil to the shore. Due to siltation a decreased water depth of approximately 2 meters have been noted at Liwonde Barrage between 2003 and 2008 (Kawejere, 2009). This is a problem not only for hydro-power generation but also for other important features such as water transport and irrigation. Many tourist lodges in the area have problems with the weed colonization due to less pleased tourists. In the end this can cause economic problems for the tourism sector. The river also becomes less accessible both in terms of swimming and daily chores such as washing cloths and dishes. More alarming are the persistent electricity blackouts that industries and society suffers from, leading to fewer investors willing to start up projects and industries in the country and a loss in revenue and new sources of income (MECCM, 2010).

Water hyacinths are growing particularly fast in nutritious waters. The proliferation in upper Shire River is probably caused by high nutrient concentrations along the river banks as well as the area's increased deforestation during the last decades (World Bank, 2013). In the last decade selling of firewood has increased, followed by a rampant charcoal burning, which makes forests in the rivers catchment area bare. More fields are also established on fragile woodland areas, such as steep slopes and arable land, not governed by any conservation plan. This change of inland use increases erosion and nutrients are washed out of soils and deposed on riverbanks further contributing to an ongoing growth of water hyacinths. There are also natural contributions of nutrients flowing to Shire River from animals located in and around Liwonde National Park.

The primary problem in Malawi caused by water hyacinths is the costly interruptions in the electricity supply when turbines get clogged. Under the worst circumstances the whole power plant can break down which also happened in Blantyre district in 2003 (Kawejere, 2009). That breakdown caused an operation stop at two plants for the next six years and according to MECCM (2010) there is a loss of approximant 140 megawatt power every day due to interference from water hyacinths.

2.1.3.1 Workarounds

There have been several actions in order to decrease the number of water hyacinths and ensure a continuous generation of electricity in the country. Measures taken are mostly harvesting the weed both mechanically and by fishermen. The harvest is then disposed in Malosa Forest Reserve and along the main road between Blantyre and Lilongwe, Figure 6. At these dumping places the plants are building up in large piles with no further plan to do something with them at the moment.The major electricity supply company in Malawi, ESCOM, has also established a permanent weed management section at Liwonde barrage and in 2009 around 30 technical and support staff were working there (Kawejere, 2009).

After 2004, when the harvesting projects were started, there has been fewer electricity stops caused by water hyacinths clogging the turbines (Kawejere, 2009). The number of dump areas has, however, increased and at the moment it seems like the only utilisation area for the harvested weed is for agricultural purpose by small scale farmers (Mwatseteza pers. com., 2012).

In order to decrease leakage of nutrients to water bodies the Ministry of Agriculture and Food Security of Malawi work together with donor funded programs on promoting catchment conservation programs in the area. But so far farming communities are not sufficiently supported and most of the efforts just becomes isolated point actions within he catchment area (Kawejere, 2009).

2.2 Soil status

Most of Malawi's soils are characterized as alfisols but oxisols and ultisols are also present throughout the country (USDA, 1999). Alfisols have a high abundance of aluminum and iron with relatively high nutrient values and clay-enriched subsoil (USDA, 1999). Ultisols are also known as red clay soils and are a mineral rich soil type containing of no calcareous material.

In general, soils in Malawi are moderately acid and have a loamy sand texture with low to sufficient nutrient levels. Content of organic carbon are high enough (> 0.8%) to maintain soil structure but there is an overall deficiency of nitrogen and great variation in phosphorus and zinc concentrations (Evans, 1963), Table 2. Some reported problem areas for crop production are large regions in central Malawi with moderate soil acidity, naturally low phosphorus and zinc values in Central and Southern Malawi and regions in southern Malawi that has a naturally low content of organic carbon (Snapp et al., 1998).

Table 2. Blantyre soil analysis from 220 smallholder fields (Evans, 1963)

Characteristics	Units	%> Crit. [a]	Mean	Std. dev.	Median	Min	Max
Sand	%	80	72.3	11.5	70.0	52.0	90.0
Org C	%	77	1.2	0.5	1.1	0.3	2.9
pH		78	5.9	0.4	5.8	5.1	6.9
Zn	mg/kg	90	1.7	1.3	1.3	0.0	9.6
Ca	cmol/kg	99	3.0	2.1	2.4	0.2	9.5
K	cmol/kg	99	1.1	0.9	0.9	0.0	13.0
P	mg/kg	77	45.5	42.3	38.2	0.9	119.0

[a] *The column shows percentage of the samples that is above a critical content value*

2.2.1 Nutrients

To grow and develop every organism needs a certain amount of the 16 essential nutrients, lower concentrations than the thresholds will cause deficiency symptoms and reduced growth (Eriksson et al., 2011). From water and the atmospheric carbon dioxide plants will take up oxygen (O), carbon (C) and hydrogen (H). The rest 13 nutrients are taken up from the soil where the three primary nutrient elements are nitrogen (N), phosphorus (P) and potassium (K) while the other are considered as micro nutrients (Eriksson et al., 2011), section 2.2.2. At the same time an overload of nutrients can result in toxicity in the organism. Every crop needs a different ratio of nutrients to have an optimal growth. The addition of green manure will probably increase plant uptake of nitrogen because the decomposition will release nutrients more synchronised with the crops needs (Cherr et al., 2006).

2.2.2 Metal compounds

Most metal compounds found in nature are naturally occurring and derived from the parent material of the bedrock. High concentrations of metal ions and also some compounds of metal salts can, however, represent potential environmental hazards. Atmospheric deposition and an over-use of fertilisers may cause an accumulation of these harmful metal compounds in topsoil. Many metal compounds are also essential micro-nutrients or minor elements (Mn, Cu, Zn, Mo) and it is first when they are present in too high concentration they become toxic to the organisms. Resulting in inhibition of growth and stopped decomposition of organic material (Eriksson et al., 2011). Chromium (Cr) and Nickel (Ni) are essential for some organisms and commonly discussed when it comes to environmental unfriendly components while cadmium (Cd), lead (Pb) and mercury (Hg) are toxic already when present in small quantities, so called trace elements, and not essential for any vital functions. Cd is strongly associated with Zn-rich minerals and considered interchangeable-bound in the soil. Pb on the other hand, forms strong complex-bonds to humus substances and becomes less available for plant uptake. Which component that ends up in food crops is strongly dependent on the abundance and solubility at the actual soil pH. Overall Cd is relatively available to plants, whereas the presence of Pb and Hg is mostly due to atmospheric deposition on leaf surfaces (Eriksson et al., 2011).

2.3 Fertilisers

Few farmers own livestock and access to manure is therefore limited. Overall the soil of Malawi contains low nutrient levels (Snapp et al., 2002). When applying fertiliser on arable land it is important to manage loadings in such a way that nutrient leakage is avoided. Some risks with using animal and industrial manure are increased salinity due to enlarged ion concentration. Animal and industrial manure also pose a risk of excess concentrations of phosphorous and nitrate in the soil which contribute to eutrophication if these are lost from the fields. Especially nitrate is in focus when talking about safe drinking water, and the World health organisation (WHO) presents several guidelines on how to manage the input of fertiliser. One way is by making nutrient budgets to determine realistic doses and synchronize it with the crop demand (DG Environment, 2004). Adding organic carbon, e.g. green manure, will contribute to increase the soil structure with reduced nutrient and water losses from fields as a result (WHO, 2006).

2.3.1 Green manure

Green manure is a crop that is used to improve nutrient values and structure in soils for subsequent crops. The advantage with green manure is not only the fact that it is a renewable source, it is also providing the soil with carbon and a more uptake friendly N/P ratio than synthetic fertilisers. Nitrogen is also released at a lot slower rate and the losses of nutrients will decrease. A slower release will possibly also make the plant uptake more efficient and improve crop yield (Cline and Silvernail, 2002).

The problem with using green manure as a fertiliser is the difficulties of knowing which plant will provide the best, if any at all, advantages for the crop that will be cultivated. For conventional inputs the levels of nutrients and other essential active substances is well known and adjustable. The green manure approach to crop production, however, becomes very complex because of the high variation in C/N ratio for different cover crops in combination with a variation in C/N ratio for the recipient soil. This relationship controls whether there will be an immobilization or mineralization of nitrogen in the soil and thus a positive or negative effect on crop yield (Eriksson et al., 2011). To actually receive a nitrogen release from green manure many interacting factors must be met. It is dependent on the chemical composition in the soil as well as temperature, rock characteristics and land use. Right timing for spreading and the choice of cover crop are both key factors to obtain a more effective uptake of nitrogen and later improved crop yield. Wrong timing can result in release of nitrogen either before or after the demand peak for the cultivated crop (Cherr et al., 2006).

2.3.2 Limited input to agricultural land

There are few countries that have a comprehensive regulation that limits the loads of pollutants to soil from all types of fertilisers. Instead there are several individual regulations for sewage sludge, compost, manure and mineral fertilisers. Most laws and guidelines around residual products (compost, sewage sludge, animal or green manure) used as organic soil improver or fertiliser have their focus on restrictions considering environmental and soil conservation aspects. Most commonly, regulations are set up for potential toxic elements (PTEs) such as trace elements and organic pollutants, Table 3. Since many water bodies suffer from eutrophication there are also regulations covering nutrients, with maximum annual input of nitrate and phosphorus, Table 4 (FAO, 2006).

Table 3. Metal limits for European compost standards [mg/Kg dm] and maximum dosage of potential environmental harmful metals to the soil [g/ha/y] (table A2-4 and table A2-10, DG Environment, 2004)

	Regulation	Cd	Cr (tot)	Cu	Hg	Ni	Pb	Zn	As
Heavy metal limits in compost [mg/Kg dm]									
EU ECO Label	Soil improvers and growing media	1	100	100	1	50	100	300	10
EC Reg. 2092/91	Compost from source separated Biowaste	0,7	70	70	0,4	25	45	200	-
Mean in European countries		1,4	93	143 184*	1	47	121	416 587*	23
Limits of heavy metals applied to soil [g/ha/y]									
EC/ 'sew. sludge' *	10 y basis	0,15	3	12	0,1	3	12	30	-
Mean in European countries		8,2	609	1643	7,1	29 3	617	5524	15 1

** Cu and Zn are addressed as essential nutrients and can be added in higher thresholds when there is evidence of lack in soil, case in Sweden and Denmark (DG Environment, 2004). The figures of maximum load of PTEs in Table 3 are stemming from traditional sewage sludge regulations or calculated from maximum volume of compost multiplied by maximum value of heavy metal.*

Table 4. Regulated input of nitrogen and phosphorous on agricultural land based on a dry matter basis per hectare (DG Environment, 2004)

Type of nutrient	Regulation area	Amount (kg/ha)
Nitrogen	Agricultural	150 – 250
Phosphorus	Agricultural	22 - 80

The regulation regarding the amount of metal compounds that are allowed to be spread on arable land is most often set based on soil status at the local field or by national regulations adapted to the most common soil type (DG Environment, 2004). To control the distribution of potential harmful metals in our environment caused by use of organic residues as soil improvement or fertiliser there are three methods that can be implemented. The initial levels of regulated metal ions (Ni^{2+}, Zn^{2+}, Cu^{2+}, Pb^{2+}, Cr^{3+}, Hg^{2+} and Cd^{2+}) must be below a certain level in the soil on the arable land. There is a maximum yearly input dose to agricultural land [g/ha and y] accepted and there is maximum concentration levels of metal ions within the fertiliser (DG Environment, 2004).

The regulatory act regarding fertilizers in Malawi was the Fertiliser, Farm, Feeds and Remedies Act (FFFRA). In this act the quality and the availability of fertilizers that can be traded within the country is regulated (IFDC, 2013). Fertiliser that are imported or distributed in Malawi cannot be contemned with any heavy metal or any other substance that can be harmful to the environment or public health (FFFRA, 1991). It is the Malawi bureau of standards (MBS) that is responsible for pre-inspection and sampling testing of fertilizers in Malawi in order to ensure that regulations in the act are followed.

3. Material and methods

To determine if water hyacinths harvested from Shire River contain harmful levels of metals and if the dumping area is leaching nutrients or metals back to Shire River, plants and soil from one dumping site were analysed using standard methods from AOAC (1990) and APHA (1985). In order to avoid analytic errors with respect to detection method duplicates of the plant samples were prepared and a mean of them was calculated. Due to a small incident in the laboratory work, none of the soil samples were measured as duplicates.

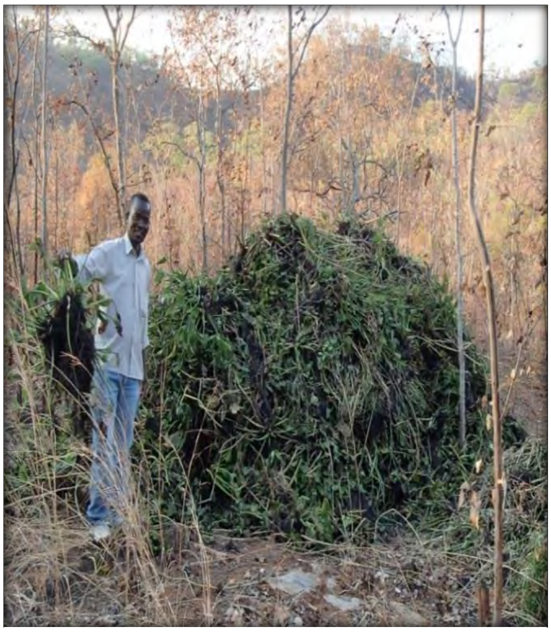

Figure 8. Pile of harvested water hyacinths together with supervisor Mwatseteza at the dumping site along the main road.

3.1 Sampling

Plant and soil samples were collected from a local dump area for water hyacinths along the main road from Blantyre to Liwonde, Figure 8. A number of fresh harvested plants were representatively picked from different heaps at the dump site. Later they were spread on the roof for sun drying. The plants were kept intact to prevent any leakage of compounds. Soil from a depth of about 5 centimeters was collected in plastic beakers both uphill and downhill the heaps of harvested water hyacinths, Figure 9. Site 1, furthest south (blue) represent a position uphill the pile of harvested weed, site 2-4 are marked in numerical order from south to north (2=red, 3=yellow, 4=purple). Number 1-4 are soil samples while number 5 (5=green) is a compost sample from underneath one pile.

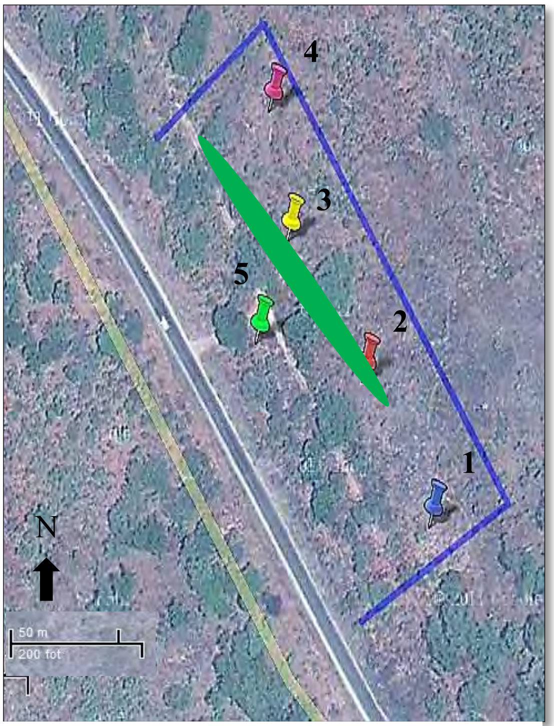

Figure 9. Soil sample places are marked with pins, numerical order from south to north. 1=blue pin, 2=red pin, 3=yellow pin, 4=purple pin and 5=green pin, where 1-4 are soil samples and 5 are compost sample from underneath one pile of water hyacinths which is represented by the green oval (Google maps, 2012).

3.2 Preparation

Different extracting methods were applied to determine the levels of both minor and trace elemental concentrations as well as nutrient contents in the collected plant and soil samples.

3.2.1 Plants

To obtain dry weight (DW) the plants were dried in an oven at 95 ^{o}C. The dried plants were divided into root, stem and leaf, and homogenised with a mechanical grinder. The crushed plant parts were placed in airtight beakers to prevent moisture to influence the weight.

Metal compounds were extracted using wet digestion, which involved the destruction of organic matter through the use of both heat and acids. This was done by adding sulphuric, nitric and perchloric acids while heating on a hot plate for one hour. Since analyses on total nitrogen levels were to be carried out, an extracting method without addition of nitric acid needed to be performed. Therefor the dry ashing method was applied on another sample set. A full description of both procedures is found in AOAC (1990). All solutions resulting from the methods were filtered through double Whatman filter paper #1 and also through a 0.45 µm membrane filter. The exact amount of dried plant used in the different methods can be seen in Appendix.

3.2.2 Soil

After collecting the soil samples they were sundried for three days to obtain the dry weight (DW) and sieved trough a 2 mm sieve.

Extraction of minor and trace elements from soil particles was carried out in a mechanical shaker with a soil/water solution of 1:5, exact amount of soil/water can be seen in Table 10 in Appendix. Extraction using only water was done in order to simulate natural conditions (Biswick pers. com., 2012). The solutions were filtered, through double Whatman filter paper #1 and also through a membrane filter (45 µm). Using a vacuum method to get rid of all clay particles in the extractions. After extraction methods for water analysis were followed (APHA, 1998).

3.3 Chemical analyses

To analyse for total levels of minor and trace elements in the extracted plant and soil solutions an atomic absorption spectrophotometer as well as an ion exchange chromatograph were used, whilst an UV/Vis spectrophotometer was used to determine iron and phosphate levels.

3.3.1 Atomic Absorption Spectrophotometer

A method for analysing metal ions (Na^+, K^+, Mg^{2+}, Mn^{2+}, Ca^{2+}, Zn^{2+}, Cu^{2+}, Pb^{2+}, Cr^{3+} and Cd^{2+}) in water suspension is to use an atomic absorption spectrophotometer (AAS). The AAS apparatus is constructed using a hollow cathode lamp, an atomising unit, a monochromator and a detector. A flame converts metal salts into free atoms and by measuring the absorption of optical radiation the concentration of metal atoms can be determined. Different lamps had to be used for each of the elements, this due to the fact that elements absorb light of different wavelength. In order to quantitatively determine the concentration of substance in the sample a couple of standard solutions of known concentration were prepared and run through the AAS, the concentration in the sample was then calculated by the Lambert-Beer law, Equation 1 (Simonsen, 2003).

$$A = \varepsilon l c \qquad \text{(Eq. 1)}$$

Where A is the absorbance, ε is the molar absorptivity for the substance and c is the molar concentration. l stands for the distance the light need to travel.

3.3.2 Ion Chromatography

Anions (nitrate, sulfate and chloride) in the samples were determined with an ion exchange chromatography (IC). The chromatograph consists of three main components: a separation column, a pump and a detector. The stationary phase, in the column, retains ions and the elution liquid transports the ions in the sample through the column to the detector. How long ions remain in the stationary phase are due to its ability to interact with other substances and compounds and is called affinity. The affinity determines the rate at which the substance is transported through the column and thereby separating different ions in the sample solution. To determine the concentrations of substances a solution of standards with known ion concentration is injected and peak is area later on compared to the peak area retained from the unknown sample (Simonsen, 2003).

3.4 Colorimetric methods

To determine phosphate in soil and plant samples the Vanadomolybdophosphoric yellow (VY) colorimetric method was carried out on acid digest using spectrophotometer. When adding NH_4-molybdate under acid conditions to a sample solution it will react and form a heteropoly acid, given that vanadium is present. Addition of vanadate-molybdate reagent will form Vanadomolybdophosphoric acid, which got a yellow color, and the intensity in its yellow color is proportional to phosphate concentration. The intensity of yellow in the sample is measured by UV/Vis-spectrophotometer. The wavelength used is dependent on assumed phosphate concentration in the sample (APHA, 1998).

Detection of iron was done with the phenanthroline colorimetric procedure. Iron (II) is reacted with *o*-phenanthroline to form a colored complex ion. The intensity of the colored sample is measured by UV/VIS at λ= 510 nm and calculated to iron concentration by Lambert-Beer law, Equation 1 (APHA, 1998).

3.4.1 UV/Vis Spectrophotometer

Ultraviolet-visible spectrophotometry (UV/VIS) uses light in the ultraviolet and visible ranges, where molecules absorb light energy in the form of photons. Basically a spectrophotometer consists of a light source that transmits light through a cuvette filled with the solution to be analysed, then records how much light is absorbed. By measuring the light absorbed in a series of standards with known concentrations of substance, a calibration curve can be constructed and used in calculation of concentrations in unknown samples.

3.5 Calculations

After analysing the samples using the different techniques described above, the concentration in ppm (mg/l) was obtained from the calibration curve of every substance. To determine the concentration in the plant- and soil samples (mg/g analyte), it was necessary to take into account the amount of dry substance used in the extraction.

3.5.1 Plant

From 100 ml of each extraction, the results are expressed in mg metal per liter, so to know how much metal was present in the sample (100 ml of extract) we need to multipliy the concentration by the volume (V=0,1 l), Equation 2 and 3.

$$conc \cdot V = y \qquad \text{(Eq. 2)}$$

Where y is the amount of metal in the sample.

$$\frac{y}{weighted\ substance} = Q \qquad \text{(Eq. 3)}$$

Where Q the concentration of metal in the plant.

3.5.2 Soil

The concentration in the extract is expressed in mg metal per liter, so to know how much metal there is in our sample we need to multiply it by the volume (in liters) of extract, Equation 4 and 5.

$$conc \cdot V = y \qquad \text{(Eq. 4)}$$

Where y is the amount of metal in the sample.

$$\frac{y}{weighed\ substance} = Q \qquad \text{(Eq. 5)}$$

Where Q is the concentration of metal in the soil.

4. Results

The amount of metals in water hyacinths, divided into root, stem and leaf, are shown in Table 5. Concentrations were detected by an Atomic Absorption Spectrophotometer (AAS) and mean value is calculated from doublets of each plant part. There was no trace of Cd, Cr and Pb. All results are expressed on a dry-matter basis of 95 degree Celsius.

Table 5. Amount of detected metals in water hyacinths from a local dumping area, expressed in mg of metal per gram DW sampled plant. The last row is the mean value when all three plant parts are taken into account. The figure within brackets represents the standard deviation for the last decimal number. Values below the detection levels are shortened by bdl.

	Na^{2+}/ $mg\ g_{DW}^{-1}$	K^{+}/ $mg\ g_{DW}^{-1}$	Ca^{2+}/ $mg\ g_{DW}^{-1}$	Mg^{2+}/ $mg\ g_{DW}^{-1}$
root	0,85(3)	0,54(7)	1,2(2)	0,66(1)
stem	1,12(6)	2,07(4)	6,2(4)	0,65(1)
leaf	0,90(1)	1,42(2)	8,09(6)	0,65(1)
Plant mean	1,0	1,3	5,2	0,7
	Zn^{2+}/ $mg\ g_{DW}^{-1}$	**Mn^{2+}/ $mg\ g_{DW}^{-1}$**	**Cu^{2+}/ $mg\ g_{DW}^{-1}$**	
root	0,13	0,73	Bdl	
stem	0,10	0,18	Bdl	
leaf	0,08	0,17	bdl	
Plant mean	0,1	0,4	-	

The amount of metals in soil samples around a local dump site for water hyacinths is shown in Figure 10. There were no trace of Zn^{2+}, Mn^{2+}, Cd^{2+}, Cr^{3+} and Pb^{2+}. Data for the soil samples are presented in the Appendix.

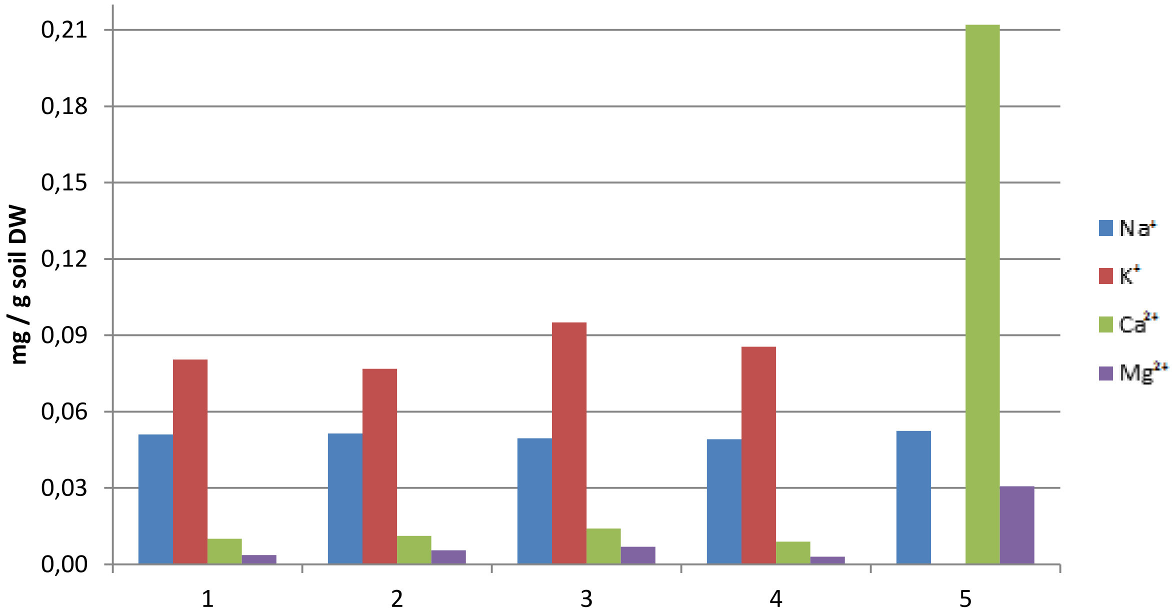

Figure10. Comparison between soil samples around a local dumping site for water hyacinths. Levels of different metals are expressed in mg metal /g soil.

Phosphate and iron(II) were detected by an UV/Vis spectrophotometer. Concentrations for the different parts of water hyacinths are shown in Table 6, expressed on a dry weight basis of 95 ^{o}Celsius. For soil samples the results are presented in Figure 11, expressed on a dry weight basis of sun drying.

Table 6. Amount of detected iron and phosphate expressed in milligrams of compound per gram DW plant part. Mean value are calculated from triplets of each plant part. The last row is the mean value when all three plant parts are taken into account.

	PO^{-3}_4/ $mg\ g_{DW}^{-1}$	Fe^{2+}/ $mg\ g_{DW}^{-1}$
root	27(7)	99(6)
stem	30(6)	7(5)
leaf	33(7)	17(3)
Plant mean	30	41

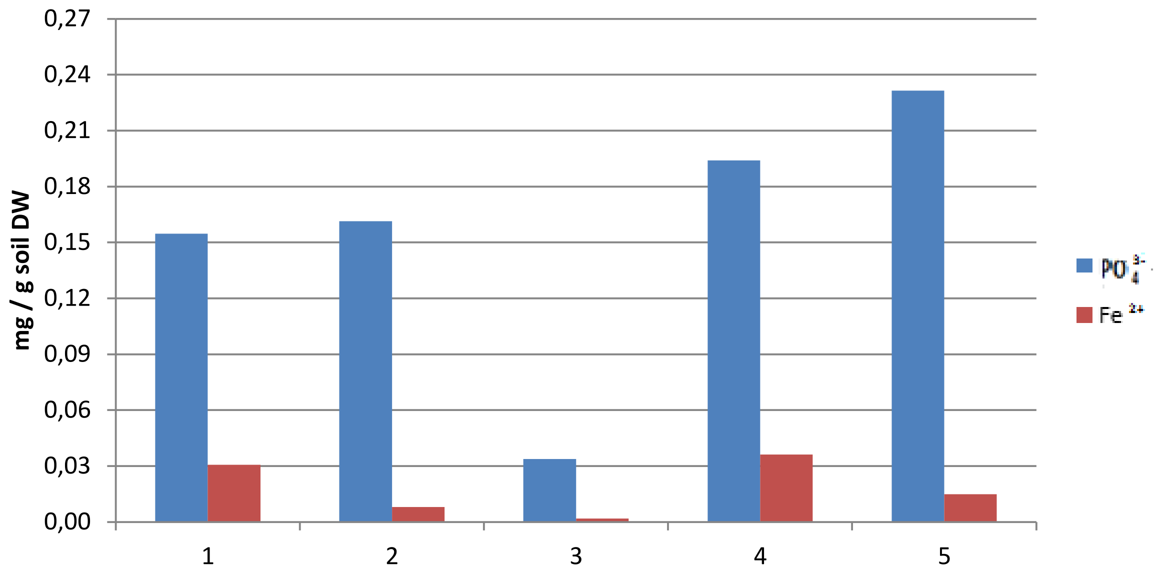

Figure 11. Phosphate and iron(II) levels in different soil samples around the local dumping area.

The IC method was used to analyse plant extract and soil samples with respect to nitrate, chloride, sulfate and fluoride, Figure 12. There was no fluoride found in any of the samples. Plant samples could not be analysed with this method because the extracting method used acids containing nitrate. Also ion activity was too high in all plant samples to be analysed through IC detection. All values are expressed on a dry weight basis of sun drying and presented as mg / g soil DW.

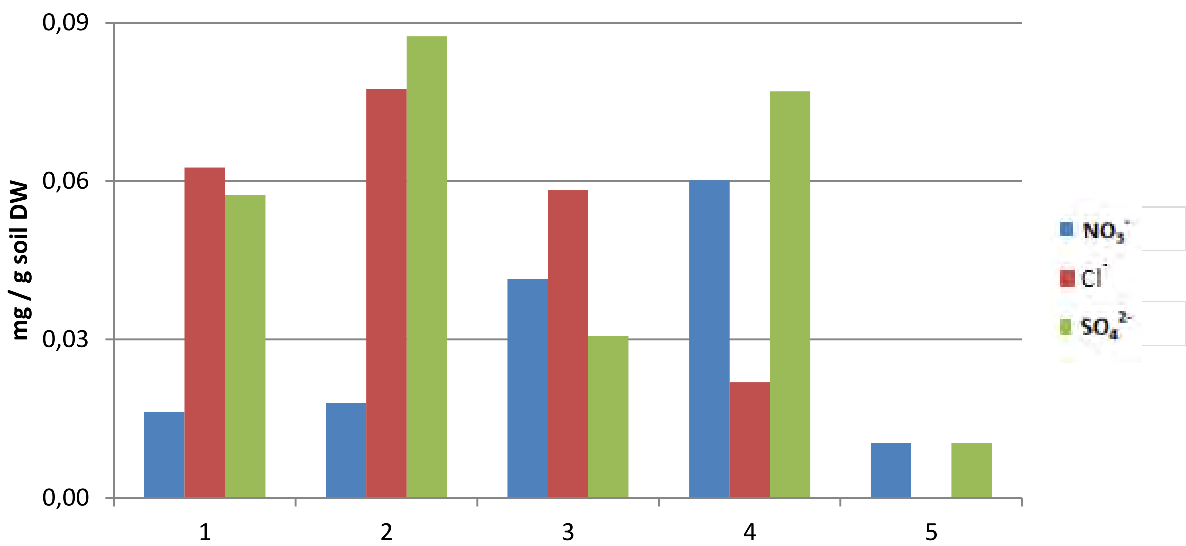

Figure 12. Levels of nitrate (NO_3^-), sulphate (SO_4^-) and chloride (Cl^-) between the different soil samples. Fluoride was below detection level and was excluded from the comparison.

4.1 Comparison of results

For each of the nutrient and minor element levels in the rot, stem and leaf a mean was calculated, Table 7, and compared to figures from Gunnarson and Mattsson (1997), see Table 1 in section 2.1. For soil samples a mean between sample points 1-4 was calculated and compared to those values for a typical Blantyre soil, see Table 2 in section 2.2. Only the substances that were possible to compare are shown in Table 7 and 8 below.

Table 7. Comparison between values in water hyacinths from this study with values from a previous study (Gunnarson and Mattsson, 1997). Only substances possible to compare are included in this table. The last row in the table shows if the measured levels are below (-), above (+) or almost equal (=) to levels found in the literature (Gunnarson and Mattsson, 1997).

mg/g plantDW	**Zn^{2+}***	**Ca^{2+}**	**K^{+}**	**PO_4^{3-}**	**Mg^{2+}**
Literature	0,2-0,4	5,8	24,4-45,3	2,6-5,3	1,7
Measured	0,1	5,2	1,3	30,2	0,7
comparison	**-**	**=**	**--**	**++**	**-**

**Maximum values in compost for European countries (DG Environment, 2004).*

Table 8. Comparison between values in soil samples from this study with values for a typical Blantyre soil (Evans, 1963). Only substances able to compare are in this table. The last row in the tables display whether the measured levels are below (-), above (+) or almost equal (=) as those levels found in literature.

mg /g soil DW	**Zn^{2+}**	**Ca^{2+}**	**K^{+}**	**Tot-P**
Literature	0,00	0,60	0,43	0,05
Measured	BDL	0,01	0,09	0,14
Comparison	**=**	**-**	**-**	**+**

5. Discussion

When water hyacinths harvested in Shire River were analysed there was no trace found of the more harmful elements of copper (Cu^{2+}), lead (Pb^{2+}) and chromium (Cr^{3+}). This indicates that none of these metal ions pose a risk to accumulate on agricultural land when using these water hyacinths as soil improvers.

The other analysed elements that could be compared with earlier published levels in water hyacinths showed that all levels obtained in this paper are well below (Mg^{2+}, K^{+}, Zn^{2+}) or equal (Ca^{2+}) to previous found levels, Table 7. From Table 7 it is also seen that measured levels of phosphorus (30 mg P/g plant) are much higher than those that Gunnarson and Mattsson (1997) presented. If this is compared with maximum input of phosphorus on agricultural land in European Union, 20-80 kg/ha DW (Table 3), it would mean that one must apply 2667 kg DW plants on one hectare of agricultural field to exceed the maximum input. Overall there is a small chance of contaminate the soil by just adding green manure, due to the large loads of weed that needs to be added (Börjesson pers. com., 2012). It would be alarming if there was an on-going release of toxic substances, such as Pb^{2+} or Cr^{3+}, into Shire River. If that was the case, water hyacinths could absorb these metal ions and eventually they could end up on agricultural fields and later in crops. It is important and also a subject for further studies, to have continuous and easily accessible updates on the water status in Shire River to prevent toxic substances to be spread in the environment.

Soil sampling was made during the winter season in Malawi which means that the climate is very dry. It probably had not rained after the current location began to be used as a dumping site. Table 8 also shows that there is no difference in trace elements between the sampling points (upstream vs. downstream the heaps) therefore one cannot determine if the dumping areas are leaching nutrients back to Shire River or not. The relatively high phosphorus levels that were obtained in this study (30 mg/g plant DW) indicate however that with a wetter season it cannot be excluded that phosphorus might escape from the dump area. Further contributing to this is the fact that there is a small river just downstream the dumpsite. This river is dry at the moment but with a wetter climate, water will have a quick way to access Shire River.

For further and more reliable studies more sampling points than four must be included. Samples at a varying soil depth should also be analysed. There is also a need to include both wet and dry seasons to be certain that there is no leakage from places used to dispose harvested water hyacinths.

5.1 Water hyacinths

Invasion of water hyacinths are affecting Malawi economically, environmentally and socially in a very concerning way. There is a hurry to find a winning strategy to fight water weeds and address and reverse the problems caused by them. On the other hand they also provide working opportunities for the local community, i.e. harvesting by local fishermen and the new established weed-management section at ESCOM.

The increased pressure on forest areas in the surrounding landscape with deforestation and the development of new agricultural fields further contributes to favourable growing conditions for water hyacinths. To decrease the magnitude of the water hyacinth-problem there has to be actions in the whole community, not only locally in Shire River. Removing the plants will also remove some of the breeding places for organisms that are vectors for tropical diseases, such as bilharzia and mosquitoes. This will contribute to enhanced living conditions for the population.

5.1.1 Controlling methods

Harvesting water hyacinths by mechanical machines is the most common and established regulation technique in Malawi. Since water hyacinths are good absorbers there are advantages with mechanical harvesting. To remove the weed also removes redundant nutrient from the water body. It is also possible to use the harvested plants in the industry or as green manure. With harvesting there is an immediate effect which usually is required to avoid temporary electricity black-outs and provide a more widely use of the water body (i.e. irrigation, power generation, drinking water supplies and access to shoreline). However, it is important to develop a sustainable way to take advantage of the harvested water hyacinths, instead of just dispose them. Especially in countries struggling with a poor economy and in order to meet tomorrow's demands for a more sustainable society.

Introducing a natural enemy to a problem area could be a good long-term way to regulate the uncontrolled reproduction of the plants. If satisfactory results are achieved it could be seen as a sustainable approach to a difficult problem. Although it is important that good research is done before introducing any further alien species to the environment.

When using chemicals in order to erase water hyacinths from aquatic systems there is always a potential risk of affecting other organisms in the ecosystem. Especially when spreading chemicals in the surface water and through potential contamination of drinking water. Besides, there is still a need of cleaning the water from dead plants after the chemical-addition, so this might not be the most preferable way of dealing with the problem.

Controlling the growth of water hyacinths is an expensive project, not directly resulting in food or income. It often requires involvement from financiers and there is a risk that the work done is of more temporary character in order to prevent economic losses. Water hyacinths are more likely to be a problem in countries with less financial strength. Because of that very limited resources have been put in to more extensive controlling projects.

5.1.2 Utilisation

Water hyacinths can be used in many different ways and every local area that suffers from a plant invasion must analyse which utilisation that makes the greatest benefit right there.

To use water hyacinths in the energy producing sector, large economical input is required. Producing biogas requires considerable efforts regarding both construction and infrastructure. Efforts that may not always be possible in developing countries where the problems with water hyacinths are greatest. There is also a demand for more research to find the most effective way to extract maximum energy.

To further improve the utilisation of water hyacinths in Malawi it might be an idea to broaden the knowledge about composting in both small and larger scale. Supplementary studies on the nutrient exchange between compost/soil and crop might be necessary to reach the local crop demand. Since water hyacinths tend to concentrate substances absorbed from the water body there is also important to know where the water hyacinths originally grow.

With more knowledge, there might also be possible to locally process them into a complement for charcoal.

5.2 Soil status and fertilisers

To strategically apply fertilisers on agricultural land the knowledge of the soils structure and characteristics as well as nutrient status and organic content are of great importance. Since no analyses were made on agricultural fields in this paper one cannot say how adding water hyacinths as a green manure affects the soil fertility. To obtain maximum outcome for subsequent crops one must be aware of the C/N ratio in the added plants in combination with the C/N ratio in the soil. In general adding extra carbon to a soil will improve the structure and benefit crop production which is necessary for countries like Malawi, who is concerned with high population density and decreasing soil fertility (MECCM, 2010). Green manure also has the ability to reduce soil acidity with the result of an increased availability of nitrogen in the soil (Pocknee and Sumner, 1997).

To develop and improve soil-management recommendations there is a need of knowing how texture, soil type and nutrient status vary throughout the landscape and especially what these parameters say about the local field.

5.3 Analytical techniques

The methods with which the analyses were performed and prepared had some sources of errors included. This was largely due to the usual uncertainties in laboratory work, the human errors, but also on poor instrument conditions and sometimes even lack of instruments. All preparations of samples and standards were done with the same disposable pipette-tip, since there was a limited amount of tips. To avoid contamination by other substances the tip was rinsed with distilled water. Also the membrane filters were reused and rinsed with distilled water. Some contamination of samples has certainly been present during the laboratory work, and there is a risk that standards prepared for analyses with AAS, IC and UV/Vis were not of fully correct concentration.

Only mechanical grinding was applied to achieve a homogenised set of dry plant parts for extraction. No sieving were conducted which might have led to a not completely homogenized set of samples and less accurate results, although, this is considered to be a relatively small source of error.

Another source of error that might affect the results were that many samples had to be diluted before run through analyse. The dilution was performed with automatic pipette and the accuracy was of the magnitude millilitre. This had to be done both to have enough liquid required for the detection machine and because many samples had too high ion concentration after the extracting procedure for analyse to work.

When extracting compounds from the soil samples only water combined with shaking were used as an extractor. This might not be sufficient enough to obtain the right levels of metals when analysing the soil. Only soluble ions may have been extracted using this method and wet oxidation might be necessary to extract metals. This is also visible in table 8 which present levels in the sampled soil well below the levels for a normal Blantyre soil.

6. Conclusions

Concentration of copper (Cu^{2+}), lead (Pb^{2+}) and chromium (Cr^{3+}) were below detection limits in the analysed water hyacinths which might indicate that none of these metal ion compounds pose a risk to accumulate on agricultural land when using water hyacinths as soil improvers.

Soil sampling was carried out during the dry season which meant that it is not possible to determine if the dumping areas are leaking nutrients. A relatively high phosphorous level was obtained in the plants and it is not excluded that a leakage of phosphorus can occur during the wet season.

The presence of water hyacinths in Shire River is a great burden for Malawi's economy and affects both the industrial and community development in a negative way due to the regular electricity black-outs. For countries that suffer from high amounts of water hyacinths, and great harvested plant piles, the use of water hyacinths as green manure serves a great logistical advantage.

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7.2 Pictures

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7.3 Oral

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8. Appendix

Figures from the extraction part of the analyze is shown in Table 9 and 10.

Table 9. Amount of dried plant used in wet- and dry ashing extraction. The final volume in all analyses were 100 ml

Wet oxidation	Weight (g)
Root	1.004
Stem	1.008
Leaf	1.002
Dry ashing	
Root	1.018
Stem	1.003
Leaf	1.004

Table 10. Amount of dry soil used for extraction of detection elements. The corresponding amount of water for a 1:5 soil solution was 150 ml

Soil	weight (g)
1	29,991
2	29,999
3	30,035
4	30,027
5	11,545*

* For sample number 5 the corresponding 1:5 solution is 57 ml. The deviation is due to lack of soil in the sample

Values underlying the figures in section 4, obtained from soil analyses.

Table 3.Amount of detected metal compounds expressed in mg of metal per gram DW sampled soil. Values below the detection levels are shortened by bdl. All concentrations are in mg / g soil DW

Sample site	Na^{2+}	K^{+}	Ca^{2+}	Mg^{2+}	Zn^{2+}	Mn^{2+}
1	0,051	0,081	0,010	0,004	bdl	Bdl
2	0,051	0,077	0,011	0,006	Bdl	Bdl
3	0,050	0,095	0,014	0,007	Bdl	Bdl
4	0,049	0,086	0,009	0,003	bdl	Bdl

Table 4. Amount of detected iron and phosphate expressed in milligrams of compound per gram DW soil.

Sample site	**PO_4^{3-}**	**Fe^{2+}**
1	0,155	0,031
2	0,161	0,008
3	0,034	0,002
4	0,194	0,036

Table 5. Amount of detected nitrate, chloride, sulfate and flouride expressed in milligram of compound per gram DW soil.

Sample site	**NO_3^-**	**Cl^-**	**SO_4^{2-}**	**F^-**
1	0,016	0,063	0,057	bdl
2	0,018	0,077	0,087	bdl
3	0,041	0,058	0,031	bdl
4	0,060	0,022	0,077	bdl