Water hyacinth as a possible bioenergy resource: A case of Lake Victoria, Kenya

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Abstract. Currently, climate change and its impacts are driving the development of renewable energy resources globally. There is a growing quest to widen the supply of biomass resources for bioenergy production. In this paper, we interviewed local people to elicit perceptions regarding current and potential uses of water hyacinth, Eichhornia crassipes, which grows in large quantities at the Lake Victoria region in Kenya. The aim was to determine peculiar problems and what possibilities lay in bio renewable energy production from the resource. Most of the respondents favoured development of the water hyacinth into viable commercial products, mainly due to its various negative effects such as: impact on water quality and fishing businesses as well as interference with irrigation systems. Our research however, observed that promotion of commercial bioenergy production from the water hyacinth may however be faced with some competition due to existing livelihood factors (e.g. source of organic fertilizer for crop production, craftwork, etc.). From the findings, we conclude that because the water hyacinth widely grows in this region, there is an opportunity to expand biomass for bioenergy in the region. This however, will require a participatory approach; to consider the livelihood values, as well as developing of affordable biofuel products. The results are expected to inform environmental/energy planning and decisions, particularly regarding the negative impacts of the water hyacinth and its potential values (e.g. as a bioenergy resource).

1. Introduction

Lake Victoria is the main contributor to water flow in the Nile River Basin, it provides industrial, domestic, irrigation and power-generation water to Kenya, Tanzania, Uganda, Sudan, and Egypt. The lake supports numerous opportunities within water transport, industrial, domestic and agricultural applications, and hydroelectric power generation for more than 30 million people in the basin and greater East Africa region [1]. Water hyacinth (Eichhornia crassipes) in the Lake is a problematic invasive species, free floating or anchored in mud aquatic weed characterized by large and rapid rate of proliferation [2-4].

The water hyacinth (WH) grows rapidly in mats and produces enormous amounts of biomass to approximately 3m thick which can reduce oxygen, light, affect water chemistry, interferes with fauna and flora, leads to practical economic and ecological challenges by impeding marine transportation, fishing, recreational activities, interferes with irrigation schemes and intakes for hydro power due to significant water loss because of evapotranspiration. It is considered a serious threat to biodiversity; as such, the rapid spread in many parts of Africa has caused great concern [5-8]. Water hyacinth
threatens agricultural production, reduction of the activity of electrical power stations, jeopardizing the power supply of the country; in addition, it impedes the water flow resulting to sedimentation, flooding and soil erosion. The rapid growth rates and elevated rate of dispersion in both constructed and natural wetlands and its problems has consequently triggered intense research towards its conversion as biomass resource or for energy production [9-11]. This is considered as a mitigation strategy to derive valuable resources from the water hyacinth [12].

As a bioenergy resource, there is an added advantage of deriving energy from non-edible resources [13], apart from the indirect benefits of reduction of energy costs and mitigation of greenhouse gas emissions caused by fuels derived from fossil sources.

1.1. Aims and objectives
The aim of this research was to initiate possible ways to alleviate various socio-economic and environmental (or ecological) challenges posed by WH within the Lake Victoria communities. Specific objectives include:

- To explore perceptions regarding WH problems peculiar to the local communities.
- To explore potential uses of the WH and what possibilities lies regarding future development as a source of energy.

2. Methodology
Data collection took place within the L. Victoria communities (Figure 1). Data was collected between January and March 2018 by administering semi-structured questionnaires developed for purpose. The different kinds of respondents are shown in Figure 2. The data was analyzed using Statistical Package for the Social Sciences (SPSS).

3. Results
3.1. Methods of WH removal
Various mechanical and chemical techniques are proposed for the removal of WH from natural water bodies such as lakes, however, these are often not only expensive but also ineffective [14]. Mechanical techniques are often labour-intensive, cost is labour-based and in most cases the method is slower. Alternative methods include the use of herbicides such as 2,4-d, Diquat, Glysoxlate, but this may also be unfriendly to native fish population and plant species. Biological control methods, which can also make use of different biological agents such as N. eichhorniae, Neochetina bruchi, Sameodes albiguttalis, and Megamelus scutellaris have also been proven not very efficient, because they can only control the plant biomass by approximately 70%, difficult to control in water bodies. A typical example of biological method is use of Mycoleptodiscus terrestris (Mt) which acts as a fungal pathogen, acting as contact bio herbicide, which has inconsistent viability, expensive and cross contamination [15]. Another option is removal by manual approach, but this is only effective for exceedingly small areas and is labor intensive with high health risks associated with malaria, Schistosomiasis (bilharzia) and water animals such as crocodiles and hippopotamuses.

Despite the risks, removal by the manual method seems to be the most readily available option for most local communities. Villamagna et al. [16] highlighted that the control of excessive WH is challenging and the available control methods are expensive for both initial and future treatment costs. Soil erosion control, control of excessive nutrients in water bodies and waste water treatment are proposed as the way forward [17].

Considering the high costs of removal, conversion of the WH into commercial products will help subsidize the removal cost. This could also be accompanied by an appropriate financial investment towards more efficient ways of removal. Our work recommends cost-effective biofuel resources to recover or subsidize the cost involved in the removal of the WH and sought to explore perceptions regarding this.
3.2. Local communities’ perceptions

Biomass plays a vital role in sustainable development; however understanding perceptions of various groups of the society regarding its development offers a better insight into societal acceptance and informing future directions. The present work explored perceptions of the local communities regarding challenges and uses of the WH. A key assumption made in the study was that local perceptions form the core of decisions based on access, local knowledge and general experiences of the local people who live near the resource. In this study, we focused on how perceptions of the local people might contribute to the effective management and possible economic utilisation of the WH that grows in the Lake Victoria region.

The WH is locally known as Buya, which the respondents described to be problematic in diverse ways. Some of the issues raised are summarized in Figure 3 and 4. Majority of the respondents were fishermen (Figure 2), who were mostly dissatisfied about manual efforts in removing the water hyacinth due to its laborious nature. They proposed mechanical methods. It was observed that with appropriate strategies these problems shown (Figure 3 and 4) could more readily trigger rather positive outcomes, by conversion of the WH into valuable resources.
Figure 3. Impacts of WH
1. Reduced water quality; 2. Damage of fishing nets; 3. Reduced quantity of fish; 4. Interference with irrigation/waterways; 5. Blockage of swimming areas; 6. Increased fish price due to reduced supply; 7. Not aware

Figure 4. Distribution of the water hyacinth along some waterways.

The problems represented in Figure 3 and 4 are however not unfamiliar issues relating to the WH. Opande et al. [18] noted that WH causes economic, social and environmental problems which might include; choking of fish and native aquatic plants leading to ecological imbalances in the lake. It also serves as a microhabitat for malaria and Schistosomiasis (bilharzia) causing organisms such as mosquitos and snails. Other negative effects include: interference with water navigation, irrigation, increased cost of water treatment, impacts on human health, reduced biodiversity, increased evapotranspiration, blockage of access to beaches for recreational activities and interference with inlets for hydroelectric power generation plants [17, 19].

Mailu [20] in his preliminary assessment of effects of the WH within the L. Victoria communities estimated a decrease of 59%, 37% and 14% in the catches of some types of tilapia species, particularly; Mormyrus, Clarius and Oreochromis. Reason being that the water at WH infested areas is often warm and still, which is undesirable for the fish. It rather turns out as breeding sites for snakes and crocodile.

This study however reveals some interesting results regarding some socio-economic uses for the WH. Most of the respondents (53.1%) pointed out uses as animal feed/fodder (Figure 5). Other responses included mulching material (22.2%), craftwork such as basket making (11.1%) and application as bio-fertilizer (13.6%).
Application of WH as fertilizer, compost or green manure involves harvest and application to croplands directly or ploughed into the ground. The goal is to improve soil fertility for increased crop yield. This approach is regarded as an alternative to expensive inorganic fertilizers.

When the respondents were asked about what they might like the WH to be used for in the future, the responses were still directed towards socio-economic values. Fertilizer production emerged as the most desired choice. This shows that crop production is an important part of the life of the people living near these communities and they may like to preserve that. Bio-fuel production emerged as second, following fertilizer production (Figure 6). Even though use as animal fodder appeared as the predominant use currently (Figure 5), the WH may contain high levels of undesirable minerals and water, hence, not suitable for all animals. A study might wish to investigate the health impact of feeding domestic animals with the WH.

Some of the recommended uses such as waste water treatment (Figure 6) have also been reported in the literature [21]. It helps in small floc removal after coagulation, resulting to a remarkable reduction in turbidity and slight decrease in organic matter content in the water.

Chen et al. [22] and Vamvuka et al. [23] noted that the current and potential effects of climate change on the environment demand the implementation of socioeconomic policies that promote sustainable energy systems towards the development of renewable or alternative energy sources such as biofuels in both industrializing and industrialize countries. WH is among the group of potential feedstocks for energy production [22], thus production in adequate amounts can create an advantage for biofuel production in the future, for example gas and bioethanol production [24-26].

3.3. Potential of WH as an energy resource

Water hyacinth (Eichhornia crassipes) biomass (WHB) has been proven suitable for bio-ethanol production [27-29]. The biomass from WH has about 48% hemicellulose, 18% cellulose 3.5% lignin [30]. Though there is a significant amount of variability in composition reported by various researchers, generally, the biomass is considered to be rich in hemicellulose and with very less lignin content. The biomass productivities of this plant is very high [31], and there is abundant availability of this plant in most parts of Lake Victoria, making it a suitable feedstock for distributed ethanol production.
The respondents were asked to rate the potential of the WH as an energy resource. 35.7% of the respondents rated it as high, 41.4% as average and 22.9% as low (Figure 7a). This re-affirms earlier observation (Figure 5 and 6) that harvesting WH for biofuel production is very likely to face competition with other viable socio-economic ventures such as fertilizer for crop production. Those who gave the high rating (35.7%) believed energy from this resource could serve as an alternative to charcoal use and other forms of fossil fuels used in these communities. These respondents believe that excessive dependence on charcoal poses risks of deforestation. This observation particularly indicates some level of environmental protection awareness among the communities. This might benefit the promotion of biofuel production from WH as a Climate change mitigation strategy.

It was however observed that any future efforts to develop biofuel production must consider cost factors (Figure 7b). The respondents who highly rated the WH as a future feedstock for energy production (Figure 7a) proposed that any such efforts must consider low cost products. In other words, bio-fuel from WH for communities living near the L. Victoria may find it as an incentive when affordable bio-fuels are produced from the WH. Future work should consider investigating local perceptions regarding energy conversion routes for the WH. Despite its low heating value, there are ways to improve on it [27].

4. Conclusions
The study was conducted to understand the perception of local communities on water hyacinth, an abundant resource in the region of Lake Victoria in Kenya. The result aligns with present literature regarding various problems encountered especially by peripheral communities along water hyacinth infested areas. However, it can be considered as a nuisance, we observed that WH could also offer various socio-economic values; such that to develop it as a bioenergy resource will be faced with some competition (e.g. source of organic fertilizer, craftwork and animal fodder). However, as an abundant resource, there is that possibility for also bioenergy from the WH. Two key factors that may be required for this is awareness creation about the environmental benefits of using energy from biomass such as climate change mitigation, as well as offering inexpensive bioenergy products. Current uses of the WH must not be ignored as these might influence negatively on the livelihood of some of the residents. Future work should mainly focus on policy development and participatory management to alleviate its negative impacts without jeopardizing current and potential uses (e.g. for bioenergy production).
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References
[1] Abila R O 2000 The development of the Lake Victoria fishery: A boon or bane for food security? *Socio-economics of the Lake Victoria Fisheries*. IUCN Eastern Africa Programme 15
[2] Williams A E, Hecky R E, Duthie H C 2007 Water hyacinth decline across Lake Victoria was it caused by climatic perturbation or biological control? *A reply Aquatic Botany* 87 94–6
[3] Zhang Y, Zhang D, Barrett S 2010 Genetic uniformity characterises the invasive spread of water hyacinth (Eichhormia crassipes), a clonal aquatic plant *Molecular Ecology* 19 1774-86
[4] Cilliers C J, Campbell P L, Naude D, S S N 2003 An Integrated Water Hyacinth Control Programme on the Vaal River, In a Cool, High Altitude Area in South Africa. *Plant Protection Research Institute, Agricultural Research Council, Pretoria, South Africa*
[5] Harley L S, Julien M H, Wright A D 1997 Water Hyacinth: A Tropical Worldwide Problem and Methods for its Control *Proceedings of the first meeting of the International Water Hyacinth Consortium. World Bank* March 18
[6] Hill G, Waage J, Phiri G The water hyacinth Problem in *Tropical Africa Proceedings of the first meeting of the International Water Hyacinth Consortium, World Bank*, 18-19 March 1997
[7] Sciences N A.1976 Making Aquatic Weeds Useful: Some Perspectives for Developing Countries
[8] Seehausen O, Witte F, Katunzi E F, Smits J, Bouton N 1997 Patterns of the remnant cichlid fauna in southern Lake Victoria *Conserv Biol* 11 890–904
[9] Gunnarsson C C, Petersen C M 2007 Water hyacinths as a resource in agriculture and energy production: A literature review *Waste Management* 27 117-29
[10] Bhattacharya A, Kumar P 2010 Water hyacinth as a potential biofuel crop *Electronic Journal of Environmental, Agricultural and Food Chemistry* 112 22
[11] Bergier I, Salis S M 2011 Ecosystem surplus and renewability of wetlands production systems. Documentos/Embrapa Pantanal (www.cpap.embrapa.br/publicacoes/online/DOC114.pdf )
[12] Malik A 2007 Environmental challenge vis a vis opportunity: the case of water hyacinth *Environ Int* 33 122-38
[13] Wildschut J, Arentz J, Rasrendra C B, Venderbosch R H, Heeres H J 2009 Catalytic Hydrotreatment of Fast Pyrolysis Oil: Model Studies on Reaction Pathways for the Carbohydrate Fraction *Environmental Progress & Sustainable Energy* 450-60
[14] Bank W 1997 *Proceedings of the International Water Hyacinth Consortium*. (Washington D.C
[15] Moran P J, Pitcairn M J, Villegas B 2016 First establishment of the planthopper Megamelus scutellaris Berg 1883 (Hemiptera: Delphacidae) released for biological control of water hyacinth in California *Pan-Pac. Entomol* 92 32-43
[16] Villamagna A M, Murphy B R 2010 Ecological and socioeconomic impacts of invasive water hyacinth (Eichhormia crassipes): A review *Freshwater Biology* 55 282–98
[17] Mayo A W, Hanai E E 2017 Modeling phytoremediation of nitrogen-polluted water using water hyacinth (Eichhormia crassipes) *Physics and Chemistry of the Earth* 100 170-80
[18] Opande G O, Onyang J C, Wagai S O 2004 Lake Victoria: the water hyacinth (Eichhormia crassipes [MART.] SOLMS), its socio-economic effects, control measures and resurgence in the Winam gulf *Limnologica* 34 105-9
[19] LVEMP 2004 *Lake Victoria Environmental Management Project*. ed W Bank
[20] Mailu A M 2001 Preliminary assessment of the social, economic, and environmental impacts of water hyacinth in the Lake Victoria basin and the status of control. In: *Global Working Group for the Biological and Integrated Control of Water Hyacinth* (Beijing, China)
[21] Haider S Z Recent Work in Bangladesh on the Utilization of Water Hyacinth. In: https://solucionespracticas.org.pe/Descargar/613/5294
[22] Chen J C, Liu J Y, He Y, Huang L M, Sun S Y, Sun J, Chang K L, Kuo J H, Huang S S, Ning X A 2017 Investigation of co-combustion characteristics of sewage sludge and coffee grounds mixtures using thermogravimetric analysis coupled to artificial neural networks modeling *Bioresour Technol* **225** 234–45
[23] Vamvuka D, Salpigidou N, Kastanaki E, Sfakiotakis S 2009 Possibility of using paper sludge in co-firing applications *Fuel* **88** 637–43
[24] Zimmels Y, Kirzhner F, Kadmon A 2009 Effect of circulation and aeration on wastewater treatment by floating aquatic plants *Sep Purif Technol* **66** 570–7
[25] Mishima D, Kuniki M, Sei K, Soda S, Ike M, Fujita M 2008 Ethanol production from candidate energy crops: water hyacinth (Eichhorniacrassipes) and water lettuce (Pistiastratiotes L) *Bioresour Technol* **99** 2590–600
[26] Luo G E, Strong P J, Wang H L, Ni W Z, Shi W Y 2011 Kinetics of the pyrolytic and hydrothermal decomposition of water hyacinth *Bioresour Technol* **102** 6990–4
[27] Intaniwet A, Chaiyat N 2017 Levelized electricity costing per carbon dioxide intensity of an organic rankine cycle by using a water hyacinth-municipal solid waste fuel *Energy* **139** 76-88
[28] Abraham, M, Kurup, G M, 1996. Bioconversion of Tapioca (Manihot esculenta) waste and water hyacinth (Eichhornia crassipes) – Influence of various physicochemical factors. *J. Ferment Bioeng* **82** 259–263
[29] Mishima D, Kuniki M, Sei K, Soda S, Ike M, Fujitha M 2008 Ethanol production from candidate energy crops: Water hyacinth (Eichhornia crassipes) and water lettuce (Pistia stratiotes L) *Bioresource Technol* **99** (7) 2495–2500
[30] Nigam J N 2002 Bioconversion of water-hyacinth (Eichhornia crassipes) hemicellulose acid hydrolysate to motor fuel ethanol by xylose-fermenting yeast *J Biotechnol* **97** 107–116
[31] Mitchell D S 1976. The growth and management of Eichhornia crassipes and Salvinia spp. in their native environment and in alien situations. In: Varshney C K, Rzoska J. (Eds.) *Aquatic Weeds in Southeast Asia Dr. W Junk B V Publishers, The Hague* p 396