Addis Ababa University

Addis Ababa Institute of Technology

School of Civil and Environmental Engineering

(major in water supply and environmental engineering)

Recovery of Nitrogen and Phosphorous From Source Separated Urine Using Biochar

By:

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Addis Ababa, Ethiopia

October, 2019



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School of Graduate Studies

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A thesis submitted to the School of Graduate Studies of Addis Ababa University in Partial fulfillment of the Degree of Master of Science in Water Supply and Environmental Engineering.

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Abstract

Nutrients mainly nitrogen and phosphorous exist in wastewater excessively. If uncontrolled, they lead to eutrophication problem which has adverse impacts on the social, economic and ecological values of surface water bodies. Urine is a significant contributor of phosphorus and nitrogen found in domestic waste water. Therefore, recovery of these nutrients from urine removes the excess amount of nutrients and prevents environmental pollution. In addition removal of Phosphorus in wastewater treatment plants is costly and limits its recovery and use as a resource. Recovery of nutrients from source separated urine would increase the efficiency in nitrogen and phosphorous removal and reuse capacity. The objective of this research was to examine different parameters affecting the recovery of nitrogen and phosphorous through adsorption process by using biochar produced from corn cob(CC), coffee husk(CH) and water hyacinth(WH) and determine nutrient recovery efficiencies of each biochar from human urine. In this research, the impacts of different parameters which can affect nutrient recovery from source separated urine using biochar were examined to get optimal values. The nutrient recovery process was conducted under different pH (3-8), biochar dosage (0.2-1g) and contact time (30-150min.) on urines of different storage time (15days, 1 month and 2 month). The optimum working values of pH and contact time were 6 and 60 minutes, respectively. The optimum dosages were 0.4g, 0.6g and 0.8g for 15 days, 1 month and 2 months stored urine. Highest NH_4^+-N and PO_4^{3-}P recoveries were obtained from urine that had two months of storage time. Therefore, urine with two months storage time was selected as optimal. Under these optimum values, the nitrogen recovery efficiencies of biochars produced from CC, CH and WH were 94.13%, 77.99% and 85.78%, respectively. The recovery efficiencies of phosphorous from human urine were 68.60%, 71.14% and 57.72 % using CC, CH and WH, respectively. CC produced biochar was the best compared to CH and WH biochars. Biochars produced from wastes have good potentials for nutrient recovery from source separated urines. Besides, the use of waste as resource is in line with sustainable waste management and contributes to environmental pollution control.

Key words: biochar, efficiency, recovery, source separated urine, nitrogen, phosphorous

Acknowledgment

I would like to express the sincere appreciation to my advisor, Dr. Agizew Niggusie, who has the attitude and substance of a true researcher, for his commendable guidance, technical and continuous support throughout the entire route of this research.

Your input has gone a long way; thank you. Mr. Zerihun Getaneh for the additional guidance and change of perspective that made this work what it is today.

Thanks to my friend Kalkidan Tegegne for her cooperation during water hyacinth sample collection for this thesis work. My appreciation also goes to Mr. Alene for his patience and tireless support during my stay at biotechnology laboratory.

I would like to thank my mother and father, for their continuous support and prudent counsel. This research would not have been possible without their diligence help.

At last but not least, I would like to thank all those who have helped me one way or another during this research.

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Acronyms and Abbreviations

APHA - American Public Health Association

CC - Corn Cob

CH -Coffee Husk

CHN -Carbon Hydrogen Nitrogen

EcoSan -Ecological Sanitation

N -Nitrogen

NBC -Nutrient Enriched Biochar

NH_4^+ -N -Ammonium Nitrogen

P -Phosphorous

PO_4^{3-} -P -Phosphate Phosphorous

rpm -Revolution Per Minute

SEM -Scanning Electron Microscopy

UDDT -Urine Diverting Dry Toilets

WH -Water Hyacinth

1. Introduction

1.1. Background

Wastewater contains a high amount of organic matter, nitrogen and phosphorus, a considerable amount of Magnesium, different macro and micro elements, and heavy metals due to this it is considered as one of the major polluting agents discharged into the environment. These pollutants come from anthropogenic, livestock, natural or industrial sources(Rahman *et al*., 2014b). It is built up of several components. One of the smallest components in terms of volume is urine, making up for less than 1% of the total wastewater stream. Even with its small volume, urine is a significant contributor of nutrients: it contains 85–90% nitrogen, 50–80% phosphorus, and 80–90% potassium excreted by humans. This aspect offers the opportunity to extract the nutrients and make them available for recovery and reuse(Ronteltap, 2009).

New technologies are, therefore, needed to recover nutrients in hygienically safe way from wastewater. Even there exist an effective wastewater treatment system; these do not recover nutrients, which is an important standard for sustainable wastewater management. Nutrient recovery can be achieved via plants, microorganisms (algae and prokaryotic), and physicochemical mechanisms including chemical precipitation, membrane separation, sorption, binding with magnetic particles, forward osmosis, membrane distillation and electro dialysis can advance wastewater nutrient recovery(Xiea *et al*., 2016).

Nitrogen and phosphorous removal from wastewater has become an emerging worldwide alarming issue because these compounds are associated with significant environmental concerns. Nitrogen is associated with concerns about climate, air quality for human health reasons, water quality and biodiversity. The environmental concerns about phosphorus are principally as a contributor to water pollution and eutrophication(Cordell, 2010). The direct drivers of nutrient pollution include energy consumption and fertilizer use which result in increased nutrients lost to the environment, as well as land-use conversion which diminishes the capacity of ecosystems to capture and cycle nutrients before they reach aquatic ecosystems.

Indirect drivers of nutrient pollution include demographic shifts, expansion of intensive agriculture, and economic growth(Selman *et al*., 2007, Howarth, 2008).

Scarcity of nutrients is likely to occur sooner than generally expected. Such scarcities will have consequences for crop yields, livestock and public health. There are three possible forms of scarcity which includes scarcity in the soil as nutrients for crops, scarcity in feed or food (for livestock and humans) and scarcity in the mineral reserves, which can be mined for the production of chemical fertilizer to supplement the naturally occurring nutrients in soil(Udo de Haes *et al*., 2012).

The manifestations of rapid population growth, urbanization, improved standards of living and concurrent intensification of socio-economic activities on the overall environmental health are well-recognized and acknowledged today(Cordell *et al*., 2009, Rockstrom *et al*., 2009). As the world's population continues to grow, farmers will need to rely increasingly on fertilizer to replenish soil and produce enough food. The major components in most fertilizers are nitrogen and phosphorus. Fortunately, a large portion of the nitrogen and phosphorus used in fertilizers eventually present in wastewater, and or its recipient(Rittmann *et al*., 2011). Since a large fraction of the synthetic fertilizer production escapes into the atmosphere, recovery of lost nutrient holds promise in mitigating this problem(Smil, 2002).

Nutrient recovery and reuse is a guarantee means that tackles the consequences. Because of the insufficiency of nutrients, recovery is the fundamental part to avoid problems coming due to the scarcity of nutrients. Wastewater can be viewed as a valuable resource with nutrients present (i.e., phosphorus, potassium, and nitrogen), however, because large volumes of wastewater are generated, it is not efficient to recover nutrients from a dilute wastewater. A change towards low-cost, nearby sourced materials for the treatment of wastewater must be considered in order to steps forward as a sustainable society(Wilsenach and Loosdrecht, 2003).

Ecological sanitation methods can achieve sustainable systems because of their ability to recover nutrients in the wastewater. Urine source separation is one of ecological sanitation methods, in which urine is collected and treated as a separate waste stream, is an original approach based on ecological sanitation methods for targeting high concentrations of nutrients and to reduce the overall loading to conventional wastewater treatment facilities(Werner *et al*.,

2003). The high concentration of nutrients in source separated urine presents an opportunity for separation and subsequent use of the urine, for example, as a nutrient product in agriculture(Lienert *et al*., 2007).

At present, biochar adsorption technology is gradually applied in the field of wastewater treatment. It has been shown that biochar has good adsorption effect on typical pollutants of wastewater such as organic pollutants, heavy metals, nitrogen, and phosphorus. At the same time, because biochar has good adsorption capacity for nitrogen and phosphorus, it can be used as a slow-release fertilizer and has the characteristics of agricultural environment-friendly(Yao *et al*., 2011).

1.2. Statement of the Problem

One of the stunning achievements of the twentieth century was the increase in agricultural productivity which enabled growth in food production to match the tripling of human population(Cordell *et al*., 2009). But, at the end of this century the world population will increase by about 4 billion(Cordell, 2010).Could we still manage to supply an extra 4 billion people with the technology and knowledge that have been used for the last century?

Ethiopia seeks to enhance production and productivity of smallholder farmers and reduce degradation of natural resources. Agriculture accounts for more than 50% of Ethiopian's GDP, 90% of foreign exchange earnings, 70% of raw materials for domestic industries, and 85% of employment for the population(Getachew, 2011). N and P consumption steadily increased from 1980 to 2015. Mean fertilizer consumption in Ethiopia has risen from 132,522 MT to 858,825 MT period(IFDC, 2015).

Nutrient over enrichment or eutrophication of freshwater and marine ecosystems is growing rapidly as a result of human activities(Mee, 2006). The drivers of eutrophication are diverse and include complex and interrelated socioeconomic factors that ultimately lead to increasing levels of nutrient pollution. The direct drivers of nutrient pollution include energy consumption and fertilizer use which result in increased nutrients lost to the environment, as well as land-use conversion which diminishes the capacity of ecosystems to capture and cycle nutrients before they reach aquatic ecosystems. Indirect drivers of nutrient pollution include demographic shifts, expansion of intensive agriculture, and economic growth(Selman and Greenhalgh, 2009).

Burning biomass (water hyacinth, corn cob and coffee husk) in an open area releases large amount of pollutants. This leads to air pollution which is the major cause of public health problems. Ethiopia is the fifth country of coffee producer in the world. Coffee generates large amount of coffee by-products/residues during processing. Coffee husks are the major solid residues from the handling and processing of coffee, since for every 2Kg of coffee beans produced, approximately 1kg of husks are generated(Pauline *et al*., 2010). Some people burn the generated coffee husk, while others dispose it on the field. This is improper way of

handling the waste. Large amount of potential that could be utilized from coffee husk cannot be achieved in this way(Zheng *et al*., 2009).On the other hand, corncob is an important byproduct of corn. For every 100 kg of corn grain approximately 18 kg of corncobs is produced(Ruzene *et al*., 2008). But, it is not managed in a sustainable manner. Usually it is burned indiscriminately; resulting environmental pollution and wastage of resource.

In Ethiopia, the proliferation of water hyacinth has become a treat in the lowlands of Ilubabor (Baro, Gillo and Pibor rivers), in the lake Tana area (marshy tracts of the Blue Nile or Abbay river near its outlet with Lake Tana), and in the Rift Valley (Awash river, Koka dam, lake Ziway and lake Ellen)(Aweke, 1993). It affects navigation, water flow, recreational use of aquatic systems, and poses mechanical damage to hydroelectric systems. It is also responsible for drastic changes in the plant and animal communities of fresh water environments and acts as an agent for the spread of serious diseases in tropical countries.

Unsustainable human excreta management is also another major issue of concern in developing countries. It results in serious environmental pollution and loss of nutrients which could have been used as fertilizer. Sustainable fecal sludge management encourages separation of urine from faeces by using urine diverting dry toilets. This enables recovery of nutrients for productive purposes and minimization of eutrophication problem and its adverse consequences.

This study tried to address these environmental concerns of poor biomass and urine management using resource-oriented waste management approach. It is, therefore, important to investigate the potentials of biochars produced from corncob, coffee husk and water hyacinth to recover nutrients from urine.

1.3. Research Objectives

1.3.1. General objectives

The overall objective of this study is to investigate the use of activated biochar for recovery of nitrogen and phosphorus from source separated urine.

1.3.2. Specific Objectives

The specific objectives are to:

- Determine and compare potentials of different biochar materials for nutrient recovery from source separated urine
- To examine the influence of different parameters on the efficiency of nutrient recovery from source separated urine
- To identify the best isotherm model that represent the nutrient recovery process

1.4. Research Questions

1. What nitrogen and phosphorus recovery potentials do biochars derived from corncob, coffee husk and water hyacinth have?
2. What are the optimum pH, biochar dosage, and contact time and storage time to gain high recovery efficiency of (NH_4^+ -N) and (PO_4^{3-} -P) from urine by using biochar?
3. Which of the biochar materials has best performance in recovering nutrients? Is Langmuir or Freundlich isotherm model best to represent the nutrient recovery by the good biochar adsorbent?

1.5. Scope of the Research

This research focuses on the potential of biochar which is produced from waste biomass (i.e. corn cob, coffee husk and water hyacinth) on the recovery of nutrients from source separated human urine. In this study laboratory based tests were carried out to recover nutrients (N and P) from stored human urine. Moreover parameters including pH, biochar dosage, contact time and storage time of urine were optimized.

1.6. Significance of the Study

This study has great significance in terms of introducing an alternative form of nutrient recovery by producing biochar from corn cobs, coffee husks and water hyacinths, which are locally available, abundant with no economical value. It also contributes to ongoing research endeavors in the area of resource-oriented solid waste and wastewater management to ongoing research endeavors in the area of resource-oriented solid waste and wastewater management.

1.7. Structure of the Thesis

Chapter One: *Introduction* part presents a general introduction about the research, describes about nutrient pollution, wastewater treatment technologies, importance of low cost technologies and related issues, statement of the problem, general objective, specific objectives, research questions, and the scope of the research.

Chapter Two: *Literature Review* presents facts to familiarize the reader with the context in which the investigations are performed. It gives a brief description about ecological sanitation in Ethiopia, treatment technologies for wastewater. Also, the composition of urine and the treatment for source separated urine was well explained. It gives sound information about application of biochar in wastewater treatment and nutrient removal related issues are discussed in conjunction with the data acquirement and processing which were in use.

Chapter Three: *Materials and Methods* give overview of the methods, biochar preparation, urine collection and storage, biochar characterization. It also provides the overall data analysis and procedure followed throughout the study.

Chapter Four: *Results and Discussions* present main results and findings from data analysis then discuss and evaluate the research outputs.

Chapter Five: C*onclusion and Recommendation* summarizes the overall results of the research and recommendations are made for the mitigation of contamination over the surrounding surface water bodies. It also provides list of recommended measures, and suggestions for future studies.

2. Literature Review

In most developing countries, wastewater treatment and disposal is a matter of concern that needs to be addressed. The countries' prospects for economic and social development, poverty and priorities for industrial investments form obstacles in making decisions about public wastewater facilities for small towns and rural communities. Since financing, constructing, operation and maintenance of sewer systems and wastewater treatment plants are quite costly, most developing countries avoid these projects(Bakir, 2001). In areas served by municipal wastewater facilities, sewage is transported away from homes in large diameter gravity sewers to a central plant where it is treated and discharged into a waterway. In coastal areas, deep sea discharge is common after pre-treatment. Outside of these areas, especially in remote regions and villages, most individual residences must rely on a septic tank and soil absorption field, or package treatment system, to dispose of their wastewater(Demir, 2002)

2.1. Wastewater Treatment Technology

For a long time wastewater has been considered a human health concern and environmental hazard, but a paradigm shift is currently underway from an attitude that considers wastewater as a waste to be treated, to a proactive interest in recovering materials and energy from these streams(Puchongkawarin *et al*., 2015).Considering wastewater as a resource is relatively new perspective, however it is a huge resource that if harnessed properly, can bring a lot of health and economic benefits, increase food production, enhance fishing, rural and urban livelihoods.

Wastewater has high organic content which can be used for energy production; the nutrients especially the phosphate can be used as fertilizers. Now a day, phosphorous is scarce due its slow cycle, but easily can be found in wastewater.

Environmental benefits can also be gained from the use of wastewater. The factors that may lead to the improvement of the environment when wastewater is used rather than being disposed of in other ways are(Smith *et al*., 2017):

• Avoiding the discharge of wastewater into surface waters.

• Preserving groundwater resources in areas where over-use of these resources in agriculture are causing salt intrusion into the aquifers.

• The possibility of soil conservation by humus build-up and by the prevention of land erosion.

• The aesthetic improvement of urban conditions and recreational activities by means of irrigation and fertilization of green spaces such as gardens, parks and sports facilities.

Most treatment plants consist of three steps to make the effluent suitable for human beings, animals and environment. These steps are physical treatment (primary), Biological (secondary) and tertiary treatment.

2.1.1. Physical (primary) treatment

Primary treatment process includes preliminary purification processes of a physical and chemical nature, is carried out by settling (sedimentation) process which is applied to get rid of suspended matters, grit, oil and grease from wastewater(Gupta *et al*., 2012). After initial screening to remove larger debris, wastewater still contains dissolved organic and inorganic constituents as well as suspended solids which are removed via the process of primary settling, sedimentation, chemical coagulation or filtration. This allows for separation of the solid and liquid phases in the wastewater by removing those settled organic solids as well as any floating materials such as fats, oil and grease(Naidoo and Olaniran, 2013). The core use of this treatment process is to remove heavier solids to reduce the loads on the biological treatment and increasing its efficiency.

2.1.2. Secondary treatment

Secondary water treatment includes biological routes for the removal of soluble and insoluble pollutants by microbes. Water is circulated in a reactor that maintains a high concentration of microbes. The microbes, usually bacterial and fungal strains, convert the organic matter into water, carbon dioxide and ammonia gas(Pendashteh *et al*., 2010, Joss *et al*., 2005).This process is carried out by single and or combined system of aerobic digestion, when air or oxygen is freely available in dissolved form in wastewater then the biodegradable organic matter undergoes aerobic decomposition, caused by aerobic and facultative bacteria(Barragan *et al*., 2007); and anaerobic

digestion in which free dissolved oxygen is not available in the wastewater then anaerobic decomposition, called putrefaction, occurs. Anaerobic and facultative bacteria convert the complex organic matter into simpler organic compounds based on nitrogen, carbon and sulphur, depending on the materials used(Van der Zee and Villaverde, 2005, Mohan *et al*., 2007). But, anaerobic digestion and activated sludge are the most widely used processes when treating sludge and municipal waste water respectively.

2.1.3. Tertiary treatment

Tertiary wastewater treatment includes odor removal, disinfection, filtration, nitrogen and phosphorus removal and recovery. Excessive amount of N and P will result in severe environmental problems like eutrophication, contamination of surface and ground water. The techniques used for this purpose are distillation, crystallization, evaporation, solvent extraction, oxidation, coagulation, precipitation, electrolysis, electro dialysis, ion exchange, reverse osmosis and adsorption.

2.2. Nitrogen and Phosphorous Availability in Wastewater

Nutrients found in waste streams are mostly compounds of carbon, nitrogen, and phosphorus (CNP). All of them are important for sustenance of various life forms(Tornroth-Horsefield and Neutze, 2008). Phosphorus (P) and nitrogen (N) are the primary nutrients that in excessive amounts pollute our lakes, streams, and wetlands. Both N and P have known point and non point sources. Control of point sources has been easier than non point sources.(Ngatia *et al.*, 2019). Nitrogen is essential to the production of plant and animal tissue. It is used primarily by plants and an animal to synthesize protein. Phosphorus is a vital nutrient for converting sunlight into usable energy, and essential to cellular growth and reproduction.

Nitrogen

Nitrogen is a critical nutrient for plants and animals, and terrestrial ecosystems and headwater streams have a considerable ability to capture nitrogen or to reduce it to N_2 gas though the process of denitrification. Nitrogen is found in a variety of forms throughout our environment and changes forms readily. Nitrogen cycling and retention is thus one of the most important

functions of ecosystems(Vitousek *et al*., 2004). When loads of nitrogen from fertilizer, septic tanks, and atmospheric deposition exceed the capacity of terrestrial systems (including croplands), the excess may enter surface waters, where it may have "cascading" harmful effects as it moves downstream to coastal ecosystems(Galloway and Cowling, 2002). Other sources of excess nitrogen include direct discharges from storm water or treated wastewater. This indicator specifically focuses on nitrate, which is one of the most available forms of nitrogen in bodies of water.

Phosphorous

Phosphorus is an essential nutrient for all forms of life. Unlike nitrogen, however, phosphorus cycles through the environment more slowly(Science Communication Unit, 2013). Most of the phosphorus is found in rocks and minerals. But like nitrogen, phosphorus that enters the environment from anthropogenic sources may exceed the needs and capacity of the terrestrial ecosystem. As a result, excess phosphorus may enter lakes and streams(Fowler *et al*., 2013). It is the key element of concern because the natural occurrence of P in surface water bodies is minimal. Because phosphorus is often the limiting nutrient in these bodies of water, an excess may contribute to unsightly algal blooms, which cause taste and odor problems and deplete oxygen needed by fish and other aquatic species.

Phosphorus is also an essential element for plant growth and agricultural productivity. Fertilizer commonly supplies the crop phosphorus requirement or replenishes P removed from a harvested crop biomass(Lukowiak *et al*., 2016). High value crops demand intensive management in order to remain competitive. In these cases, farmers tend to hedge their bets by fertilizing in excess of the crop requirement. Over the long term, this practice will increase soil P accumulation, the risk of off-site movement, and runoff may move the phosphorous into surface water sources which lead to water pollution.

2.3. Ecological Sanitation

The current world population of 7.3 billion is expected to reach 8.5 billion by 2030(UN DESA, 2016). Water scarcity, poor water quality and inadequate sanitation negatively impact on food security, livelihood choices and educational opportunities for poor families across the world. The world spends the required amount of money on sanitation but inappropriately, there is need for appropriate technologies to achieve universal access(Mara et al., 2010).The technologies for effective sanitation should provide access and reduce public health risks.

To address the water scarcity problem, and to benefit the reduction of polluted water, ecological sanitation minimizes water usage as much as possible. By having systems that minimize water usage, and treat waste, the UN millennium development goals about water supply and sanitation are benefitted (UN 2016). The UN goal is set to "*ensure access to safe water sources and sanitation for all"*. Ecological sanitation systems are made to achieve this goal together with providing hygienic services at a lower cost than conventional sanitation(Esrey et al., 2001). EcoSan have an important role to play in this topic, if the system is used widely and adequately, it can contribute to better access to safe water sources and sanitation.

Ecological sanitation systems are systems which allow for the safe recycling of nutrients to crop production in such a way that the use of non-renewable resources is minimized. These systems have a strong potential to be sustainable sanitation systems if technical, institutional, social and economic aspects are managed appropriately(Kvarnstrom *et al*., 2012). Ecosan differs from other decentralized sanitation system (such as a pit latrine) as there is a deliberate focus on the reuse of excreted material as opposed to treating it as waste(Langergraber and Muellegger, 2005).The basic principle of ecosan is to close the nutrient loop between sanitation and agriculture. It claims to address the aforementioned shortcomings in our systems of sanitation and food production by initiating a paradigm shift in the way we perceive and manage human wastes(Esrey, 2001). Ecosan promotes recycling of nutrients contained in excreta to grow crops and fruits; thus enhancing food security and reducing the need to rely on agriculture fertilizers. Human excreta contain nutrients suitable for agriculture such as nitrogen, urea, potassium and phosphorus(Schuen and Parkinson, 2009)

2.3.1. EcoSan and source separation of wastes

The working strategy and distinguishing feature in EcoSan are the concept of source separation, split-stream collection and individual treatment of various wastewater fractions, urine (yellow water), faecal matter (brown water), black water (urine plus feces) and grey water (excreta-free household wastewater). To allow the separation of these streams at source, i.e. households, the technological solution employed is urine diversion through the use of a diverting toilet(Larsen *et al*., 2001). These toilets take advantage of human physiology which separately excretes faeces and urine; the toilets are engineered so as to facilitate the collection of urine in a front end bowl and faeces in the rear ended bowl(Beal *et al*., 2008). The applicability and feasibility of diverting toilets as an alternative to conventional sanitation systems seems to be well established. This is evident through the number of installations of diverting toilets across the world; this includes the sale of over 300,000 UDTs by the Sweden based company(Munch and Winker, 2009), the large scale rural and peri urban sanitation program in Durban, South Africa which encompasses75,000 UDDTs serving nearly 450,000 inhabitants, the community led total sanitation WASH program implemented in Liberia which provided access to improved sanitation for over 100,000 people, as well as UDDT installation of around 900 in Bolivia, and 500 pit latrines at Farchana refugee camp in chad(Okem *et al*., 2013).

2.3.2. Urine diversion dry toilets in Ethiopia

Ethiopia is one of the countries with the lowest sanitation coverage with less than 15% of the total population having access to improved sanitation. Problems with current sanitation systems includes Collapsing of pit latrines, wastewater exfiltration from pits and septic tanks resulting in groundwater pollution, lack of faecal sludge management and treatment facilities, irregular water supply restricting the use of water flushed toilets and Need for inexpensive and hygienic fertilizer(Meinzinger *et al.*, 2009).

Like in the majority of countries in Africa urbanization is increasing, thus, appropriate provision of infrastructure in the urban agglomerations becomes more and more urgent. The Ethiopian government decided to solve this challenge by supporting the construction of large

condominium housing programs all over the country. In 55 cities across the country about 400,000 so called condominium houses are going to be constructed. These condominium housing programs differ from conventional housing areas due to the high population density and the implementation of multi-story apartment houses(Oldenburg *et al*., 2009).

The multi-story buildings regularly face problems related to water-supply and wastewater management. Water supply is irregular, which makes the use of water-flushed toilets inconvenient. Lack of transporting and treatment facilities for septage pose hygienic risks to people and the environment. Centralized sewerage systems are usually not within reach of the municipalities due to the high costs for sewers and treatment facilities.

Thus, alternative sanitation concepts are required and a project called ―Ecological Sanitation Ethiopia‖ was established to develop alternative sanitation solutions (i.e. urine-diverting dry toilets) for the condominium sites and to implement these in cooperation with the Ministry of Works and Urban Development(Oldenburg *et al.*, 2009).

UDDTs in multi-storey buildings will have chutes that connect the waterless toilets with collection containers in the basements are used. The innovation that was developed for the Ethiopian case is based on the so-called double-vault system with urine diversion. Two vaults are used alternately on every story to allow storage and dehydration of the fecal material. The toilet is designed as a box allowing the on-site storage of feces and drying additives such as ash. Urine is diverted and collected in $5m^3$-storage tanks outside the buildings. In order to prevent smell from the urine containers entering into the bathrooms, a smell trap is integrated into the urine pipe.

The challenge faced now is the integration into higher density areas. In contrast to other implementations of UDDT into multi-story buildings using long chutes, the approach of double-vault toilets is piloted in one multistory block of apartments in Hawassa, Ethiopia(Oldenburg *et al*., 2009).

Although urine can be collected separately in big buildings or public places like airports and universities, the use of urine itself as a fertilizer is not feasible on a large scale. There are several constraints that make urine unattractive. For example: it is expensive to transport large

volumes of urine to farms, urine has an unpleasant smell, urine is not acceptable in many societies and urine can contain pharmaceutical residues and pathogens

2.4. Chemical Composition of Urine

Human urine is a liquid waste product of the human body secreted by the kidneys by a process of filtration from blood called urination and excreted through the urethra. Each individual produces 1-1.5l of urine per day in 4-5 times and an adult person excretes on average of 500 l urine per year. It is estimated that 550 l of urine contains 4 kg of nitrogen, 365 g of phosphorus and 1 kg of potash(Jonsson *et al*., 2004).

However, the composition of human urine varies from person to person and from region to region depending upon his/her feeding habit, the amount of drinking water consumed physical activities, body size and environmental factors(Jonsson *et al*., 2004). Most of the nitrogen fractions in urine are taken up by plant and which is same as that of the urea or ammonium fertilizer with nitrogen efficiency approximately 90% of that of mineral fertilizer(Jonsson et al., 2005).Loss of nitrogen during storage can be minimized by minimizing temperature and avoiding aeration above the liquid surface in storage tanks(Hoguland, 2001).

If the waste water with the excessive amount of Phosphorus and nitrogen is disposed into the environment, it will cause Eutrophication of waters and causes a serious environmental issue, harming marine ecosystems, pollute lakes, streams, and wetlands and contributing to global warming(Kc and Shinjo, 2017). Sustainable development in wastewater management includes recovery of nutrients to reduce eutrophication, but also ways to recycle the removed nutrients. About 80% of the nitrogen, 50% of the phosphorus and 60% of the potassium from domestic wastewater reside in urine(Ganrot *et al*., 2007).

2.5. Treatment of source separated urine

Collection and treatment of urine can be used as an alternative sanitation system that reduces environmental pollution. Source separation of urine has a lot of advantages. It is resource efficient, high nitrogen removal can be achieved and removal of pharmaceuticals may be easy

to implement(Larsen et al., 2009).Urine separation can lead to savings in energy compared to enhanced treatment.

Nitrogen (N) and phosphorus (P) in domestic sewage can lead to eutrophication(Zheng *et al*., 2013). The source collection of urine to recover N and P has recently gained more attention than the nutrient removal process in conventional sewage treatment. Obstacles to using urine separation technology are the storage and transport of large amounts of urine.

Separation of urine is a promising technique for the new improved wastewater systems. But, in today's society urine is often seen as a waste product that requires a lot of energy to handle, but in fact urine contains a lot of substances and could be seen as a resource. Many ways of recovering nutrients from urine have been investigated; microalgae growth, precipitation by adding magnesite and zeolite to hydrolysed urine, precipitation by adding magnesium chloride(Ronteltap, 2010), electrolysis with graphite electrodes, forward osmosis dewatering, and forward osmosis combined with membrane distillation(Liu *et al*., 2016).

Urine treatment has to prevent possible negative effects of urine, such as environmental pollution, hygienic risks and malodor. Inadequate sanitation is reportedly the main source of high nitrate concentrations in groundwater(Tredoux, 2004)and a major cause of eutrophication in urban areas of sub-Saharan Africa(Nyenje *et al*., 2010). However, urine is also a source of valuable nutrients. By recovering these nutrients as a fertilizer, the nutrient cycle to agriculture is closed and the environmentally adverse production of synthetic fertilizers is reduced. Besides these beneficial effects for the environment, financial valorization of human excreta could offset the costs of sanitation(Tilley and Gunther, 2013). Thus, there are many justifications for the separate treatment of urine, but realistically, it will only be implemented on a large scale if the investment and operational costs are low and if the treatment technologies are reliable and easy to operate.

2.6. Effects of Nutrients on Streams and Rivers

As nutrients cycle through the soil-plant-atmosphere continuum, some are recovered by plant uptake, some incorporated into the soil organic matter (SOM), and some precipitated as solid

minerals(John *et al*., 2014).The remainder can be transported to surface water, groundwater, and the atmosphere.

Plant nutrients have different impacts on water quality both on surface and ground water sources. Fertilization of surface water or eutrophication is the common problem. It is the enrichment of surface water with plant nutrients. Agriculture is the main source for eutrophication of surface water. On the other hand, ground water is polluted by nitrates. Nutrients, mainly high level of N and P cause low level of dissolved oxygen in the water.

Phosphorus and nitrogen enhance the growth of algal blooms in the water bodies (rivers, lakes and seas), which reduce light penetration and available oxygen in the water bodies, reduced growth of submerged aquatic vegetation and benthic organisms. This phenomenon is known as eutrophication(Rahman *et al*., 2014a). Eutrophication impairs the physicochemical properties of water, creating turbidity and unpleasant odor and taste, decreasing the dissolved oxygen and increasing its pH, which results in the precipitation of calcium carbonate and magnesium hydroxide. Eutrophic water bodies contain dead zones. Water from such water bodies may cause outbreaks of diarrheal diseases or poisoning of cattle and poultry(Frumin, 2015).

Therefore, it is obligatory to remove nitrogen and phosphorus from wastewaters before discharging it into the water bodies to create healthy, pollution-free environment.

2.7. Potential application of biochar

Biochar is a carbon-rich, fine-grained residue which can be produced either by ancient techniques (such as covering burning biomass with soil and allowing it to smoulder) or state-of-the-art modern biomass pyrolysis processes. Biochar has many environmental benefits, such as carbon sequestration, global warming mitigation, soil amelioration and contaminant removal(Xie *et al*., 2015). Various kinds of biomass, including agricultural wastes(Zhang et al., 2019), forestry residues(Kizito *et al*., 2015)(; Wang *et al*., 2015) and sewage sludge(Zhang and Wang, 2016), can be employed as feedstock for preparing biochar via pyrolysis. These sources make biochar a low-cost material compared with activated carbon depending on complicated activation treatments(Tarpeh *et al*., 2017, Liu *et al*., 2015)

2.7.1. Biochar as soil conditioner

In certain poor soils (mainly in the tropics), positive effects on soil fertility were seen when applying untreated biochar. These include the higher capacity of the soil to store water, aeration of the soil and the release of nutrients through raising the soil's pH-value(Glazunova *et al*., 2018). In temperate climates, soils tend to have humus content of over 1.5%, meaning that such effects only play a secondary role.

Indeed, fresh biochar may adsorb nutrients in the soil, causing at least in the short and medium term a negative effect on plant growth. These are the reasons why in temperate climates biochar should only be used when first loaded with nutrients and when the char surfaces have been activated through microbial oxidation(Kizito et al., 2019).

The best method of loading nutrients is to co-compost the char. This involves adding 10–30% biochar (by volume) to the biomass to be composted. Co-composting improves both the biochar and the compost. The resulting compost can be used as a highly efficient substitute for peat in potting soil, greenhouses, nurseries and other special cultures.

Because biochar serves as a carrier for plant nutrients, it can produce organic carbon-based fertilizers by mixing biochar with such organic waste as wool, molasses, ash, slurry and pomace(Schmidt, 2014). These are at least as efficient as conventional fertilizers, and have the advantage of not having the well-known adverse effects on the ecosystem. Such fertilizers prevent the leaching of nutrients, a negative aspect of conventional fertilizers. The nutrients are available as and when the plants need them. Through the stimulation of microbial symbiosis, the plant takes up the nutrients stored in the porous carbon structure and on its surfaces.

A range of organic chemicals are produced during pyrolysis. Some of these remain stuck to the pores and surfaces of the biochar and may have a role in stimulating a plant's internal immune system, thereby increasing its resistance to pathogens(Usmani, 2019). The effect on plant defense mechanisms was mainly observed when using low temperature biochars (pyrolyzed at 350° to 450°C)(Glaser and Lehr, 2019). This potential use is, however, only just now being developed and still requires a lot of research effort.

2.7.2. Biochar as construction material

The two interesting properties of biochar are its extremely low thermal conductivity and its ability to absorb water up to 6 times its weight. These properties mean that biochar is just the right material for insulating buildings and regulating humidity(Yang *et al*., 2019).In combination with clay, but also with lime and cement mortar, biochar can be added to clay at a ratio of up to 50% and replace sand in lime and cement mortars. This creates indoor plasters with excellent insulation and breathing properties, able to maintain humidity levels in a room at 45–70% in both summer and winter(Gupta and Kua, 2017).. This in turn prevents not just dry air, which can lead to respiratory disorders and allergies, but also dampness and air condensing on the walls, which can lead to mould developing.

Biochar is an efficient adsorber of electromagnetic radiation, meaning that biochar-mud plaster can prevent "electro smog"(Ruamsook and Thomchick, 2014). Biochar can also be applied to the outside walls of a building by jet-spray technique mixing it with lime. Applied at thicknesses of up to 20 cm, it is a substitute for Styrofoam insulation. Houses insulated this way become carbon sinks, while at the same time having a more healthy indoor climate(Usmani, 2019). After demolition, the biochar-mud or biochar-lime plaster can be recycled as a valuable compost additive.

2.7.3. Potential of biochar in wastewater treatment

Biochar has so far mainly been promoted as a soil amendment, but as a good adsorbent, it may also hold promise in low cost wastewater treatment. Activated carbon is already being used, but biochars may form a lower cost alternative. Several authors have found that biochar can remove various heavy metals, phosphorous, and nitrogen from solution (Kołodynska *et al*., 2012). Biochar could potentially be used to adsorb nutrients from wastewater, and then the loaded biochar or mixture of sludge and biochar could be added to soil. Digestate from anaerobic digestion of sewage sludge, manure and residues from the food/beverage or agricultural industry usually contains high levels of nutrients which makes it suitable for utilization as an organic soil fertilizer(Wheatley *et al*., 2008). Using biochar to extract and concentrate the nutrients could eliminate current difficulties associated with the storage of high

volumes of the digestate and other waste liquids, and also eliminate environmental concerns relating to spreading the high volumes of liquid fertilizer on soil. In some wastewaters, adsorption of heavy metals and other harmful substances in addition to nutrient could be a problem, but in the case of farm waste or residues from the food beverage industry it should be safe.

2.7.4. Biochar for nutrient removal

Nutrient removal using biochar has been focused on recently. Compared with activated carbon and zeolite, nutrient-enriched biochar can be directly applied in soil without regeneration because of its advantages of soil amelioration and low-cost production. Furthermore, this will also benefit biomass waste treatment, especially in developing countries where the uncontrolled burning of biomass waste poses air pollution and fire risks(Qiu *et al*., 2016). Therefore, biochar may be an attractive adsorbent for nutrient removal while yielding nutrient enriched material (NBC) fertilizer.

Ammonium in source-separated urine could be effectively removed via surface adsorption yielding N-enriched biochar(Tarpeh *et al*., 2017). However, most biochars rarely adsorb phosphate because their surfaces are commonly negatively charged(Vassileva *et al*., 2009, Hale *et al*., 2013). Surface modification by metal oxides can dramatically improve the adsorption capability of biochar for phosphate(Park *et al*., 2015).

2.8. Adsorption

Adsorption is recognized as an effective and economic method of pollutant removal from wastewaters. The process is characterized by the concentration of molecules on the surface of a sorbent(Owlad *et al.*, 2009). Adsorption offers significant advantages like low cost, high availability, profitability, flexibility in design and operation, and the reversibility of the process(Fu and Wang, 2011), which is very important especially from economic and environmental points of view.

Adsorption is the process by which a solid holds molecules of a gas or liquid or solute as a thin film. It is the accumulation or enrichment of chemical substances onto a surface. The

adsorbing phase is defined as the adsorbent, and the material being adsorbed the adsorbate. The adsorbent is required to have an extremely large surface area on which the adhesion of contaminants can occur. It can occur between two phases, such as: gas-liquid, gas-solid, liquid-liquid, or liquid-solid interface. In the field of water treatment, adsorption has been proven as an efficient removal process for numerous types of pollutants, where ions or molecules are removed from liquids by adsorption onto solid surfaces(Worch, 2012)

Solid surfaces are active and energetic sites, which are able to interact with solutes due to their specific electronic and spatial properties. Since adsorption is a surface-based process, the surface area plays an important role in determining adsorbents' quality.

2.8.1. Adsorption mechanisms

Four main steps of the process can be summarized as follows(Sotelo *et al*., 2013):

a) Solute is transferred from the liquid to adsorbent's boundary layer.

b) External diffusion occurs, whereby the solute is transferred to the surface of the adsorbent through the boundary layer.

c) The solute is diffused from the surface to active sites, termed intra-particle diffusion.

d) Sorption of the adsorbate to the solid phase, by several forces described below.

In most cases, two primary driving forces lead to the adsorption of a solute from an aqueous. The first driving force is linked with the solvent disliking (lyphobic) character of the solute. A hydrophobic substance tends to be adsorbed while a hydrophilic sub-stance tends to stay in the water. The solubility of a dissolved substance is essential in determining the intensity of adsorption process. The second driving force is the electrical attraction of the solute to the solid. This type occurs as a result of chemical interaction or van der Waals attraction with the adsorbent. The adsorption induced by van der Waals force is defined as physisorption, and the other type of adsorption is termed as chemisorption. In adsorption processes, these two types interact together and it is quite difficult to differentiate them(Cecen and Aktas, 2011, Worch, 2012).

Chemisorption

In chemisorption, electrons in specific surface sites and solute molecules are ex-changed, resulting in the formation of a strong chemical bond. Chemically adsorbed adsorbates are immobilized within the surface or on the surface. Since chemical reactions happen more rapidly at higher temperatures, chemisorption is more predominant at high temperatures compared to physical adsorption. It also has high adsorption en-thalpy (40-800 kJ/mol) (Cecen and Aktas, 2012).

Physisorption

In physisorption, intermolecular attractions occur between favorable energy sites. The adsorbate is attached to the surface by weak van der Waals forces in physisorption; hence it is less strongly attached to the surface compared to chemisorption. There is not any exchange of electrons in this process. In contrary to chemisorption, physical adsorption is predominant at temperatures below 150^{o}C and its adsorption enthalpy is low (5-40 kJ/mol) (Cecen and Aktas, 2012).

2.8.2. Factors affecting adsorption process

Adsorption is not a homogeneous process and a variety of factors affect its efficiency. Besides physical properties of the adsorbent, wastewater's properties also have significant influences on the overall removal efficiency. The most important characteristics of the feed solution and the adsorbents are reviewed below.

pH

The effect of pH on the adsorption of nitrogen and phosphorus onto different adsorbents has been investigated in many studies. Coir-pith carbon activated chemically by H_2SO_4 achieved the highest adsorption of phosphorus in the pH range of 6-10(Kumar *et al*., 2010b).(Krishnan and Haridas, 2008) observed that phosphorous was effectively removed from wastewater by natural coir pith in the pH range of 2.0 - 3.5. In another study(Benyoucef and Amrani, 2011)reported the effective pH range for phosphate uptake by Aleppo pine sawdust to be 3.5-7.5. Varying results on the influence of pH on the adsorption process indicate its complex

nature. However, most results infer that the optimum pH is slightly acidic to around neutral (4-7) for the majority of sorbents.

Adsorbent Dosage

All scientific studies indicated that phosphorus adsorption increased with increasing adsorbent dose up to a specific level, and then it remained constant. One simple explanation for this is that by adding more adsorbent to the solution, more binding sites are available for the sorption process. Thus, high amounts of phosphate ions can be adsorbed.

Temperature

Adsorption is affected by the relations between the properties of the adsorbent and the solute. As a result, the effects of temperature are different for different adsorbents and solutes. Mezenner and Bensmaili (2009) showed that the adsorption capacity of iron hydroxide eggshell increased as the solution was heated from 20 to 45^{o}C. (Saha *et al*., 2010) found that at pH 3, the maximum amount of nutrient adsorbed per gram of added granular ferric hydroxide occurred at 45^{o}C. Conversely, it is important to note that higher temperature is not always beneficial for the process. In a study conducted by (Yue *et al*., 2010), there was a decrease in the sorption capacity of modified giant reed as the temperature increased from 30^{o}C to 60^{o}C.

Contact Time

The design and economics of any adsorption system are heavily influenced by the process. The required contact time varies between different adsorbents and contaminants. Generally, the adsorption of phosphorus and nitrogen by most adsorbents reached equilibrium in less than 1 hour. The adsorption of phosphorus by modified giant reed reached equilibrium after 25 minutes (Yue *et al*., 2010). (Benyoucef and Amrani, 2011)observed the process reached equilibrium after 40 minutes when using modified Aleppo pine. On the other hand, several studies reported slower uptake speed. 3 h was necessary for the removal process by coir pith activated carbon to reach equilibrium (Kumar *et al*., 2010b).

Interfering Ions

Since wastewater contains various anions, which may interfere in the process, many researchers have studied their potential effects on the adsorption efficiency. Divya et al. (2012) stated that the presence of anions like Cl_2, SO_4^{2-}, $NO_3^-$and CO_3^{2-} did not show any significant influence on phosphate adsorption, whilst some cations such as Ca^{2+}, Mg^{2+}, Cu^{2+}, Fe^{2+} and Zn^{2+} facilitate the process. These findings coincide with those reported by (Chen *et al*., 2014). They concluded that anions of Cl^-, NO_3^-, and SO_4^{2-} had a negligible effect on phosphorus adsorption by natural pyrite. Then again, a study conducted by (Zhang *et al*., 2012)showed that SO_4^{2-} and CO_3^{2-} had a negative influence on the phosphate uptake of lanthanum-doped activated carbon fiber. These results demonstrated the complex nature of adsorption process, especially when competing ions are involved.

2.8.3. Adsorption isotherm models

Adsorption isotherm is a model that defines a relationship between the equilibrium amount of adsorbed adsorbate and the remained adsorbate in solution(Karri *et al*., 2017). Generally, the required data for identifying the adsorption isotherm could be obtained by performing static adsorption which is performed in a batch system. Typically, the solution containing adsorbate with the desired concentration is added to the known amount of adsorbent. After retaining sufficient time to reach equilibrium, the concentration of adsorbate could be correlated to the amount of adsorbed adsorbate molecules. Hence, the equilibrium adsorbed amount could be drawn versus the equilibrium concentration. In this step, the adsorption phenomenon governing the system could be well described using appropriate isotherm model(Barzamini et al., 2014).

Adsorption isotherm study was carried out on four isotherm models, namely the Langmuir, Freundlich, Temkin and Dubinin-Radushkevich isotherm models.

Langmuir isotherm model

The Langmuir isotherm model is based on the assumption that there is a finite number of active sites which are homogeneously distributed over the surface of the adsorbent These

active sites have the same affinity for adsorption of a mono molecular layer and there is no interaction between adsorbed molecules.

Based upon these assumptions, Langmuir represented the following equation:

$$qe = \frac{\text{Qo} * \text{KL} * Ce}{(1 + KL * Ce)}$$

Langmuir adsorption parameters were determined by transforming the Langmuir equation into linear form

$$\frac{1}{qe} = \frac{1}{Qo} + \frac{1}{QoK\text{l}Ce}$$

Where: C_e = the equilibrium concentration of adsorbate (mg/L-1)

q_e = the amount of metal adsorbed per gram of the adsorbent at equilibrium (mg/g).

Q_o = maximum monolayer coverage capacity (mg/g)

K_L = Langmuir isotherm constant (L/mg)

Limitations of Langmuir Adsorption Equation

The limitations of Langmuir include:

- The adsorbed gas has to behave ideally in the vapor phase. This condition can be fulfilled at low pressure conditions only. Thus Langmuir Equation is valid under low pressure only.
- Langmuir Equation assumes that adsorption is monolayer. But, monolayer formation is possible only under low pressure condition. Under high pressure condition the assumption breaks down as gas molecules attract more and more molecules towards each other.

- Another assumption was that all the sites on the solid surface are equal in size and shape and have equal affinity for adsorbate molecules i.e. the surface of solid if homogeneous. But we all know that in real solid surfaces are heterogeneous.
- Langmuir Equation assumed that molecules do not interact with each other. This is impossible as weak force of attraction exists even between molecules of same type.
- The adsorbed molecules has to be localized i.e. decrease in randomness is zero (ΔS = 0).This is not possible because on adsorption liquefaction of gases taking place, which results into decrease in randomness but the value is not zero.

Freundlich isotherm model

This is commonly used to describe the adsorption characteristics for the heterogeneous surface. This model assumes that as the adsorbate concentration increases, the concentration of adsorbate on the adsorbent surface also increases and, correspondingly, the sorption energy exponentially decreases on completion of the sorption centers of the adsorbent.

$$Qe = KfCe^{\frac{1}{n}}$$

Where *K*f = Freundlich isotherm constant (mg/g)

n = adsorption intensity

Ce = the equilibrium concentration of adsorbate (mg/L)

Qe = the amount of metal adsorbed per gram of the adsorbent at equilibrium (mg/g).

The Linearized equation of Freundlich is:

$$logQe = logKf + \frac{1}{n} * logCe$$

The constant K*f* is an approximate indicator of adsorption capacity, while 1/n is a function of the strength of adsorption in the adsorption process. If value of 1/n is below one it indicates a normal adsorption. On the other hand, 1/n being above one indicates cooperative adsorption. K*f* and *n* are parameters characteristic of the sorbent-sorbate system, which must be

determined by data fitting and whereas linear regression is generally used to determine the parameters of kinetic and isotherm models.

3. Materials and Method

3.1. Collection and Characterization of Urine Sample

Urines were collected from voluntary males. The samples were collected using polypropylene containers in order to avoid rusting and leakage of the urine. Following the collection of urine, samples were transported to AAiT wastewater laboratory and stored for 15days, 1 month and 2 months at 20^{o}C to inhibit NH_3 volatilization. After the storage time ended the urine analyzed for pH, initial nitrogen and initial phosphorous.

The initial pHs of urine samples were measured using HANNA pH meter (HI-8100). After adjusting the pH meter 150ml of urine sample was measured and transferred into the beaker then the pH value was measured and recorded. The urines sample were filtered using Whatman filter paper with pore size of 125mm to remove fine particles from the sample. Measurement of nitrogen (NH_4^+-N) and phosphorous (PO_4^{3-}-p) were analyzed following standard methods by using palintest photometer 7100(UK). All the analysis were done triplicate and results are presented as an average.

3.2. Biochar Preparation

The biochars used in this study were produced from three organic wastes: corn cob (CC), water hyacinth (WH) and coffee husk (CH). WH was collected from Lake Tana, Bahir Dar. CC and CH were collected from a farmland in Shone, Hadiya Zone.



a b c

Figure 3-1materials used for biochar production (a) corn cob (b) water hyacinth (c) coffee husk

All biochar producing materials were first air dried and cut into small pieces, and then grinded and passed through a 0.5mm sieve. The powder were inserted into aluminum vessel then converted into biochar throw slow pyrolysis in a muffle furnace under an anoxic condition at 450^{o}C for 1.5 hours with a heating rate of 5^{o}C min^{-1}(Pituya et al., 2017). Biochar was allowed to cool to ambient temperature inside the furnace following the experiment. After the cooling stage, biochar samples were washed 3 times by shaking with distilled (deionized) water and decanting the water. Washed biochar was dried in an oven at 100^{o}C for 3 hours and stored under desiccation at room temperature until use.

3.3. Biochar Characterization

Biochar pH values were obtained using a ratio of 1.0 g of biochar in 20 ml deionized water with shaking for 1.5 h, using a shaker to ensure sufficient equilibration between solution and biochar surfaces as used by (Rajkovich et al., 2012). The elemental composition of C, H, and N were performed using a CHN analyzer (EA 1112 Flash CHNS/O- analyzer) under Carrier gas flow rate of 120 ml/min, reference flow rate 100 ml/min, oxygen flow rate 250 ml/min; furnace temperature of 900 °C and oven temperature of 75 °C. Sample was run in triplicate and the average values were taken.

The morphological properties of biochars were analyzed by Scanning Electron Microscopic (SEM) imaging. A range of SEM images (Magnification: 500× to 2000×) were captured with a JEOL JSM-6490 operating at 20KV at Ethiopian Leather Institute, Addis Ababa. Image analysis was done with ImageJ version 2.0 with appropriate threshold and size range values.

3.4. Experimental Procedures

Investigation run was conducted from January to June 2019. For each run different experimental parameters were done including pH, biochar dosage, and contact time. When one parameter is optimized the rest kept constant. All experiments were done at room temperature (20-250^{o}C) by using distilled water.

To adjust the required pHs commercial grade of NaOH and HCl were prepared. Sodium hydroxide (NaOH feed) with concentration of 2M and 0.5M of HCl were used to achieved the

reaction pH to the desired value or required range as practiced by other scholars due to its more effectiveness (Pastor et al., 2008, Fattah et al., 2008) . The pH values were adjusted to3, 4, 5, 6, 7, and 8. After fixing optimal pH the experiments were carried out by varying adsorbent dosage (0.2g, 0.4g, 0.6g and 1g). Contact time of 30min, 60 min, 90 min, 120 min, and 150min were optimized. The mixture was then shaken in a mechanical shaker at 200rpm to achieve equilibrium. The supernatants were filtered and analyzed for concentrations of $NH4^{+}$-N and PO_4^{3-}-P by using palintest photometer.

3.5. Effect of Storage Time for Adsorption Equilibrium

The urine samples were collected at once and divided into three jars to store for different period. Finally, three samples were obtained (15 days, 1 month and 2 month). For each samples the amount of Nitrogen in the form of NH_4^{+}-N and phosphorus in the form of $PO4^{3-}$ -P were measured. Then, parameters (pH, biochar dosage and contact time) were optimized for stored urine to examine the effect of storing urine on the recovery of $NH4^{+}$-N and PO_4^{3-} -P and select the optimal storage time.

After the optimum pH, biochar dosage, contact time and storage time were found, the experiments were done using the optimum values to obtain the best biochar sample.

3.6. Adsorption Isotherm

Langmuir and Freundlich adsorption models were used to fit the nutrient adsorption isotherm data:

The Langmuir model:

$$qe = \frac{qmax * Kl * Ce}{1 + Kl * Ce}$$

The Freundlich model:

$$qe = Kf * Ce^{\frac{1}{n}}$$

Where, Ce is the equilibrium concentration (mg/l)

qe is the amount of nutrients adsorbed at equilibrium(mg/g)

q_{max} is the maximum adsorption capacity of the solute(mg/g)

K_L is adsorption coefficients of Langmuir isotherm model (L/mg)

K_F is adsorption coefficients of Freundlich isotherm model (mg/g)

n is the Freundlich linearity constant related to the surface site heterogeneity.

The essential characteristic separation constant factor, R_L, for the Langmuir isotherm was defined as:

$$Rl = \frac{1}{1 + Kl * Co}$$

The value of R_L illustrate the shape of the isotherm to be either unfavorable (R_L>1), linear (R_L=1), favorable (0< R_L<1) or irreversible (R_L=0).

3.7. Sampling and Analyses

The analyses of selected chemical characteristics (pH, N and P) of influent samples were done at AAiT wastewater laboratory. Effluent samples were collected subsequently, centrifuged and filtered for chemical analysis. Influent samples for N and P analysis were collected from the storage tanks, whereas the effluent samples were collected from the centrifuge tubes. All samples were filtered using whatman filter papers with a pore size of 125mm to remove fines from the sample. The constituents of orthophosphate-phosphorus (PO_4^{3-}-P) and ammonium-nitrogen (NH_4^+-N) were analyzed following standard methods. NH_4^+-N and PO_4^{3-}-P were analyzed using UV-Visible spectrophotometer. All the analyses were done in triplicate and the results are presented as an average.

The efficiency of reduction for the various parameters were calculated using

$$E = \left(\frac{C\ in - C\ out}{C\ in}\right) * 100$$

Where

E- The efficiency (percent),

C_{in}- influent concentration (mg/l).

C_{out}- effluent concentration (mg/l).

3.8. Quality Control and Assurance

All chemicals and reagents used in the laboratory test procedures were of analytical grade and standard approved make. The glassware, containers and bottles used for the sampling and analysis were initially cleaned with tap water followed by nitric acid before rinsing with distilled water. Standard solutions and necessary reagents were prepared on a regular basis to achieve the best possible results. "Blank control" tests were conducted whenever necessary in order to determine the background concentrations during the sample analysis. Approximately 20l of urine samples were collected with polypropylene jar from healthy male volunteers for 3 days. The urine in the storage tank was closed well and not mixed with anything before sampling. The urine samples were stored for 15days, 1 month and 2 month at AAiT wastewater laboratory. The biochars were air dried and washed with distilled water. Samples were vigorously shaken to obtain homogeneous quality before they were pipetted out for any test analysis. Instrumental calibrations were performed on a regular basis. All experimental development, calibrations, standard preparations, experimental methods, data generation, and documentation of activities were conducted on the guidelines of APHA.

4. Result and Discussion

4.1. Biochar Characterization

4.1.1. Chemical characteristics of biochar

The elemental composition of each biochar sample is shown in Table 4-2. It mainly consists of carbon(C). The weight percentages of C in the biochar sample of CC, CH and WH were 74.08%, 65.625%, and 51.56%, respectively. The calculated molar ratio indicates that the biochar sample of CC has high C content.

Table 4-1 elemental composition of biochar samples

Raw material	Temperature(^{o}C)	pH	Elemental composition (%)			
			C	H	N	S
Corn Cob	450	9.5	74.079	2.731	-	-
Coffee Husk	450	9	65.625	2.798	0.851	-
Water Hyacinth	450	6.3	51.559	1.853	2.885	-

According to the findings of (Gai *et al*., 2014), the biochar yield and contents of N, H and O decreased as pyrolysis temperature increases whereas contents of ash, pH and carbon increases with higher pyrolysis temperatures. This revealed negative relationships between C and H content and pyrolysis temperature(Shareef *et al.*, 2018).In general, high pyrolysis temperature leads to larger specific surface area and higher aromaticity of biochar(Ahmad *et al*., 2012). Biochars which are produced from 400 to 700^{o}C are well carbonized and their specific surface area are more than biochars which are produced at temperatures from 300 to 400^{o}C(Chun *et al*., 2004).From the literature of corn cob characterization, it was observed that carbon is the major element in the corn cob feedstock. The ultimate analysis of CC biochar produced at 450^{o}C was done to measure the elemental composition. A significant C content was seen in the biochar (i.e. 77.6%)(Intani *et al*., 2018). The results of this study are, therefore, in line with reported findings of similar scientific investigations.

The biochar sample of CH and WH had also with good carbon contents. (Li *et al*., 2016) demonstrates that the carbon content in WH biochar sample increased from 47.17% to 53.39%

and decreased to 51.34%, whereas oxygen, nitrogen, and hydrogen contents decreased at 300^{o}C, 500^{o}C, 700^{o}C, respectively. The result conducted by (Reigna *et al*., 2017), indicates that, coffee husk has 47.38% extractive content of C.

The biochar samples of CH and WH also contained other elements like hydrogen and nitrogen, but CC did have the element N. The corn cob feedstock had low percentage of sulfur and nitrogen, usually below 1.0 by weight. However, (Liu *et al.*, 2014a)reported 1.89 by weight of nitrogen for the corn cob feedstock. The low percentage of nitrogen and sulfur in the feedstock could contribute towards environmental protection as lower percentage of nitrogen oxide and sulfur oxide will be released during the pyrolysis process(Noor *et al*., 2012).

In general, the biochar characterization results are clear demonstrations of the considerable difference in the composition of biochar produced from different feed stocks even when they are pyrolyzed under the same temperature.

4.1.2. Physical characteristics of biochar

Biochars are typically comprised of abundant minerals and organic structures. The surface morphology of all the biochar materials is highly diverse in structural composition.

As Figure4-1 show the SEM image of the CC biochar indicated large and randomly distributed pore structure on the surface of the material and pores that appeared to be distributed all over the surface. Whereas, the SEM image of the CH and WH showed a solid structure with narrow occurrence of micropores. With these findings, it is clear that corn cob biochar had the highest pore volume. In contrast, water hyacinth biochar possessed the smallest pore distribution. This means that a biochar produced from CC would have better capacity to hold nutrients in macropores than the other biochar materials investigated in this study.

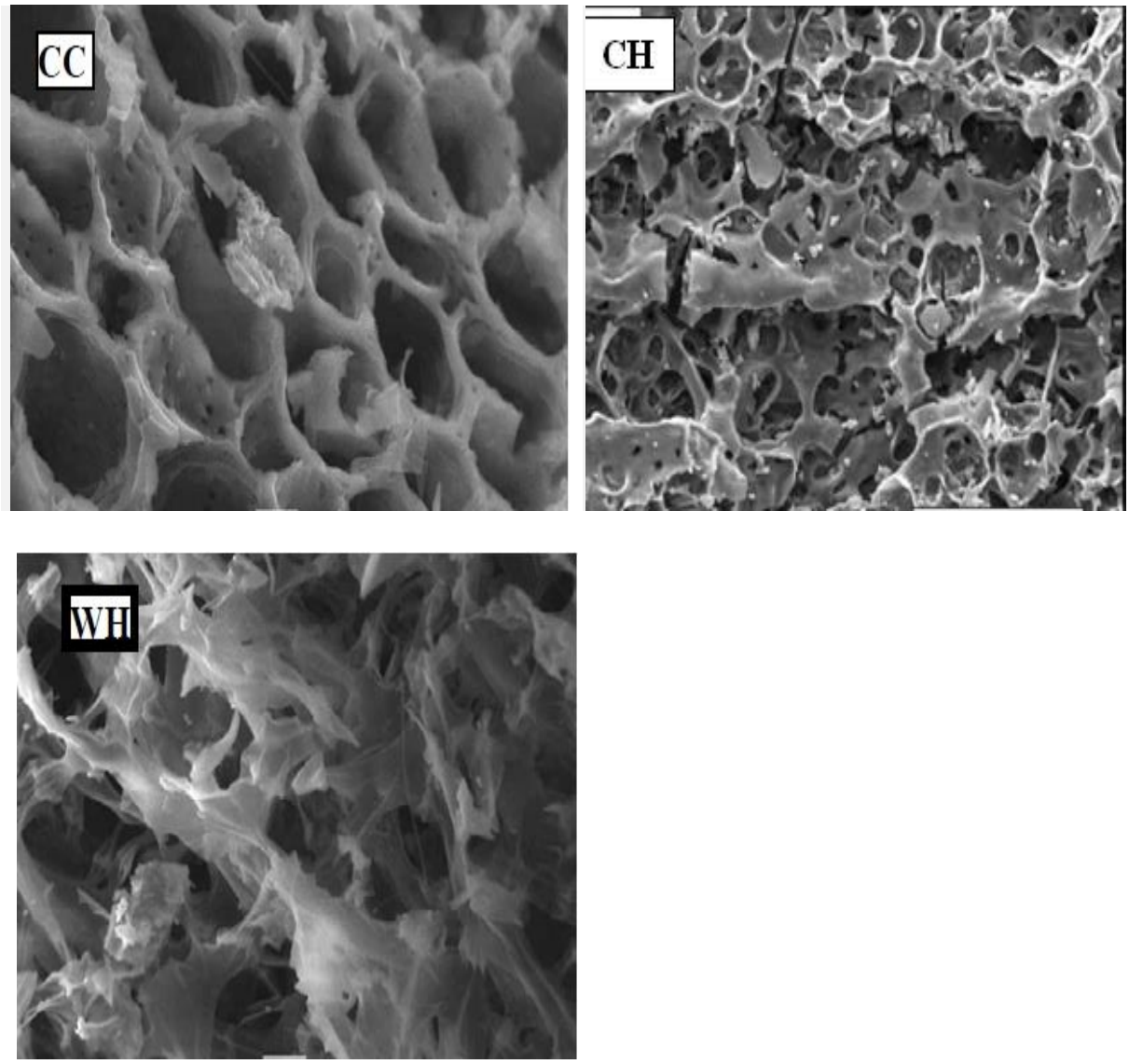


Figure 4-1 SEM images of CC, CH and WH before analysis

4.2. Investigation of N and P Recovery

4.2.1. Characteristics of Human Urine

The characteristic of urine for different storage periods is described in Table 4-1. Urine was collected in the months of December to January, 2019 from volunteers. Human urine contains most of the soluble nutrients with very high concentrations. Separation and direct use of urine as a fertilizer increases nutrient recovery, improves wastewater effluent quality, and decreases operational energy consumption, due to lower nutrient concentration in wastewater(Maurer et

al., 2003). The pHs of urines stored for 15, 30 and 60 days were 6.7, 7.3 and 8.23, respectively. The pH of fresh urine is normally between 4.8 and 7.5 but after collection it is around 9.0(Schonning, 2001). As (Neethling, 2015) explained, two months stored urine has a pH of approximately 8.9. When the storage time increases the pH will also increases. The pH value obtained in this study was in agreement with Neethling, 2015 and schonning, 2001.

Table 4-2characteristics of sample urine

Storage time(days)	15	30	60
pH	6.7	7.3	8.23
N(mg/l)	4760	6600	7800
P(mg/l)	884	943	1460

In this study, the initial ammonium and phosphate concentration were determined as 4760mg/l, 6600mg/l and 7800mg/l and 884mg/l, 943 mg/l and 1460mg/l for 15 days, one month and two months stored urine, respectively. (Ganesapillai et al., 2016), however, reported higher initial urea and phosphate concentrations of 18750 mg/l and 595 mg/l, respectively. In other study(Endalew, 2019) conducted using 1 month store urine the initial concentration of NH_4^+-N and PO_4^{3-}-P were estimated 4980mg/l and 765.1mg/l, respectively. The results in this study were near to the results of the authors mentioned above.

The effects of different parameters such as pH, biochar dosage, contact time and storage time of urine on the adsorption process were investigated. Removal and recovery of PO_4^{3-}-P was not as efficient in biochar material as in the activated biochar which was rich in terms of mineral and metal content. Therefore, optimal values were selected depending on the recovery efficiency of NH_4^+-N as they can efficiently remove ammonium from stored human urine(Perez-Mercado et al., 2018).

4.2.2. Effect of pH

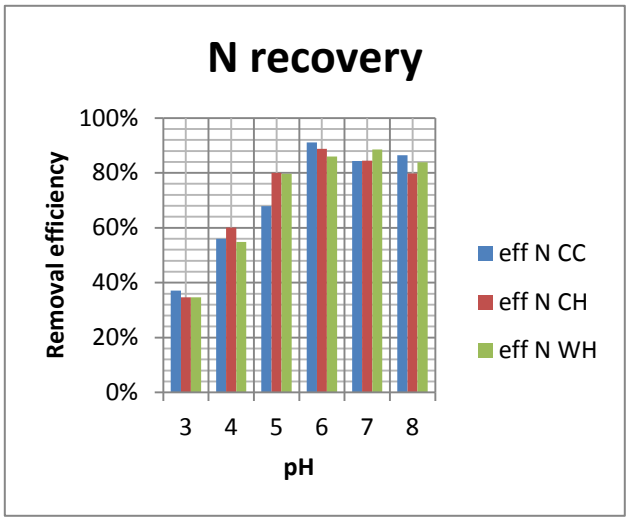
pH is one of the most important parameters affecting the adsorption process. In order to determine the effects of pH on NH_4^+-N and PO_4^{3-}-P recovery efficiencies, experiments were carried out using various pH levels in the range of 3.0–8.0. It appears that the biochar

adsorption capacity shows a remarkable increase with increasing pH from 3.0 to 6.0, and then the adsorption capacity decreases within the pH range of 6.0–8.0(Figure 4-2).

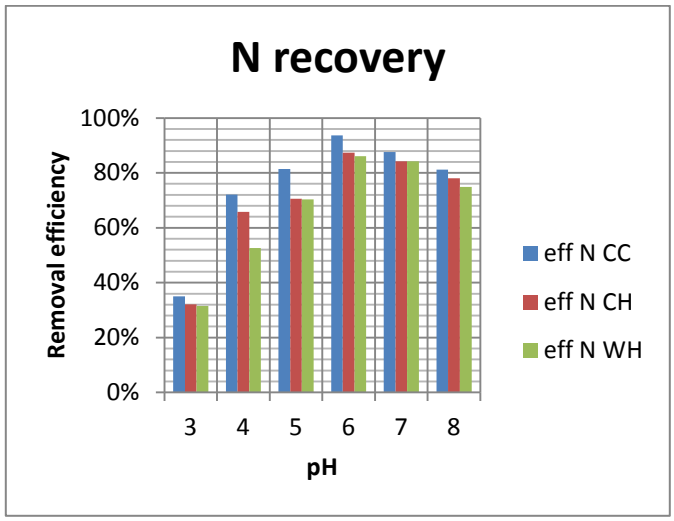
As the pH increases from 3 to 8 the concentration ofNH_4^+- N was reduced from4760mg/l to 42mg/l, 53mg/l and 66 mg/l, from 6600mg/l to 32mg/l, 53mg/l and 54mg/l for 1 month stored urine and from 7800mg/l to 16mg/l, 111mg/l and 150mg/l for 2 month stored urine within 3hrs reaction time. The highest percentage recovery efficiencies are 91.08%, 88.75% and 85.99% by using CC, CH and WH, respectively, from 15 days stored urine. 93.64% with CC, 87.42% with CH and 86.06% with WH of NH_4^+- N was recovered from 1 month stored urine. Around 93.33% with CC, 77.18% with CH and 74.6% with WH of NH_4^+- N was recovered from 2 month stored human urine.

The pH of biochar generally varies from neutral to alkaline, while acidic biochar has been also reported(Liu *et al*., 2014b, Qi *et al*., 2017). The pH of biochar increases with the increase of pyrolysis temperature, which resulted from the decomposition of bionic acid and the increase of mineral substance concentration (Ahmad *et al*., 2014). In a study which was conducted by (Zheng *et al*., 2012)on ammonia nitrogen absorption, using composite hydrogel, highest absorption capacity observed in pH 4-8 and concluded that an optimum NH_4^+-N removal efficiency obtained in neutral pH conditions.

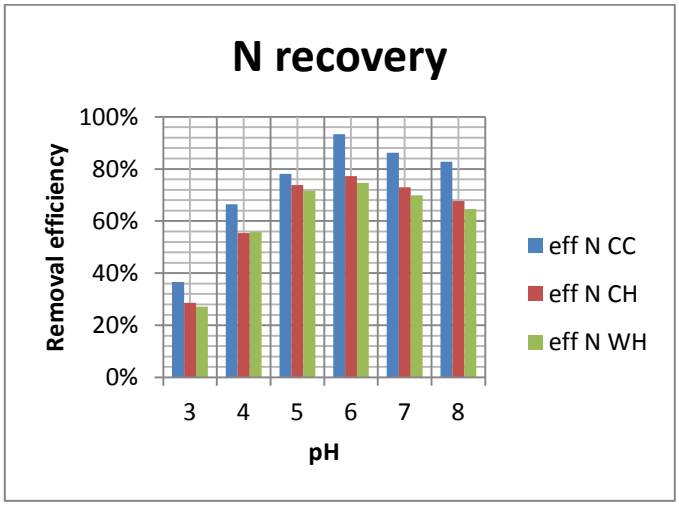
When pH is over 8, NH_4^+ was converted into NH_3 which will not be exchanged on the biochars(Huang et al., 2010). The same as PO_4^{3-}-P remove efficiency, at relatively high pH values, OH^- concentration increased and competed with PO_4^{3-}-P on the adsorbent, leading to a lower phosphorous adsorption rate. At higher pH values (such as initial pH 10.0), NH_4^+-N is neutralized by hydroxyl ion rendering it uncharged and the ion strength of NH_4^+-N solution is increased, resulting in a decrease in the recovery capacity(Karadag *et al*., 2007).



(a)



(b)



(c)

Figure 4-2 percentage recovery efficiency of N at different pH (a) 15 days (b) 1month (c) 2 months

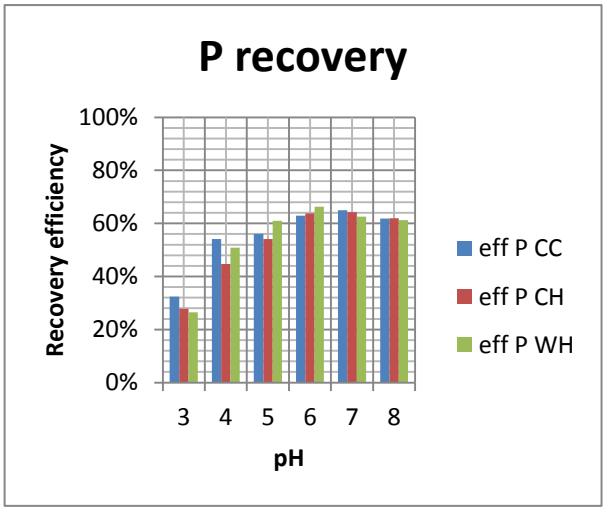
Similar to nitrogen recovery the concentration of PO_4^{3-} -P was reduced from 884 mg/l to 504mg/l, 514mg/l and 486mg/l for 15 days stored urine, 943mg/l to 321mg/l, 521mg/l and 539mg/l for 1 month stored urine, and from 1440mg/l to 267mg/l, 304mg/l and 353 mg/l for 2 month stored urine by using 0.2g of biochar produced from CC, CH and WH mixed with 50ml

urine, respectively, at PH 6 within 3hrs reaction time. (Xu *et al*., 2011)explored that modified biochar produced from cotton stalk re-moved phosphorus efficiently in the pH range of 4 - 9.

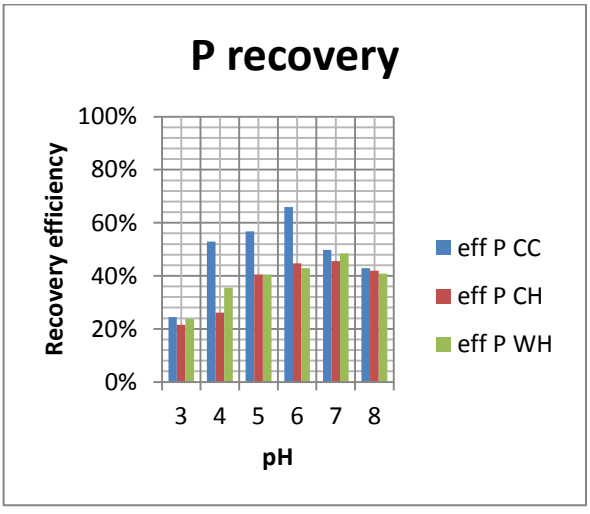
At pH 6, Figure 4-3 showed that 15 days stored urine WH got the highest percentage recovery efficiency of PO_4^{3-} -P 66.25%, and then followed by CH and CC. For one month and two month stored urine CC biochar sample was with the highest efficiency of 65.96% and 70.25%, respectively. CH biochar sample were at lowest recovery efficiency.

The effect of pH on the biosorption of phosphorus onto different adsorbents has been investigated in many studies. Coir-pith activated carbon achieved the highest adsorption of phosphorus in the pH range of 6-10(Kumar *et al*., 2010a). In another study, (Benyoucef and Amrani, 2011)reported the effective pH range for phosphate uptake by Aleppo pine sawdust biochar to be 3.5-7.5.

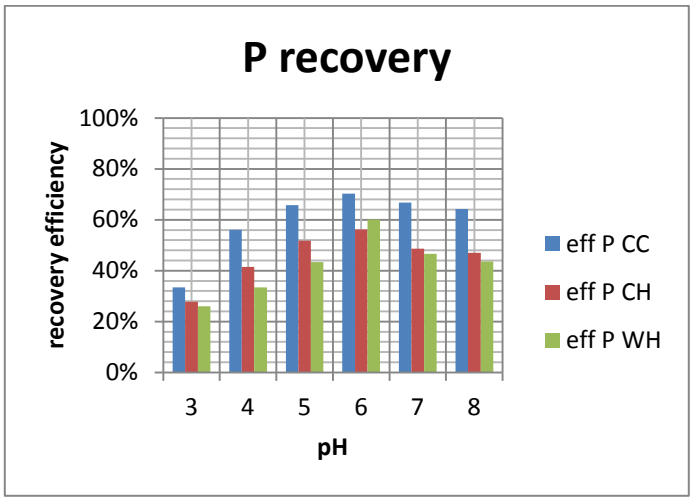
Unreliable results on the influence of pH on the adsorption process signify its complex nature. However, most results infer that the optimum pH is slightly acidic to around neutral (4 - 7) for the majority of sorbents. The results of this study were compatible with the studies referred in the discussion. This study got an Optimum pH at 6 and all other experiments were done at this pH.



(a)



(b)



(c)

Figure 4-3 Percentage recovery efficiency of P at different pH (a) 15 days (b) 1 month (c) 2 months

4.2.3. Effect of Biochar Dosage

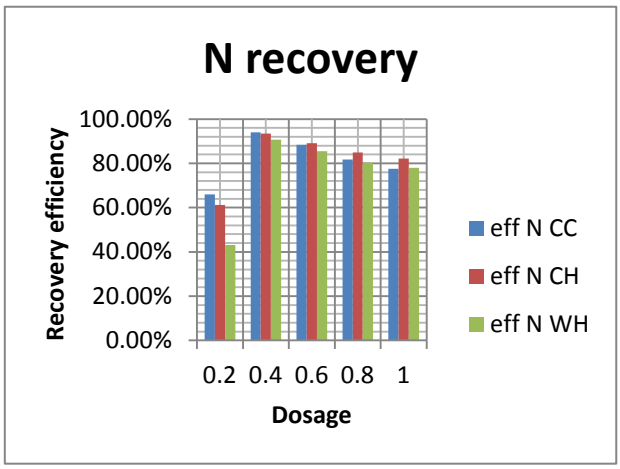
In order to investigate the influence of adsorbent dosage on adsorption of NH_4^+-N and PO_4^{3-}-P, series of experiment were undertaken for different biochar dosages (0.2 - 1 g). In parallel 15 different experiments were conducted by using 50ml of urine mixed with different biochar sample. In each experiment different weight of biochar dosage was added.

When adsorbent dosage increases N and P recovery first increases then decreases. As shown in Figure 4-4, the percentage recovery of NH_4^+- N for 15 day stored urine increases sharply from 66.03% to 94.06%, 61.15% to 93.42% and 43.10% to 90.66% with increasing dosage from 0.2 to 0.4g using biochars produced from CC, CH and WH, respectively. Beyond 0.4g, the percentage was not increased significantly and reached the maximum. For 1 month stored urine the recovery efficiency of biochars from CC, CH and WH increased from 69.09% to 95.15% with increasing dosage from 0.2 to 0.6g, 63.33% to 91.06% with increasing dosage from 0.2 to 0.8g and 53.03% to 86.06% with increasing dosage from 0.2 to 0.6g, respectively. With increasing dosage from 0.2g to 0.8g the recovery efficiency of NH_4^+- N from two month stored urine increases. Using biochar sample CC the efficiency increases from 71.03% to

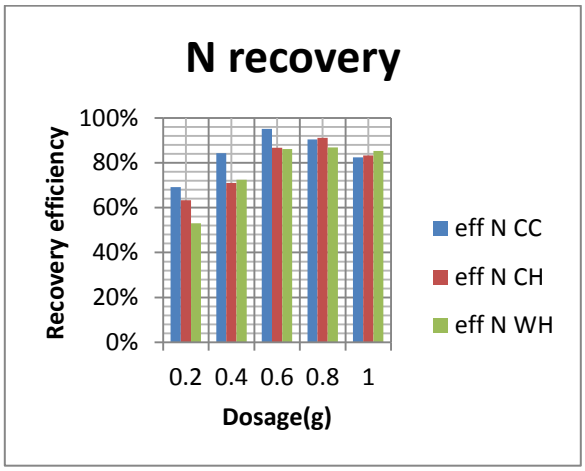
93.72%, using CH the efficiency increases from 69.87% to 88.59% and the efficiency increases from 64.36% to 85.77% using biochar produced from WH.

At lower adsorbent concentration number of active sites is higher. With the increase in adsorbent dosage aggregation of particles takes place, as result efficiency decreases(Padmavathy *et al.*, 2016). (Chen *et al.*, 2011)reported that increased biochar concentration decreases adsorption effectiveness, although the increase of adsorbent concentration may result in an increased total removal efficiency, due also to the increase of active site availability.

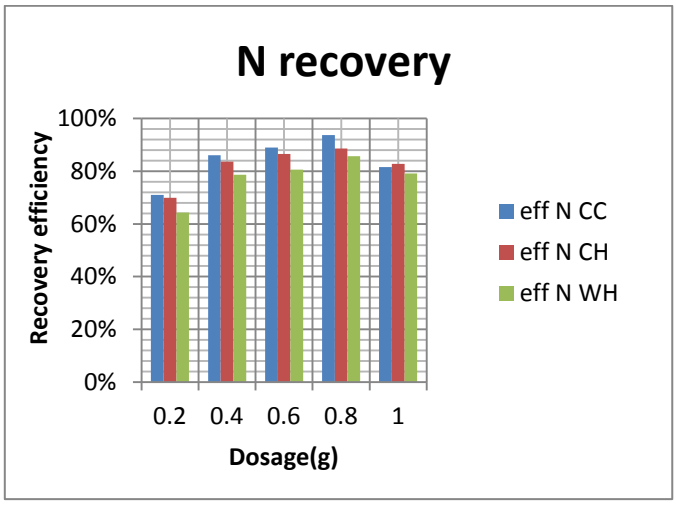
This phenomenon can be due to the greater availability of active sites or surface area making easier penetration of the NH_4^+- N ions to the adsorption sites of biochar, and increasing beyond dosage of 0.4 g, 0.6g and 0.8g of biochars into 15 days, 1 month and 2 month stored urine respectively, had no much effect after equilibrium is reached. These results are in agreement with other work reported in the literature.



(a)



(b)



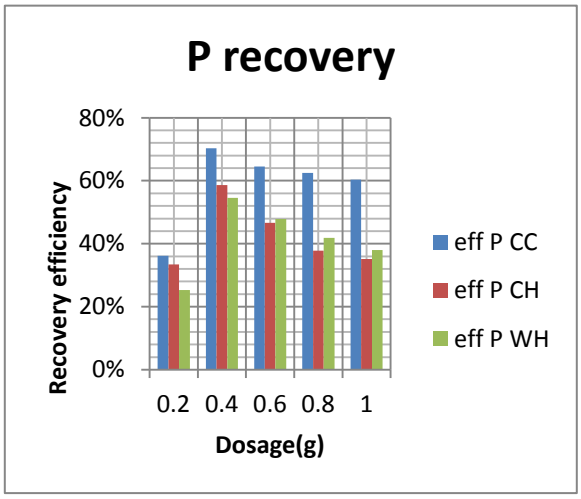
(c)

Figure 4-4 percentage recovery efficiency of N at different biochar dosage (a) 15 days (b) 1 month (c) 2 months

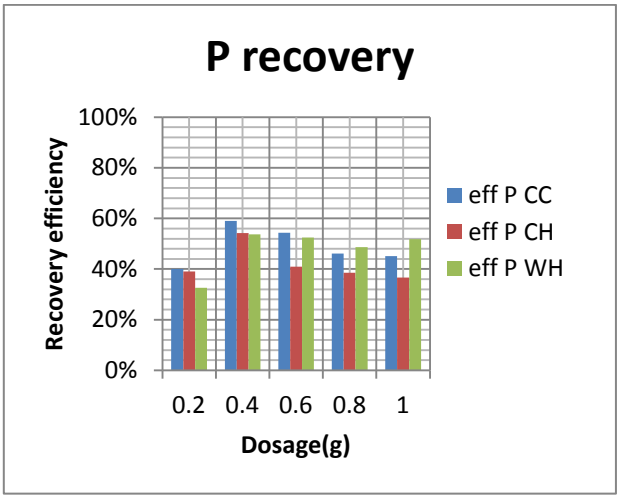
Figure 4-5(a) shows the percentage recovery of PO_4^{3-} -P for 15 days stored urine increases from 36.18% to 70.36%, 33.43% to 58.60% with increasing dosage from 0.2g to 0.4g and from 25.24% to 54.61% with increasing dosage from 0.2g to 0.6g then decreases to 37.43% with increasing dosage 0.4g to 0.8gusing biochars of CC, CH and WH, respectively. The efficiency increases with increasing dosage 0.2g to 0.6g from 40.08% to 59.07% using CC, 39.02% to 54.19% using CH and from 32.56% to 53.76% using WH for 1 month stored urine, Figure 4-5 (b). It was made known in Figure 4-5(c) for 2 month stored urine the recovery efficiency of biochars from CC, CH and WH increased from 57.47% to 77.15% with increasing dosage from 0.2 to 0.6g, 50.57% to 67.08% with increasing dosage from 0.2 to 0.8g and 42.53% to 57.13% with increasing dosage from 0.2 to 0.6g, respectively. The optimum biochar dosage was 0.4g, 0.6g and o.8g for 15 days, 1 month and 2 month stored urine, respectively. The next experiments are done with these values.

Most studies indicated that phosphorus adsorption increased with increasing adsorbent dose up to a specific level, and then it remained constant. Thus, high amounts of phosphate ions can be adsorbed by adding more adsorbent to the solution. In most studies, the range of adsorbent dosage is between 0.5 and 2 g/L for 250 ml wastewater(Kumar *et al*., 2010a). But the pH of

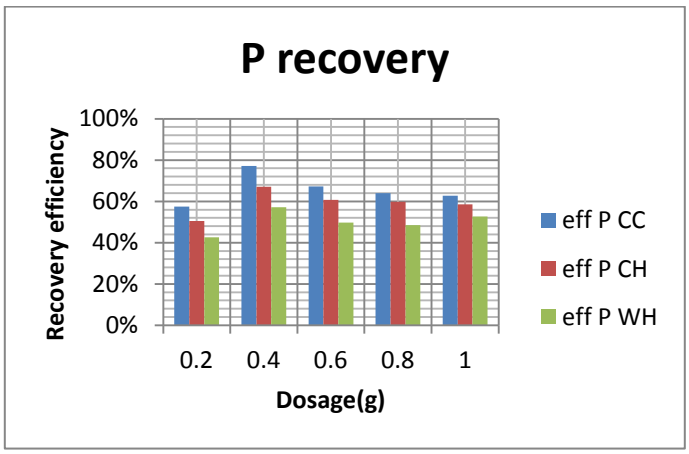
biochar also affects the dosage added for adsorption process. If the biochar sample is highly alkaline the best recovery efficiency is gained at low biochar dosage. Then the efficiency will decrease with the increase of dose of biochar. There exists an interaction between pH and biochar dose, increasing the pH led to a decrease in the response. At lower biochar dosage, the response was more sensitive to changes in the pH. It was clear that low pH was more beneficial at all studied levels of biochar dose(Nguyen, 2015).These results are in agreement with other work reported in the literature.



(a)



(b)



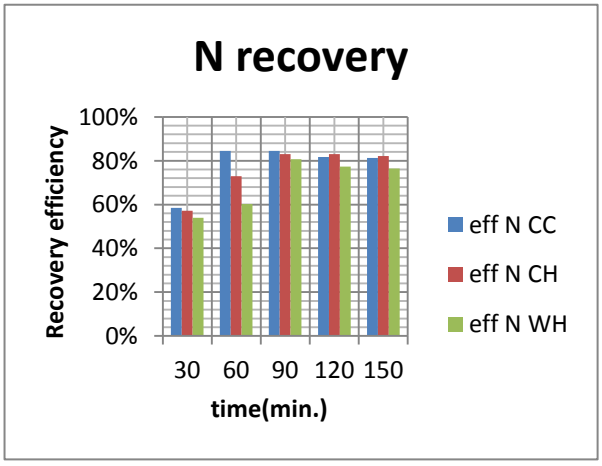
(c)

Figure 4-5 Percentage of recovery efficiency of P at different biochar dosage (a) 15 days (b) 1 month (c) 2 months

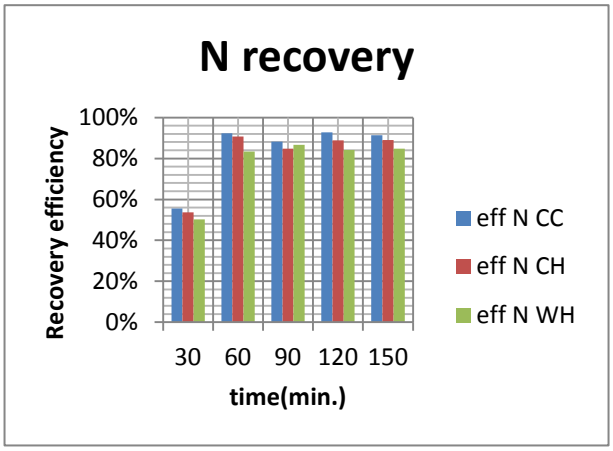
4.2.4. Effect of contact time

Figure 4-6 and 4-7, shows plot of nutrient recovery efficiency against contact time. The rate of NH_4^+- N recovery was found to be very rapid during the first 60 min and to remain nearly constant thereafter. The NH_4^+- N recovery efficiencies reached up to 84.45%, 82.98%, and 80.67% for 15 days stored urine, 92.34%, 90.69%, and 86.64% for 1month stored urine and 98.76%, 92.21%, and 86.46% for 2 month stored urine by using biochar samples from CC, CH and WH, respectively. As adsorption process time goes, any further increase in the contact time will has no effect on the sorption process. This indicates that the available surface for the sorption process has reached it maximum capacity within the first 60 minutes of contact time and no further enhancement in the percentage recovery could be achieved by increasing the contact time.

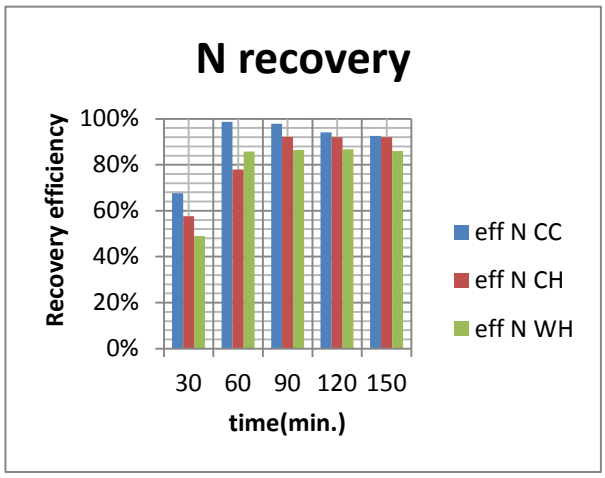
As (Zhao *et al*., 2017) explained adsorption of ammonium nitrogen by biochar was first increased, then gradually stabilized saturation with the increase of adsorption time. This may be due to the increase of the adsorption time and the adsorption of ammonia nitrogen by a single partition function into the distribution and surface adsorption. The removal efficiency of ammonium ions was initially fast, with up to 85% being achieved within the first 60min.The rate then slowed considerably with increased contact time and remained almost constant before reaching equilibrium(Kotoulas *et al*., 2019).



(a)



(b)



(c)

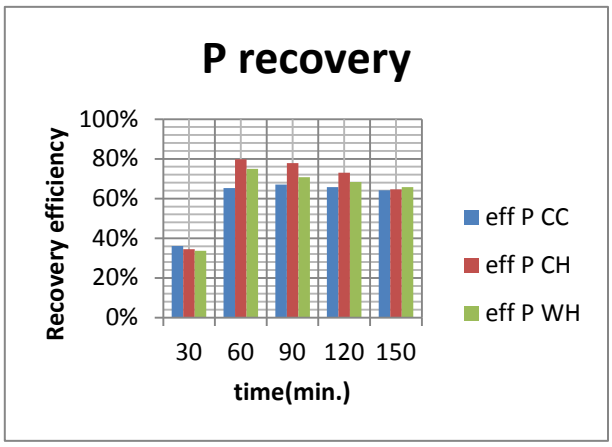
Figure 4-6 Percentage of recovery efficiency of N at different contact time (a) 15 days (b) 1 month (c) 2 months

The percentage recovery efficiencies of PO_4^{3-} -P increased up to 60-90 minutes of contact. With increasing of contact time from 30 to 60 minutes the efficiency increases from 36.03% to 65.34%, 34.52% to 79.86% and 33.63% to 75.00% by using CC, CH and WH, respectively, for 15 days stored urine. For one month stored urine the efficiencies were increase from 46.81% to 71.39%, 43.98% to 70.58% and 38.12% to 66.73% with increasing time from 30 min to 90 min. Similar to one month stored urine, the efficiencies for two month stored urine increase as the contact time increases from 30 to 90. The efficiencies increase from 53.96% to 82.32%, 45.73% to 71.14%, and 33.74% to 63.82% by using CC, CH and WH, respectively.

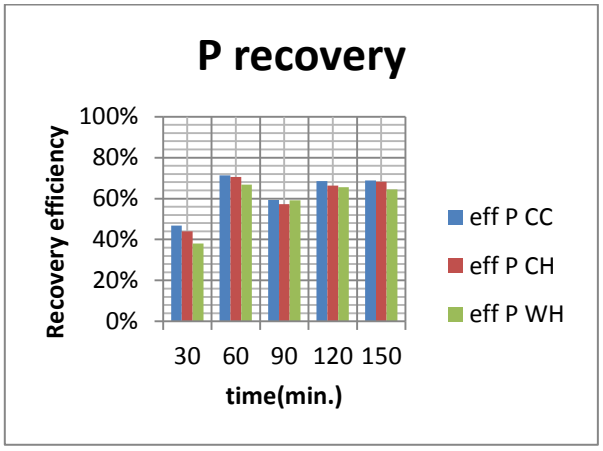
As time of adsorption is changed from 20 to 120 minutes, efficiency first decreased from 72 to 69% and further increased to 72 % and afterwards no change is observed. As time progresses the surface coverage of the adsorbent is high and further no adsorption take place(Padmavathy *et al.*, 2016). Different scientific researchers reported the adsorption of phosphorus by most adsorbents reached equilibrium in less than 1 hour. (Benyoucef and Amrani, 2011) observed the process reached equilibrium after 40 minutes when using modified Aleppo pine. Other study stated that 30 min was required in the case of using hydroxide-eggshell (Mezenner&Bensmaili, 2009). Also (Biswas *et al.*, 2007) explained that the phosphorous uptake by metal loaded orange waste only reached equilibrium after 15 hours. However,

different authors have concluded that processes occurring in less than one hour are more favorable and get more ready acceptance in the science community than those requiring longer contact times. The results are supported and in agreement with the authors mentioned above.

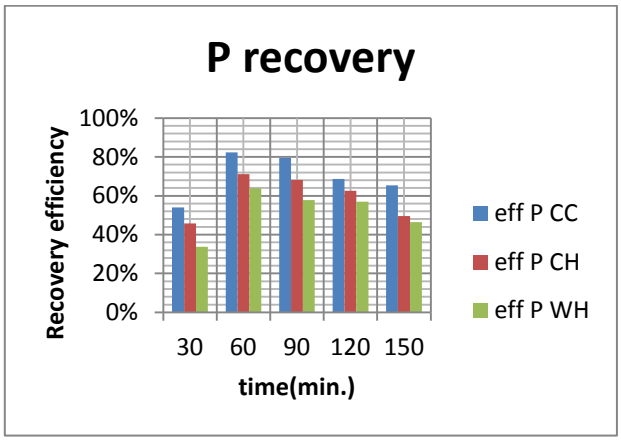
In this study, there are percentages of recovery efficiencies which are high at 90 min. But the difference between percentage of recovery efficiencies at 60min. and 90min. are not large. Therefore, contact time of 60 minute is selected as an optimum. All other experiments are done with this contact time.



(a)



(b)



(c)

Figure 4-7 Percentage of recovery efficiency of P at different contact time (a) 15 days (b) 1 month (c) 2 months

4.3. Effect of Storage Time

According (Xu et al., 2015) explained during transportation and storage, urea is hydrolyzed to ammonium and bicarbonate ions, leading to a significant increase of ammonium concentration. The recommended storage time at 20^{o}C is at least six months, after which urine is considered safe to use as a fertilizer for any crop since pathogenic microorganisms have assumed to be dead and/or inactivated(Hoglund et al., 2002, WHO, 2006, Winker et al., 2009).The enteric microorganisms usually die off in two months' time, which is why shorter than six month storage periods are commonly applied(Akpan-Idiok et al., 2012).

This study was conducted with fifteen days, one month and two months stored urine. Different parameters (pH, dosage and contact time) which influence the removal and recovery process were examined on urines stored for different period of time. The optimal pH for each storage time was found to be 6. However, biochar dosage and contact time to reach equilibrium were somehow different. The biochar dosage was increasing with increasing of storage time. It is due the increase of ammonium with increasing of storage time. During storage of urine the reaction take place in the storage tank is hydrolysis (i.e. urea to ammonium). Therefore, the optimal dosage for 15days, 1 month and 2 month were 0.2g, 0.6g and 0.8g, respectively. The optimal contact time for each storage time was concluded to be 1 hour. It is because the difference in percentage recovery efficiency for different contact time is not large after 1 hour.

Subsequent to finding the optimal values of pH, dosage and contact time; comparing the percentage recovery efficiency of biochars from stored urine is possible. The initial concentration of both ammonium and phosphate for 15 days, 1 month and 2 month were with high difference. It was increasing with increasing storage time. The initial concentration of ammonium was 4760mg/l, 6600 mg/l and 7800 mg/l, correspondingly the initial concentration of phosphate was 884mg/l, 943mg/l and 1460mg/l for 15 days, 1 month and 2 month stored urine, respectively. This shows that two month stored urine is with high initial concentration of NH_4^+- N and PO_4^{3-}-P.

While the ammonia loss is supposedly low during storage and transport, it might be high, if stored urine is spread as fertilizer. However, a study conducted by the Stockholm Water

Company using stored urine showed that the nitrogen losses were only 1 to 10 %(Johansson, 2000). The ventilation of the collection and storage system should be kept at a minimum, to prevent losses of nitrogen in the form of ammonia. Present research results show that the loss of nitrogen is marginal in closed storage tanks(Udert et al., 2006).

After the stored urine is mixed with biochar the final concentration was measured and recorded low, this is due to NH_4^+- N and PO_4^{3-}-P was moved into the sites of the adsorbent, biochar. Since it is able to recover both nutrients on the biochar, it is better to use the urine with high amount of NH_4^+- N and PO_4^{3-}-P in order to gain best recovery efficiency and use for fertilizer and soil amendment purposes. As a result, two month stored urine is selected as best and or most advantageous for recovery of both nutrients in the case of this study. This was due to the two month stored urine was with highest nutrient concentration, also high amount of N and P recovery were recorded (Figure 4-6c, Figure 4-7c).

4.4. Comparison of CC, CH and WH Produced Biochars

In order to compare biochars produced from different biomass waste; different analysis were done, including elemental composition of biochar, SEM, and percentage of recovery efficiency of each biochars were done using urine which was stored for different duration.

According to the chemical and physical characterization and the adsorption experiments taken the biochar produced from corn cob was best adsorbent for nutrients from urine mainly for NH_4^+- N. Results from chemical characteristics of biochar Table 4-2 showed that the type of feedstock had a major impact on the properties and composition of biochar. Also pyrolysis temperature had a great impact on the characterization of biochar but in this study all feedstock were pyrolyzed at 450^0C. Corn cob biochar was with highest C content compared to CH and WH. Results of the characterization studies of the biochar are clear demonstrations of the significant difference in the composition of biochar produced from different feed stock even when they are pyrolyzed under the same temperature(Novak et al., 2009). Based on the experiment at pH 6, the three biochar samples exhibited different adsorption capacities. WH biochar was with the lowest performance on NH_4^+- N recovery compared to CC and CH. This is due to pH of biochar samples. A biochar with acidic pH has the lowest recovery efficiency

of N. Because both NH_4^+- N and H^+ has positive ion so they will repel each other. But alkaline biochars adsorb more N as a result of the attraction force exists between opposite ions.

Also the structure of biochar samples affects their adsorption capacity. Since adsorption process depends on the pore size of the adsorbent; the greater the pore size the greater the adsorption takes place. From the three adsorbents CC was with highest and WH was with lowest pore size. The large surface area of biochar and its porous nature partly explain increased retention of nutrients and water(Barrow, 2012). Figure 4-8 shows CC was with the best NH_4^+- N recovery efficiency which was 8750 mg/l. Compared to CH and WH, CC biochar recover 98.76% of NH_4^+- N from the two month stored urine.

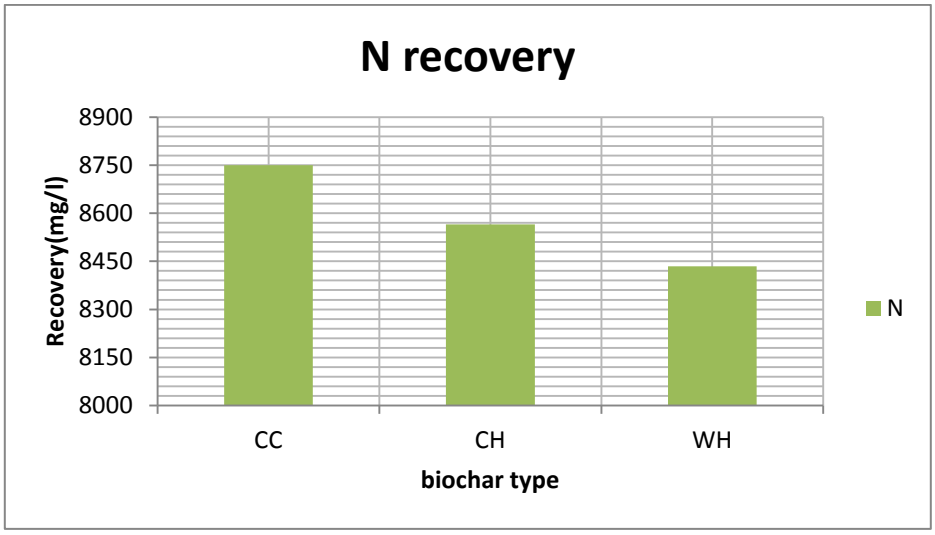


Figure 4-8 comparison of biochars on N recovery

Similar to nitrogen, PO_4^{3-} -P recovery was influenced by the factors mentioned above. Figure 4-9 illustrate the highest percentage of recovery efficiency was recorded with biochar sample of CC. The CC biochar sample recovered 810mg/l of PO_4^{3-} -P from the stored urine. Also, the difference in recovery efficiency using the three biochars was not large.

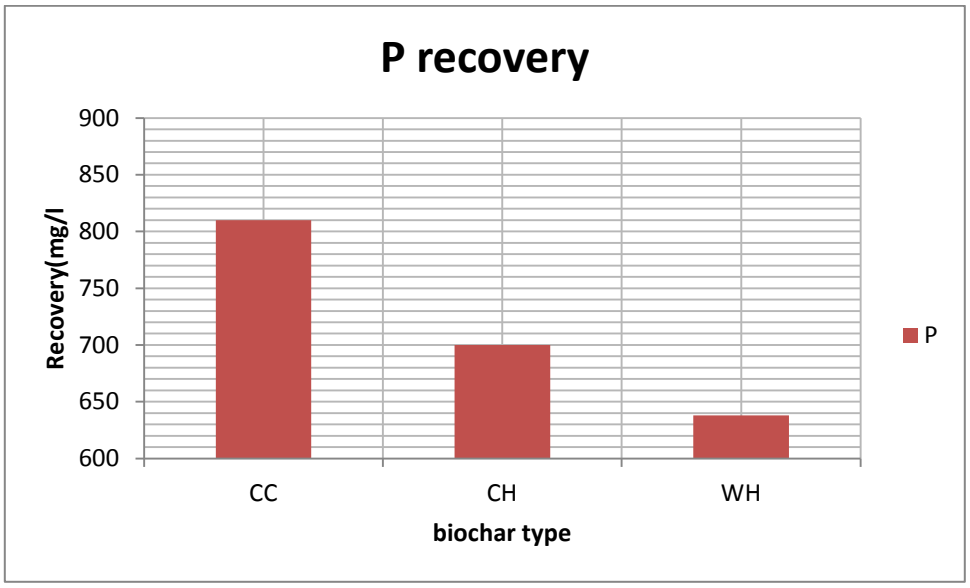


Figure 4-9 comparison of biochars efficiency on P recovery

4.5. Adsorption Isotherm

Langmuir and Freundlich isotherm models were applied to study the adsorption behavior and to determine the capacity of the adsorption of NH_4^+ -N and PO_4^{3-} -P on the CC biochar. The Langmuir and Freundlich parameters are summarized in Table 4-3. The Langmuir parameters q_{max} and K_L and the Freundlich parameters K_F and n were computed from the slope and intercept of the plot of C_e/q_e versus C_e (Figure 4-10) and log q_e versus log c_e (Figure 4-11), respectively. Based on the correlation coefficients (R^2), it can be concluded that both N and P recovery fitted well with Langmuir model with R^2 of 0.998 for N and 0.936 for P, and it is the most probable model to describe N and P recovery on corn cob. As (Hale et al., 2013) described, the sorption isotherms of NH_4^+ -N and PO_4^{3-} -P on corn cob biochars revealed small adsorption capacity of PO_4^{3-} -P but better of NH_4^+ -N adsorption to a certain extent.

Table 4-3 Regression parameters for Langmuir and Freundlich adsorption isotherms for N and P recovery by corn cob

		Langmuir Isotherm Model			Freundlich Isotherm Model		
Nutrient	Biochar	q_m(mg/g)	K_L(l/mg)	R^2	K_F(mg/g)	N	R^2
N	CC	1216	0.0051	0.998	85	2.68	0.918
P	CC	41.3	0.00021	0.936	0.142	0.866	0.822

Based on Langmuir isotherm, the maximum adsorption capacity of N and P were 1216mg/g and 41.3mg/g, respectively, which is greater than the reported adsorption capacity of other solid adsorbent such as rice straw biochar (425mg/g) for nitrogen(Halil et al., 2018) and activated coir-pith carbon (7.62mg/g) for phosphorous(Kumar et al., 2010b). To check the favorability of Langmuir isotherm the essential characteristic separation constant factor, R_L, was calculated. It was found to be 0.022 and 0.83 for N and P, respectively. Therefore, these values were less than 1 showing that N and P recovery by this biochar is favorable process.

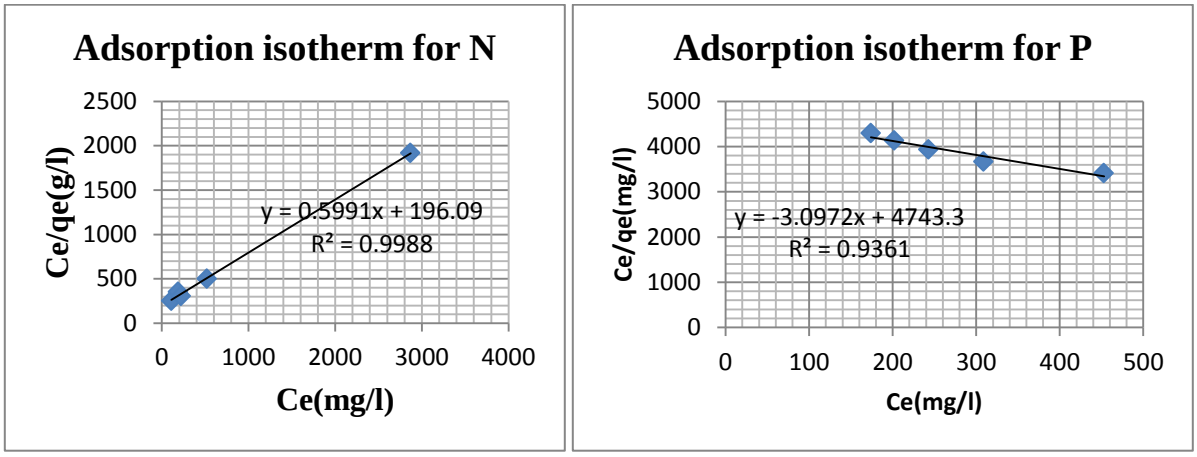


Figure 4-10 Langmuir isotherm for the adsorption of N and P on CC biochars

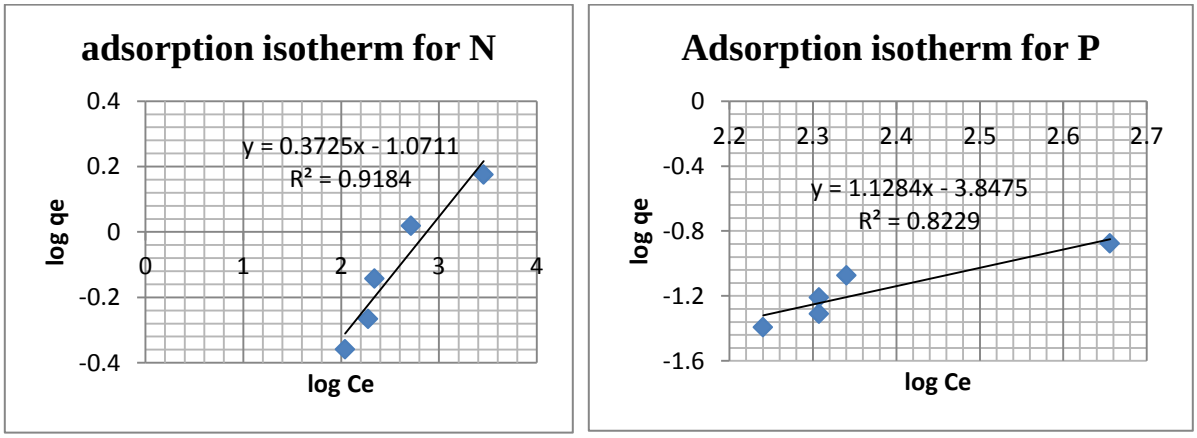


Figure 4-11 Frendluich isotherm for adsorption of N and P on CC biochars

5. Conclusion and Recommendation

5.1. Conclusion

In summary, direct discharge of wastewater into natural surface water sources with the effect of nutrient existence, will have impacts on the environment. Increasing of nutrients in surface water bodies lead to eutrophication. Although the solution of the impact is lacking, the wastewater management system is challenging issue now and then. Source separation of urine could be a promising means for reduction of nutrients from wastewater and also for load reduction on wastewater treatment plants.

Biochars could virtually be a cure for innumerable environmental and industrial uses. It can be produced from locally available biomass waste, due this it could be used as low cost adsorbent. As a result, solid waste (biomass waste) will be used as resources, and then sustainable environment will be maintained.

The proposed biochar samples were successfully used for nutrient recovery from human urine. In this study, the recovery of NH_4^+- N and PO_4^{3-}-P in human urine were carried out by using biochar produced from biomass waste (CC, CH and WH). Different parameters were optimized to examine the potential of biochar on nutrient removal and recovery. Investigation of the influence of pH value on the adsorption process resulted in, an optimal pH value of 6. The optimum conditions for NH_4^+- N and PO_4^{3-} -P recovery were 60 minutes of contact time, 0.8g biochar dosage. Examining the effect of storage time on the adsorption the two months stored urine was selected as the best storage time to gain better amount of nutrients recovered from urine. The maximum recovery efficiency of NH_4^+- N and PO_4^{3-} -P at the optimum values were found to be 98.76%, 92.21% and 85.78% and 82.32%, 71.14% and 57.72% with CC, CH and WH biochars, respectively.

The biochar characterization was done to compare all biochar samples. CC and CH biochars were found to be more alkaline (pH 9 and 10.5) compared to WH (pH 6). CHN analysis indicates that CC biochar has the highest carbon content which is 74.079%, followed by CH and WH with 65.625% and 51.559%, respectively. SEM analyses indicated that the CC biochar has a better pore volume and distribution, making it a good adsorbent. Overall, the

efficiencies of CC, CH and WH biochars in recovering nutrients are good. The removal efficiency of CC, however, is better due to its higher carbon content and pore volume.

In general, the findings of this research showed that nutrient recovery from source separated human urine using biochar is efficient and best alternative to improve the pollution of surface water sources.

5.2. Recommendation

Nutrients are a fact with range of impacts, and recovery is the most fundamental factor in its mitigation. This study was done at laboratory scale using centrifuge tube for all experiments and gave emphasize for nutrient recovery from source separated human urine using biochar produced from different biomass wastes. The study, however, has some limitations in terms of the type of factors to be optimized. Therefore, it is recommended that further studies be conducted, by considering and optimizing more parameters and check the nutrient recovery efficiency. It is also recommended to scale-up the experiment from laboratory to pilot and treatment plant scale.

The major advantage of this research is that it gives alternative method to recover nutrients. But the study has limitations in terms of indicating the fate of biochar byproduct after the recovery process. As biochar can be relevant as fertilizer, it is suggested to check the efficiency by applying into crops and verify the use of biochar after nutrient recovery from source separated urine.

The main objective of this study was to recover nitrogen and phosphorous from source separated urine using biochar. Recovery efficiency of phosphorous, however, was not as higher as nitrogen. For future studies, it is recommended to check phosphorous recovery using activated biochar and compare with biochar material.

References

Ahmad, M., Lee, S. S., Dou, X., Mohan, D., Sung, J. K. & Yang, J. E. 2012. Effects of pyrolysis temperature on soybean stoverand peanut shell-derived biochar properties and TCE adsorption in water. *Bioresource Technology,* 118**,** 536-544.

Ahmad, M., Rajapaksha, A. U., Lim, J. E., Zhang, M., Bolan, N., Mohan, D., Vithanage, M., Lee, S. S. & Ok, Y. S. 2014 Biochar as a sorbent for contaminant management in soil and water: a review. *chemosphere,* 99**,** 19-33.

Akpan-Idiok, A. U., Udo, I. A. & Braide, E. I. 2012. The use of urine as an organic fertilizer in the production of okra (Abelmoschus esculentus) in South Eastern Nigeria. *Resources, Conservation and Recycling* 62**,** 14-20.

Aweke, G. 1993. The water hyacinth (Eichhornia crassipes) in Ethiopia. *AGRIS.* National Herbarium, Addis-Abeba (Ethiopia).

Bakir, H. A. 2001. Sustainable wastewater management for small communities in the Middle East and North Africa *Journal of environmental management* 61**,** 319-28.

Barragan, B. E., Costa, C. & Marquez, M. C. 2007. Biodegradation of azo dyes by bacteria inoculated on solid media. *Dyes and Pigments* 75**,** 73-81.

Barrow, C. J. 2012. Biochar: Potential for countering land degradation and for improving agriculture. *Applied Geography* 34**,** 21-28.

Barzamini, R., Falamaki, C. & Mahmoudi, R. 2014. Adsorption of ethyl, iso-propyl, n-butyl and iso-butyl mercaptans on AgX zeolite: equilibrium and kinetic study *Fuel,* 130**,** 46-53.

Beal, C., Gardner, T., Ahmed, W., Walton, C. & Hamlyn-Harris, D. 2008. Urine–separation and reuse trial. *AWA Water (Australia),* 35**,** 46-49.

Benyoucef, S. & Amrani, M. 2011. Adsorption of phosphate ions onto low cost Aleppo pine adsorbent. *Desalination,* 275**,** 231-236.

Biswas, B. K., Inoue, K., Ghimire, K. N., Ohta, S., Harada, H., Ohto, K. & Kawakita, H. 2007. The adsorption of phosphate from an aquatic environment using metal-loaded orange waste. *Journal of Colloid and Interface Science,* 312**,** 214-223.

Cecen, F. & Aktas, O. 2011. Activated Carbon for Water and Wastewater Treatment: Integration of Adsorption and Biological Treatment. WILEY-VCH

Chen, T. H., Wang, J. Z., Wang, J., Xie, J. J., Zhu, C. Z. & Zhan, X. M. 2014. Phosphorus removal from aqueous solutions containing low concentration of phosphate using pyrite calcinate sorbent. *International Journal of Environmental Science and Technology,* 12**,** 885-892.

Chen, X., Chen, G., Chen, L., Chen, Y., Lehmann, J., Mcbride, M. B. & Hay, A. G. 2011. Adsorption of copper and zinc by biochars produced from pyrolysis of hardwood and corn straw in aqueous solution. *Bioresource Technology,* 102**,** 8877-8884.

Chun, Y., Sheng, G., Chiou, C. T. & Xing, B. 2004. Compositions and Sorptive Properties of Crop Residue-Derived Chars. *Environmental Science and Technology* 38**,** 4646-4655.

Cordell, D. 2010. The story of phosphorus: sustainability implications of global phosphorus scarcity for food security. *Department of Water and Environmental Studies, [The Tema Institute],*. Linköping University, Linköping.

Cordell, D., Drangert, J. O. & White, S. 2009. The story of phosphorus: global food security and food for thought. *Global Environmental Change,* 19**,** 292–305.

Demir, I. 2002. *Alternative Approaches for Wastewater Treatment and Disposal in Developing Countries*. Wasser-Wissen.de.

Endalew, M. 2019. *Recovery of phosphorus and nitrogen from human urine by dolomite rock.* master of science, Arba Minch University.

Esrey, S., Anderson, I., Hillers, A. & Sawyer, R. 2001. Closing the Loop: Ecological sanitation for food security. *Water Resources,* 18.

Esrey, S. A. 2001. Towards a recycling society: ecological sanitation – closing the loop to food security. *Water Science and Technology,* 43**,** 177-187.

Fattah, K. P., Mavinic, D. S., Koch, F. A. & Jacob, C. 2008. Determining the feasibility of phosphorus recovery as struvite from filter press centrate in a secondary wastewater treatment plant. *Journal of Environmental Science and Health,* 43**,** 756-764.

Fowler, D., Coyle, M., Skiba, U., Mark A. Sutton, Cape, J. N., Reis, S. & Sheppard, L. J. 2013. The global nitrogen cycle in the twenty-first century. *Philosophical Transactions of the Royal Society B,* 368**,** 1621.

Frumin, G. 2015. Eutrophication of Water Bodies – A Global Environmental Problem.

Fu, F. & Wang, Q. 2011. Removal of heavy metal ions from wastewaters: A review. *Journal of Environmental Management,* 92**,** 407-418.

Gai, X., Wang, H., Liu, J., Zhai, L., Liu, S. & Ren, T. 2014. Effects of feedstock and pyrolysis temperature on biochar adsorption of ammonium and nitrate. *PLoS One* 9.

Galloway, J. & Cowling, E. 2002. Reactive nitrogen and the world: 200 years of change. *AMBIO,* 31**,** 64-71.

Ganesapillai, M., Simha, P., Gupta, K. & Jayan, M. 2016. Nutrient Recovery and Recycling from Human Urine: A Circular Perspective on Sanitation and Food Security. *Procedia Engineering,* 148**,** 346-353.

Ganrot, Z., Dave, G. & Nilsson, E. 2007. Recovery of N and P from human urine by freezing,struvite precipitation and adsorption to zeolite and active carbon. *Bioresource Technology* 98**,** 3112-3121.

Getachew, B. 2011. Bio-Slurry – is it a fertilizer in the making? *SNV Netherlands Development Organization*.

Glaser, B. & Lehr, V. 2019. Biochar effects on phosphorus availability in agricultural soils: A meta-analysis. *Scientific Reports,* 9**,** 9338.

Glazunova, D., Kuryntseva, P., Selivanovskaya, S. & Galitskaya, P. 2018. Assessing the Potential of Using Biochar as a Soil Conditioner. *IOP Conference Series: Earth and Environmental Science*.

Gupta, S. & Kua, H. 2017. Factors Determining the Potential of Biochar As a Carbon Capturing and Sequestering Construction Material: Critical Review. *Journal of Materials in Civil Engineering*.

Gupta, V. K., Ali, I., Saleh, T. A., Nayak, A. & Agarwal, S. 2012. Chemical treatment technologies for waste-water recycling—an overview. *Royal Society of Chemistry Advances*.

Hale, S. E., Alling, V., Martinsen, V., Mulder, J., Breedveld, G. D. & Cornelissen, G. 2013. The sorption and desorption of phosphate-P, ammonium-N and nitrate-N in cacao shell and corn cob biochars. *Chemosphere,* 91**,** 1612-1619.

Halil, A., Sergeevich, N. & Belousova, V. 2018. Removal of ammonium from fish farms by biochar obtained from rice straw: Isotherm and kinetic studies for ammonium adsorption. *Adsorption Science & Technology,* 36**,** 1-16.

Hoglund, C., Ashbolt, N., Stenstrom, T. A. & Svensson, L. 2002. Viral persistence in sourceseparated urine. *Advances in Environmental Research,* 6**,** 265-275.

Hoguland, C. 2001. *Evaluation of microbial health risks associated with the reuse of source-separated human urine* masters Degree, Royal Institute of Technology.

Howarth, R. W. 2008. Coastal nitrogen pollution: A review of sources and trends globally and regionally." Harmful Algae. *Harmful Algae,* 8**,** 14-20.

Huang, H., Xiao, X., Bo, Y. & Yang, L. 2010. Ammonium removal from aqueous solutions by using natural Chinese (Chende) zeolite as adsorbent. *Journal of Hazardous Materials,* 175**,** 247–252.

Ifdc 2015. ASSESSMENT OF FERTILIZER CONSUMPTION AND USE BY CROP IN ETHIOPIA

Intani, K., Latif, S., Muller, J. & Islam, M. S. 2018. Phytotoxicity of Corncob Biochar before and after Heat Treatment and Washing. *Sustainability,* 11**,** 30.

Johansson, M. 2000. Urine Separation – ClosingThe Nutrient Cycle. *Final Report on the R&D Project:Source-Separated Human Urine-A Future Source of Fertilizer for Agriculture in the Stockholm Region.* Stockholm: Stockholm Vatten: Stockholmshem & HSB National Federation.

John, L., Havlin, S. L. T. & Nelson, W. L. 2014. Soil Fertility and Fertilizers: An Introduction to Nutrient Management. 8th edition ed. Boston: Pearson.

Jonsson, H., Baky, A., Jeppsson, U., Hellstrom, D. & Karrman, E. 2005. Composition of urine, feces, grey water and bio-waste for utilization in the URWARE Model. *Urban Water.* Chalmer, Sweden: Stockholm Environment Institute.

Jonsson, H., Richert, A. S., Vinneras, B. & Salomon, E. 2004. Guidelines on the Use of Urine and Faeces in Crop Production. Stockholm: Stockholm environment institute.

Joss, A., Keller, E., Alder, A. C., Gobel, A., Mcardell, C. S., Ternes, T. & Siegrist, H. 2005. Removal of pharmaceuticals and fragrances in biological wastewater treatment. *Water Research,* 39**,** 3139-3152.

Karadag, D., Tok, S., Akgul, E., Turan, M., Ozturk, M. & Demir, A. 2007. Ammonium removal from sanitary landfill leachate using natural Gordes clinoptilolite. *Journal of Hazardous Materials,* 153.

Karri, R. R., Sahu, J. N. & Jayakumar, N. S. 2017. Optimal isotherm parameters for phenol adsorption from aqueous solutions onto coconut shell based activated carbon: Error analysis of linear and non-linear methods. *Journal of the Taiwan Institute of Chemical Engineers,* 80**,** 472-487.

Kc, S. & Shinjo, H. 2017. Effectiveness of ecological sanitation from the viewpoint of urine application on vegetables in Central Nepal. *MATTER: International Journal of Science and Technology,* 3**,** 55-66.

Kizito, S., Luo, H., Lu, J., Bah, H., Dong, R. & Wu, S. 2019. Role of Nutrient-Enriched Biochar as a Soil Amendment during Maize Growth: Exploring Practical Alternatives to Recycle Agricultural Residuals and to Reduce Chemical Fertilizer Demand. *sustainability,* 11**,** 3211.

Kizito, S., Wu, S., Kirui, W. K., Lei, M., Lu, Q., Bah, H. & Dong, R. 2015. Evaluation of slow pyrolyzed wood and rice husks biochar for adsorption of ammonium nitrogen from piggery manure anaerobic digestate slurry. *Science of Total Technology,* 505**,** 102-112.

Kołodynska, D., Wnetrzak, R., Leahy, J., Hayes, M. H. B., Kwapinski, W. & Hubicki, Z. 2012. Kinetic and adsorptive characterization of biochar in metal ions removal. *Chemical Engineering Journal,* 197**,** 295-305.

Kotoulas, A., Agathou, D., Triantaphyllidou, E. I., Tatoulis, T. I., Akratos, C. S., Tekerlekopoulou, A. G. & Vayenas, D. V. 2019. Zeolite as a Potential Medium for Ammonium Recovery and Second Cheese Whey Treatment. *water,* 11**,** 136.

Krishnan, A. K. & Haridas, A. 2008. Removal of phosphate from aqueous solutions and sewage using natural and surface modified coir pith. *Journal of Hazardous Materials,* 152**,** 527-535.

Kumar, P., Sudha, S., Chand, S. & Srivastava, V. 2010a. Phosphate Removal from Aqueous Solution Using Coir-Pith Activated Carbon. *eparation Science and Technology* 45**,** 1463-1470.

Kumar, P., Sudha, S., Chand, S. & Srivastava, V. C. 2010b. Phosphate Removal from Aqueous Solution Using Coir-Pith Activated Carbon. *Separation Science and Technology,* 45**,** 1463-1470.

Kvarnstrom, E., Dagerskog, L., Norstrom, A. & Johansson, M. 2012. Nutrient reuse as a solution multiplier. *A policy brief by the SIANI Agriculture-Sanitation expert group, SIANI policy brief 1.1.* Sweden.

Langergraber, G. & Muellegger, E. 2005. Ecological Sanitation—a way to solve global sanitation problems? *Environment International,* 31**,** 433-444.

Larsen, T. A., Alder, A. C., Eggen, R. I. L., Maurer, M. & Lienert, J. 2009. Source separation: Will we see a paradigm shift in wastewater handling? *Environmental Science and Technology,* 43**,** 6121-6125.

Larsen, T. A., Peters, I., Alder, A., Eggen, R., Maurer, M. & Muncke, J. 2001. Re-engineering the toilet for sustainable wastewater management. *Environmental Science and Technology,* 35**,** 192-197.

Li, F., Shen, K., Long, X., Wen, J., Xie, X., Zeng, X., Liang, Y., Wei, Y., Lin, Z., Huang, W. & Zhong, R. 2016. Preparation and Characterization of Biochars from Eichornia crassipes for Cadmium Removal in Aqueous Solutions. *PLoS One,* 11.

Lienert, J., Burki, T. & Escher, B. I. 2007. Reducing micropollutants with source control: substance flow analysis of 212 pharmaceuticals in faeces and urine. *Water Science Technolology,* 56**,** 87-96.

Liu, Q., Liu, C., Zhao, L., Ma, W., Liu, H. & Ma, J. 2016. Integrated forward osmosis membrane distillation process for human urine treatment. *Water Research,* 91**,** 45-54.

Liu, W., Jiang, H. & Yu, H. 2015. Development of biochar-based functional materials: Toward a sustainable platform carbon material. *Chemical Revolution,* 115**,** 12251–12285.

Liu, X., Zhang, Y., Li, Z., Feng, R. & Zhang, Y. 2014a. Characterization of corncob-derived biochar and pyrolysis kinetics in comparison with corn stalk and sawdust. *Bioresource Technology* 170**,** 76-82.

Liu, X. L., Zeng, Z. X., Chen, Q. W. & Zou, H. L. 2014b. Effects of biochar and lime additives on non-point load of heavy metals in paddy soil. *Journal of Hydraulic Engineering,* 45**,** 682-690.

Lukowiak, R., Grzebisz, W. & Sassenrath, G. F. 2016. New insights into phosphorus management in agriculture-A crop rotation approach. *Science of The Total Environment,* 542**,** 1062-1077.

Mara, D., Lane, J., Scott, B. & Trouba, D. 2010. Sanitation and Health. *PLoS Medicine,* 7.

Maurer, M., Schwegler, P. & Larsen, T. A. 2003. Nutrients in urine: energetic aspects of removal and recovery. *IWA Publishing, London,UK.*

Mee, L. 2006. "Reviving Dead Zones." *Scientific American*, 295**,** 79–85.

Meinzinger, F., Oldenburg, M. & Otterpohl, R. 2009. New Sanitation Concepts for Condominium Housing Urine-Diverting Dry Toilets in Multi-Storey Buildings in Ethiopia. Institute of Wastewater Management and Water Protection, Hamburg University of Technology, Germany

Mohan, S. V., Babu, V. L. & Sarma, P. N. 2007. Anaerobic biohydrogen production from dairy wastewater treatment in sequencing batch reactor (AnSBR): Effect of organic loading rate. *Enzyme and Microbial Technology*, 41**,** 506-515.

Munch, E. V. & Winker, M. 2009. Technology Review: Urine Diversion Components.

Naidoo, S. & Olaniran, A. O. 2013. Treated wastewater effluent as a source of microbial pollution of surface water resources. *International Journal of Environmental Research and Public Health,* 11**,** 249-270.

Neethling, J. E. 2015. Continuous Flow Applications for Managing Source-Separated Urine Nutrient Recovery. *Civil Engineering Graduate Theses & Dissertations***,** 145.

Ngatia, L., Iii, J. G., Moriasi, D. & Taylor, R. 2019. Nitrogen and Phosphorus Eutrophication in Marine Ecosystems. *Monitoring of Marine Pollution*.

Nguyen, N. T. 2015. *Adsorption of Phosphorus from Wastewater onto Biochar: Batch and Fixed-bed Column Studies.* Helsinki Metropolia University of Applied Sciences.

Noor, N. M., Shariff, A. & Abdullah, N. Slow Pyrolysis of Cassava Wastes for Biochar Production and Characterization. 2012. Iranica Journal of Energy & Environment 60-65.

Novak, J. M., Busscher, W. J., Laird, D. L., Ahmedna, M., Watts, D. W. & Niandou, M. a. S. 2009. Impact of Biochar Amendment on Fertility of a Southeastern

Coastal Plain Soil. *Soil Science,* 174**,** 105-112.

Nyenje, P. M., Foppen, J. W., Uhlenbrook, S., Kulabako, R. & Muwanga, A. 2010. Eutrophication and nutrient release in urban areas of sub-Saharan Africa--a review. *Science of the Total Environment,* 408**,** 447-455.

Okem, A. E., Xulu, S., Tilley, E., Buckley, C. & Roma, E. 2013. Assessing perceptions and willingness to use urine in agriculture: a case study from rural areas of eThekwini municipality, South Africa. *Journal of Water Sanitation Hygiene Development,* 3**,** 582-591.

Oldenburg, M., Meinzinger, F., Lisanework, A. A., Gutema, K., Krusche, P. & Jebens, O. 2009. Experience with the introduction of dry , urine diverting sanitation systems in Ethiopia. 1-5.

Owlad, M., Aroua, M. K., Daud, W. a. W. & Baroutian, S. 2009. Removal of Hexavalent Chromium-Contaminated Water and Wastewater: A Review. *Water, air, and soil pollution,* 200**,** 59-77.

Padmavathy, K. S., Madhu, G. & Haseena, P. V. 2016. A study on effects of pH, adsorbent dosage, time, initial concentration and adsorption isotherm study for the removal of hexavalent chromium (Cr (VI)) from wastewater by magnetite nanoparticles. *Procedia Technology,* 24**,** 585-594.

Park, J. H., Ok, Y. S., Kim, S. H., Cho, J. S., Heo, J. S., Delaune, R. D. & Seo, D. C. 2015. Evaluation of phosphorus adsorption capacity of sesame straw biochar on aqueous solution: Influence of activation methods and pyrolysis temperatures. *Environmental Geochemical health,* 37**,** 969-983.

Pastor, L., Mangin, D., Barat, R. & Seco, A. 2008. A pilot-scale study of struvite precipitation in a stirred tank reactor: Conditions influencing the process. *Bioresource Technology,* 99**,** 6285-6291.

Pauline, M., Mama, N. & Ustin, F. 2010 Development of a method for the mineralization of coffee husk (Coffea canephora P.) to obtain raw material for soap factories *African Journal of Biotechnology* 9**,** 8362-8364.

Pendashteh, A. R., Fakhru'l-Razi, A., Chuah, T. G., Radiah, A. B. D., Madaeni, S. S. & Zainal, Z. A. 2010. Biological treatment of produced water in a sequencing batch

reactor by a consortium of isolated halophilic microorganisms. *Environmental Technology,* 31**,** 1229-1239.

Perez-Mercado , L. F., Lalander, C., Berger, C. & Dalahmeh, S. S. 2018. Potential of Biochar Filters for OnsiteWastewater Treatment: Effects of Biochar Type, Physical Properties and Operating Conditions. *Water,* 10**,** 1835.

Pituya, P., Sriburi, T. & Wijitkosum, S. 2017. Optimization of Biochar Preparation from Acacia Wood for Soil Amendment. *Engineering Journal* 21**,** 100-105.

Puchongkawarin, C., Gomez-Mont, C., Stuckey, D. C. & Chachuat, B. 2015. Optimization-based methodology for the development of wastewater facilities for energy and nutrient recovery *Chemosphere,* 140 150-158.

Qi, F., Dong, Z., Lamb, D., Naidu, R., Bolan, N. S., Ok, Y. S., Liu, C., Khan, N., M.A.H., J. & Semple, K. T. 2017. Effects of acidic and neutral biochars on properties and cadmium retention of soils. *Chemosphere,* 180 564-573.

Qiu, X., Duan, L., Chai, F., Wang, S., Yu, Q. & Wang, S. 2016. Deriving high-resolution emission inventory of open biomass burning in China based on satellite observations. *Environmental Science and Technolology,* 50**,** 11779–11786.

Rahman, M., Amran, M., Salleh, M., Rashid, U., Ahsan, A., Mujaffar, M. & Six, C. 2014a. Production of slow release crystal fertilizer from wastewaters through struvite crystallization – A review. *Arabian Journal of Chemistry,* 7**,** 139-155.

Rahman, M., Salleh, M. A., Rashid, U., Ahsan, A., Mujaffar, M. H. & Six, C. R. 2014b. Production of slow release crystal fertilizer from wastewaters through struvite crystallization – A review. *Arabian Journal of Chemistry,* 7 139-155.

Rajkovich, S., Enders, A., Hanley, K., Hyland, C., Zimmerman, A. R. & Lehmann, J. 2012. Corn growth and nitrogen nutrition after additions of biochars with varying properties to a temperate Soil. *Biology and Fertility of Soils,* 48**,** 271-84.

Reigna, T., Lima, J., Dessimoni, L. D. A., Pego, M., Soares, J. R. & Trugilho, P. 2017. Different plant biomass characterizations for biochar production. *Cerne,* 23**,** 529-536.

Rittmann, B. E., Mayer, B., Westerhoff, P. & Edwards, M. 2011. Capturing the Lost Phosphorus. *Chemosphere,* 84**,** 846-853.

Rockstrom, J., Steffen, W., Noone, K., Persson, A., Stuart, C. F. & Lambin, E. F. 2009. A safe operating space for humanity. *Nature,* 461**,** 472-475.

Ronteltap, M. 2009. *Phosphorus recovery from source separated urine through the precipitation of struvite.* Doctor of Technical Sciences Doctoral Thesis, Wageningen University.

Ronteltap, M. 2010. Struvite precipitation from urine – Influencing factors on particle size. *Water Research,* 44**,** 2038-2046.

Ruamsook, K. & Thomchick, E. 2014. *MarketT opportunity for lignocellulosic biomass.* The Pennsylvania State University.

Ruzene, D. S., Yagiz, E., Marangoz, D., Silva, D., Vicente, A. A. & Teixeira, J. A. 2008. Hydrothermal treatments of corn cob and hemicelluloses extraction. *In:* (DEB), U. D.

M. D. D. E. B. (ed.) *International Chemical and Biological Engineering Conference.* Braga,Portugal.

Saha, B., Griffin, L. & Blunden, H. 2010. Adsorptive separation of phosphate oxyan-ion from aqueous solution using an inorganic adsorbent. *Environmental Geochemistry and Health*, 32**,** 341-347.

Schmidt, H. P. 2014. Terra Preta – model of a cultural technique. *The Biochar Journal*

Schonning, C. 2001. *Urine diversion: hygienic risks and microbial guidelines for reuse.* Swedish Institute for Infectious Disease Control

Schuen, R. & Parkinson, J. 2009. Study for financial and economical analysis of ecological sanitation in Sub-Saharan Africa. *In:* INFORMATION, D. O. P. (ed.). WASH Resoure.United Nations.

Science Communication Unit, U. O. T. W. O. E., Bristol 2013. Science for Environment Policy Indepth Report: Sustainable Phosphorus Use. *Report produced for the European Commission DG Environment*.

Selman, M. & Greenhalgh, S. 2009. Eutrophication: Sources and Drivers of Nutrient Pollution. *World Resources Institute*.

Selman, M., Guiling, J., John, J. & Greenhalgh, S. 2007. Paying For Environmental Performance: Using Reverse Auctions to Allocate Funding For Conservation. *World Resources Institute,Washington, DC.* , 3.

Shareef, T. M. E., Zhao, B. & Filonchyk, M. 2018. characterization of biochars derived from maize straw and corn cob and effects of their amendment on maize growth loess soil property. *Fresenius Environmental Bulletin* 27**,** 3678-3686.

Smil, V. 2002. Nitrogen and food production: proteins for human diets. *AMBIO: Human Environment* 31**,** 12-31.

Smith, D., Odusoga, B. & Bastian, R. 2017. Water Reuse and Recycling: Community and Environmental Benefits. united states environmental protection agency.

Sotelo, J. L., Ovejero, G., Rodriguez, A., Alvarez, S. & García, J. 2013. Study of Natural Clay Adsorbent Sepiolite for the Removal of Caffeine from Aqueous Solutions: Batch and Fixed-Bed Column Operation. *Water, Air, & Soil Pollution*, 224**,** 1-15.

Tarpeh, W. A., Udert, K. M. & Nelson, K. L. 2017. Comparing ion exchange adsorbents for nitrogen recovery from Source-Separated urine. *Environmental Science and Technology*, 51**,** 2373–2381.

Tilley, E. & Gunther, I. 2013. Collection based on incentives: Encouraging urine collection with financial incentives. *Environmental science and technology*.

Tornroth-Horsefield, S. & Neutze, R. 2008. Opening and closing the metabolite gate. *Proceedings of the National Academy of Sciences of the United States of America*, 105**,** 19565-6.

Tredoux, G. 2004. Nitrate and associated hazard quantification and strategies for protecting rural water supplies Pretoria, South Africa: Water research commission.

Udert, K. M., Larsen, T. A. & Gujer, W. 2006. Fate of major compounds in source-separated urine. *Water Science and Technology,* 54**,** 413-420.

Udo De Haes, H., Voortman, R., Bastein, T., Bussink, W., Rougoor, C. & Weijden, W. 2012. Scarcity of micronutrients in soil, feed, food, and mineral reserves: Platform Agriculture, Innovation & Society. *Report and advisory memorandum for the Dutch Minister of Agriculture and Foreign Trade.* dutch.

Un Desa, D. O. E. a. S. A. 2016. World population projected to reach 9.7 billion by 2050

Usmani, S. 2019. Applications of Biochar. *BioEnergy Consult powering clean energy future*.

Van Der Zee, F. P. & Villaverde, S. 2005. Combined anaerobic–aerobic treatment of azo dyes-A short review of bioreactor studies. *Water Research,* 39**,** 1425.

Vassileva, P., Zvetkova, P. & Nickolov, R. 2009. Removal of ammonium ions from aqueous solutions with coal-based activated carbons modified by oxidation. *Fuel,* 88**,** 387-390.

Vitousek, P. M., Hattenschwiler, S., Allison, S. & Olander, L. 2004. Nitrogen and nature. *Ambio* 31**,** 97–101.

Werner, C., Bracken, P., Mang, H. P. & Klingel, F. 2003. Reasons for and principles of ecological sanitation. *Ecosan-closing the loop 2nd international symposium on ecological sanitation.* Lubeck, Germany.

Wheatley, R., Abdullahi, Y. A., Akunna, J. C., White, N. A. & Hallett, P. D. 2008. Investigating the effects of anaerobic and aerobic post-treatment on quality and stability of organic fraction of municipal solid waste as soil amendment. *Bioresource technology,* 99**,** 8631-8636.

Who 2006. World Health Organization Guidelines for the safe use of wastewater, excreta and greywater. *Excreta and greywater use in agriculture,* 4**,** 204.

Wilsenach, J. & Loosdrecht, M. V. 2003. Impact of separate urine collection on wastewater treatment systems. *Water Science and Technology,* 48**,** 103–110.

Winker, M., Vinneras, B., Muskolus, A., Arnold, U. & Clemens, J. 2009. Fertiliser products from new sanitation systems: Their potential values and risks. *Bioresource Technology,* 100**,** 4090-4096.

Worch, E. 2012. Adsorption Technology in Water Treatment-Fundamentals, Processes, and Modeling,Germany.Walter de Gruyter, GmbH & Co. KG, Berlin. 345.

Xie, T., Reddy, K. R., Wang, C., Yargicoglu, E. & Spokas, K. 2015. Characteristics and Applications of Biochar for Environmental Remediation: A Review. *Critical Reviews in Environmental Science and Technology,* 45**,** 939-969.

Xiea, M. H., Shonb, K., Stephen, R. & Menachem, G. E. 2016. Membrane-based processes for wastewater nutrient recovery: Technology, challenges, and future direction. *Water Research,* 89**,** 210-221.

Xu, S., Luo, L., He, H., Liu, H. & Cui, L. 2015. Nitrogen and phosphate recovery from source-separated urine by dosing magnesite and zeolite. *Polish Journal of Environmental Studies,* 24**,** 2269-2275.

Xu, X., Gao, Y., Gao, B., Tan, X., Zhao, Y. Q., Yue, Q. & Wang, Y. 2011. Characteristics of diethylenetriamine-crosslinked cotton stalk/wheat stalk and their biosorption capacities for phosphate. *Journal of Hazardous Materials,* 192**,** 1690–1696.

Yang, S., Wi, S., Lee, J., Lee, H. & Kim, S. 2019. Biochar-red clay composites for energy efficiency as eco-friendly building materials: Thermal and mechanical performance. *Journal of Hazardous Materials,* 373**,** 844-855.

Yao, Y., Gao, B., Inyang, M., Zimmerman, A. R., Cao, X., Pullammanappallil, P. & Yang, L. 2011. Removal of phosphate from aqueous solution by biochar derived from anaerobically digested sugar beet tailings. *Journal of Hazardous Materials,* 190**,** 501-507.

Yue, Q. Y., Wang, W. Y., Gao, B. Y., Xu, X., Zhang, J. & Li, Q. 2010. Phosphate Removal from Aqueous Solution by Adsorption on Modified Giant Reed. *Water Environment Research,* 82**,** 374-381.

Zhang, F., Li, C., Yu, Y. & Johnson, D. M. 2019. Resources and Future Availability of Agricultural Biomass for Energy Use in Beijing. *Energies,* 12**,** 1828.

Zhang, J. S. & Wang, Q. Q. 2016. Sustainable mechanisms of biochar derived from brewers' spent grain and sewage sludge for ammonia-nitrogen capture. *Journal of Clean Production,* 112**,** 3297-3934.

Zhang, L., Liu, J., Wan, L., Zhou, Q. & Wang, X. 2012. Batch and Fixed-Bed Col-umn Performance of Phosphate Adsorption by Lanthanum-Doped Activated Carbon Fiber. *Water, Air, & Soil Pollution,* 223**,** 5893-5902.

Zhao, H., Zheng, S., Li, T., Yao, X., Li, Z. & Wang, P. 2017. Effects of Environmental Conditions on the Adsorption of NH4+-N by Rice-straw Biochar. *Asia-Pacific Engineering and Technology Conference.* Jiangsu, China.

Zheng, M., Liu, Y. C., Wang, C. W. & Xu, K. N. 2013. Study on enhanced denitrification using particulate organic matter in membrane bioreactor by mechanism modeling. *Chemosphere,* 93**,** 2669-2674.

Zheng, Y., Pan, Z. & Zhang, R. 2009. "Overview of biomass pretreatment for cellulosic ethanol production". . *International Journal Agricultural and Biological Engineering,* 2 pp. 51-68. .

Zheng, Y., Xie, Y. & Wang, A. 2012. Rapid and wide pH-independent ammonium-nitrogen removal using a composite hydrogel with three dimensional networks. *Chemical Engineering Journal,* 179**,** 90-98.

Appendix

Appendix A: Measurements of Nitrogen and Phosphorus using palintest

Method for Nitrogen

The palintest Ammonia test is based on indophenols method. Ammonia reacts with alkaline salicylate in the presence of chlorine to form a green blue indophenols complex. Catalysts are provided in the form of two tablets for maximum convenience. The test is simply carried out by adding one of each tablet to a sample of the water. The intensity of the color produced in the test is proportional to the ammonia concentration and is measured using palintest photometer.

Test instructions

- Fill the tube with sample to the 10m mark
- Add one ammonia number 1 tablet and number 2 tablets, crush and mix to dissolve.
- Stand for ten minutes to allow color development
- Select phot004 on photometer to measure Ammonia mg/ N or select phot062 on photometer to measure Ammonium mg/ NH4.

NB: 1. At low temperature the rate of color development in the test may be slower. If the sample temperature is below 20^0C allow 15 minutes for the color to develop.

2. Ammonia concentration can be expressed in a number of different ways. The following factors may be used for the conversion of readings:

- To convert from N to NH4 multiply N reading by 1.3
- To convert from N to NH3 multiply N reading by 1.2

Method for phosphorous

The palintest phosphate HR test is based on the Vanadom Olybdate method. In the test phosphate react with ammonium molybdate, in the presence of ammonium vanadate, to form the yellow phosphovanado molybdate. The intensity of the color produced in the test is

proportional to the phosphate concentration and is measured using palintest photometer number 029.

Test Instruction

- Fill test tube with sample to the 10m mark
- Add one photometer high range tablet, crush and mix to dissolve
- Stand for 10 minutes to allow full color development
- Select phot029 on photometer
- Take photometer reading in usual manner
- The result is displayed as mg/ PO_4

Appendix B: Laboratory equipment pictures



A) Palintest photometer 7100



B) Hanna educational pH meter- HI 8010



C) Mechanical shaker



D) Centrifuge tube 50ml



E) Sieve analysis



F) Grinding machine

Annex

Annex A: Optimization of pH

Urine storage time: 15 days Mixing speed: 200rev/min

Contact time: 90min.

Adsorbent: corn cob (0.2g)

	final value at different pH					
pH	3	4	5	6	7	8
N(mg/l)	2.96	2.07	1.51	0.42	0.74	0.64
P(mg/l)	973	660	633	534	504	549
eff N CC	37.15%	56.05%	67.94%	91.08%	84.29%	86.41%
eff P CC	32.43%	54.17%	56.04%	62.92%	65.00%	61.88%

Adsorbent: coffee husk(0.2g)

	final value at different pH					
pH	3	4	5	6	7	8
N(mg/l)	3.08	1.88	0.94	0.53	0.73	0.95
P(mg/l)	1040	797	661	521	514	548
eff N CH	34.61%	60.08%	80.04%	88.75%	84.50%	80%
eff P CH	27.78%	44.65%	54.10%	63.82%	64.31%	62%

Adsorbent: water hyacinth(0.2g)

	final value at different pH					
pH	3	4	5	6	7	8
N	3.08	2.13	0.96	0.66	0.54	0.76
P	1059	708	561	486	539	558
eff N WH	34.61%	54.78%	79.62%	85.99%	88.54%	83.86%
eff P WH	26.46%	50.83%	61.04%	66.25%	62.57%	61.25%

Urine storage time: 1 month Mixing speed: 200rev/min

Contact time: 90min.

Adsorbent: corn cob (0.2g)

	final value at different pH					
pH	3	4	5	6	7	8
N	4.29	1.84	1.23	0.42	0.82	1.24
P	71.3	44.4	40.8	32.1	47.4	53.8
eff N CC	35.00%	72.12%	81.36%	93.64%	87.58%	81.21%
eff P CC	24.39%	52.92%	56.73%	65.96%	49.73%	42.95%

Adsorbent type: coffee husk(0.2g)

	final value at different pH					
pH	3	4	5	6	7	8
N(mg/l)	4.48	2.26	1.94	0.83	1.04	1.45
P(mg/l)	74	69.7	56.1	52.1	51.4	54.8
eff N CH	32.12%	65.76%	70.61%	87.42%	84.24%	78.03%
eff P CH	21.53%	26.09%	40.51%	44.75%	45.49%	41.89%

Adsorbent type: water hyacinth

	final value at different pH					
pH	3	4	5	6	7	8
N(mg/l)	4.52	3.13	1.96	0.92	1.04	1.66
P(mg/l)	71.9	60.8	56.1	53.9	48.6	55.8
eff N WH	31.52%	52.58%	70.30%	86.06%	84.24%	74.85%
eff P WH	23.75%	35.52%	40.51%	42.84%	48.46%	40.83%

Urine storage time: 2 month Mixing speed: 200rev/min

Contact time: 90min. Biochar dosage: 0.2g

Adsorbent type: corn cob

	final value at different pH					
pH	3	4	5	6	7	8
N(mg/l)	4.95	2.62	1.71	0.52	1.08	1.34
P(mg/l)	58.8	38.8	30.3	26.3	29.4	31.6
eff N CC	36.54%	66.41%	78.08%	93.33%	86.15%	82.82%
eff P CC	33.48%	56.11%	65.72%	70.25%	66.74%	64.25%

Adsorbent type: coffee husk

	final value at different pH					
pH	3	4	5	6	7	8
N(mg/l)	5.57	3.48	2.04	1.78	2.11	2.52
P(mg/l)	63.9	51.7	42.6	38.7	45.4	46.9
eff N CH	28.59%	55.38%	73.85%	77.18%	72.95%	67.69%
eff P CH	27.71%	41.52%	51.81%	56.22%	48.64%	46.95%

Adsorbent type: water hyacinth

	final value at different pH					
pH	3	4	5	6	7	8
N(mg/l)	5.68	3.45	2.22	1.98	2.35	2.76
P(mg/l)	65.4	58.8	50.1	35.3	47.2	49.8
eff N WH	27.18%	55.77%	71.54%	74.62%	69.87%	64.62%
eff P WH	26.02%	33.48%	43.33%	60.07%	46.61%	43.67%

Annex B: Optimization of biochar dosage

Urine storage time: 15 days Mixing speed: 200rev/min Biochar dosage=0.2g

Contact time: 90min. pH: 6

Adsorbent type: corn cob

	final values at different dosage				
Dosage(g)	0.2	0.4	0.6	0.8	1
N (mg/l)	1.6	0.28	0.55	0.86	1.06
P (mg/l)	928	431	516	546	577
eff N CC	66.03%	94.06%	88.32%	81.74%	77.49%
eff P CC	36.18%	70.36%	64.51%	62.45%	60.32%

Adsorbent type: coffee husk

	final values at different dosage				
Dosage(g)	0.2	0.4	0.6	0.8	1
N(mg/l)	1.83	0.31	0.51	0.71	0.84
P(mg/l)	968	602	776	904	943
eff N CH	61.15%	93.42%	89.17%	84.93%	82.17%
eff P CH	33.43%	58.60%	46.63%	37.83%	35.14%

Adsorbent type: water hyacinth

	final values at different dosage				
Dosage(g)	0.2	0.4	0.6	0.8	1
N(mg/l)	2.68	0.44	0.68	0.93	1.04
P(mg/l)	1087	660	758	846	901
eff N WH	43.10%	90.66%	85.56%	80.25%	77.92%
eff P WH	25.24%	54.61%	47.87%	41.82%	38.03%

Urine storage time: 1 month Mixing speed: 200rev/min

Contact time: 90min.pH: 6

Adsorbent type: corn cob

	final value at different dosage				
Dosage(g)	0.2	0.4	0.6	0.8	1
N(mg/l)	2.04	1.04	0.32	0.63	1.16
P(mg/l)	56.5	38.6	43	50.8	51.7
eff N CC	69.09%	84.24%	95.15%	90.45%	82.42%
eff P CC	40.08%	59.07%	54.40%	46.13%	45.17%

Adsorbent type: coffee husk

	final value at different dosage				
Dosage(g)	0.2	0.4	0.6	0.8	1
N(mg/l)	2.42	1.91	0.88	0.59	1.1
P(mg/l)	57.5	43.2	55.7	57.9	59.8
eff N CH	63.33%	71.06%	86.67%	91.06%	83.33%
eff P CH	39.02%	54.19%	40.93%	38.60%	36.59%

Adsorbent: water hyacinth

	final value at different dosage				
Dosage(g)	0.2	0.4	0.6	0.8	1
N(mg/l)	3.1	1.82	0.92	0.87	0.97
P(mg/l)	63.6	43.6	44.9	48.4	45.4
eff N WH	53.03%	72.42%	86.06%	86.82%	85.30%
eff P WH	32.56%	53.76%	52.39%	48.67%	51.86%

Urine storage time: 2 month Mixing speed: 200rev/min

Contact time: 90min.pH: 6

Adsorbent type: corn cob

	final value at different dosage				
Dosage(g)	0.2	0.4	0.6	0.8	1
N(mg/l)	2.26	1.09	0.86	0.49	1.44
P(mg/l)	37.6	20.2	29	31.9	33
eff N CC	71.03%	86.03%	88.97%	93.72%	81.54%
eff P CC	57.47%	77.15%	67.19%	63.91%	62.67%

Adsorbent type: coffee husk

	final value at different dosage				
Dosage(g)	0.2	0.4	0.6	0.8	1
N(mg/l)	2.35	1.28	1.05	0.89	1.34
P(mg/l)	43.7	29.1	34.7	35.6	36.7
eff N CH	69.87%	83.59%	86.54%	88.59%	82.82%
eff P CH	50.57%	67.08%	60.75%	59.73%	58.48%

Adsorbent type: water hyacinth

	final value at different dosage				
Dosage(g)	0.2	0.4	0.6	0.8	1
N(mg/l)	2.78	1.66	1.51	1.11	1.63
P(mg/l)	50.8	37.9	44.4	45.6	41.8
eff N WH	64.36%	78.72%	80.64%	85.77%	79.10%
eff P WH	42.53%	57.13%	49.77%	48.42%	52.71%

Annex C: Optimization of contact time

Urine storage time: 15 days Mixing speed: 200rev/min

Biochar dosage: 0.4g pH: 6

Adsorbent type: corn cob

	final value at different contact time				
time(min.)	30	60	90	120	150
N(mg/l)	1.98	0.74	0.74	0.87	0.89
P(mg/l)	934	506	482	501	523
eff N CC	58.40%	84.45%	84.45%	81.72%	81.30%
eff P CC	36.03%	65.34%	66.99%	65.68%	64.18%

Adsorbent type: coffee husk

	final value at different contact time				
time(min.)	30	60	90	120	150
N(mg/l)	2.04	1.29	0.81	0.81	0.85
P(mg/l)	956	294	323	394	516
eff N CH	57.14%	72.90%	82.98%	82.98%	82.14%
eff P CH	34.52%	79.86%	77.88%	73.01%	64.66%

Adsorbent type: water hyacinth

	final value at different contact time				
time(min.)	30	60	90	120	150
N(mg/l)	2.19	1.89	0.92	1.08	1.12
P(mg/l)	969	365	426	462	501
eff N WH	53.99%	60.29%	80.67%	77.31%	76.47%
eff P WH	33.63%	75.00%	70.82%	68.36%	65.68%

Urine storage time: 1 month Mixing speed: 200rev/min

Biochar dosage: 0.6g pH: 6

Adsorbent type: corn cob

	initial	final value at d/ent contact time				
time (min)		30	60	90	120	150
N(mg/l)	6.66	2.96	0.78	0.51	0.48	0.58
P (mg/l)	98.9	52.6	40.3	28.3	31.1	30.8
eff N CC		55.56%	88.29%	92.34%	92.79%	91.29%
eff P CC		46.81%	59.25%	71.39%	68.55%	68.86%

Adsorbent type: coffee husk

Biochar dosage: 0.8g

	initial	final value at different contact time				
time (min)		30	60	90	120	150
N(mg/l)	6660	3090	1010	620	740	730
P(mg/l)	989	555	423	291	333	314
eff N CH		53.60%	84.83%	90.69%	88.89%	89.04%
eff P CH		43.88%	57.23%	70.58%	66.33%	68.25%

Adsorbent type: water hyacinth

Biochar dosage: 0.6g

	initial	final value at different contact time				
time(min)		30	60	90	120	150
N(mg/l)	6660	3310	1110	890	1050	1010
P(mg/l)	989	612	404	329	346	352
eff N WH		50.30%	83.33%	86.64%	84.23%	84.83%
eff P WH		38.12%	59.15%	66.73%	65.02%	64.41%

Urine storage time: 2 month Mixing speed: 200rev/min

Biochar dosage: 0.8g pH: 6

Adsorbent type: corn cob

	initial	final value at different contact time				
time(min.)		30	60	90	120	150
N(mg/l)	8860	2870	110	520	190	220
P(mg/l)	984	453	174	309	202	243
eff N CC(%)		67.61%	98.76%	94.13%	97.86%	97.52%
eff P CC(%)		53.96%	82.32%	68.60%	79.47%	75.30%

Adsorbent type: coffee husk

	initial	final value at different contact time				
time(min.)		30	60	90	120	150
N(mg/l)	8860	3760	1950	690	710	710
P(mg/l)	984	534	284	313	369	496
eff N CH		57.56%	77.99%	92.21%	91.99%	91.99%
eff P CH		45.73%	71.14%	68.19%	62.50%	49.59%

Adsorbent type: water hyacinth

	initial	final value at different contact time				
time(min.)		30	60	90	120	150
N(mg/l)	8860	4520	1260	1200	1180	1240
P(mg/l)	984	652	416	356	423	528
eff N WH		48.98%	85.78%	86.46%	86.68%	86.00%
eff P WH		33.74%	57.72%	63.82%	57.01%	46.34%

Annex D: laboratory works

Before pyrolysis



A) Corn cob

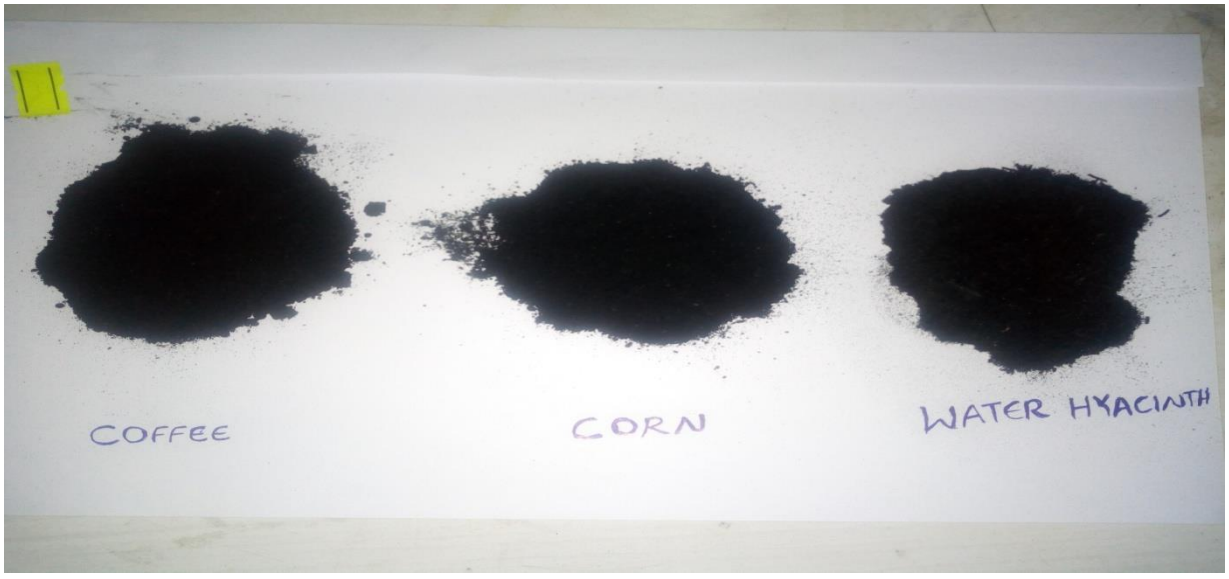


(B) Coffee husk



C) Water hyacinth

After pyrolysis





sample mixed with biochars