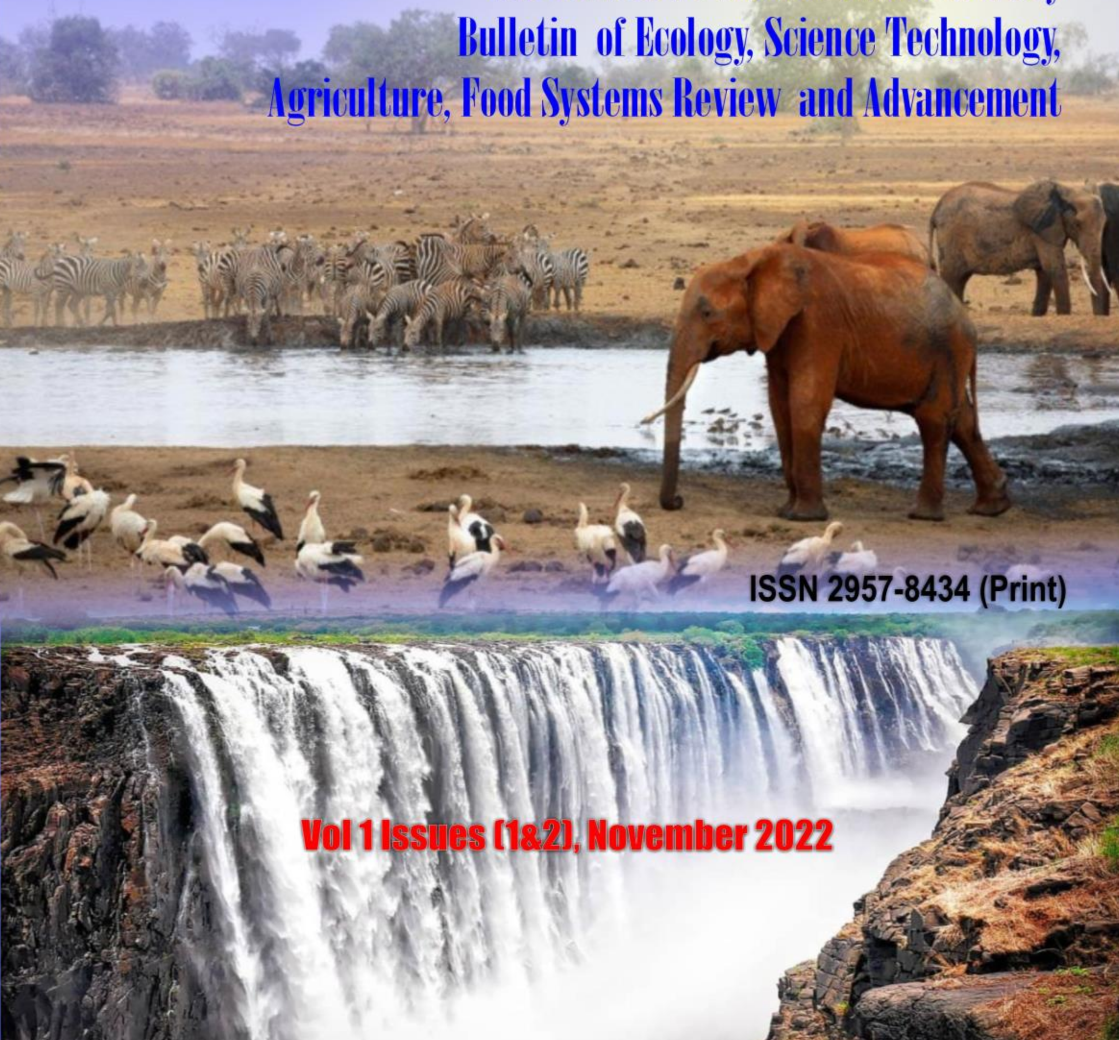
ZEGU
ZIMBABWE
EZEKIEL GUTI
UNIVERSITY
Committed to Excellence

Oikos

The Zimbabwe Ezekiel Guti University Bulletin of Ecology, Science Technology, Agriculture, Food Systems Review and Advancement



ISSN 2957-8434 (Print)

Vol 1 Issues (1&2), November 2022

Published by the Zimbabwe Ezekiel Guti University Press
Stand No. 1901 Barrassie Rd,
Off Shamva Road
Box 350
Bindura, Zimbabwe

Typeset by Divine Graphics
Printed by ZEGU Press

SUBSCRIPTION AND RATES
Zimbabwe Ezekiel Guti University Press Office
Stand No. 1901 Barrassie Rd,
Off Shamva Road
Box 350
Bindura, Zimbabwe
Telephone: ++263 8 677 006 136 | +263 779 279 912
E-mail: zegupress@admin.uz.ac.zw
http://www.zegu.ac.zw/press

About the Journal

JOURNAL PURPOSE

The purpose of *the Oikos - The Zimbabwe Ezekiel Guti University Bulletin of Ecology, Science Technology, Agriculture and Food Systems Review and Advancement* is to provide a forum for scientific and technological solutions based on a systems approach and thinking as the bedrock of intervention.

CONTRIBUTION AND READERSHIP

Natural scientists, engineering experts, technologists, and multidisciplinary teams are encouraged.

JOURNAL SPECIFICATIONS

Oikos - The Zimbabwe Ezekiel Guti University Bulletin of Ecology, Science Technology, Agriculture and Food Systems Review and Advancement

ISSN 2957-8434(Print)

SCOPE AND FOCUS

The journal is a forum for the discussion of ideas, scholarly opinions and case studies of natural and physical science with a high proclivity to multidisciplinary approaches. The journal is produced bi-annually.

Guidelines for Authors for the *Oikos* Journal

Articles must be original contributions, not previously published and should not be under consideration for publishing elsewhere.

Manuscript Submission: Articles submitted to the *Oikos - The Zimbabwe Ezekiel Guti University Bulletin of Ecology, Science Technology, Agriculture and Food Systems Review and Advancement* are reviewed using the double-blind peer review system. The author's name(s) must not be included in the main text or running heads and footers.

A total number of words: 5000-7000 words and set in 12-point font size with 1.5 line spacing.
Language: British/UK English
Title: must capture the gist and scope of the article
Names of authors: beginning with the first name and ending with the surname
Affiliation of authors: must be footnoted, showing the department and institution or organisation.
Abstract: must be 200 words
Keywords: must be five or six containing words that are not in the title
Body: Where there are four authors or more, use *et al.*
Italicise *et al., ibid.,* words that are not English, not names of people or organisations, etc. When using more than one citation confirming the same point, state the point and bracket them in one bracket and in ascending order of dates and alphabetically separated by semi-colon e.g. (Falkenmark, 1989, 1990; Reddy, 2002; Dagdeviren and Robertson, 2011; Jacobsen *et al.,* 2012).

Referencing Style: Please follow the Harvard referencing style in that:
— In-text, citations should state the author, date and sometimes the page numbers.
— The reference list, entered alphabetically, must include all the works cited in the article.

In the reference list, use the following guidelines, religiously:

Source from a Journal

Anim, D.O and Ofori-Asenso, R (2020). Water Scarcity and COVID-19 in Sub-Saharan Africa. *The Journal of Infection*, *81*(2), 108-09.

Banana, E, Chitekwe-Biti, B and Walnycki, A (2015). Co-Producing Inclusive City-Wide Sanitation Strategies: Lessons from Chinhoyi, Zimbabwe. *Environment and Urbanisation*, *27*(1), 35-54.

Neal, M.J. (2020). COVID-19 and Water Resources Management: Reframing Our Priorities as a Water Sector. *Water International*, *45*(5), 435-440.

Source from an Online Link

Armitage, N, Fisher-Jeffes L, Carden K, Winter K, *et al.,* (2014). Water Research Commission: Water-sensitive Urban Design (WSUD) for South Africa: Framework and Guidelines. Available online: https://www.greencape.co.za/assets/Water-Sector-Desk-Content/WRC-Water-sensitive-urban-design-WSUD-for-South-Africa-framework-and-guidelines-2014.pdf. Accessed on 23 July 2020.

Source from a Published Book

Max-Neef, M. (1991). Human Scale Development: Concepts, Applications and Further Reflections, London: Apex Press.

Source from a Government Department (Reports or Plans)

National Water Commission (2004). Intergovernmental Agreement on a National Water Initiative. Commonwealth of Australia and the Governments of New South Wales, Victoria, Queensland, South Australia, the Australian Capital Territory and the Northern Territory. Available online: https://www.pc.gov.au/inquiries/completed/water-reform/national-water-initiative-agreement-2004.pdf. Accessed on 27 June 2020.

The source from an online Newspaper article

Herald, The (2020). Harare City Could Have Used Lockdown to Clean Mbare Market. *The Herald*, 14 April 2020. Available online: https://www.herald.co.zw/harare-city-could-have-used-lockdown-to-clean-mbare-market/. Accessed on 24 June 2020.

Environmental Impacts of Unutilised Fly Ash and its Potential Utilisation for Soil Productivity and Food Security

TINASHE MAGADA MWAROZVA, SOLOMON MOMBESHORA[1] AND HALLELUAH CHIRISA[2]

Abstract

The combustion of coal during thermal electricity generation produces huge volumes of fly ash solid waste. The disposal and storage of dry fly ash in the environment have resulted in high nutrient concentration levels becoming toxic to humans, air, soil and water environments. Soil nutrient deficiency is limiting sustainable food productivity with soil nutrient deficiencies and limited access to fertilizers or biological options aggravating the predicament of hunger. This study focused on assessing the environmental impacts of fly ash and its potential utilisation in crop production. The study was conducted at Harare Power Station (17^0 50′ S and 31^0 1′ E) and Harare Experimental Station (17^0 49′S and 31^o2′ E). Mixed research methods were used. To unearth the environmental impacts of fly ash qualitative research approach guided by the interpretivism paradigm was applied. Purposive sampling of six key informants was implemented and data was gathered using in-depth and semi-structured interviews. Thematic content analysis was used to analyse the data. To evaluate the potential utilisation of fly ash for sustainable crop production, laboratory analysis of the physical and nutrient composition of fly ash was undertaken. To evaluate the effects of fly ash on tomato, cucumber and rape crops, a field experiment was set up. A Randomised Complete Block Design (RCBD) with five treatments, replicated three times, was implemented on each of the crops. The analysis of variance was used for analysing the results. Results showed that dumped and stored fly ash caused air pollution, groundwater contamination, human health

[1] Faculty of Social and Gender Transformative Sciences. Women's University in Africa, Zimbabwe

effects and soil pollution. Fly ash can potentially be used in crop production to control soil-borne pests and diseases and improve the physical and nutrient characteristics of soil for improved crop yields. The application of fly ash had a significant effect ($P<0.05$) on the growth and yield of tomatoes, cucumbers and rape. The highest yields were realised at 25% fly ash soil concentration, while 100% fly ash was toxic.

Keywords: Waste; Sustainable; Nutrients, management; Soil

INTRODUCTION

Sub-Saharan Africa continues to face multiple environmental management challenges that include pollution, poor waste management, deforestation and land degradation (ZINDC, 2016). Coal combustion during thermal electricity generation produces huge volumes of fly ash solid waste that is finally disposed into the environment becoming a major concern to African communities (Kishor *et al*., 2010). Where fly ash is generated, piles accumulate as waste, resulting in high nutrient concentration levels becoming toxic to air, soil and water ecosystems. Exhaustion of allocated fly ash landfills and increased demand for more space to dispose of the fly ash have resulted. Environmentally sound production systems aimed at ending poverty and hunger, climate action and building sustainable cities and communities are crucial for Sub-Saharan Africa to achieve sustainable development. The exhaustion of soils over many years of cultivation and limited access to fertilisers or biological options aggravates the predicament of attaining sustainable development. Farmers have resorted to the application of agricultural lime to amend soil acidity status and increase crop yields. However, the method contributes to global warming as the carbon in lime is finally released into the atmosphere as carbon dioxide (Basu *et al., 2009*). Due to the nutrient composition of fly ash, its controlled utilisation in crop production can improve soil texture, amend water holding capacity, increase soil pH and enhance soil fertility (Carlson and Adriano, 1993). Thus fly ash can be utilised as a by-product in crop production to enhance the low nutrient and depleted status of Sub-Saharan African soils, rather than stored as unutilised waste at power stations. Therefore, exploring the controlled utilisation of fly ash in crop production creates a platform for sustainable waste recycling and increased food production. Currently, farmers' practice of applying fly ash in cropping fields is negligible because there is limited lab-to-land research to unearth optimum rates of fly ash application for crop production. Given developmental problems like a burgeoning population, growing food demand and shrinking natural resources, it is necessary to sustain the production of crop yields and soil health in an eco-friendly way. Thus there lies a challenge to convert the environmental threat of fly ash into an opportunity for ensuring food security.

Industrialisation, urbanisation and population growth are traits of present-day African society that are becoming inevitable, contributing to growing electricity demand (Lockeshappa and Dikshit, 2011; UN, 2019). Industrialisation's negative impacts on the environment and social life are the production of large quantities of industrial waste and the problems associated with waste's safe management and disposal, scarcity of land, materials and resources for developmental activities (Senapati, 2011). Urbanisation and population growth require more electricity from coal-based thermal power plants, resulting in large amounts of waste being generated causing environmental health degradation The disposal of fly ash into the environment is a major concern throughout the world (Kishor *et al*., 2010) and may become costly (Basu *et al*., 2009). Fly ash can be considered either as a waste or as a resource yet to be fully utilised (Lokeshappa and Dikshit, 2011). According to Wang and Wu (2006), sustainable methods for the utilisation of fly ash to avert its increasing toxic threat to the environment and to streamline affordable waste disposal techniques are being sought.

In Sub-Saharan Africa, soil nutrient deficiency has increasingly become a stumbling block to sustainable food production and exhaustion of soils over many years. Also, high costs of fertilizers or biological options aggravate the problem of land, food shortages and poverty. Sustainable fly ash waste management in agriculture production systems complements the green economy concept that results in improved human well-being and social equity, while significantly reducing environmental risks and ecological scarcities (UNEP, 2011). Agriculture can logically offer economically and environmentally sustainable fly ash waste management in crop production rather than disposal in landfills (Singh *et al*., 2010). Utilising fly ash in amending dilapidated soil status provides opportunities for economic growth, poverty alleviation and food security without liquidating or eroding natural assets.

THEORETICAL FRAMEWORK

Solid waste management and food security can be best comprehended from the Integrated Sustainable Waste Management (ISWM) and Sustainable Livelihoods Approach (SLA) frameworks. The ISWM examines the physical and governance aspect of waste management (Wilson *et al*., 2013). The physical aspects involve collection, disposal and recycling, while governance aspects include users and service providers, financial sustainability and coherent and sound institutions underpinned by proactive policies. It is an approach to reaching better and more sustainable solutions to fly ash solid waste problems (Solomon, 2011). The important principle of ISWM is that a waste management system should be appropriate for local conditions and be feasible from a 'technical, environmental, social, economic, financial, institutional and political perspective' (Anschutz *et al*, 2004 cited in Solomon, 2011). The ISWM offers the greatest opportunity to develop a sustainable fly ash waste management system by considering the environmental, economic and social aspects of waste management. In the case of fly ash, ISWM will aim at combining waste streams, waste collection, treatment and disposal methods into a practical waste management system that aims to provide environmental sustainability and social benefits for the Sub-Saharan African populace. It considers the total system and looks for the best mix of treatment methods in crop production to minimise the economic costs of crop production and maximise environmental protection and food security social benefits. The level of integration within the ISWM system will be dependent upon the current prevailing dilapidated soil conditions and its potential to improve soil productivity for increased food security. Within the context of sustainable development, there is a need to curb the growth of unutilised fly ash in the environment. Therefore, where fly ash is produced, there is a need to recognise it as a resource and recover more value from it. Thus the fundamental aim of any waste management strategy should be the maximisation of resource efficiency by promoting sustainable waste management.

The SLA is a way how marginalised communities utilise available resource portfolios on both short and long-term basis to be able to cope with and recover from shocks and stresses through adaptive coping strategies that should be economically sound, ensuring that livelihood activities do not irreversibly degrade natural resources within a given ecosystem. The SLA refocuses development efforts on the elimination of poverty and encouragement of economic growth that benefits the poor through sustainable development, whose aims are to create sustainable livelihoods for marginalised people by promoting development and conserving the environment (Solesbury, 2003). Due to population growth, rapid urbanisation, poverty, growing food demand and shrinking natural resource base, the SLA is best suited as it stresses utilising and building on the best existing tools for the circumstances which may include reducing, recycling, re-using waste and also an analysis of how they will affect the environment by incorporating the sustainability context. Thus, environmental impacts of unutilised fly ash utilisation come as waste material generated and managed by institutions which can be utilised as a resource input for use in degraded soils by farmers for sustainable crop production so that they achieve short-term and long-term household food security and increasing output per unit land area hence poverty reduction.

METHODOLOGY

A case study to identify the impacts of unutilised fly ash was carried out at the Harare Power Station. The station is a thermal-based electricity production plant located in the Workington area of the Harare Central Business District (17^0 50′ S and 31^0 1′ E). To evaluate the potential use of fly ash in sustainable crop production and evaluate the effects of fly ash on tomato, cucumber and rape production, a glasshouse experiment and laboratory analysis, were conducted at the Harare Experimental Station, Zimbabwe. The site lies on 17^0 49′S and $31^o2'$ E at an altitude of 1513m above sea level.

The guiding paradigm of this research was triangulation using qualitative and quantitative research methods. A case study to understand the environmental impacts of fly ash and its potential use in crop production was explored using interpretivism grounded in phenomenology. Key informants from the Environmental Management Agency (EMA), National Social Security Authority (NSSA) and the Zimbabwe Power Company (ZPC), explained in detail the potential environmental impacts resulting from fly ash piles. The Department of Research and Specialist Services key informants and a farmer using fly ash as cropping media were also interviewed to unearth the potential use of fly ash in cropping systems. Data samples from the total population were drawn based on the quality of information they could provide. In data generation, the selection of the units was based on the characteristics of the sample relative to the understanding of the environmental impacts of unutilised fly ash and from which one can learn the most and gain understanding and insight. Qualitative data were generated through key informant interviews and semi-structured interviews using interview guides. Thematic content analysis was used to analyse the qualitative data obtained from the key informant interviews.

To evaluate the potential utilisation of fly ash in sustainable crop production, laboratory analysis for the chemical and nutrient composition of fly ash was undertaken. Fly ash samples collected from different parts of the Harare Power Station landfill were mixed to form a composite sample, while the Domboshava soils were also independently analysed to determine the initial nutrient composition.

Table 1

Property	Method of analysis	Reference
Texture ($g\ Kg^{-1}$):	hydrometer	Bouyoucos
Nitrogen(%)	Kjeldahl	(Barker and Pilbeam, 2010)
Phosphorus%	Spectrophotometer	(Faithfull, 2002)
Calcium%	AAS	(Fertasa, 2016)
Potassium %	1.0M Extraction	(Fertasa, 2016)
Sulphur%	Gravimetric	(Fertasa, 2016)
Magnesium%	AAS	(Tan, 2015)
Iron p.p.m	EDTA	(Fertasa, 2016)
Manganese p.p.m	EDTA	(Fertasa, 2016)
Zinc p.p.m	EDTA	(Fertasa, 2016)
Boron p.p.m	Hot water	(Fertasa, 2016)
Copper p.p.m	EDTA	(Fertasa, 2016)
Soil organic Carbon($g\ Kg^{-1}$)	Walkely-Black	(Okalebo *et al.*, 2002)
EC (s m^{-1})	Electrode	(Fertasa, 2016)
pH	$CaCl_2$	(Fertasa 2016)

To evaluate the effects of fly ash on tomato, cucumber and rape crops, a pot experiment in a glasshouse was done. A Randomised Complete Block Design (RCBD) with five treatments, replicated three times, was implemented on each of the crops. To reduce experimental errors, blocking was done against light intensity gradient and light direction. The treatment levels applied were zero (control), 25%, 50%, 75% and 100% concentration levels of fly ash. A total population of 30 plants in the gross plot areas for each of the crops was planted for evaluation. The cucumber shoots percentage was determined by a score count. Plant height was measured from the ground surface to the apical meristem using a graduated metal tape measure. Plant girth was measured at the plant crown using a vernier calliper. A physical stem count was done weekly and fully developed leaves were considered. The crop biomass yield was weighed using the electric sensitive scale (Salter- AND Ep 12Ka) to ensure yield accuracy. Collected data were subjected to Analysis of Variance (ANOVA) using GenStat 14th edition. Separation of means was done using the Least Significant Difference (LSD) test at a 0.05 probability level.

RESULTS AND DISCUSSION

ENVIRONMENTAL IMPACTS OF UNUTILISED FLY ASH

From the interviews, respondents indicated that there were environmental impacts resulting from the failure to utilise fly ash. The impacts revealed from interviews include air pollution, groundwater contamination and human health effects.

ATMOSPHERIC AIR POLLUTION

On atmospheric air challenges being faced by the Harare Power Company on their current handling and disposal system, the respondent highlighted that:

> "In the early summer season when it is dry, neighbouring industries complain a lot about dust emanating from our coal heaps and mists of grey dust are most common during the August and September period. This is one of the most difficult periods because environmental inspectors are always at our throats as they try to attend to complaints about dust brought before them by our surrounding community that operates within our vicinity."

The findings indicate that particulate matter of unutilised fly ash is easily blown by the wind into the atmosphere in large quantities and causes a lot of dust. Thus fly ash causes visual distortions to motorists which may result in accidents as the power station is situated near the Central Business District where there is high traffic movement. The transfer of fine grains of fly ash dust from heaped piles settles on the leaves of nearby vegetation around the power station, thereby reducing the photosynthetic area of plants and subsequent limitation of carbon sequestration. The movement of fly ash dust particles contaminates any food that is in proximity to the fly ash heaps. TheHarare Power Company is near a pig meat industrial company, hence it is be possible that the meat is exposed to potential contamination from fly ash. The dust particles also distort breathing air for those closer which may easily cause choking and long-term health after-effects. In this regard, the findings concur with Basu *et al*. (2009) that fly ash particles are ionospheric in nature, thus they are less dense (1- 8g cm^{-3}) such as non-magnetic and magnetic particles of 2.7g cm^{-3} and 3.4g cm^{-3} respectively and can easily be blown by the wind for long distances (Kishor *et al*., 2010; Basu *et al*., 2009; Natusch and Wallace., 1974). Furthermore, in responding to the question of possible environmental hazards caused by fly ash, the occupational health practitioner indicated that dust is a major environmental hazard:

> "Most of the employees' internal health risks working with fly ash are related to the dust they breathe in the work environment. They inhale mineral dust through the nose and straight to the brain. This is why we advocate for the maximum mouth, eyes and ear protection gear for workers in the thermal electricity generation industry and enforce the frequent measuring of air dust particulate matter to check on the low threshold levels."

These are the reasons occupational health practitioners seeking to eliminate dust pollution, advocate for dust control measures at the Harare Power Station. It is these air pollution factors that contribute to global warming as greenhouse effects become evident through the mist and it further contributes to climate change and human health defects, creating unsustainable livelihoods. Based on ISWM, when air is being polluted, it is an environmental cost (Solomon, 2011) that has been created causing shocks and stress factors that are not sustainable for development based on the tenets of the SLA (Chambers and Conway, 1992). Thus it potentially creates the hazard of food contamination and related health effects that could reduce the human, financial, social and environmental capital of a nation.

HUMAN HEALTH IMPACTS

Accumulation of fly ash at the Harare Power Station landfill and its accumulation at the regulated dumpsite is directly associated with negative human health impacts because of direct exposure to fly ash as unearthed by this research study. When examined for potential conditions emanating from unprotected exposure to fly ash, the occupational health agent interviewed said:

> "Exposure to fly ash without efficient protection may cause three major internal health diseases, namely *Pneumoconiosis* also known as black lung disease, *Emphysema* (airway obstruction in the respiratory system) and industrial *bronchitis*. Generally, it also causes occupational cancers and asthma. Secondly, due to the nature of fly ash, it may initiate a spontaneous ignition which may result in a fire that may cause dermal burns on those exposed".

In addition, from an environmentalist point of view, he posited that:

> "Fly ash is a solid waste hazardous material which is injurious to human health because it contains sulphur, nitrous oxide and sulphur dioxide which in my understanding causes skin irritations, bronchi inflammation and skin sensitising phenomena to those exposed"

It is crystal clear that fly ash exposure to humans is hazardous and poisonous through direct conduct, inhalation and ingestion. The finding concurs with Sajwan *et al*. (1999) who noted that fly ash contains toxic trace elements described as poisonous that lead to detrimental health effects. This could be due to continued exposure that may eventually lead to lifetime injuries or death. Based on the response of the occupational therapist above, the causal agents of internal diseases pneumoconiosis, emphysema and industrial bronchitis could be attributed to the finer fractions of fly ash that are deposited into the lungs, respiratory tract and alveolar respectively as also identified by Senapati (2011), Singh *et al.* (2017) and Sajwan *et al*. (1999). Furthermore, Arsenic and Lead could be blamed for cancers and asthma (Benhard *et al*.,1986). The evidence provided by the environmentalist about inert concentrations of sulphur, nitrous oxide and sulphur dioxide in fly ash could be true that it may cause dermal disorders as also shown by Basu *et al.* (2009) that fly ash contains sulphur, which may be toxic with heavy concentrations. However, Hodgson and Holliday (1966) indicate that these toxic elements are drastically reduced through oxidation, and Page *et al. (*1979) support this view as they indicate that the toxic elements from Aluminium are bound in insoluble alumina-silicate, hence confining its biological toxicity. The handling, storage and disposal of fly ash should be done with extreme caution to avoid injuries or death. To avoid such hazards, the best alternative is to dispose of the fly ash. However, the researchers observed that the Harare Power Station offers workers protective clothing in the form of mouth muffs, helmets, rubber gloves, gumboots, work suits and transparent goggles. To reduce occupational hazards from an occupational health agent perspective, the company recommended that:

> "Regular watering fly ash, regular worker rotations, medical surveillance and withdrawing those detected, environmental surveillance by measuring dust particles and dust masking are the probable solutions to health risks associated with fly ash."

These procedures are expensive. For example, watering fly ash is wasting water which is a scarce resource while regular worker rotations require a larger labour force which is costly to replace and train more and environmental surveillance kits are deemed expensive given resource limitations. Thus, the only solution would be the implementation of the ISWM, the fly ash management system being appropriate to local conditions and being feasible from technical, environmental, socioeconomic, financial, institutional, political and technological perspectives (Anschutz *et al*.,2004; cited in Solomon 2011). The health issues presented by un-utilising fly ash should be tackled in their entirety by considering the interconnectedness of components, operations and functions and therefore should recognise the full complexity of waste management practices (McDougall *et al*., 2001) by considering recycling and reusing fly ash as a major input in crop production. Thus total disposal of fly ash from landfill sites for agricultural purposes enhances increased production by deriving the nutrients in fly ash. It then provides coping mechanisms that are feasible to eliminate occupational shock and stress of sickness and injury at work, while increasing the worker's longevity to reduce household poverty as they remain in employment. This is how the SLA could achieve sustainable development when health impacts caused by fly ash are eliminated through fly ash utilisation.

GROUNDWATER CONTAMINATION

The interviews did not reveal much about the level of groundwater contamination. However, an analysis of how unutilised fly ash can contaminate groundwater can be made based on the 1993 chemical analysis done by Wankie Colliery in respect of fly ash waste used at the Harare Power Station. Table 1 indicates the inherent chemistry of the fly ash.

Table 1: Chemical analysis of fly ash from Harare Power Station

Element Analysed	Ultimate Analysis (%)
Carbon	88.29
Hydrogen	3.63
Nitrogen	1.99
Sulfur	2.87
Phosphorus	0.025
Chlorine	0.08
Silica	41.3
Alumina	33
Iron Oxide	14.8
Magnesium oxide	0.8
Titanium oxide	1.2
Alkalis	4.1

Results in Table 1 indicate that fly ash produced at the Harare Power Station contains an appreciable base, and essential and trace elements. Leaching of these elements from fly ash landfills into the ground causes water pollution. The fly ash contains Carbon, Nitrogen, Hydrogen, Sulphur, Phosphorus and Chlorine as bases. When in an aqueous environment, Nitrogen and Phosphorus are highly associated with algae formations. Furthermore, the addition of nitrogenous material into the water system results in increased acidification of the groundwater, hence the alteration of the groundwater to saline conditions. Heavy metal elements, Iron, Sulphur, Calcium, Magnesium and alkalis, have heavy leaching characteristics as propounded by Sadasivan *et al*. (1994). These elements percolate from unutilised fly ash in landfills, resulting in groundwater contamination (Basu *et al*., 2009). However, Rohriman (1979) noted that the solubility of trace and heavy metals in fly ash is less than 10%. According to Natusch (1975), 5-30% of toxic elements such as Copper are leachable and the concentration of this element is considered low. Its chances of leaching are also considered negligible to cause groundwater pollution. These findings simulate that the alkalis components of the fly ash analysis are 4.1% and are considered negligible to cause groundwater contamination. However, it is not clear on the safety level of the groundwater for consumption as no analysis has been done (Basu *et al*., 2009).

Failure to utilise fly ash and recover value from it (ISWM) results in contamination of groundwater which depletes the water resource for use by future generations. This entails a livelihood becoming unsustainable without the capacity to cope with and recover from stress and shock situations, undermining its capacities and assets, leading to failed contribution on net benefits to other livelihoods at all levels in the short and long term (Chambers and Conway, 1992).

POTENTIAL UTILISATION OF FLY ASH IN CROP PRODUCTION PEST AND DISEASE CONTROL

It has been established that soil-borne pests and diseases can be controlled by using fly ash in crop production. Responding to how the farmer got to know about the use of fly ash in crop production, the farmer:

"Our first ever tomato crop under greenhouse production and using the conventional production system suffered over 25% crop loss from nematode destruction. We then inquired how we would be able to tackle the problem from a seasoned farmer from the Goromonzi District who recommended we use coal rubble as a hydroponic production system. In trying to source coal rubble, we could not find it on the market and we settled for fly ash which we only got after failing to acquire coal rubble. On our first crop under fly ash production, we have not lost a single plant due to nematodes".

From the response given, it is evident that fly ash has the potential to control nematodes. This may have been possible through the creation of unfavourable conditions for the survival of the pest. This is achieved through disturbing microbial-mediated processes in the soil ecosystem (Babich, 1983). The application of fly ash was reported to inhibit microbial respiration and enzymatic activity of soil habitat micro-organisms (Garau *et al*., 1991; Karpagavalli and Ramabadran, 1997). Pitchel (1990) reported that the addition of 20% fly ash in soil reduces the growth of soil-borne pathogenic bacteria. Similar outcomes were noted by Khan *et al*. (1997) when 30% fly ash and soil mixture reduced the penetration and reproduction of nematodes in tomatoes. Furthermore, Ahmad and Alam (1997) reported a reduction in root galling signs, resulting from root-not nematode infestation when fly ash was applied to the tomato crop.

The availability of excessive soluble salts and trace elements in fly ash is thought to be an inhibitor for the survival of the nematode pest as it cannot survive in extremely alkaline conditions (Sim *et al*., 1995; Basu *et al*., 2009). This notion is evident from the laboratory analysis of the fly ash which recorded a pH value of 7.9, contained high exchangeable cations (Potassium 0.29mg/100g; Calcium 70.28; Magnesium 0.88mg/100g) and heavy metals, Zinc 123.6ppm and Copper 17.4ppm), creating alkaline conditions which inhibited nematode infestation in the tomato crop. However, Gaind and Gaur (1991) identified fly ash's ability to enable the proliferation of micro-organisms that enhance the availability of Phosphorus. The micro-organism is known as *Arbuscular mycorrhiza.* These bacteria are beneficial in tomato and cucumber production and are available and effective at alkaline pH for Phosphorus fixation (Hayman and Mosse, 1971). However, high alkaline properties of fly ash have inhibitory effects (Basu *et al*., 2009) on microbial respiration and enzyme activities of Rhizo-bacteria that are responsible for nitrogen fixation (Pitchel 1990; Garau *et al*., 1991 and Karpagavalli and Rambadran 1997) in legumes. The detrimental effects are, however, reduced during natural leaching (Sims *et al*., 1995).

In light of the ISWM, fly ash has been used to detoxify the soil in a manner that is ecologically friendly, reducing economic loss and maximising social benefits in a socially acceptable manner (Wilson, 2013). Thus fly ash has been utilised as a replacement for ozone-depleting Methyl-bromide in preventing root-not nematode infestation. Thus sustainable fly ash waste management complemented the green economy by significantly reducing environmental risks and ecological scarcity according to UNEP (2011). Relating to SLA, unutilised fly ash material that poses danger to the environment as a green solid waste was used in livelihood crop production activities to avoid shocks of economic loss from nematode infestation and cost of fumigants and poverty by safeguarding production. This was also done in an eco-friendly manner by observing the Montreal Protocol policy as the farmer avoided using chemicals such as Methyl-bromide that depletes the ozone layer.

IMPROVED SOIL PHYSICAL CHARACTERISTICS FOR SUSTAINABLE CROP PRODUCTION

One of the benefits of using fly ash in crop production, as stated by the farmer, was that fly ash has abilities that can be used as an effective soil medium for crop growth. The farmer used coal rubble in a hydroponic system which is a crop-growing media. A follow-up question was how the farmer was using the available fly ash as a hydroponic system to their advantage and the farmer said that:

> "We fill 5-kg black poly-sleeves with fly ash and we grow our plants in there, we practice all agronomic practices such as fertilization and irrigation while the plants are in these plastic sleeves."

Fly ash waste can certainly be used as a soil medium in which crops can be grown. It has properties that enable it to be classified as a good soil medium. It showed that fly ash has an excellent draining and water-holding capacities and minimises leaching. The view is also supported by the finding of the laboratory analysis which unearthed that fly ash possesses fine-grained clay loam, showing that it is capable of retaining sufficient water and nutrients without leaching them to enable efficient and effective crop growth.

Plate 1: Cucumber crop grown on fly ash by the farmer.

Photos by Tinashe Magada M in Harare (31/01/2017; 24/02/2017 and 03/03/2017)

Fly ash exhibited properties such as availability, ability to reproduce crops, good moisture and nutrient retention, optimum infiltration, aeration and drainage, good cation exchange capacity and alkaline pH as similarly highlighted by Arteca (2015). Concurrently, Ghodrati *et al*. (1995) identified microporosity and water-holding capacity to be advantages derived from fly ash use in the soils. The application of fly ash in crop production was shown to improve the structure, reduce soil crusting and promote good seed emergence in fine-textured soils.

The fine-grained silt clay textural characteristic extracted from the laboratory soil analysis results shows that fly ash has a low-bulk density compared to some soils which are crucial for effective crop growth. The results were further supported by the experience of the farmer who indicated that:

> "We are now able to produce throughout the season. Previously, during the summer rainy season, our land was mostly clay and highly water logging to the extent that no cropping took place and fly ash emerged to solve this problem".

The response showed that fly ash has abilities to drain excess water from the soil. Water-logging restricts root respiration, resulting in total crop failure which is a characteristic of clay soils. The bulk density characteristics of fly ash could be attributed to circumventing waterlogging conditions. Plate 2 shows evidence of water-logging that inhibits all year-round crop production.

Plate 2: Water-logging conditions precluding conventional crop production leading to fly ash utilisation by the farmer.
Photos by Tinashe Magada M in Harare (31/01/2017)

Chang *et al*. (1977) and Basu *et al*. (2010) identified bulk density as the physical properties that enable fly ash to be considered a cropping medium. Jones and Amos (1976) reported a low-bulk density when 50% fly ash was added to soils. Fly ash application rates of 5%, 10% and 15% weight to clay soils were observed to lower the bulk density of the soil (Kene *et al*., 1991; Garg *et al*., 2005). Prabakar *et al*. (2004) claimed that the reduction of dry density of soil in the order of 15-20% when fly ash was added at 46%, resulted in low specific gravity of the soil. Fly ash has a high surface area and it is light textured, resulting from porous carbonaceous cenosphere particles with a range of 4µm-

70µm in size, comprising 8-85% silt, 0-10% clay, 7-90% sand (Kishor *et al*., 2010) which reduces its density to less than 1% (Hodgson and Holliday, 1966).

The outcome of the ability of fly ash to work as an effective soil medium identified through this study emanates from the characteristics of fly ash. The characteristics, as propounded by Kishor *et al*. (2010) and Natusch and Wallace (1974), are that fly ash bulk density ranges between 1-8gcm^{-3}, water-holding capacity is generally between 49-66% on a weight basis, while moisture retention from 6.1% at 15 bar and 13.4% at 1/3 bar. Additionally, the specific gravity of fly ash ranges between 2.1 to 2.6 g/cm^{-3} with average particle densities for non-magnetic and magnetic particles of 2.7 and 3.4 g cm^{-3}, respectively (Basu *et al*., 2010).

Rather than dumping fly ash in landfills or dumping sites as the current norm, agricultural crop production can offer economic and sustainable fly ash waste management solutions as a cropping medium, proving the view held by Singh *et al*. (2010). Thus, it has properties to be involved in the ISWM as a waste resource with benefits. It has abilities to create physical and biological characteristics of soil that improve the soil structure for efficient crop production.

SOIL AMELIORATE

From the laboratory analysis, fly ash from the Harare Power Station has potentially proven good characteristics as a soil amendment input. Based on the calcium chloride scale, pH of 7.9, Calcium-70.28, and medium-free carbonates have shown that it is highly alkaline and can be mixed in the soil as a liming agent to amend soil acidity which inhibits efficient and effective crop growth. From the results, fly ash has demonstrated capabilities to be a potential liming material without a doubt. The analysis of Domboshava soil shows that it could have limited crop growth as it had pH 5.0 resulting in limited crop growth in the control treatment compared to 25% fly ash.

Similar pH and carbonates are the major chemical characteristics in fly ash said to be principal benefits of its ability to neutralise acidic soils (Matsi and Keramidas, 1999; Pathan *et al*., 2003; Cetin and Pehlivan, 2007). Its liming capabilities and alkaline nature were recorded to be able to neutralise soil acidity and provide plant nutrients (Phung *et al*., 1978; Taylor and Schumann, 1988). According to Mittra *et al*. (2004), soil Phosphorus is made available mainly for plant uptake when soil pH is increased, while the acidity is reduced. The application of fly ash to soil was identified to reduce soluble metal toxicity, affect micronutrient availability and enhance soil organism nitrification and soil conditioning (Hayman and Mosse., 1971). It was further unearthed that a decrease in pH below 5.5 results in an increase in aluminium and manganese availability to the plant and reaches a point of toxicity to those plants (Mittra *et al*., 2004). Through continuous cultivation, Zimbabwean soils have been identified to have highly acidic with multiple nutrient deficiencies (Nyamangara and Mpofu, 1996), leading to pH values of less than 5.0 which are prone to Aluminium toxicity, resulting in impediment of maximum crop yields for sustainable livelihoods. To avert this, farmers have resorted to using agricultural lime (Sanchez, 2004), a practice that has been identified to contribute to climate change (Basu *et al*, 2009), due to global warming as the carbon in agricultural lime is finally released in the atmosphere as carbon dioxide (IPCC, 2007; Basu *et al*, 2009). Integrating fly ash, regarded as waste by local police authorities, in crop production as a soil amending resource, assists in sequestering carbon dioxide in the atmosphere, ensuring sustainable livelihood through increased crop output and contributing to minimising global warming as noted Ferreira (2003) and Montes *et al*. (2008). It thus leads to the amalgamation of the ISWM and SLA approaches to development by eliminating the effects of global warming and ensuring food security and increased income at household levels. It also contributes to reducing land degradation caused by lime mining as fly ash would be readily available.

SOURCE OF CROP NUTRIENTS

Fly ash derived from the Harare Power Station is a source of essential plant nutrients. The laboratory soil analysis report from the Ministry of Agriculture unearthed that fly ash is a source of Potassium (0.29mg/100g), Magnesium (0.82mg/100g) Calcium (70.28mg/100g). It also contains heavy metals (Zinc,123.6 and Copper, 17.4) that are essential for maximising crop growth. However, it has low readily available Nitrogen (5 ppm) and Phosphorus (9 ppm) that are not sufficient for crop growth. Mixing the fly ash with soils from Domoshava which are medium-grained sandy with an acidic pH(5.0) containing Potassium (1.04mg/100g), Magnesium (0.88mg/100), Zinc (2.4) and Copper (16.8) will improve te potential capabilities of the soil to efficient crop production that maximise yields. The fly ash has also proved to be able to withhold plant nutrients and avoid leaching due to its high conductivity of 1320 micromhos.

Fly ash has both soil-amending and nutrient-enriching properties, it helps improve crop growth and yield in low-fertile soils (Basu *et al*., 2004). Correspondingly to the findings of this study, fly ash was also identified to contain essential plant nutrients Calcium, Iron, Magnesium and Potassium (Koreak, 1995; Kachroo *et al*., 2006; Lee *et al*., 2006; Inam, 2007; Basu *et al*., 2009). In legumes, fly ash was identified to hasten the uptake of Calcium and Magnesium (Page *et al*., 1979). Furthermore, increased fly ash concentration from 0, 10, 20 and 100% in a normal field, increased the soil pH, hence increasing the availability of Sulphate, Carbonate Bicarbonate, Chloride, Phosphorus, Potassium, Calcium, Copper Zinc and Boron (Khan and Khan 1996). On the contrary, fly ash is not acknowledged as an optimum source of Phosphorus (Martens, 1971). Due to the inherent Nitrogen and Phosphorus deficiency of fly ash, it is necessary to supplement to ensure desirable crop growth. According to Inam(2007), fly ash dose at 10t ha^{-1} supplemented with 20kg ha^{-1} proved effective while a mixture with 40kg ha^{-1} was toxic to the mentioned crop.

SUSTAINABLE YIELDS

Application of fly ash from the farmer's point and pictorial findings is a testimony that flies ash waste from the Harare Power Company has agronomic benefits that result in high yields. Responding to the inquiry on the yields the farmer is getting from utilising fly ash in cucumber and tomato crops, she said:

> "Since it is our first crop with fly ash, we haven't read much into it but currently we have managed 3.5kg per plant of cucumber which when converted to a 1ha with 33 333 plants will yield 116t/ha. Given the scenario that over the years we never got a yield on this part of the land area due to logging, this year is a great achievement. However, we are in our initial stages of harvesting our tomatoes but they are promising a good harvest as well"

From the farmers’ perceptions, it could be suggested that fly ash has been able to provide a meaningful yield that would be economically beneficial. This outcome could be attributed to the fact that the farmer can use the land all year round even if water logging occurs. Furthermore, the said yield of 116t/ha adds income during the climatic stress season. Sustainable value is also attained as the farmer will biologically control soil-borne diseases using fly ash as earlier discussed, thereby cost-cutting on soil fumigants. Plate 3 presents the potential utilisation of fly ash to produce a good tomato harvest.

Plate 3: Tomato crop grown on fly ash at early, vegetative and ripening stages by the farmer.
Photos by Tinashe Magada M in Harare (25/01/2017; 01/03/2017 and 16/05/2017).

With this evidence, the research is also convinced that a bumper yield will be attained on this crop. It has been proven by Basu *et al*. (2009) that fly ash is capable of increasing crop growth and yield. Tomato yield was found to increase when 5% fly ash was added to the soil(Ahmad and Alam, 1997). Similar results were further found to increase tomato yield when 40-50% fly ash compared to un-amended soil (Khan *et al*., 1997). Fly ash has also been found to increase the yield of Sabai grass (Grewal *et al*., 2001; Hill and Lamp, 1980, Sridhar *et al*., 2006).

Thus fly ash use on agricultural soil is suggested by Schoeman and van Deventer (2004) to be a promising endeavour from an environmental viewpoint. Thus it provides a reuse principle of fly ash waste and provides high yield aimed at ending poverty, addressing hunger, clean water and sanitation and sustainable cities as enshrined in the sustainable development goals (FAO, 2016).

EFFECTS OF FLY ASH ON CROP PRODUCTION

EFFECTS OF FLY ASH ON CUCUMBER GROWTH

A significant effect ($p<0.001$) between fly ash treatments was recorded on cucumber girth and shoot count growth and a significant effect ($p<0.05$) was obtained on plant height (Figure 1).

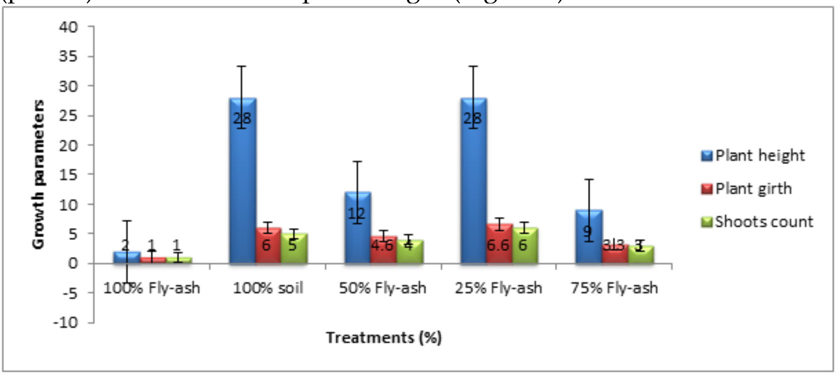


Figure 1: Effects of fly ash application rate on growth parameters of Cucumber

VERTICAL BARS REPRESENT STANDARD ERROR BARS OF MEANS

Figure 1 reveals that both control treatment and 25% fly ash showed the highest and almost similar levels of growth while treatment of 100% fly ash produced the least cucumber growth patterns. The results of poor growth of cucumber on 100% fly ash can be attributed to excessive application rates of fly ash. Because of these outcomes, Singh and Siddiqui (2003) identified a gradual decline in rice growth parameters at high rates (60%-100%) of fly ash amendments of soil against improved growth rates when a lower (40%) application rate was used. The poor performance of cucumber growth can be attributed to higher toxicity resulting from higher pH (7.9) and concentration level of nutrients (Magnesium- 0.82mg/100g and Zinc-123.6ppm) evident from the laboratory analysis and free bases (Sulphur- 2.87%, Chlorine- 0.08%, Aluminium- 33% and Titanium- 1.2%) chemical analysis. These negative effects on the growth of cucumber are in agreement with the findings of Singh and Siddiqui (2003) who related the negative effects of crop growth resulting from high salinity from sulfate, carbonate and bicarbonate in fly ash. A higher application rate of fly ash causes toxicity to plants (Kalra *et al.*, 2000).

Plate 4: Effects of fly ash on cucumber crop in the experiment

Photo by Tinashe Magada M in Harare (23/04/2017)

EFFECTS OF FLY ASH ON FRESH YIELD OF RAPE

The application of fly ash had a significant ($p<0.001$) effect on the fresh yield of Rape (Figure 2).

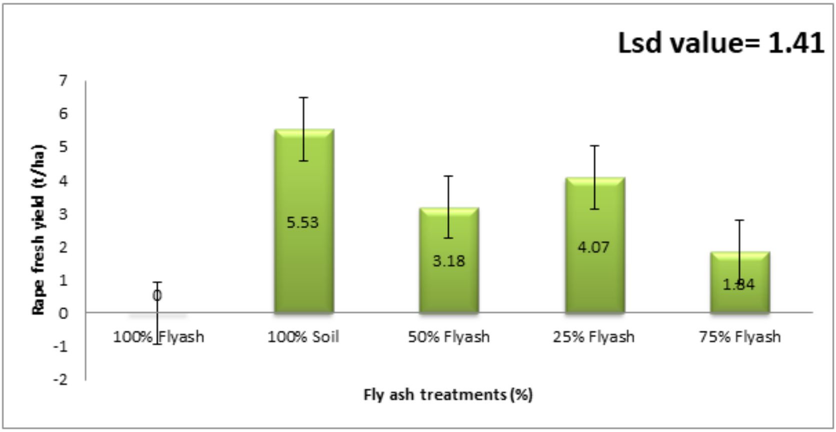


Figure 2. Effects of fly ash application rate on fresh leaf yield of Rape

VERTICAL BARS REPRESENT STANDARD ERROR BARS OF MEANS

The control treatment produced the highest (5.3 t/ha) yield while plants treated with 100% fly ash resulted in (0t/ha) total Rape failure. No significant effects (p>0.05) on fresh yield of Rape were noted between 100% soil (control) treatment and 25% fly ash treatment which produced the highest yield (4.07t/ha) among the fly ash treatments (Figure 2).

Based on results from the laboratory soil and fly ash analysis, the highest (5.53t/ha) fresh leaf yield of Rape in the 100% soil (control) treatment can be attributed to the residual high (71ppm) and (360ppm) Nitrogen and Phosphorus nutrient of the Domboshava soil, respectively. The Rape plants in the 100% fly ash did not survive from the onset. The result may be due to the high pH (7.9) of the fly ash sample, considered strongly alkaline. This is a probable indication that at full concentration level, fly ash is detrimental to the Rape crop. However, 25% fly ash treatment produced the highest (4.7t/ha) fresh leaf yield amongst the fly ash treatments but was significantly the same with 100% soil treatment. This outcome shows that the addition of 25% fly ash to soil enhanced the yield of Rape, resulting from an improvement of the physical properties of the composite medium as also reported by Buck *et al.* (1990). To this effect, fly ash was able to improve the Domboshava soil water-holding capacity by regulating the infiltration rate of water. This is similar to the the outcome that Chang *et al*. (1977) unearthed that soil-amended fly ash increases water-holding capacity by 8% and reduces encrustation. This amount of water available for plants would be enhanced (Taylor and Schumann, 1988) which would be beneficial for the growth of plants under rain-fed agriculture (Basu *et al*., 2010). The Domboshava soil, due to its texture, is prone to high leaching of nutrients, hence high (1320) conductivity of nutrients in the 25% fly ash medium was greatly increased leading to the insignificant difference between the 100% soil (control) and 25% fly ash treatments.

Plate 5: Effects of fly ash on rape crop under experiment
Photo by Tinashe Magada M in Harare (23/04/2017)

EFFECTS OF FLY ASH ON TOMATO GROWTH

A significant effect ($p<0.001$) between treatments was recorded on plant height, girth and the number of shoots of Tomato while a significant effect ($p < 0.05$) was recorded on flower count at six weeks after transplanting (Figure 3).

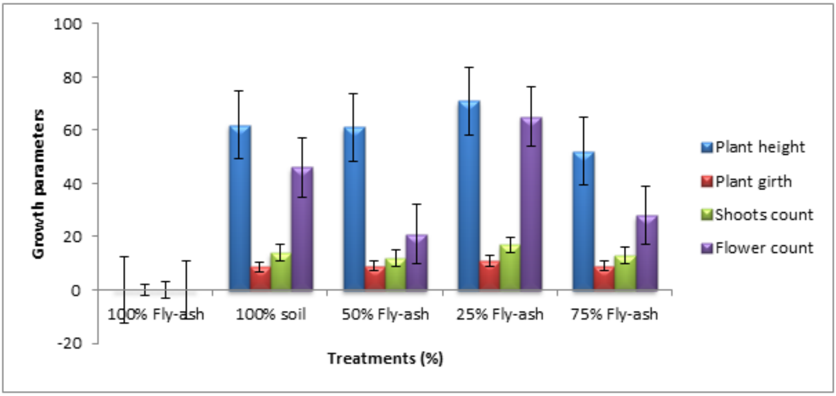


Figure 3. Effects of fly ash application rate on growth parameters of Tomato

VERTICAL BARS REPRESENT STANDARD ERROR BARS OF MEANS

Tomato plants treated with 25% fly ash performed highest (71cm, 11mm, 17 and 65) on all growth parameters (height, girth, shot count and flower count), respectively, while 100% fly ash treatment scored zero (0) on all growth parameters. The 25% was superior against the control treatment (100% soil) which recorded 62cm height, 8.6cm girth, 14 shoots and 46 flowers.

In explaining this result, it can be stated that the effect of 25% fly ash on Tomato is superior against all other treatments, though not significantly to the control treatment. The superiority may have resulted from the ability of the fly ash to alter the pH of the medium. Mixing of fly ash with soil in the ratios 25%, and 75% respectively managed to adjust the pH of the soil from acidic conditions pH (5.0) to an average pH (6.4). In addition, fly ash and soil managed to combine their residual nutrients (Phosphorus, Calcium, Potassium, Nitrogen, Magnesium, Zinc and Copper) into a composite growing media, hence gaining superior Tomato growth against other treatments. Furthermore, due to the fine-grained sandy clay characteristics of fly ash, the 25% fly ash treatment managed to retain moisture and avoid the leaching of nutrients for the benefit of the crop, a situation that the control treatment (100% soil) could not withhold. On the contrary, fatality on Tomatoes in 100% fly ash could be a result of strongly alkaline pH 7.9 and Calcium 70.28mg/100g exhibited through analysis of fly ash. This could have resulted in toxicity. From the result, it can also be noted that the more the fly ash concentration, the lesser the Tomato crop growth response.

Plate 6: Effects of fly ash on tomato crop under experiment
Photo by Tinashe Magada M in Harare (23/04/2017)

Similar to the findings, Furr *et al.* (1978) recorded an increase in Tomato growth when 125mt ha^{-1} of fly ash was added on slightly acidic soils, while Ahmad and Alam (1997) obtain increased growth of Tomatoes when 5% fly ash was added to the soil. One of the ways of enhancing crop productivity in acidic soils is using alkaline fly ash as a soil ameliorant (Senapati, 2009). According to Matsi and Keramidis (1999) the use of fly ash, as a liming substitute in acidic soils, improves soil properties, resulting in an increase in crop performance. Application of fly ash to amend soil pH improves crop growth by making available some Calcium and Magnesium (Mittra *et al*., 2004) and reduces soluble metal toxicity, affects phosphorus availability and micronutrient availability, enhances soil organism nitrification and soil conditioning (Hayman and Mosse, 1971). Yet, crop response varies from being beneficial to toxic, hence it depends on the concentration level (Kalra *et al* 2000; Grewal *et al*. 2001). Higher concentrations of fly ash proved to be deleterious on Soybean and Maize (Shukla and Mishra, 1986). Hence, it unearths the negative impacts on vegetation surrounding its dumpsites.

Based on the technical application of the ISWM concept, fly ash as a waste resource provides a cheaper source of liming material to increase crop yields. On the other hand, crop productivity relies on soil amendments inputs to address low crop output, hence providing a sustainable disposal site for fly ash. The process application of fly ash into the field would entail a livelihood activity that aims at increasing crop yield at a minimum cost of inputs and deriving maximum yields for a sustainable livelihood.

CONCLUSION AND RECOMMENDATIONS

A huge quantity of fly ash on landfills and dumpsites and the type of coal that generates fly ash at the Harare Power Station creates environmentally degrading scenarios. Due to the chemical characteristics of the fly ash, as noted in the study, extreme concentrations of base elements (Zinc, Copper, Sulphur, Chlorine, Nitrogen, Phosphorous, Silica, Aluminium, Iron, Magnesium, Titanium, Calcium and Potassium) and strongly alkalines contribute to groundwater contamination, air pollution, human health hazards and vegetation loss. Algae formations and high water pH preclude safe water for drinking while the less dense particle (Cenospheric) of fly ash results in rising dust that, if inhaled, causes pneumoconiosis, emphysema, occupational cancers and asthma and further distorts visibility within the Central Business District of Harare. Settling of fly ash dust on leaves distorts the photosynthesis processes of vegetation. Death of Tomato, Cucumber and Rape crops in the field experience from 100% fly ash concentration is a testimony of the negative effects that fly ash has on vegetation that may lead to loss of plant biodiversity. Thus, it can be concluded that unutilised fly ash results in negative impacts on the environment.

The pH of 7.9 and nutrient composition (Potassium, 0.29mg/100g; Calcium, 70.28mg/100g; Magnesium, 0.82mg/100g; Zinc, 123.6ppm and 17.4ppm) based on soil analysis, proves the fact that fly ash is rich in crop nutrients, sufficient for crop growth. In addition, the fine-grained sandy clay texture and 1320 micromhos conductivity level of fly ash is sufficient to enhance water-holding capacity and avoid leaching of nutrients which are prerequisite characteristics of a growing medium that ensures efficient and effective crop production. Conclusively, fly ash can potentially be utilised to attain sustainable crop production as it can neutralise acidic soils that hinder efficient and effective crop production.

It is the conclusion of the present study that the application of fly ash to soils at a 25% concentration rate had significant growth and yield effect on Tomatoes, Cucumber and Rape. At higher concentrations (50%, 75% and 100%) growth is retarded and total crop failure is at a 100% rate. Mixing fly ash and soil at 25% to 75%, respectively reduces the negative toxicity of fly ash on the environment and provides a sustainable optional use as a beneficial input of the so-called solid waste commodity.

Considering Integrated Sustainable Waste Management (ISWM), the generation of fly ash is an inevitable consequence in the Zimbabwean context due to increasing electricity demand. The landfill and dumpsite disposal methods currently in place compromise the future generation to achieve their environmental benefits. Utilising fly ash in crop production provides environmental sustainability and social acceptance that ensure safe human health while considering economic growth technology. Crop production provides a platform to ensure maximum fly ash resource utilisation efficiency on amending the soil's physical and nutrient deficiencies that had become stumbling blocks to sustainable food production, aggravated by high fertilizer costs and exhaustion of soils through continuous cultivation. Considering the environment, the application of fly ash at a 25% rate to amend acidic soils, reduces the amount of fly ash waste on landfills and dumpsites that cause air pollution, contaminate groundwater and cause human health hazards. Furthermore, open-cast mining of lime for crop production enhances land degradation and the lime contributes to global warming through its carbon dioxide release. Thus fly ash provides an eco-friendly means to increase crop production without deteriorating the ecosystem sustainability potential for the future generation.

In the process, the Sustainable Development Goals (SDG) that include ending poverty, zero hunger, clean water and sanitation, sustainable cities and communities, responsible consumption and production and climate action can be attained through utilising fly ash to increase crop growth and yield per unit area. Thus, fly ash utilisation in crop production qualifies for integration into the sustainable livelihoods approach to eliminate poverty and encourage economic growth that benefits marginalised people by promoting agriculture development and environmental conservation.

From the findings of the study, it could be recommended that:

- Fly ash can be applied at a 25% content mixture to acidic soils to amend deficient pH and improve the physical and chemical properties of such soils for increased crop growth, hence it should not be handled at power stations and disposed of at dumpsites where it causes environmental degradation.
- When using fly ash as an organic soil ameliorant in sustainable crop production, Phyto-toxicity concerns are likely to occur due to its substantial amounts of heavy metals, especially Zinc. Thus a comprehensive compositional analysis of the food crops produced under fly ash needs to be determined before consumption is recommended.
- Effects of fly ash utilisation in Tomato, Cucumber and Rape production were undertaken under greenhouse conditions, hence trials under natural field conditions in which most farmers operate need to be further tested.
- Fly ash should be considered as a soil ameliorant for sustainable crop production to improve national and household food security due to its nutrient composition.
- Considering the short period in which the study was undertaken, long-term trials on crop production using fly ash to determine long-term impacts need to be considered.
- The Harare Power Station should formulate a policy framework with the Ministry of Environment, Water and Climate and Ministry of Agriculture as an Integrated Sustainable Waste Management (ISWM) strategy on

considering fly ash as a standardised input for use in crop production to curb the negative impacts it poses on the environment and encourage the Sustainable Livelihood Approach (SLA) of combating hunger and poverty.

REFERENCES

Adriano, D. C; Page, A. L and Elseewi, A. A. (1980). Utilization of fly ash and other coal residues in terrestrial ecosystems: a review. J Environ Qual; 9:333–44.

Ahmad, A and Alam, M. M. (1997). Utilization of fly ash and Paecilomyces lilacinus for the control of Meloidogyne incognita. Int J Nematol; 7:162–4.

Akkucuk, U. (2016). The handbook of research on Waste management techniques for sustainability.IGI Global. Hershey.

Arthur, M. F; Zwick, T. C; Tolle, D.A and Vanvoris, P. (1984).Effect of fly ash n microbial CO2 evolution from an agricultural soil", Water Air & Soil Pollution.

Arteca R.N. (2015). Introduction to Horticultural Science 2^{nd} edition. Cengage Learning. Stamford

Asokan, P; Saxena, M and Bose, S. K.Z. 1995). Proceedings of the workshop on Fly ash Management in the State of Orissa.RRL.Bhubhaneshwar.

Babich, H; Bewley, R. J and Stotzky, F. (1983). "Application of the „Ecological Dose‟‟ concept to the impact of heavy metals on some microbe mediated ecological process in soil".ArchEnvironment Contamination and Toxicology,

Barker, A.V and Pilbeam, D.J. (2010). *Handbook of plant nutrition*.CRC press. New York.

Basu M; Pande, M; Bhadoria, P. B. S and Mahapatra, S.C. (2009). *Potential fly ash utilization in agriculture: A Global Review*. Progress in Natural Science 19: 1173-1186

Bernhard, M, Brinckman, F.E and Sadler, P. J. (1986). *The importance of chemical speciation in environmental processes*.Springer-Verlag. Heidelberg.

Best, J. W and Khan, J.V. (2009). *Research in Education*. PHI Learning Private Limited. New Delhi

Buck, J.K; Honston, R. J and Beimborn, W.A. (1990). Direct seeding of anthracite refuge using coal fly ash as a major soil amendment. In: Proceedings of the mining and reclamation conference and exhibition. West Virginia Univ. Pub. Service No. 2.

Butterly C, Baldock J and Tang C. (2010). *Chemical mechanisms of soil pH change y agricultural residues*. 19th World congress of soil SCIENCE, soil solutions for a changing world. Brisbane

Capp, J. P. (1978). *Power plant flies ash utilization for land reclamation in the eastern United States.* In: Schaller FW, Sutton P, editors. Reclamation of drastically disturbed lands. ASA. Madison. WI.

Carlson, C.L and Adriano, D.C. (1993). *Environmental impacts of coal combustion residues*. J. Environ. Qual. 22:222-247.

Carney D (1998). Sustainable rural livelihoods: What contribution can we make? Department for international development.

Cetin, S and Pehlivan, E. (2007). The use of fly ash as a low-cost, environmentally friendly alternative to activated carbon for the removal of heavy metals from aqueous solutions. Colloids Surf; 298:83–7.

Chambers R and Conway G.R (1992). *Sustainable rural livelihoods: Practical Concepts for the 21st century*. Institute of development studies. Sussex.

Chang, A.C; Lund, L. J and Page, A. L. (1977). *Physical properties of fly ash amended soils*. J Environ Qual;6:267–70.

Chen, J and Li, Y. (2006). Coal fly ash as an amendment to container substrate for Spathiphyllum production. Bioresour Technol; 97:1920–6.

Cohen, M. L. (1994). *Research Methods in Education.*Routledge. London.

Cone, J. D. and Foster, S. F. (2006). *Dissertations and theses from start to finish: Psychology and related fields.*American Psychological Association.Washington, DC

Cozby, P. C. (2004). *Methods in Behavioral Research (8th ed.).* McGrawhill. New York.

Crockett, B (2007). *Issues in Social Science Research.*Admission publishers, Addis Ababa.

Denzin, N. K. and Lincoln, Y.S. (1994). *Handbook of Qualitative Research.*Sage Publication. London.

Desmukh, A; Matti, D. B and Bharti B. (2000). *Soil properties as influenced by fly ash application.* J Soils Crops; 10:69–71.

Dwivedi, A and Jain, M. K. (2014). *Fly ash waste management: a review*. Recent research in science and technology vol 6 No 1.
EMA.(2016). *Safety precautions in handling hazardous substances*.Htpps://www.ema.co.zw. Accessed on 27/03/2017.
Elseewi, A.A; Bingham, F. T and Page, A. L. (1978). *Availability of sulfur in fly ash to plants.* J Environ Qual; 7:69–73.
Elseewi, A.A; Bingham, F. T and Page, A. L. (1978). *Growth and mineral composition of lettuce and Swiss chard grew on fly ash-amended soils.* In: Adriano DC, Brisbin IL, editors. Environmental chemistry and cycling processes, Conf-760429. Springfield, VA.
El-Mogazi, D; Lisk, D. J and Weinstein, L. H. (1988). A review of physical, chemical, and biological properties of fly ash and effects on agricultural ecosystems. Sci Total Environ; 74:1–37.
Faithfull, N. T. (2002). *Methods in agricultural chemical analysis*: A practical handbook. CABI. Wallingford.
FAO.(2011). A policymaker's guide to the sustainable intensification of smallholder crop production.FAO. Rome
FAO.(2016). Overview of the SDGs Process and FAO's contribution to the monitoring framework.APCAS 26TH session. Bhutan.
Ferreira, C; Ribeiro, A and Ottosen, L. (2003). *Possible applications for municipal solid waste fly ash.* J Hazard Mater; 96(2–3): 201–16.
Flick, U. (2006). An Introduction to Qualitative Research 3rd Edition. Thousand Oaks: SAGE. London.
Furr, A. K, Parkinson, T. F, Hinrichs, R. A. (1977). *A national survey of elements and radioactivity in fly ashes.*Absorption of elements by cabbage grown in fly ash soil mixtures. Environ Sci Technol; 11:1194–201.
Garau, M. A, Dalmau, J. L, Felipo, M. T. (1991). Nitrogen mineralization in soil amended with sewage sludge and fly ash. Biol Fertil Soil.
Garg, R. N, Pathak, H and Das D. K. (2005). Use of fly ash and biogas slurry for improving wheat yield and physical properties of soil. Environ Monit Assess;107:19.
Garg, R.N; Kalra, N; Harit. R. C. (2003). Fly ash incorporation effect on soil environment of texturally variant soils. Asia Pac J Environ Dev; 10:59–63.

Ghodrati, M; Sims, J. T; Vasilas, B.S. (1995). *Evaluation of fly ash as a soil amendment for the Atlantic coastal plain. I*. Soil hydraulic properties and elemental leaching. J Water Soil Air Pollut; 81:349–61.

Goetz, L. (1983). Radiochemical techniques applied to laboratory studies of water leaching of heavy metals from coal fly ash. Water Sci Technol; 15:25–47.

GoZ.(2013). *Zimbabwe National Climate Change Strategy*.www. climatechange.org.zw. Accessed on 07/05/2017

Grant, P.M. 1981. *The fertilization of sandy soils in peasant agriculture*. Zimbabwe Agricultural Journal, 78, 169-175.

Grant, P.M., Tanner, P.D. and Madziva, T.J.T. 1973.*Soil acidity factors affecting maize yield in Rhodesia*. Fertilizer Society of South Africa Journal, 1, 39-43.

Grewal, K.S; Yadav, P. S and Mehta, S. C. (2001). The direct and residual effect of fly ash application to soil on crop yield and soil properties. Crop Res; 21:60–5.

Hayman S.D and Mosse B (1971). Plant growth responses to Vascular arbuscular mycorrhiza.In the growth of endogenous inoculated plants in phosphate deficient soils. New phytology. 70:19-21.

Heidrich, C. (2003). *Ash utilization- an Australian perspective*.International ash utilization symposium. Centre for applied energy research. Paper No 3.

Heidrich, C; Feuerorn H. J and Weir, A. (2013). *Coal combustion products: a global perspective.*World of coal ash (WOCA) conference. Lexington

Hodgson, D. R and Holliday, R. (1966). *The agronomic properties of pulverized fuel ash*. Chem Ind; 20:785–90.

Hoy, W. K. (2010). *Quantitative education research*: A primer. Sage. Los Angeles.

Huysamen, G. (2001). Methodology for the Sociological and Behavioral Sciences.Oxford University Press. Oxford

Inam, A. (2007). Use of fly ash in turnip (Brassica rapa L.) cultivation. Pollut Res; 26(1):39 42.

Inam, A. (2007). Response of methi to nitrogen and fly ash supplemented as a source of nutrients. Pollut Res; 26(1):43–7.

IPCC. (2007). Climate change- the physical science basis: contribution of a working group to the fourth assessment report of the IPCC. Cambridge university press. Cambridge

Jamwal, N. (2003) *Is it all grey?* Down Earth.6:38–41.

Jansen, A. J (1996). Management of urban biodegradable wastes: collection, occupational health, biological treatment, product quality criteria and end-user demand. James and James ltd. London

Jala, S and Goyal, D. (2006). Fly ash as a soil ameliorant for improving crop production a review. Bioresour Technol; 97:1136–47.

Jones, C. C, Amos, D. F. (1976*). Physical changes in Virginia soils resulting from additions of high rates of fly ash.*Proceedings of the 4th international ash utilization symposium US Energy Research Development Administration MERC/SP-76-4, Morgantown. WV.

Karpagavalli, S and Ramabadran, R. (1997). *Effect of lignite fly ash on the growth and dry matter production (DMP) of soil-borne pathogens*. National Sem on Bio-Utilization of Khallikote. Berhampur.

Kene, D.R; Lanjewar, S. A and Ingole, B. M. (1991) *Effect of application of fly ash on Physico-chemical properties of soils*. J Soils Crops; 1(1):11–8.

Khan, R.K and Khan, M. W. (1996). *The effect of fly ash on plant growth and yield of tomato*. Environ Pollut; 92(2):105–11.

Khan, N.R; Khan, M. W and Singh, K (1997). Management of root-knot disease of tomato by the application of fly ash in the soil. Plant Pathol; 46:33–43.

Kishor, P; Gosh, A.K and Kumar, D. (2010). *Use of fly ash in Agriculture: A way to improve fertility and productivity.* Asian Journal of Agriculture 4(1): 1-14

Kumar, R (2005). Research Methodology A Step-by-step Guide for Beginners, 2nd edition: Pearson Education. Perth

Kumar, V; Kiran; A. Z and Goswami, G. (2000). *Fly ash use in agriculture: a perspective*. In: Proceedings of the 2nd international conference on fly ash disposal and utilization, vol. I. CBIP. New Delhi.

Kuchanwar, O.D, Matte, D.B, Kene, D.R. (1997). Evaluation of graded doses of fly ash and fertilizers on nutrient content and uptake of groundnut grown on a vertisol. J Soils Crops ;7(1):1–3.

Kumar, V; Mathur, M and Kharia S. P. (2000). *Fly ash management: a vision for the new millennium.* In: Proceedings of 2nd international conference on fly ash disposal and utilization, Vol. I. CBIP. New Delhi.

Lee, S. B; Lee, Y. B and Lee, C. H. (2008). *Characteristics of boron accumulation by fly ash application in paddy soil*. Bioresour Technol; 99(13):5928–32.

Lokeshappa, B and Dikshit A. K. (2011). Disposal and management of fly ash.International conference on life science and technology IPCBEE.Vol 3. Latest press. Singapore.

Lyer, R.S and JA Scott, J.A. (2001). Power station flies ash- a review of value-added utilization outside of the construction industry. Resource.Conservation Recycling 31. 217-228

Matani, A. G. (1998). *Fly ash from thermal power stations: Utilization and Disposal techniques.*Research Journal of Chemistry and Environment, 1: 71-73.

McCauley A, Jones C and Rutz KO (2017). *Soil pH and organic matter*.Nutrient module 8. Montana State University.

McDougall *et al.* (2001). Integrated solid waste management: a Lifecycle inventory. Blackwell Science. Oxford)

Mhazo, M.L, Ngwerume, F.C and Masarirami M.T. (2013). Garlic propagation alternatives using bulblets and cloves of different sizes in a semi-arid subtropical environment. Annual research and review in biology 4(1): 238-245

Mittra, B. N; Karmakar, S and Swaine, D. K. (2003). *Fly ash potential source of soil amendment and a component of an integrated plant nutrient supply system*. In: International ash utilization symposium Center for Applied Energy Research. The University of Kentucky.

Matsi, T and Keramidas, V.Z. (1999). Fly ash application on two acid soils and its effect on soil salinity, pH, B, P and on ryegrass growth and composition. Environ Pollut; 104:107–12.

Mattigod, S. V; Dhanpat, R and Eary, L. E. (1990). Geochemical factors controlling the mobilization of inorganic constituents from fossil fuel combustion residues: A review of the major elements. J Environ Qual; 19:188–201.

Montes, H. G, Perez L. R and Renard F. (2008). *Mineral sequestration of CO2 by aqueous carbonation of coal combustion fly ash.* J Hazard Mater; 181(2–3):1347–54.
Morse S and McNamara N (2013). Sustainable livelihoods approach A critique of theory and practice. Springer. Dordrecht
Mupambwa, H.A; Dube, E and Mnekeni, P.N.S (2015). *Fly ash composting to improve fertilizer value- a review.* South African Journal science 111:1-8.
Murugan, S and Vijayarangam, M. (2013). *Effects of fly ash in an agricultural field on soil properties and crop productivity.* International journal of Engineering research and technology Vol 2 issue 12.
Nachmias, D. and Nachmias, C. (1976). *Research Methods in the Social Sciences*.Edward Arnold, London.
Narayanasamy, P. (2002). *Lignite fly ash as an eco-friendly insecticide*. Available from: http://www.hinduonnet.com (accessed 02.04.17).
Narayanasamy, P. (2003). *Fly ash in the plant protection scenario of agriculture.*In: Mathur GN, editor. Third international conference on fly ash utilization and disposal, Proceedings of the II Central Board of irrigation and power. New Delhi.
Narayanasamy, P. (2005). *Prospect of use of fly ash as a dust insecticide and a carrier in the pesticide formulation.* In: Proceedings of the national business meeting on the use of fly ash in agriculture, FAUP. New Delhi.
Natusch, D.F.S. (1975). Characteristics of pollutants from coal combustion and conversion process. Fort Collins. Colorado.
Natusch, D. F. S, Wallace J. R. (1974). *Urban aerosol toxicity: the influence of particle size*. Science journal; 186:695.
Nawaz, I. (2013). *Disposal and utilization of fly ash to protect the environment*.International journal of innovative research in science, engineering and technology. Vol 2 issue 10.
Neelima, M. R; Khandual, S and Tripathy, A. (1995). Proceedings of the workshop on Fly ash Management in the State of Orissa.RRL.Bhubhaneshwar.
Nyamangara, J. and Mpofu, S.E. 1996. *Soil pH and lime requirement for high potential communal areas of Zimbabwe.*Journal of Applied Science in Southern Africa, 2, 77 81.

Okalebo RJ, Gathua KW, Woomer PL. 2002. *Laboratory methods of soil and plant analysis: A Working Manual.*TSBF-CIAT and SACRED Africa, Nairobi, Kenya.

Page, A. L; Elseewi, A. A and Straughan, I. R. (1979). Physical and chemical properties of fly ash from coal-fired power plants with special reference to environmental impacts. Residue Rev; 71:83–120.

Pathan, S.M; Aylmore, L. A. G and Colmer, T.D. (2003). *Properties of several fly ash materials to use as soil amendments.* J Environ Qual; 32:687–93.

Perrings, C (1994) *Environmental and resource economics*.Edward Elgar publishers. Chaltenham.

Petruzzelli, G; Lubrano, L and Cervelli, S. (1986). *Heavy metal uptake by wheat seedlings grown on fly ash-amended soils.* J Environ Qual; 8:171–5.

Phung, H. T; Lund, I. J and Page, A. L. (1978). *Potential use of fly ash as a liming material*. In: Adriano DC, Brisbin IL, editors. Environmental chemistry and cycling processes, Conf-760429. Springfield, VA.

Pitchel, J. R. (1990). *Microbial respiration in fly ash/sewage sludge amended soils*. Environmental Pollution, 63, pp.225–237.

Plank, C.O, Martens, D.C. (1974). Boron availability is influenced by the application of fly ash to soil. Soil Sci Soc Am Proc; 38:974–7.

Polit, D and Hungler, B. (1991). *Nursing research: Principles and methods*. 3rd edition.J B Lippincott. New York.

Prabakar, J; Dendorkar, N and Morchhale, R. K. (2004). *Influence of fly ash on strength behaviour of typical soils.* Constr Building Mater; 18:263–7.

Prasad, B and Mandal, K. (2008). *Heavy metals leaching in Indian Fly ash*.Journal of Environmental Science Engineering. 50(2):127-132

Proctor, R. W and Capaldi, E.J. (2008). Why science matters: understanding the methods of psychological research. Wiley Blackwell. Malden.

Raj, S and Mohan, S. (2008). *Approach for improved plant growth using fly ash amended soil.* International journal of emerging technology and advanced engineering. Vol 4:6

Randolf, J. (2004). Environmental land use planning and management.Island Press. London

Rautaray, S.K; Ghosh, B. C and Mittra, B.N. (2003). Effect of fly ash, organic wastes and chemical fertilizers on yield, nutrient uptake, heavy metal content and residual fertility in a rice-mustard cropping sequence under acid lateritic soils. Bioresour Technol; 90: 275–83.

Ritchie, J and Lewis, J (2003). *A guide for social science students and researchers*.Sage publications. London.

Rohriman, F.A. (1971). Analysing the effect of fly ash on water pollution. Power; 115:76.

Rose CW (2004). An introduction to the environmental physics of soil, water, and watersheds.Cambridge university press. Cambridge.

Sachs, J. (2004). *Economics and nutrition: how do they intersect?*In SCN News Nutrition and the Millenium Development Goals.Lavenham. UK

Sadasivan, S, Meenaksy, Negi B. S, Krishnamoorthy, T.M and Nambi, K.S.V.(1994). Composition and leachability of trace elements in coal ash and their migration in groundwater at the thermal power plant site at Manuguru.Bhabha research centre. Bombay.

Sajwan, K.S. (1995). The effect of fly ash/sewage sludge mixtures and application rates on biomass production. J Environ Sci Health A Environ Sci Eng; 30(6):1327–37.

Sanchez, P. (2002). *Millenium Project Hunger Task Force.*In SCN News Nutrition and the Millenium Development Goals.Lavenham press. The UK.

Sankari, S, Narayanasamy P. (2006). *Fly ash: a new potential termiticide*. Pestology; 30(8):39–42.

Sao, S; Gothalwal, R and Thetwar, L. K. (2007). Effects of fly ash and plant hormone treated soil on the increased protein and amino acid contents in the seeds of ground nut (Arachis hypogaea). Asian J Chem; 19(2):1023–6.

Sarangi, P. K; Mishra, T. K and Mishra, P.C. (1997). *Soil metabolism, growth and yield of Oryza sativa L. in fly ash amended soil*. Indian J Environ Sci; 1(1):17–24.

Sarangi, P. K; Mahakur, D and Mishra, P.C. (2001). Soil biochemical activity and growth response of rice Oryza sativa in fly ash amended soil. Bioresour.Technol 76.

Sarkar, A and Rano, R. (2007). Water holding capacities of fly ashes: effect of size fractionation. Energy Sources Part A; 29(5):471–82.

Schensul, J., Singer, M., Marshall, P., Trotter, R., Weeks, M., Simmons, J.E. and Radda, K. E (1999). *Ethics, Ethnography, Drug Use and AIDS: Dilemmas and Standards in Federally Funded Research.*National Institute on Drug Abuse.Bethesda

Schnappinger, M.F, Martens, D. C and Plank, C. D. (1975). *Zinc availability is influenced by the application of fly ash to soil.* Environ Sci Technol; 9:258–61.

Sekaran, U. (1984). Research methods for managers: A skill-building approach: John Wiley & Sons Inc. New York

Senapati, M.R. (2011). Fly ash from thermal power plants: Waste management and overview.Current science, Vol 100: 12.

Sharma, S.K and Kalra, N. (2006). Effect of fly ash incorporation on soil properties and productivity of crops: a review. J Sci Ind Res; 65(5):383–90.

Shumba, E.M. 1984. *Yields of maize in the semi-arid regions of Zimbabwe*. Zimbabwe Agricultural Journal, 81, 91-94

Singh, L. P and Siddiqui, Z.A. (2003). Effects of fly ash and Helminthosporium oryzae on growth and yield of three cultivars of rice. Bioresour Technol; 86:73–8.

Solomon, A.O. (2011). The role of households in solid waste management in East Africa capital cities.Wageningen University.Wageningen.

Solesbury, W. (2003). *Sustainable livelihoods: A case study of the evolution of DFID policy*. Overseas Development Institute working paper 217. London.

Steven, B. Alemu, G, Ross, P and Chandler, D. (2012). The use of the constructivist grounded theory method to explore the role of socially constructed metadata (web 2.0) approaches.The University of Portsmouth. Portsmouth

Straughan, I; Elseewi, A.A and Page, A. L. (1978). *Mobilization of selected trace elements in residues from coal combustion with special reference to fly ash*. In: Hemphill DD, editor. Trace substances in environmental health-XII. A symposium. Columbia: University of Missouri.

Strauss, A. and Corbin.J. (1998). Basics of qualitative research: techniques and procedures for developing grounded theory (2nd Edition). Thousand Oaks, London.

UNEP. (2011). *Implementation strategy to reduce the environmental impact of energy-related activities in Zimbabwe.*UNEP collaborating centre on energy and environment working paper No. 5. Riso National Laboratory. Denmark.

Tan, K.H. (2005). Soil sampling, preparation and analysis 2nd edition.CRC press. London

Tan, Y. (2008). *Resettlement in the Three gorges project*. Hong Kong University Press. Aberdeen.

Taylor, E. M and Schumann, G. E. (1988). *Fly ash and lime amendment of acidic coal soil to aid revegetation.* J Environ Qual; 17:120–4.

This, T.L.; Ripp, J.A and Villaume, J.F. (1989). *Physical and chemical characteristics of unsaturated pore water and leachate at a fly ash disposal site.* In: 43rd Purdue industrial waste conference proceedings. Lewis Publishers. MI.

Thetwar, L. K; Sahu, D. P and Vaishnava, M.M (2006). Analysis of Sesamum indicum seed oil from plants grown in fly ash amended acidic soil. Asian J Chem; 18(1):481–4.

Tiwari, K. N; Sharma, D. N and Sharma V. K. (1982). *Evaluation of fly ash and pyrite for sodic soil rehabilitation in UP, India*. Arid Soil Res Rehabil; 6(2):117–26.

Tolle, D.A; Arthur, M. F, Pomeroy, S. E. (1982). Fly ash used for agriculture and land reclamation: a critical literature review and identification of additional research needs. Battelle Columbus Laboratories. Ohio.

Tuckman, B. W (1972*). Conducting Educational Research*.Holt, Rinehart & Winston. New York

Van Hook R. I. (1979). Potential health and environmental effects of trace elements and radionuclides from increased coal utilization. Environ Health Perspect; 33:227–47.

Wang, E. (1997). Development of a Generic process-Oriented model for simulation of crop growth.Heret Utz Verlag Wissenschaft.Munchen.

Wilson, D.C; Velis, C.A and Rodic, L. (2013). Integrated Waste Management in developing countries.Proceedings of the institution of civil engineers.Waste and resources management, 166 (2). 52-68

Wong, M. H and Wong, J. W. C. (1986). *Effects of fly ash on soil microbial activity*. Environ Pollut Ser.

ZINDC. (2015). *Intended Nationally Determined Contributions. Climate policy database*. http://www4.unfccc.int. Accessed on 07/03/2017