ASSESSMENT OF URANIUM LEVELS IN SELECTED SOILS AND ITS UPTAKE BY RICE, MAIZE AND MILLET IN BAHI DISTRICT, TANZANIA

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A DISSERTATION SUBMITTED IN PARTIAL FULFILMENT
OF THE REQUIREMENTS FOR THE DEGREE OF MASTER
OF SCIENCE IN SOIL SCIENCE AND LAND MANAGEMENT
OF THE SOKOINE UNIVERSITY OF AGRICULTURE.
MOROGORO, TANZANIA.

2014

ABSTRACT

This research aimed to determine levels of uranium (U) contamination in selected agricultural soils of Bahi District and its uptake by food crops in order to enhance public awareness and safety. The research involved determination of spatial distribution of U in agricultural soils, its uptake and translocation in plant/crop tissues. Soil, plant and water samples were collected randomly from farmers' fields and water sources, respectively. Laboratory sample analysis was done at the Government Chief Chemist Laboratory in Dar es Salaam and Soil Science Laboratory at the Sokoine University of Agriculture. Substantial differences of U concentrations in soils, plants and water were determined. The highest U level in soil profiles was 74.8 $\mu g\ kg^{-1}$ at Mpamantwa and the lowest was 18.3 $\mu g\ kg^{-1}$ at Ilindi. Along the studied transects, the highest U level was 743 $\mu g\ kg^{-1}$ at Bahi and lowest was 13.6 $\mu g\ kg^{-1}$ at Ilindi. Uranium concentrations in maize and rice were below detectable limit (<10 $\mu g\ L^{-1}$) except for finger millet where U accumulation levels ranged from 10.4 to 32.0 $\mu g\ kg^{-1}$. The concentration of U in water differed from village to village. The highest U level of 1233 $\mu g\ L^{-1}$ was found in Ilindi village at Ilindi Playa Lake whereas in Bahi the highest U concentration was 62.9 $\mu g\ L^{-1}$ found in one of the Bubu tributaries under the bridge. The concentrations of U in water in Ilindi and Bahi villages were more than 30 $\mu g\ L^{-1}$ the tolerable limit set by WHO for human and animal consumption. The levels of U in soils and crops were within the tolerable limit for agricultural use and the environment. Further studies should be carried out for other types of crops that are grown in the Bahi District villages to assess their safety for human consumption.

DECLARATION

I, Clavery Athanas Makoti, do hereby declare to the Senate of Sokoine University of Agriculture that this dissertation is my own original work and that it has neither been submitted nor being currently submitted for a degree award in any other institution.

Makoti — 14/8/2014

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ACKNOWLEDGEMENTS

All acclamations and appreciations are to Almighty GOD, Who is the Creator of the Universe, the Cherisher and Sustainer of the world, Lord of all things, Master of the Day of Judgment and Hath Power over all things (the Most Gracious, the Most Merciful). All respects are due to Holy Jesus Christ (Peace be upon him), the greatest social reformer and revolutionary, who is a symbol of guidance and fountain of knowledge (GOD's bless for us all).

Sincere appreciations are due to my supervisors, Dr. E.M. Marwa and Dr. A.K. Kaaya, of the Department of Soil Science, SUA, for their stimulating and relentless guidance and counseling throughout this study. The acknowledgements of the help I received from them are made with both pleasure and emphasis. They have been instrumental and always remained a positive factor even in the worst moments. I am profound of their insistence on nothing less than excellence at every opportune time.

I wish to express my special thanks to Mr. Eliakira Kisetu of Sokoine University of Agriculture who provided additional technical skills on graphics drawings and interpretations, GenStat Software applications and the editing time he devoted on polishing this manuscript to scientifically sounding and shiny document.

I am once again highly indebted to Mr. Eliakira Kisetu of the Sokoine University of Agriculture (SUA) who markedly encouraged me to apply for sponsorship in Masters Programme under RUFORUM Project tenable at SUA. This study could not be done without full financial support from the RUFORUM Secretariat.

I wish to express my profound gratitude to Prof. B.M. Msanya, and Mr. Joel Meliyo for their appreciable assistance on reference materials and unreserved advice they provided to me during the course of this study. Their assistance made the outcomes of this study a success.

Lastly, my sincere thanks go to my employer Ministry of Agriculture, Food Security and Cooperatives for giving me permission to join for a course.

DEDICATION

This work is specifically dedicated to my lovely parents. Athanas Makoti (father) and Emelensiana Jokoma (mother) for their role as parents and tireless encouragements and assistance from birth to date, for them which paved the way and I surpassed.

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LIST OF ABBREVIATIONS AND ACRONYMS

AM	Arbuscular Mycorrhizal
ANOVA	Analysis of Variance
ATSDR	Agency for Toxic Substances and Disease Registry
b.w	Body weight
C.V	Coefficient of Variation
CCME	Canadian Council of Ministers of the Environment
CEC	Cation Exchange Capacity
EN ISO	European International Standard Organization
FAO	Food and Agriculture Organization
H_2O_2	Hydrogen Peroxide
HNO_3	Nitric Acid
ICP-OES	Inductively Coupled Plasma- Optical Emission Spectrometer
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
ISO	International Standardization Organization
LOAEL	Lowest-Observed-Adverse-Effect-Level
LSD	Least Significance Difference
$NaHCO_3$	Sodium Hydrogen Carbonate
NDMRT	New Duncan's Multiple Range Test
NOM	Natural Organic Matter
RUFORUM	Regional Universities Forum for Capacity Building in Agriculture
s.e.	Standard Error
SRI	System of Rice intensification
SUA	Sokoine University of Agriculture
TDI	Tolerable Daily Intake

U	Uranium
UNESCO	United Nations Educational. Scientific and Cultural Organization
URT	United Republic of Tanzania
USEPA	United State Environmental Protection Agency
WHO	World Health Organisation
WRB	World Reference Base

CHAPTER ONE

1.0 INTRODUCTION, JUSTIFICATION AND OBJECTIVES

1.1 Introduction

Uranium is broadly distributed in nature and occurs in most rocks in concentrations of 2000 – 4000 μg kg^{-1} and is as common in the earth's crust as tin, tungsten and molybdenum (Bleise *et al.*, 2003). Geologically, the main natural sources of U are hydrothermal veins, sedimentary rocks and pyritic conglomerate beds of Precambrian age (Bleise *et al.*, 2003). Generally, felsic rocks such as granite usually contain more U than mafic rocks such as basalt and dunite.

In agricultural soils, U is enriched by weathering of parent rocks, particularly granites (Sasmaz and Yaman, 2008), which are dominant rocks in study area. Weathering of these rocks releases the element to the soils and makes it available for plant uptake. However, migration and accumulation of U in plants depend on factors such as soil characteristics, climatic conditions, type of plants, part of the plant concerned, physico-chemical form of the U and the interfering elements (Tome *et al.*, 2003). For example, the availability of calcium (Ca) and potassium (K) in soil affect U uptake plant. This is because calcium and potassium tend to replace U in soil solution by letting U to be adsorbed in soil colloids leaving calcium and potassium in soil solution and makes them easily available to plant compared to U. In addition, soil clay factors such as illite clays of alluvial soil, which trap K in its crystal lattice and the contents of phosphate that forms insoluble compounds with U has been reported to reduce radionuclide availability of U to plants (Köhler *et al.*, 2000).

High level of U in agricultural soils enhances the chance of its assimilation and translocation to various parts of plants (Ankle *et al.*, 2009; Singh, 1997). Once released from parent rocks, U exists as U^{4+} in the reducing state and as U^{6+} in the oxidizing state. The existence in reducing and oxidizing states determine the mobility and solubility of U (Ankle *et al.*, 2009). According to Meinrath *et al.* (2003), U is soluble and mobile in oxidizing environments and it is generally insoluble in reducing conditions. Antunes *et al.* (2007) reported that U-acetates, U-sulphates, U-carbonates, U-chlorides and U-nitrates can easily dissolve in groundwater and surface waters. However, a study by Sheppard and Thibault (1992) insisted that U-carbonate is highly soluble and henceforth facilitates transportation of U to wetlands where it can be deposited and infiltrate into groundwater.

Natural organic matter (NOM) contains functional groups that can form complexes with metals, including U and the formed complexes can affect the physical and chemical properties of the affected metal (Nierop *et al.*, 2002). Complexion affects metal and radioisotope mobility, sorption to soils and bioavailability (Davydov *et al.*, 2006). Soils with high levels of organic matter greater than 17.2% possess high affinity for U, thereby causing little U released into the groundwater and plant roots due to complexes formed between insoluble organic matter fractions of the soil with U^{4+} (Crançon *et al.*,2010). In unsaturated conditions, U^{6+} in the presence of arsenates, vanadates, silicates and phosphates form insoluble minerals (Langmuir, 1978). There exists a wide variation among plant species in the ability to absorb U from soils via roots or the translocation within the plant (Neves *et al.*, 2009). Laroche *et al.* (2005) reported that dicotyledonous plant species accumulate more U than monocotyledons. It has been reported that the U distribution in plants follow a pattern similar to that of Ca, which is accumulated more in older than in younger leaves of plants (Mortvedt, 1994).

U can produce chemical toxic effects especially when influencing internal organs and radiation through short distance alpha radiation of the U staying in the body. The primary means of human exposure to U are ingestion of food and water containing U isotopes or inhalation of U contaminated dust. U inhalation may result in a greater initial kidney burden than U taken via the oral route (Department of Energy, 1988). The mechanisms of toxicity involve inhibition of enzyme systems and binding to nucleic acids. Based on the observations from an experiment conducted to measure minimum radiation of U in soil and air around experimental plants, the toxic effects of U were mainly caused by chemical toxicity rather than radiation-related (Ankle *et al.*, 2009).

1.2 Problem Statement and Justification

A superficial U deposit of commercial level has recently been confirmed in Bahi District in Central Tanzania (Mbogoro and Mwakipesile, 2010). The deposits occur in the lowlands surrounding isolated hills of granites and these granites are believed to be the primary source of U (Sasmaz and Yaman, 2008). Weathering of granite releases U in sediments and facilitates its mobility by moving water. Once it is released from granites, U is mechanically moved from elevated areas to wetlands as sediments or in soluble forms and wetlands act as sinks for U accumulation (Owen and Otto, 1995). These wetlands in the area targeted by the present study are used for rice cultivation and vegetable production. Despite various studies indicating that U can be taken and accumulated in plants, the residents (local community) of Bahi District exploit these wetlands for rice and vegetable production, grazing of domestic animals as well as source of drinking water. In addition, Bahi areas are famous for maize and finger millet cropping as staple food crops. Residues of annual crops including straws after harvesting are used for feeding domestic animals, which are also consumed by man as milk and meat.

Since members of the Brassica species are classified as hyper-accumulators of U (Laroche *et al.*, 2005), it is also possible for crops like rice, maize and finger millet grown in Bahi District to accumulate high contents of U. Consequently, U in soils and in plants could be transferred from the soil to humans and other living species through the food chain where it might causes health problem such as development of cancer, kidney failure and other associated diseases (Bensoussan *et al.*, 2009). Since the local communities depend on agriculture for their livelihood, there is every possibility that the food crops grown in this district could contain U and this could have negative health effects to humans as well as livestock.

This study is intended to generate information on the levels of U contamination in agricultural soils, water and plant tissues in selected villages in Bahi District in order to create public awareness on the potential hazards posed by U to the vulnerable communities in the District. In addition, the study focuses on improving scientific knowledge on U soil/plant interactions, its mobility and contamination levels in soils and water resources as well as better understanding the ability of food crops to accumulate U in their conductive tissues.

The rationale of the research is to bring to the attention of the vulnerable communities and the government of Tanzania, the environmental and health hazards posed by U in the areas where superficial U deposits have been discovered in order to develop proper preventive measures that could be taken. This is because U and its compounds are known to be carcinogenic and highly toxic (Sasmaz and Yaman, 2008).

The broad objective of this study was therefore to assess the levels of U contamination in agricultural soil and water resources and its uptake by plants in selected villages of Bahi District. The specific objectives of this study were:

(i) To determine the concentration and spatial distribution of U in the selected soils in Bahi District.

(ii) To determine U levels in surface and underground waters used for drinking and crop irrigation in Bahi District.

(iii) To determine the extent of uptake and translocation of U in rice, maize and finger millet in Bahi District.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Uranium in Soils

2.1.1 Sources of Uranium in soils

In agricultural soils, U is enriched by weathering of parent rocks particularly granites (Sasmaz and Yaman, 2008). Most granites contain less than 0.07 wt. % U, but some may contain up to 0.3 wt. % U, the level that is regarded to be of high grade (Zhao *et al.*, 2011). Weathering of granites releases U from the parent rock and makes it available in soils for plant uptake.

A considerable quantity of U is contained in phosphate fertilizers, which could be another source of U in agricultural soils. Uranium levels in agricultural soils could be elevated by a long-term application of P-containing fertilizers (Sowder *et al.*, 2003). This idea is supported by Blanco *et al.* (2005) who reported that most of the U applied in superphosphate fertilizers to clay loam soil during periods up to 100 years was retained in the surface 23 cm deep layer of the soils. However, a study by Sowder *et al.* (2003) revealed that the degree of U accumulation in surface soils is influenced by many factors including soil type and application rate and quality of P fertilizers.

Takeda *et al.* (2005) reported that the U concentrations in the surface soils cultivated with applied phosphate fertilizers accumulated relatively higher U levels than those of neighbouring non-agricultural areas, probably because of successive application of P fertilizer (Matsuyama *et al.*, 2005).

High level of U in agricultural soils enhances the chance of its assimilation and translocation in various parts of plants (Ankle *et al.*, 2009; Singh, 1997). Uranium in soils can reach the concentration as high as hundreds of mg kg^{-1} (Rufyikiri *et al.*, 2004).

According to Ankle *et al.* (2009), soils originating from weathered granites like those found in the study area at Ilindi, Mpamantwa and Bahi villages, will produce vegetable, forage and food crops that are rich in U and when taken by grazing animals or human beings they can be a source of diseases like cancer and others associated with kidney malfunctions. This is possible because U in soils is available for plants uptake at the pH range of 4.0 to 7.5, and is most mobile as U^{6+} in hydrolyzed forms (Meinrath *et al.*, 1996). Its mobility increases the ability to spread in agricultural soils and, hence, the chance to be taken up by many crops and grasses/shrubs used for grazing animals. Semi-arid soils have less affinity for U than moist soils, increasing U mobility from the surface to deeper soil (Crançon *et al.*, 2010). U enrichment in very rich organic soils, is believed to be the result of U^{6+} transport, adsorption, or complexation by humic materials, and reduction of dissolved U(VI) to U(IV), followed by the formation of uraninite (UO_2) (Bednar *et al.*, 2007). Uranium (VI) can also be reduced by micro-organisms.

2.1.2 Uranium mobility

U transport generally occurs in oxidizing surface water and groundwater as the uranyl ion, U^{6+}, or as uranyl fluoride or carbonate complexes. The U^{6+} and uranyl fluoride complexes dominate in oxidizing acidic waters, whereas the carbonate complexes dominate in near-neutral and alkaline oxidizing waters, respectively. In contrast, the uranous ion, U^{4+}, is essentially insoluble (Gavrilescu *et al.*, 2009). An important point in considering U migration in soils is that when U^{6+} is reduced to U^{4+} by humus, peat, or other organic matter or anaerobic conditions, it is essentially immobilized. It should also be noted that phosphates and sulphides usually precipitate U and hence stop migration, a behaviour that can be exploited in remedial operations (Fellows *et al.*, 1998).

On the other hand, soil properties that affect U mobility and its subsequent uptake by biota include aeration (water saturation, high biological or chemical oxygen demand), carbonate content (organic material content, pH, parent material, weathering), and cation exchange capacity (texture, clay content, organic matter, pH) (Gavrilescu *et al.*, 2009). Soils with higher cation-exchange-capacity retain more U, while carbonate in the soil increases the mobility of U through the formation of anionic U and CO_3^- complexes (Duff and Amrhein, 1996). Uranium does not migrate substantially in loam compared to sandy soils (Schimmack *et al.*, 2007). Uranium migration in soil occurs over the period of a few months, depending on sorption, and may be upwards when there is a net water deficit or downwards as a result of net leaching (McGowen *et al.*, 2000).

2.1.3 Uranium standards in soils

According to the Canadian Council of Ministers of the Environment (CCME, 2005), both environmental and human health soil quality guidelines have been developed for four land uses: agricultural, residential/parkland, commercial and industrial. According to the recommendation given by CCME basing on Canadian Soil Quality Guidelines for the protection of environmental and human health, the acceptable levels of U are 23 000 µg kg^{-1} for agricultural land use, 23 000 µg kg^{-1} for residential/parkland land use, 33 000 µg kg^{-1} for commercial land use, and 300 000 µg kg^{-1} for industrial land use.

2.2 Uranium in Water

Drinking surface and groundwater is another possible means by which people and animals could be exposed to U (Bensoussan *et al.*, 2009). Concentration of U in drinking waters may vary between 0.05 and 8.6 µg L^{-1} (Ankle *et al.*, 2009). According to Duff and Amrhein (1996), U could be transported by water in soluble form as the uranyl ion (U^{6+}) which is a complex formed with carbonates and phosphates. Closed drainage systems that feed wetland areas like the experimental site in Bahi might have favoured accumulation of soluble U (Owen and Otto, 1995) and, thus, could be the potential source for U contamination.

In addition, thermodynamic calculations suggest that the calcium uranyl carbonate complexes may be the predominant forms of dissolved U in contaminated ground waters (Echevarria *et al.*, 2001; Davis *et al.*, 2004). Uranium acetates, sulphates, carbonates, chlorides and nitrates readily dissolve in water and their chemical form in typical groundwater and surface waters is generally dominated by the presence of carbonate species, although sulphate and phosphate may also form important species in other circumstances (Antunes *et al.*, 2007).

Under weakly acidic conditions and in groundwater, the chemical speciation of U may become dominated by the formation of stable complexes with soil organic matter. This commonly results in the retention and accumulation of U in peat deposits, although in situations where a significant proportion of the organic matter is in the dissolved form, this may assist in the dissolution and mobilization of soil-bound U (Ebbs *et al.*, 1998).

2.3 Uranium in Plants

U is a heavy metal and does not play any known nutritional role in plants. Like other heavy metals, U is tolerated in small quantities and results in toxicity when more than 40 $\mu g\ kg^{-1}$ is accumulated in plants (Singh, 1997). Uranium is absorbed by plants as hexavalent U^{6+} and that oxidation state does not change when in plant parts and remain hexavalent U^{6+} (Duquene *et al.*, 2006). Normally, U absorbed by plant tends to concentrate in their tissue in the seedling stage than in the flowering stage (Laroche *et al.*, 2005). Plants are known to absorb U through their roots, and soil sorption affects the rate of uptake in a complex nonlinear manner which cannot be understood without specific site data. On the one hand, a high U sorption rate corresponds to more U trapped within the upper soil layer, and therefore more U accessible to a plant's root structure (Sevostianova *et al.*, 2010). However, for highly immobilizing soils, plants absorb U more efficiently through their leaf stomata, in which case resuspended surface U in the atmosphere could dominate (Oxenberg *et al.*, 2006).

Uranium accumulation varies with plant species, many members of the *Brassica species* are classified as hyper-accumulators (Laroche *et al.*, 2005). Furthermore, U uptake and accumulation in plant is influenced by soil properties such as pH, cation exchange capacity (CEC), organic matter and aeration. High soil pH, CEC and good soil aeration favours U uptake while soils with high organic matter reduces uptake of U by plants (Meinrath *et al.*, 2003). Neves *et al.* (2009) found that the uptake of U by lettuce tissues was positively correlated with soil U content, but no significant differences were obtained from contaminated soils irrigated with different water quality. On other hand, arbuscular mycorrhizal (AM) has potential to reduce U uptake by plants, especially by limiting its translocation from roots to shoot (Malcova *et al.*, 2003). The increase in U accumulation around root region reduces U concentration in shoot was hypothesized as the main mechanism involved and the hyphae markedly contribute to this retention in the host root (Leyval and Joner, 2001).

In studying soil–plant transfer factors Al-Kharouf *et al.* (2008) found that the green parts (leaves, stems and roots) of most crops tend to accumulate U of about two orders of magnitude higher than fruits.

Plants also possess the potential to take up U present in soil and associated water bodies (Neves *et al.*, 2009). U in soil does not always create a radiological hazard to humans, but can cause toxicity to plants (Sheppared *et al.*, 1992; Achakzai *et al.*, 2006). The dangers arising from the biochemical toxicity of U as a heavy metal are considered to be about six times higher than those from its radioactivity (Schnug *et al.*, 2005).

2.4 Uranium Toxicity

Various studies indicate that U and its compounds are carcinogenic and highly toxic (Sasmaz and Yaman, 2008; Department of Energy, 1988). Variations in toxicity are caused by physical and chemical properties of U. The first is the short-term chemical toxicity of soluble compounds like U^{6+} by influencing directly the function of internal organs, especially of the kidneys. The second is the long term influence, because of the effect of the short distance alpha radiation of the U in the body, which could cause the development of cancer and genetic defects by deformation of chromosomes (Sasmaz and Yaman, 2008).

The mechanisms of toxicity involve inhibition of enzyme systems and binding to nucleic acids (Bensoussan*et al.*, 2009). Uranium penetrates into the organism by different paths: pulmonary (inhalation), ingestion (gastro-intestinal system) or trans-cutaneous (skin and wounds) (Calabrese, 2004). Its fate is then determined by the U compound solubility and U valence. In addition, the metal and its species are not essential or beneficial to either plants or animals. In humans, U affects brain by altering behaviour and metabolism of neurotransmitters, causes kidney failure as well as liver and heart diseases (Sasmaz and Yaman, 2008; Bensoussan *et al.*, 2009).

Uranium is assumed to be deposited on the bone surface, and the uranyl ion (U^{6+}) is assumed to be exchanged with calcium ions at the surfaces of bone mineral crystals but not to participate in crystal formation (Leggett, 1994). Gradually, U is redistributed in the bone and other tissues. The current biokinetic model of the International Commission on Radiological Protection suggests three compartments for U in human bone, bone surface, exchangeable bone volume and non-exchangeable bone volume (Burkat *et al.*, 2005). It also suggests that U leaves bone surfaces more slowly than does calcium and that the removal from the non-exchangeable bone compartment may occur but with the rate of bone turnover (Pellmar, 2003).

The ability of U to cause toxicity depend on factors such exposure pathway, particle size and solubility. The soluble U compounds are like U^{6+} are said to cause toxicity when are subsequently absorbed in blood and deposited in kidney or other organs. on the other hand. Insoluble and sparingly soluble U compounds such as UO_2, UO_3, and U_3O_8 are believed to have little potential to cause renal toxicity but could cause pulmonary toxicity through inhalation exposure (Burkart *et al.*, 2005).

According to ATSDR (1999), permissible limit of U in drinking water is 2.0 $\mu g\ kg^{-1}\ d^{-1}$ whereas the recommended limit set by United State Environmental Protection Agency (USEPA) is 3.0 $\mu g\ kg^{-1}\ d^{-1}$ (Craft *et al.*, 2004). In humans. some studies suggest small functional changes in the kidney when humans are exposed to high (natural) U doses with drinking water. Slight functional effects on the kidney are reported at doses of 20 to 200 $\mu g\ U\ d^{-1}$ (Zamora *et al.*, 2009).

CCME (2005), defined the term Tolerable Daily Intake (TDI) as the intake of a chemical to which it is believed that a person can be exposed daily over a lifetime without deleterious effect. In other words, the TDI is the amount of exposure that is considered to be unlikely to cause adverse health effects in the general population, including sensitive individuals, but excluding those with allergy or other hypersensitivity. Based on a sub-chronic study using rats CCME (2005) derived a Tolerable Daily Intake (TDI) for U being 0.6 $\mu g\ kg^{-1}$.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Description of the Study Area

3.1.1 Location

This study was conducted in three villages of Bahi District in Dodoma Region, namely Ilindi, Mpamatwa and Bahi. The three villages were selected basing on topographic features and economic potentials. In those villages there are lowlands/wetlands surrounded by hills of granites which are believed to be the primary source of U and wetlands act as the sink were U can accumulate. Administratively, Bahi District has four divisions, 21 wards and 56 villages (Swai *et al.*, 2012). The District is situated in the central Tanzania about 56 km west of Dodoma City (Fig.1). It lies between Latitudes 4° and 8° South and Longitudes 34° and 38° East. It borders Kondoa District to the North and Manyoni District to the West.

3.1.2 Climate

Bahi is a semi-arid District (Swai *et al.*, 2012). It has a dry savannah type of climate, which is characterized by uni-modal and erratic rainfall that falls between late November and mid April. The annual average rainfall is about 500 to 700 mm and means monthly temperature is about 22.6 °C (Swai *et al.*, 2012). The District experiences flash floods during rainy seasons. In addition, it has high evaporation rate and severe soil erosion, which is caused by strong winds and relative low humidity. The District experiences long dry seasons from mid April to late November each year.

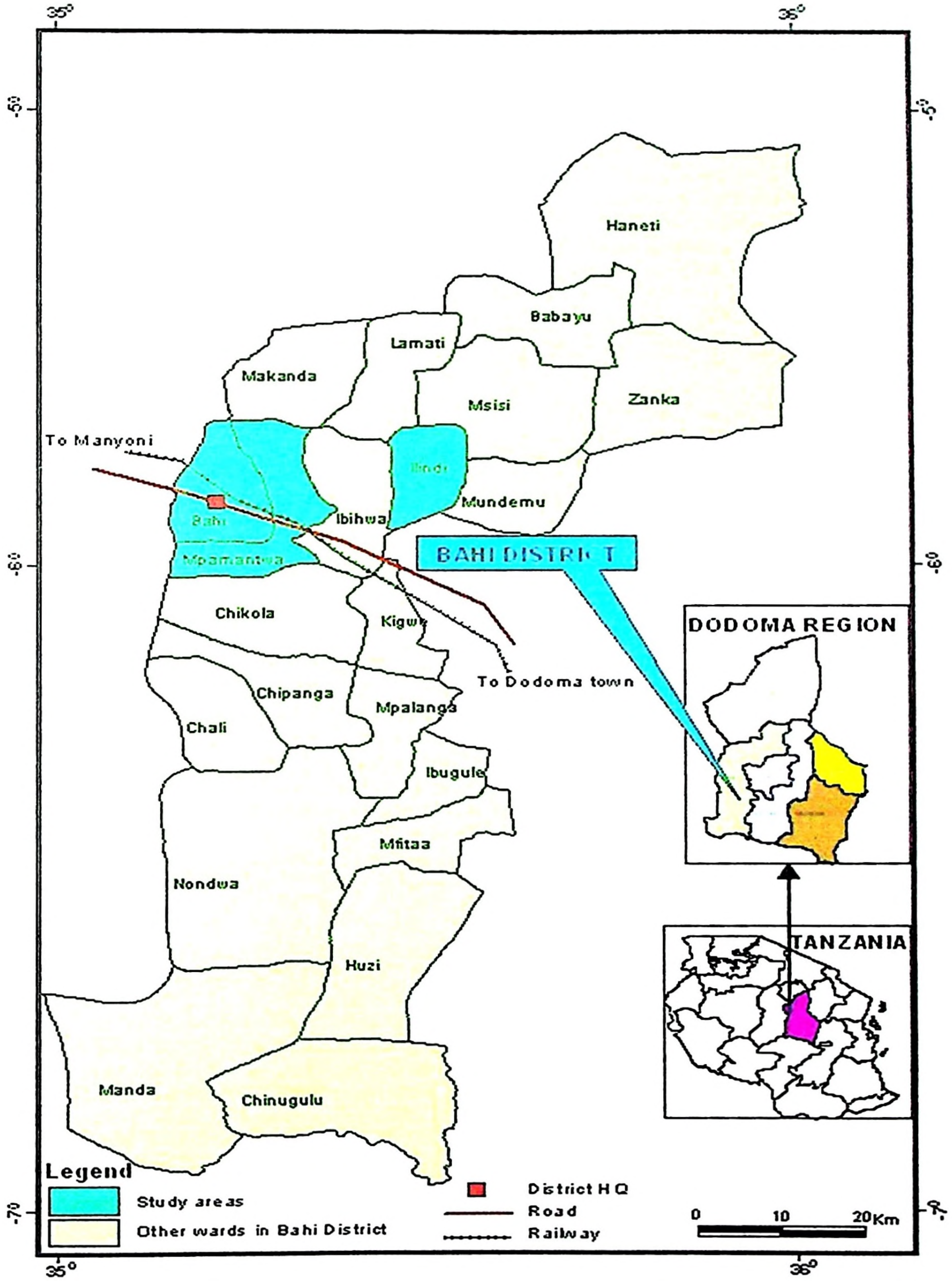

Figure 1: Location map of the study area

3.1.3 Land use

The economics of Bahi District depend mainly on agriculture (crops and livestock production). About 80 percent of the population is engaged in the agricultural related activities. The major food and cash crops grown include finger millet, sorghum, maize, paddy, cassava, potatoes, peanuts, groundnuts, sunflower, simsim, grapes and pigeon peas (URT, 2003). Cattle and goat are the dominant livestock that are found in the district. Livestock are used as a source of meat, milk and cash when sold. Productions of salt and soda ash as well as fishing are another economic activities taking place in the studied area. Fishing is carried out in swamps and rivers, which are in Bahi and Ilindi villages. Salt and soda ash are mainly produced at Ilindi village for local consumption in Dodoma Region and some are exported to other areas within the country and outside the country to Burundi and Rwanda.

3.1.4 Topography

Bahi District is situated in the central Tanzanian plateau, which is a peneplain with a number of isolated hills of granites (granitic in selbergs). Among these hills is Chenene hill on the North of Bahi District. Between and around these granitic hills are lower lying relatively flat areas with elevation of 800 m above sea level. A number of depressions are associated with these lower areas. They are generally water lodged during the rainy season and have a tendency of salinity because of limited out flows and are locally known as mbuga. A number of these water lodged wetlands are seasonal; most of them get dry during dry seasons. Water leaves these wetlands mostly by evapotranspiration. The District has one river system called Bubu River, which has impeded drainage. The river drains its water into Bahi swamp, which is used by farmers for growing rice and livestock keepers for grazing domestic animals. Water in this swamp is slightly saline. The Bubu River is along the southern tip of the Gregory Rift valley, which extends from Ethiopia via Kenya.

3.1.5 Geology

Bahi District is within the Tanzanian Craton, which covers part of Dodoma, Singida, Tabora, Shinyanga, Mwanza and Mara Regions. The Craton is the stable part of the continental crust that has not undergone much of plate tectonic or orogenic activity for millions of years. The rocks in these regions are more than 570 million years old. Rocks in the western part of Dodoma Region including the Bahi District belongs to what is called "DodomanSupergroup". This group of rocks consists mainly of Precambrian granites with some migmatites, gneisses, amphibolites, and schist. In some areas these rocks have been intruded by mafic dykes and quartz veins (Macheyeki *et al.*, 2008). Granites are the dominant rocks (Plate 1).

The main depression in the study area is Bahi depression. This Bahi depression, which trend nearly north-south, is half graben structure bound by south-west trending faults, locally called Bubu faults and the south-eastern side down-thrown Faults, called Bahi and Sansawa faults (Knivsland, 2012). On the eastern side, this depression is bound by Dodoma-Kigwe faults. All these faults are part of the East Africa Rift System (Macheyeki *et al.*, 2008).

The ancient land surfaces in some areas of the study area have been exposed to prolonged weathering which has resulted in the formation of a mantle of alteration products (regolith). The regolith is normally built up of a collapse zone on the top with the weathered overburden (saprolite) below. Extensive weathering has led to the formation of lowlands locally known as Dambo areas ormbuga.

Plate 1: Granitic rocks in Bahi District

3.1.6 Soil

Bahi District is largely covered by granites rocks (Plate 1). Weathering of these granites has resulted into sandy soils dominated by sandy particles, classified as Cambisols. The soils dominated by sandy particles are usually of low fertility status and low soil organic matter. Majority of these soils are of shallow depth typically overlaying weathered basement rock.

On the other hand, the area around Bahi Swamp is characterized by different types of soil. Some soils are dominated by clayey subsoils classified as Vertisols. The soil is of greyish brown to dark gray colour. Sand washes are found on the soil surface in lowlands, which is believed to be brought from upland through sheet erosion. The parent materials are composed of colluvial (gravitational flow from upland) and recent alluvial materials deposited by the Bubu River. Salt content in soils is generally high in some areas and during dry season salt pans crystallize at the top soil.

3.2 Field Sampling of Soils, Water and Plant Materials

3.2.1 Soil sampling and characterization

Based on information gathered from topographic map of the area, two transects were identified in each village. Along these transects, depending on the length of the slope, topsoils were systematically sampled at upper, middle and lower slopes at an interval of approximately 100 m in Ilindi, 200 m in Mpamantwa and about 400 m in Bahi. Taking into consideration the average rooting depth of the most common annual crops grown in area, one composite top soil (0-30 cm) was taken from each of these locations, making a total of 3 topsoil samples from each transect. From each sampling site about 1 kg of composite soil was made up by mixing at least four subsamples. Therefore, a total of six soil samples were collected from each of the three villages. In total, 18 composite soil samples were collected from the selected transects for further characterization in the Soil Science Laboratory at Sokoine University of Agriculture.

With the information from the topographic map, a quick reconnaissance survey was carried out to identify existing land use, vegetation cover and the dominant soil types were identified in each village for further characterization. In each village, a representative soil profile was excavated in the identified dominant soil type. The soil profile was then examined and described using the descriptive terminology outlined in the Guidelines for Soil Profile Description (FAO, 1990). Moist and dry soil colours were described using Munsell Soil Colour Charts (1992). Bulk soil samples were taken from each horizon for further physical and chemical analysis in the Laboratory. Physical and chemical analyses of selected soil properties were carried out in the Soil Science Laboratory at Sokoine University of Agriculture. The same soil samples were also taken to Government Chief Chemist Laboratory in Dar es Salaam for analysis of U contents.

Plate 2: Describing soil profile at Ilindi village

3.2.2 Water sampling

Water samples were collected to assess whether water is a carrier of U and to evaluate their safety for domestic use. Four water sources were randomly selected from each village and water samples of 0.25 L each was collected in triplicate from each source. The surface water from the rivers was taken in different position such as upstream, at the middle and downstream at approximately 100 m. In dams, water samples were taken from the edges and at the middle of the damas shown in Plate 3. Water samples from the taps water were left to run for about 2 minutes, in order to empty standing water before collection.

Plate 3: Water sampling in one of Bahi water source

3.2.3 Sampling of soil and plants parts to determine uranium uptake and translocation

The main objective of this sampling was to determine U contents in soil and plant parts as well as to deduce translocation factor of U from soil into maize, rice and finger millet tissues. Samples of soil, rice, finger millet and maize tissues were randomly selected from Ilindi, Mpamantwa and Bahi villages in farmers' field at maturity stage. Sampling involved collection of triplicate sets of soils, plant shoot and grain samples in each farm at approximately 30 m apart. In Bahi village, a total of 15 samples of soils, rice shoots and rice grains were collected from five farms. In Mpamantwa, a total of 18 samples were collected from six farms of which 9 samples were collected from 3 maize farms and 9 samples were collected from 3 finger millet farms. In each farm, three set of soil, shoot and grains of maize and finger millet were collected. A total of 18 samples were also collected from Ilindi village with the same manner as described in Mpamantwa. In Bahi, samples of soil, rice shoot and grains were also collected making total of 51 samples collected in all three villages. The rice, maize and finger millet shoots were cut approximately 15 cm from ground to avoid soil contamination.

3.3 Laboratory Analyses

3.3.1 Preparation of soil samples and laboratory analyses

The soil samples from the field were air dried, crushed and sieved through 2 mm sieve to obtain fine earth for physical and chemical analyses. Analysis of the physical and chemical properties of the soil samples was conducted in the Soil Science Laboratory of the Sokoine University of Agriculture while analysis for U concentrations in these samples were carried out at the Government Chief Chemist Laboratory, Dar es Salaam.

Plants samples of shoots and grains of maize, millet and rice were washed thoroughly with dionized water and then oven-dried at 70 °C to the constant weight. Then the samples were ground to pass a 0.5 mm sieve and these were used for chemical analyses.

3.3.2 Physical and chemical analysis of soil samples

Particle size analysis of the soil samples was carried out by hydrometer method (Gee and Bauder, 1986) after dispersion with sodium carbonate and shaking overnight. For chemical analysis, the following chemical properties were determined: pH in both water and KCl, organic carbon, total nitrogen, available phosphorus, exchangeable bases and cation exchange capacity.

The soil pH was determined with a pH meter (combination electrode) in the supernatant suspension of 1:2.5 soils: liquid mixture as outline by Ranst *et al.* (2000). This was done both in water and in 1 M KCl solution. Organic carbon was determined following the wet-oxidation method of Walkley and Black which involves wet combustion of organic matter with potassium dichromate –sulphuric acid mixture followed by titration of residual dichromate with ferrous sulphate (Nelson and Sommers. 1982). Organic matter was obtained by multiplying the corresponding organic carbon value by the Vant Hoff's factor of 1.72 as recommended by Kalra *et al.* (1991). Total N was determined by Semi-Micro Kjeldahl method (Bremner and Mulvaney, 1982). Available Phosphorus in soils with pH < 7.0 was extracted by Bray and Kurtz method, whereas Olsen method using $NaHCO_3$ for extraction was employed in neutral and alkaline soils as outlined by Olsen and Sommers (1982).

The cation exchange capacity (CEC) and exchangeable bases were determined by saturating the soil with neutral 1 M Ammonium acetate (CH_3COONH_4) (Sumner and Miller. 1996). The adsorbed NH_4^+ ions were displaced with K^+ using 1 M KCl and then determined by the Kjeldahl distillation method for the estimation of CEC of the soils. The exchangeable bases Ca^{2+}, Mg^{2+}, Na^+ and K^+ displaced by NH_4^+ were measured by atomic absorption spectrophotometer (Sumner and Miller, 1996).

3.3.3 Laboratory analysis of soils, plants, and water for uranium contents

3.3.3.1 Determination of uranium in soils

Fine earth was used for laboratory U analysis. Exactly 0.5 g of soil samples was weighed in a test tube by using an analytical balance (EN ISO 20483, 2006). The tubes were then placed in fume chamber and 5 ml of hydrogen peroxide (H_2O_2) were added followed by 10 ml of 60% nitric acid (HNO_3) and finally 5 ml of hydrogen peroxide (H_2O_2) was added making the ratio of nitric acid against hydrogen peroxide to be 1:1. About 5 granules of aluminum trioxide were added with the aim of minimizing overflow of the digested liquid from the tube. The temperature of the hot plate digester was left to reach 180 °C and then soil samples for digestion were put on the digestion block for 1 h. The digested samples were transferred into 100 ml volumetric flask and topped up to the volume with distilled water. Blank and reference standard (Spexcertiprep, from the United States of America) were prepared following the same procedures used by samples. The purpose of this was to control the quality of the analysis by assessing contamination introduced during sample preparation. The liquid standard was made in different concentrations and put into auto sampler together with other samples.

Analyses of U from the extracts were carried out using an Inductively Coupled Plasma Optical Emission Spectrometer (ICP-OES) as shown in plate 4usingthe method recommended by ISO217 (2007). The laboratory analysis of soil was carried out in Dar es Salaam at the Government Chief Chemist Laboratory.

3.3.3.2 Laboratory analysis of the plant samples

The 0.5g of finger millet, rice and maize samples were weighed and then transferred into the digestion tubes. Digestion procedures recommended by ISO217 (2007) were also used for plant analysis. The extract obtained after digestion were placed in 100 ml volumetric flask and top up to volume with distilled water. About 10 ml was put into vials and U concentration was read directly using Inductively Coupled Plasma Optical Emission Spectrometer (ICP-OES) and result expressed in µg kg-^{1}.

3.3.3.3 Laboratory analysis of water samples

Nine ml of water sample was mixed with 1ml of 1% H_2NO_3 making a total volume of 10 ml. This volume was put into vials and U concentration was read directly using Inductively Coupled Plasma Optical Emission Spectrometer (ICP-OES).

Plate 4: The ICP-OES machine used for U analysis

3.4 Statistical Data Analysis

Statistical data evaluation on U concentration was done by statistical software GenStat 14th edition. The analysis of variance (ANOVA) was employed and the means were compared by the Least Significance Difference (LSD) at 5% level of probability based on Duncan's New Multiple Range Test where high and low levels of U in soils, shoots and grains were identified.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Physical and Chemical Properties of Soils

4.1.1 Morphological and physical properties

The soils of Ilindi and Mpamantwa villages are moderately deep to deep and well drained whereas soils of Bahi village are deep and somewhat poorly drained to moderately drained. The soils of Ilindi and Mpamantwa have developed from the weathering of granite rocks found in the area while those of Bahi have developed from alluvial materials. The effective soil depth is locally restricted by impervious parent material, which is weathered granite. Site observations carried out during this study revealed that the soils of Ilindi village are yellowish brown to yellowish-brown and were classified as Cambisols (Appendix 1). In Mpamantwa village, the soils are reddish brown to light brown in colour (Appendix 2). In both villages, the soils are sandy with wet consistence being non-sticky and non-plastic throughout the profile. When dry both soils are slight hard throughout the profile with many media (1-2 cm) hard spherical black and brownish iron-manganese (sesquioxides). Based on the low pH and low Percentage Base Saturation (PBS) the soils of Ilindi and Mpamantwa villages were classified as *Dystric Cambisols* (WRB, 2006).

In contrast, in Bahi village the dominant soil is very dark greyish brown to greyish brown in colour. At the top, the soil is sandy clay loam because of alluvial sands deposited by Bubu River while the subsoils are mainly clayey (Appendix 3). The topsoil in Bahi village is mainly moderate fine to strong medium angular block. The wet consistence of this soil is very sticky and very plastic throughout the profile. The soil is very hard when dry and firm when moist.

The subsoils are characterized by accumulation of calcium carbonates. The soil surface was characterized by gilgai micro-relief due to alternating swelling and shrinking of expanding clays. Deep and closely to moderate widely spaced cracks were observed on the surface. The presence of Bubu River indicates that the soil in Bahi village has developed from alluvial /fluvial deposition. Due to occurrence of carbonates in the subsoils, the soils were classified as *Calcic Vertisols* based on WRB (2006). Similar classification of soils of Bahi was reported by Martin (2008).

4.1.2 Chemical properties

Laboratory analysis showed that soils in Ilindi and Mpamantwa villages have low cation exchange capacity (CEC) and low base saturation indicating that these soils are infertile (Appendices 1 and 2). The topsoils in Ilindi and Mpamantwa villages had low CEC of <10.67 and <7.9 cmol (+) kg^{-1}, respectively due mainly due to high sand contents. The CECs of Ilindi and Mpamantwasoils profiles increased slightly with soil depth due to increase of clay contents with soil depth. The base saturation is < 31% throughout the two profiles. The level of exchangeable sodium in the top soil is low with value of 0.11 cmol (+) kg^{-1}, but slightly increased with soil depth to 0.52 cmol (+) kg^{-1} (Appendices 1 and 2).

The pH of the top-soils for the soils from Ilindi Village was strongly acid (pH 5.5) but increased with depth to slightly acidic (pH 6.6). In contrast, the pH of the top-soils for the soils from Mpamantwa village was slightly acid (pH 6.1) and decreased with depth to strongly acid (pH 5.1), indicating that the sub-soils were more acidic compared to the top-soils. This could be associated with increase in concentrations of acid forming cations such as Al^{3+} and partly Fe^{3+} and acid soluble ions such as Cu^{2+} and Mn^{2+} in the underlying bedrock, which were beyond the scope of this study. According to Brady and Weil (1990) the soil pH below 7.0 favours solubility to sufficiency levels of some micronutrients including Fe, Zn and Mn, an observation which is similar to the findings obtained by Kisetu *et al.* (2013) in highly weathered soils of Morogoro.

The levels of total N at Ilindi and Mpamantwa villages decreased with increase in soil depth from 0.07% in the topsoils to 0.02% in the subsoils. Being sandy soils, organic carbon levels were very low 0.16 to 0.09% throughout the soil profiles in both villages. Due to low levels of soil organic matter, the soils in these villages are likely to have low levels of soil fertility and poor water holding capacity (Hudson, 1994).

In Bahi village, the soil had medium cation exchange capacity (CEC) of 18.53 to 19.27 cmol (+) kg^{-1} and medium to high base saturation of 61% to 71% indicating that the soil is generally fertile using rating criteria given by Landon (1991). The topsoil had low CEC of 18.53 cmol (+) kg^{-1} and base saturation of > 71.3% throughout the profile. Generally, the CEC increased with depth but with slight decrease at lower horizons due to decrease of clay content. The level of exchangeable sodium in the top soil was generally medium with the value of 0.31 cmol (+) kg^{-1} and increased with soil depth to 5.93 cmol (+) kg^{-1}, indicating possibility of sodicity problems (Landon, 1991).

The topsoil pH in Bahi village soil profile was neutral with value of 6.8 and increased to very strongly alkaline (Brady and Weil, 1990) with pH value of 9.7 in subsoils. The pH of the topsoil was within the optimal range for many crops (Crozier *et al.* 2003). The levels of total N were low in top soil 0.08% and decreased with increase in soil depth to very low in the subsoil. Organic carbon levels were generally very low throughout the profile. This indicates that application of inorganic fertilizers and incorporation of organic resides in order to improve N levels and organic matter contents in the soil for crop production are inevitable.

4.2 Uranium Concentration in Soil Profiles

The levels of U in the three soil profiles namely Ilindi, Bahi and Mpamantwa are presented in Table 1. Results showed that the U content increase with depth along the soil profile in all the three profiles. Generally, there is low U content in the upper surface horizons and increases with increasing soil depth. The low amount of U in upper horizons could be due to leaching especially when U form soluble compounds with other materials like carbonates (Navas *et al.*, 2002). This could be the case for Bahi village where there is accumulation of carbonates in the subsoil. However, low levels of U in horizon Bcn2 of Bahi soil profile could probably be that most of it is held by clays in the overlying horizon Bcn1.

According to Vukašinovic *et al.* (2010), U variation in soils is also influenced by the variation in the pH of the soil. At pH values around 6.5 or higher, U is considered mobile and, thus, leaches easily to the deeper soil layers. The increase in U levels along the profile could also be influence by the weathering of underlying granite. It is well known that granite rocks are primary source of U and release U during weathering (Sasmaz and Yaman, 2008). The increase of U along the profile might be due to weathering which is taking place in deeper soil horizons particularly at Ilindi and Mpamantwa villages, where soils have developed on weathered granite.

Increase in clay content with soil depth and the retention of U by interlayer space of clays might be another reason for accumulation of U in subsoils compared to topsoils. This has also been postulated earlier by DeCraen *et al.* (2000) who reported that U content increases with decrease in soil particle size below 100 µm. Most clay minerals are negatively charged; hence, they have ability to retain U cations which are positive. This could be the case, because clay content in the studied profiles increased with depth.

Table 1: Distribution of Uranium in soil profiles

Village	Coordinates	Elevation (m)	Soil horizon	Depth (cm)	Textural Class	U (µg kg^{-1})
Ilindi	05°56'58.4"S & 035°32'20.8" E	990	Ap	0 – 10	LS	20.6±7.0
			AB	10 – 28	LS	18.3±6.0
			Bw	28 – 60	SCL	28.4±7.0
			Bco	60 –130	SL	35.0±6.0
Mpamantwa	05°57'33.6" S & 035°23'08.9"E	952	Ap	0 – 10	LS	58.5±6.2
			AB	10 – 61	SCL	74.8±5.4
			Bw	61 – 162	SCL	73.5±6.5
Bahi	05°58'18.8" S & 035°18'29.5" E	831	Ap	0 – 20	SCL	16.3±6.0
			AB	20 – 50	SCL	37.7±7.0
			Bcn1	50 – 82	C	50.1±6.0
			Bcn2	82 – 153	C	36.5±6.0

Textural classes: LS = Loamy sand; SCL = Sandy clay loam; SL = Sandy loam; C = Clay. All values of U are with standard errors. N=3

4.3 Uranium Distribution in Topsoils

The concentrations of U in the top soils along transect in Mpamantwa, Ilindi and Bahi villages are presented in Tables 2, 3 and 4. The results showed that soils from Bahi village have high levels of U followed by Ilindi and lastly Mpamantwa villages. Moreover, results from Ilindi showed that concentration of U in subsoils along transect west of Ilindi Playa Lake was 187.5 µg kg^{-1} in the upper slope and 238.5 µg kg^{-1} in the lower slope. Likewise, the U levels for transect located in the East of the Lake was 13.6 µg kg^{-1} in the upper slope and 80.0 µg kg^{-1} in the lower slope. This implies that U concentration in Ilindi village increases down the slope towards the Playa Lake. This may be due to mobility of U from upper slope to lower slope, which is facilitated by the loamy sand soil texture, on the surface and presence of carbonate minerals in the area as reported by Navas *et al.* (2002). Uranium is soluble and combines with carbonate to form uranyl-carbonate complexes, which make it easy to move down slope by water towards the lake. This is possible because in the western side of the lake, where there is high level of U, soda ash is locally produced for domestic uses. This proves the presence of carbonate in the area. In Mpamantwa, this was not the case. U concentrations showed irregular patterns. This could have been contributed by nearly flat topography, absence of carbonate and limited amount of rainfall to cause U mobility. The village receives low amounts of rains of about 600 mm annually (Swai *et al.*, 2012).

Table 2: Variation of Uranium in Ilindi transects (0-30 cm)

Village	Transect	Slope Position	Coordinates	Elevation (m)	U (μg kg^{-1})
Ilindi	West of Ilindi Playa lake	Upper part	05°58'15.2" S & 035°31'08" E	995	187.2
		Middle part	05°58'12.5"S & 035°31'11.8" E	977	125.7
		lower part	05°58'10.8" S & 035°31'14.0" E	965	238.5
	East of Ilindi Playa lake	Upper part	05°56'58.3"S & 035°32'22.2" E	992	13.6
		Middle part	05°56'57.4" S & 035°32'20.8"E	990	48.0
		Lower part	05°5657.4" S & 035°32'17.3" E	988	80.0

All means of U levels differed significantly at 5% level of probability based on New Duncan's Multiple Range Test.

Table 3: Variation of Uranium in Mpamantwa transects (0-30 cm)

Village	Transect	Slope	Coordinates	Elevation (m)	U (µg kg^{-1})
Mpamantwa	West of the village	Upper part	05°57'41.9"S & 035°23'07.2" E	963	114.2
		Middle part	05°57'33.9" S & E 035°23'08.3" E	958	30.2
		Lower part	05°57'23.1"S & E 035°23'11" E	944	23.9
	East of the village	Upper part	05°57'41.07"S & 035°23'05.3" E	962	65.3
		Middle part	05°57'33.0"S & 035°23'07.1" E	954	112.8
		Lower part	05°57'23.1"S & 035°23'11" E	944	23.9

All means of U levels differed significantly at 5% level of probability based on New Duncan's Multiple Range Test.

Table 4: Variation of Uranium in Bahi transects (0-30 cm)

Village	Transect	Slope	Coordinates	Elevation (m)	U (µg kg^{-1})
Bahi	North of Bahi wetland	Upper part	05°58'25.1" S & 035°18'18.3" E	836	743.0
		Middle part	05°59'30.0" S & 035°19'12.0" E	834	468.2
		Lower part	05°59'33.3" S & 035°19'10.7"E	829	420.2
	South of Bahi wetland	Upper part	05°58'27.5" S & 035°18'18.3" E	835	618.6
		Middle part	05°59'30.9" S & 035°19'09.5" E	833	448.0
		Lower part	05°59'33.1" S & 035°19'13.0" E	826	222.8
s.e					19.9
CV (%)					14.3

All means of U levels differed significantly at 5% level of probability based on New Duncan's Multiple Range Test.

Result for soil samples collected in Bahi village showed high levels of U in upper part of the wetland and low values towards the lower part for both transects. The transect located North of Bahi wetland recorded 743.0 µg kg^{-1} and 420.2 µg kg^{-1} in upper and lower parts, respectively, while transect located South of Bahi wetland had 618.6 µg kg^{-1} U level in upper part and 222.8 µg kg^{-1} being U level in lower part. This indicates that the levels of U decreased towards the centre of the wetland. This implies that the main source of U is from the surrounding granitic hills and not within the wetlands. The variation in the soil could be attributed to the presence of clays which hinder mobility of U from the surrounding towards the centre of the wetland. Although the soil has carbonate, the mobility of U might have been restricted by the presence of clays in the soil profile. This could be the case because clay minerals have high ability of retaining cations in their interlayer space as compared to other materials (De Craen *et al.*, 2000).

Although the highest recorded value of U obtained in soils in the study area was 743 µg kg^{-1}, this value is unlikely to impose toxicity to the environment. According to the guideline established for Canadian Agricultural Soil Quality (CCME, 2005), U levels exceeding 23 000 µg kg^{-1} may impose toxic effect to human and surrounding environment. Thus, the soils in all villages could be used for agriculture without any problem.

4.4 Uranium in Selected Farms and its Uptake by Maize, Millet and Rice

The locations of the surveyed farms in Bahi District are presented in Table 5. These farms were located in areas with elevation ranging from 827 to 988 m above the sea level. The farms located in Ilindi village are higher in elevations followed by Mpamantwa and the lastly Bahi village. Ilindi and Mpamantwa villages lie in undulating hills while Bahi village is lying in the plain of Bahi wetland.

Table 5: Location of surveyed farms in Bahi District

Villages	Farm	Coordinates	Elevation (m)
Ilindi	Maize farm1	05°94'85"S & 35°54'13"E	982
	Maize farm2	05°95'10"S & 35°54'08"E	985
	Maize farm3	05°95'16"S & 35°54'00"E	979
	Millet farm1	05°94'78"S & 35°54'13"E	988
	Millet farm2	05°95'21"S & 35°54'12"E	974
	Millet farm3	05°94'56"S & 35°5436"E	988
Mpamantwa	Maize farm1	05°98'06"S & 35°39'11"E	927
	Maize farm2	06° 00'11"S & 35°38'53"E	889
	Maize farm3	06°00'05"S & 35°3859"E	895
	Millet farm1	05°96'36"S & 35°38'59"E	953
	Millet farm2	05°95'93"S & 35°38'65"E	936
	Millet farm3	05°95'72"S & 35°38'56"E	930
Bahi	Rice farm1	05°98'62"S & 35°30'12"E	831
	Rice farm2	05°98'82"S & 35°29'58"E	832
	Rice farm3	05°99'94"S & 35°32'27"E	829

Table 6: Summary of Uranium levels in soils, maize, millet and rice tissues from 15 farms in Bahi District

No. of farms	Material analysed	No. of samples	U levels ($\mu g\ kg^{-1}$)		
			Min	Max	Mean
6	Soil	18	21.2	286.0	153.6
6	Maize shoot	18	<10	<10	<10
6	Maize grains	18	<10	<10	<10
6	Soil	18	18.0	24.3	21.5
6	Millet shoot	18	<10	<10	<10
6	Millet grains	18	10.4	32.0	21.45
3	Soil	9	136.8	185.2	161.8
3	Rice shoot	9	<10	<10	<10
3	Rice grains	9	<10	<10	<10

The levels of U in soils and plant tissues from 15 farms in Bahi District are as shown in Table 6. The level of U in soils from six maize farms ranged from 21.2 to 286.0 $\mu g\ kg^{-1}$ with the mean of 153.6 $\mu g\ kg^{-1}$, while U levels in soils from six finger millet farms were between 18.0 and 24.3 $\mu g\ kg^{-1}$ with the mean value of 21.5 $\mu g\ kg^{-1}$. Soils in maize and finger millet farms were all collected in Ilindi and Mpamantwa villages. Concentrations of U in soils from three rice farms, which were sampled in Bahi village, were between 136.8 and 185.2 μg kg^{-1}. The mean value for U in rice farms was 161 μg kg^{-1}. Results of the means showed that the levels of U in maize, rice and finger millet farms were highly variable. Finger millets were somehow grown in soils with less U as compared to maize and rice. Levels of U obtained in maize, rice and finger millet farms were low to cause toxicity to plants since plants can survive in U contaminated soils of 3000 μg kg^{-1} (Singh, 1997). Thus, the levels of U in agricultural soils in the study area were low and are more likely not to cause environmental health hazards to plants, livestock and human beings. Similarly, the levels of U assimilated in maize, rice and finger millet tissues (grains and shoot) in the study area were very low. The finger millets accumulated U in grains and the level ranged from 10.4 to 32.0 μg kg^{-1}. The levels of U in finger millet may impose health problem to human beings due to the fact that WHO (2005) has established a tolerable daily intake (TDI) for soluble U of 0.6 g kg^{-1} b.w. per day, based on the lowest-observed-adverse-effect-level (LOAEL) for U nephrotoxicity of 0.06 mg kg^{-1} b.w per day. This suggests that when U concentration above TID is consumed, a person is at risk of getting cancer or other diseases caused by consuming high levels of U.

4.5 Translocation of U from Soil to Plant Tissues

Since the values of U in maize and rice tissues were less than the values the ICP-OES instrument can detect, transfer factors for these crops were not determined. The translocation of U from soil to the plant for maize and rice were below detectable limit. This indicates that U is insignificantly transferred from soils to maize and rice tissues. Similarly, the transfer factor for U from soil to finger millet shoot was not computed for the same reason.

Although U in soils where finger millet is grown was less as compared to that found in maize and rice farms, a significant amount of U was assimilated by finger millet in grains (Table 6). The transfer factors for U from soils in Ilindi and Mpamantwa villages to finger millet grains ranged between 0.23 and 1.51 μg kg^{-1}. The mean value obtained was 0.74 μg kg^{-1}.

Maize and millet were grown in similar type of soil (*Dystric Cambisols*) at Ilindi and Mpamantwa villages. The difference in ability to accumulate U might be due to difference in their root system. Finger millet has permanent adventitious roots that develop from the second internodes and above. The roots branch laterally (about 1 m^{2}) interlacing the soil vertically, and are mainly responsible for supplying nutrients to the plant. In addition, the roots can grow to more than 2 m deep in pursuit of water and soil nutrients (ICRISAT, 2007). This gives finger millet higher ability to extract soluble nutrients and other materials including U in soils than maize. This is why finger millet can grow well in dry areas.

A study by Vandenhove *et al.* (2007) revealed that U taken up by maize concentrates mainly in the first few mm from the root tip. At the level of shoot, no sign of U was found, implying that its translocation is prohibited in maize. Inability of U translocation within maize plant may be largely contributed by what is taking place within the root and around root surfaces. Sheppard (1980) reported that once U is absorbed by the plant roots it is stored as a yellow deposit in the cell nuclei of the meristem. This results in destruction of the chromatin, and cessation of cell nuclear activity, preventing U translocation. In other words, U uptake by plants may be limited to the outer membrane of the root system and may not occur on the interior of the root at all and this raises the question of the selectivity of roots to U. The apparent selectivity is attributable to insoluble calcium uranyl phosphates which are deposited on the root surface, allowing only a small portion to enter the root sap (Netten and Morley, 1983; Sheppard *et al.*, 1983).

Some plants shares reasons for failing to accumulate U but in this case rice could have a separate reason for failing to assimilate U in its tissues. Rice is normally grown in water logging condition or marsh areas. This condition which may limit U uptake by rice as it has been reported by Sheppard (1980) that high soil-U concentrations impart high plant-U concentrations except in marshy areas, where the plant-U content has been found to be lower than the soil U content. This is due to redox reaction happening in paddy fields. Under water logging conditions which is mostly reduced environment, U forms UO_2, which has low solubility hence reducing possibilities of U uptake by paddy. When paddy soil is drained and is under oxidized environment, UO_2 is solubilized again as UO_2^{2+} and then U may be redistributed among soil components. However, the mode of paddy cultivation in Bahi is flooding of water for most of the time creating little chances for U uptake unless they grow the rice under new system called System of Rice Intensification (SRI). This is the system which makes less use of water leaving paddy field most of the time dry which might favour the oxidized condition allowing solubility of U and hence, creating chances of U uptake by rice. However, the behaviour of U in paddy soil is complex due to the alternating changes under redox conditions.

4.6 Uranium in Surface and Underground Water

Table 7 shows variation of U content in water among the studied villages. The highest concentration of 1233 ± 12.06 µg L^{-1} was found in Ilindi Playa Lake followed by 95.5 ± 12.06 µg L^{-1}in a water well near Ilindi Primary School. The water well near Ilindi Primary School is the source of drinking water for pupils and other villagers around the area. U level from that Well was above the recommended limit by WHO (2011) for drinking water which should be less than 30 µg L^{-1}. The concentration of U in drinking water above the limit recommended by WHO (2011) is likely to pose risk to people at Ilindi village. Water from the Playa Lake is used by livestock and for preparing salt and soda ash for domestic use.

High U concentration of 62.9 µg L^{-1} in water at Bahi was found in one location near the bridge crossing one of the tributaries of Bubu River. This water is also used by livestock for drinking and irrigation of vegetable during dry season. The remaining water samples were below the tolerable levels recommended by the WHO (2011). On the other side, water samples from Mpamantwa were found to contain low levels of U (<10 µg L^{-1}). Thus, based on this data the water in Mpamantwa is safe for domestic use.

Variation of U in water sources among and within the villages may be largely contributed by two things, pH of the water where sample was taken and the concentration of U in surrounding rocks. Water from U rich materials will have high values of U compared to those located or passing in U low materials (Ankle *et al.*, 2009). Concentration of U in surface water, like that under the bridge where the Bubu River is crossing the road might have been elevated by passing through U rich materials.

Uranium variation seems to be contributed by the pH; wherever the pH is high also U level is high. This is because at high pH U forms U-carbonate complex. This agrees with research findings by Waite *et al.* (1994) who found that U-carbonate complexes are predominant at neutral to alkaline pH values.

Table 7: Uranium levels in surface and underground water

Villages	Coordinates	Elevation (m)	Site Description	pH (H_2O)	U (µg L^{-1})
Ilindi	05°56'45.0"S & 035°32'26.3" E	987	Well near Ilindi Primary School	7.8	95.4
	05°57'07.8"S & 035°32'41.3" E	1010	Well for irrigation	8.6	<10
	05°57'49.9"S & 035°31'34.2" E	966	Ilindi Playa Lake	9.3	1233
Mpaman-twa	05°57'19.3"S & 035°23'10.9" E	939	Tap water near village office	7.5	<10
	05°59'122.3"S& 035°23'04.0" E	910	Well near Mpamantwa Secondary School	7.7	<10
	05°58'20"S & 035°23'38.4"E	953	well for irrigation	8.5	<10
Bahi	05°58'18.1"S & 035°18'23.8"E	830	Surface water under the bridge	8.7	62.9
	05°58'19.1"S & 035°18'21.6" E	837	Private tap water for Juma's family	7.3	20.7
	05°58'19.8"S & 035°18'21.4"E	840	Private tap water for Mtandika	8.5	17.6
LSD(0.05)			Villages		10.44
			Sites		12.06
			Interaction		20.89
s.e					12.34
CV (%)					10.0

The means along the same column sharing similar letter(s) are not significantly different at 5% level of probability based on New Duncan's Multiple Range Test (NDMRT). s.e = standard error. CV=Coefficient of Variation, n=3.

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

From the results of this study, it was concluded that:

i. U values in soil profiles increased with the increase in soil depth and clay content in the study area. Low levels occurred in top soils and high levels in sub soils where clay content is high .Generally, along the transects, there are higher levels of U in soils on the upper parts of the slope near the granitic hills than in the lower parts of the slope suggesting that the major source of the U could be the granitic rocks.

ii. Levels of U found in agricultural soils were within the tolerable limits as per WHO recommendations.

iii. The levels of U found in finger millet, rice and maize tissues were within the tolerable limit to human and the environment. However, finger millet indicated increased ability to accumulate high levels of U in grain as compared to maize and rice. This could be due to ability of its root system to penetrate deeper the soil.

iv. Low levels of U in maize, rice and finger millet shoots provide assurance that they are safe for livestock consumption.

v. Underground water near Ilindi Primary School and surface water of Ilindi Playa lake as well as water in Bubu river have higher U levels than provisional standard given by WHO (2011), and hence are likely to be unsafe for humans and livestock consumption.

5.2 Recommendations

In view of the results of this study, the following recommendations are given:

i. Since water samples collected from Ilindi Playa Lake and Bubu River contained high levels of U and still it is used as the main source of water for livestock, the study recommends stopping using the water for domestic/ drinking and looks for alternative resources of water, which is safe to humans and livestock.

ii. The generated data on the levels of U in drinking water and their effects on human beings should be communicated to the community in the study area by the relevant authorities in the District.

iii. More detailed and controlled study including mapping of soils, and conducting field trials with known plant populations and crop varieties is required. Such studies will generate more quantifiable data like how much U is accumulated in various plant parts, how much U enters into food chain, how much is consumed by livestock and humans. This will form basis for more concrete conclusions and recommendations to the District authority.

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APPENDICES

Appendix 1: DESCRIPTION OF SOIL PROFILE ILINDI

1.0 GENERAL INFORMATION

1.1 Registration and Location

1.1.1 Profile number ILINDI 1

1.1.2 Date of description: 26/1/2013

1.1.3 Authors: Makoti, C.A., Kaaya, A.K. and Marwa, E. E

1.1.4 Location: About 12 km north eastern of Msembeta village along Dodoma -Singida Highway.

1.1.5 Elevation:990 m

1.1.6 Coordinates:05°56'58.4"S & 035°32'20.8" E

1.2 Soil Classification: FAO- Unesco:*Dystric Cambisols*(CMx)

1.3 Land form and Topography

1.3.1 Slope gradient (%): ≤ 2%

1.3.2 Type of the slope: Straight,

1.3.3 Length of the slope: ≥ 1 km

1.3.4 Position of the slope: Middle

1.4.0 Land use and Vegetation

1.4.1 Land use: Rainfed a cultivation and animal grazing. The area is currently under cultivation of food crops including maize, finger millet, cassava and sweat potatoes.

1.4.2 Vegetation: *Accassia nigrescens* is dominant trees species

1.5.0 Surface Characteristics

1.5.1 Root out crops (%): No

1.5.2 Surface stoniness (%): None

1.6 Soil-Water relationships

1.6.1 Drainage class: Well drained

1.6.2 Internal drainage: Profile is never saturated with water

1.6.3 Flooding: None

1.6.4 Ground water: Not observed within profile depth 130+ cm at time of description.

1.6.5 Moisture conditions: Dry throughout at the time of description1

1.7 Human influence: Cultivation of finger millet, maize, sorghum and vegetables.

Soil profile at ILINDI Village

WRB: *Dystric Cambisol*

2.0 SOIL HORIZON DESCRIPTION

Horizon	Depth (cm)	Description
Ap	0-10	Brown (10YR4/3) moist, Brown 1(0YR5/3) dry; loamy sand; weak fine crumb structure; non sticky and non plastic (wet), very friable (moist), slightly hard (dry); fine medium pores; common fine few roots; smooth, clear boundary to
AB	10-28	Yellowish brown (10YR5/4) moist, Light yellowish brown 10YR6/4 dry; loamy sand; moderate, fine, sub angular blocky structure; non stick y and non plastic (wet), very friable (moist), slightly hard (dry); very fine and fine medium pores; common very to fine and very few fine roots; smooth, clear boundary to
Bw	28-60	Light yellowish brown (10YR6/4) moist, Very ale brown (10YR7/4) dry; sand clay loam; strong fine sub angular blocky structure; non sticky and non plastic (wet), very friable (moist), slightly hard (dry); very fine and fine medium pores; very fine, and very few very fine roots; smooth, clear boundary to
Bco	60-130 +	Pale brown (10YR6/3) moist, Very pale brown (10YR7/4) dry; sandy loam; sub angular block structure; non sticky and non plastic (wet), very friable (moist), hard (dry); very fine and fine few pores; very fine and few fine root;, many medium (1-2 cm), hard, spherical, block and brownish iron-manganese (sesquioxides) nodules;

3.0 Some physico-chemical properties of soil profile ILINDI

Horizon		Ap	AB	Bw	Bco
Depth (cm)		0-10	10-28	28-60	60-130
Texture: % clay		15.0	15.0	21.0	19.0
% silt		1.0	1.0	3.0	3.0
% sand		84.0	84.0	76.0	78.0
Textural class		LS	LS	SCL	SL
pH in H_2O		5.5	5.3	5.1	6.7
pH in KCL		4.0	3.8	3.7	4.7
Organic C (%)		0.52	0.43	0.30	0.11
Organic matter (%)		0.90	0.74	0.51	0.19
Bray P mg/kg		13.93	31.98	31.68	1.23
Total N (%)		0.07	0.05	0.4	0.3
Exchangeable bases	Ca^{2+}(cmol(+)kg^{-1})	1.15	0.97	0.98	0.98
	Mg^{2+} (cmol(+)kg^{-1})	0.24	0.11	0.18	0.76
	K^{+}(cmol(+)kg^{-1})	0.20	0.12	0.08	0.16
	Na^{+} (cmol(+)kg^{-1})	0.11	0.11	0.20	0.52
CEC (cmol(+)kg^{-1})		10.67	11.13	13.00	7.80
% Base Saturation		15.90	11.70	11.10	31.00

[1] Textural classes: LS = Loamy sandy; SCL = Sandy clay loam; SL = Sandy loam

Organic Matter % = Organic Carbon % x 1.72

Appendix 2: Description of Soil Profile Mpamantwa

1.0 GENERAL INFORMATION

1.1 Registration and Location

1.1.1 Profile number: MPAMANTWA 1

1.1.2 Date of description: 26/1/2013

1.1.3 Authors: Makoti, C.A., Kaaya, A.K. and Marwa, E. E

1.1.4 Location: About 50 km from Dodoma and it is along Dodoma - Singida Highway

1.1.5 Elevation:952 m

1.1.6 Coordinates: 05°57'33.6" S & 035°23'08.9" E

1.2 Soil Classification: WRB: *Dystric Cambisol*

1.3 Land form and Topography

1.3.1 Slope gradient (%): Very gentle slope

1.3.2 Type of the slope : Straight/ uniform

1.3.4 Length of the slope: ≥ 1 km

1.3.5 Position of the slope: Middle

1.4.0 Land use and Vegetation

1.4.1 Land use: Rainfed cultivation and animal grazing. The area is currently under cultivation of food crops including maize, finger millet, cassava and sweat potatoes. Animal grazing are mainly cattle and goat.

1.4.2 Vegetation: *Accassia nigrescens* is dominant trees species.

1.5.0 Surface Characteristics

1.5.1 Root out crops (%): No

1.5.2 Surface stoniness (%): None

1.6.0 Soil- Water relationships

1.6.1 Drainage class: Well drained

1.6.2 Internal drainage: Profile is never saturated

1.6.3 Flooding: None

1.6.4 Ground water: Not observed within profile depth 164+ cm at time of description.

1.6.5 Moisture conditions: Dry throughout at the time of description

1.7.0 Human influence: Cultivation of maize, finger millet, sorghum and vegetables.

Soil profile MPAMANTWA

WRB: *Dystric Cambisol*

2.0 SOIL HORIZON DESCRIPTION OF MPAMANTWA

Horizon	Depth (cm)	Description
Ap	0-10	Reddish brown (2.5Y5/3) moist. Light reddish brown (2.5Y6/3) dry; loamy sand; weak very fine crumb structure; non sticky and non plastic (wet), very friable (moist). soft (dry); fine medium pores; fine and few roots; smooth. clear boundary to
AB	10-61	Yellowish brown(10YR5/4) moist, Light yellowish brown(10YR6/4) dry; sandy clay loam; moderate medium angular blocky structure; non sticky and non plastic (wet), friable (moist), hard (dry); very fine and fine medium pores; very fine and very few fine roots; smooth, gradual boundary to
Bw	61- 162	Yellowish brown (10YR5/4) moist. Light yellowish brown (10YR6/4) dry; sandy clay loam; weak medium sub angular blocky structure; non sticky and non plastic (wet), friable (moist), slightly hard (dry); very fine and fine medium pores; very fine and very few very fine roots; abrupt boundary to
Ferricrete layer	162-164 +	Rock fragment; abundant quartz and feldspar; abundant medium to course; hard and irregular brownish iron-manganese (sesquioxides) nodules.

3.0 Some physico-chemical properties of soil profile MPAMANTWA

Horizon	Ap	AB	Bw
Depth (cm)	0-10	10-61	61-153
Texture: % clay	15.0	25.0	25.0
% silt	1.0	1.0	3.0
% sand	84.0	74.0	72.0
Textural class	LS	SCL	SCL
pH in H_2O	6.1	4.9	5.1
pH in KCL	4.5	3.9	3.9
Organic C (%)	0.37	0.21	0.09
Organic matter (%)	0.64	0.36	0.16
Bray P mgkg^{-1}	13.6	4.08	10.09
Total N (%)	0.05	0.04	0.02
Exchangeable bases Ca^{2+}(cmol(+)kg^{-1})	0.5	0.52	0.53
Mg^{2+} (cmol(+)kg^{-1})	0.1	0.07	0.19
K^+(cmol(+)kg^{-1})	0.2	0.18	0.09
Na^+ (cmol(+)kg^{-1})	0.1	0.48	0.10
CEC (cmol(+)kg^{-1})	7.9	7.47	8.73
% Base Saturation	11.1	16.9	10.9

[1]Textural classes: LS = Loamy sandy; SCL = Sandy clay loam;

Organic Matter % = Organic Carbon % x 1.72

Appendix 3: Description of Soil Profile Bahi

1.0GENERAL INFORMATION

1.1 Registration and Location

1.1.1 Profile number BAHI 1

1.1.2 Date of description: 26/1/2013

1.1.3 Authors: Makoti, C.A., Kaaya, A.K. and Marwa, E. E

1.1.4 Location: About 55 km from Dodoma along Dodoma – Singida Highway.

1.1.4 Elevation:831m

1.1.5 Coordinates:05°58'18.8" S &035°18'29.5" E

1.2.0 Soil Classification: WRB: *Calcic Vertisol*

1.3.0 Land form and Topography

1.3.1 Slope gradient (%): < 1%

1.3.2 Type of the slope : uniform

1.3.3 Length of the slope: > 1 km

1.3.4 Position of the slope: Middle

1.4.0 Land use and Vegetation

1.4.0 Land use: Mainly for irrigated rice

1.4.1 Vegetation: Area is covered by grasses (cyperusspp). thick vegetation coverage and Makomanga herbs (Hyptis Suaveolens).Acacia bushes with sharp thorny is dominant.

1.5.0 Surface Characteristics

1.5.1 Cracking: Observed at a time of description

1.5.2` Sealing/ crusting: None

1.5.3 Root out crops: None

1.5.4 Surface stoniness (%): None

1.6.0 Soil- Water relationships

1.6.1 Drainage class: class 3

1.6.2 Flooding: Once per season

1.6.3 Groundwater: at 153+ cm the time of description.

1.6.4 Ground water level: At 153 cm from surface at the time of description

1.6.5 Moisture conditions: Moist throughout at time of description

1.7.0 Human influence: Cultivation of rice.

Soil Profile: BAHI

WRB: *Calcic Vertisol*

2.0 SOIL HORIZON DESCRIPTION OF BAHI SOIL PROFILE

Horizon	Depth (cm)	Description
Ap	0-20	Very dark grayish brown (10YR3/2) moist, Dark grayish brown (10YR4/2) dry; sand clay loam; strong medium angular blocky structure; very sticky very plastic (wet), firm (moist), very hard (dry);very fine and few pores; gradual smooth boundary to
ABcn	20- 50	Dark grayish brown (10YR4/2) moist; sandy clay loam; moderate fine medium angular blocky structure; very sticky and very plastic (wet), firm (moist); very fine and very few pores; common fine medium and very few fine roots; reacted with carbonates; smooth gradual boundary to
Bcn1	50- 82	Grayish brown 10YR5/2 moist, clay, moderate fine to medium angular blocky structure, very sticky and very plastic (wet), firm (moist), very fine and very few pores, common fine medium and very few fine roots, carbonates nodules , gradual smooth boundary to
Bcn2	82-153+	Brown 10YR5/3 moist, clay, massive structure, very stick and very plastic (wet), friable(moist), very fine and very few pores, common fine to medium and very few fine roots, carbonates nodules , few irregular quartz.

Some physico-chemical properties of soil profile BAHI

Horizon	Ap	AB	Bco$_1$	Bco$_2$
Depth (cm)	0-20	20-50	50-82	82-153
Texture: % clay	33.0	33.0	74.0	74.0
% silt	3.0	3.0	25.0	25.0
% sand	64.0	64.0	1.0	1.0
Textural class	SCL	SCL	C	C
pH in H_2O	6.8	7.5	9.3	9.7
pH in KCL	5.3	5.9	7.0	7.7
Organic C (%)	0.48	0.19	0.17	0.15
Organic matter (%)	0.83	0.32	0.29	0.26
Olsen P mgkg^{-1}	11.05	0.20	2.48	0.00
Total N (%)	0.08	0.04	0.03	0.03
Exchangeable bases Ca^{2+}cmol(+)kg^{-1}	9.48	9.73	7.90	6.72
Mg^{2+} (cmol(+)kg^{-1})	3.11	1.56	0.81	0.57
K^+(cmol(+)kg^{-1})	0.32	0.13	0.15	0.08
Na^+(cmol(+)kg^{-1})	0.31	0.33	2.08	5.93
CEC (cmol(+)kg^{-1})	18.53	19.27	17.67	15.27
% Base Saturation	71.3	61	62	87

[1] Textural classes: SCL = Sandy clay loam; C = Clay

Organic Matter % = Organic Carbon % x 1.72

Appendix 4: U contents for Water samples from the studied villages- ANOVA

Source of variation	**DF**	**U (μgkg-^{1})**
Replication	2	77.9
Villages	2	407699.9***
Sites	3	353344.5***
Interaction	6	362887.8***
Residual/error	22	152.2
Total	35	
F pr.	Villages	<.001
	Sites	<.001
	Interaction	<.001

Key: ***= very highly significant

Appendix 5: U contents for transect soils of the studied villages –ANOVA

Source of variation	DF	U (μgkg-^{1})
Replication	1	289.7
Villages	2	476997***
Plots	2	19257.9***
Interaction	4	20487.7***
Residual/error	8	785.3
Total	17	
	Villages	<.001
F pr.	Plots	<.001
	Interaction	<.001

Key: ***= very highly significant