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Pitout JDD, Church DL, Gregson DB, Chow BL, McCracken M, Mulvey M, Laupland KB (2007). Molecular epidemiology of CTXM-producing Escherichia coli in the Calgary Health Region: emergence of CTX-M-15-producing isolates. Antimicrob. Agents Chemother. 51: 1281-1286.

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Full Length Research Paper

Non-carbon benefits for effective implementation of REDD+: The case of Bale Mountains Eco-Region, Southeastern Ethiopia

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The study was conducted in four districts, namely Nansebo, Harenna Buluk, Dolo Mena and Dodolla, Southeastern Ethiopia with the following objectives - to: (i) investigate species richness and similarity, diversity, evenness and stand structure of the woody species; (ii) determine the amount of carbon stock stored in the above-ground biomass of woody species; (iii) establish the relationship between the Shannon diversity indices and carbon stock, (iv) identify the most important forest non-carbon benefits obtained by the local communities from the forests; and (v) determine contribution of forest resources to the local economy when compared with other incomes generated from agriculture, including livestock. Data generated by FARM Africa were used to achieve objectives (i) - (iii). To achieve objectives (iv) and (v), a focus group discussion and household survey were conducted. A total of 125 species of woody species, representing at least 45 families and 77 genera, were recorded. The Shannon diversity and evenness indices of the woody species ranged between 2.8 (Dodolla) and 3.5 (Harenna Buluk) and 0.79 (Nansebo) to 0.82 (Dolo Mena), respectively. The woody species had densities ranging from 550 (Dodolla) to 2106 (Harena Buluk) individuals ha^{-1}. The above-ground carbon stock stored ranged between 148.88 (Dodolla) and 246.27 (Dolo Mena) tons ha^{-1}. About 10 products and services were mentioned by the respondents as important non-carbon benefits from the forests. The non-carbon benefit with the highest contributions in the three districts was fuelwood, while coffee had the highest contribution in Dolo Mena. The contribution of forests to the local economy was significantly compared with other incomes. Forests contributed 40.2% to the household income in Harenna Buluk District and 18.8% in Nansebo District. Considering non-carbon benefits in the design and implementation of reducing emissions from deforestation and forest degradation (REDD+) is important to ensure its acceptance by local communities.

Key words: Bale, eco-region, non-carbon benefit, reducing emissions from deforestation and degradation (REDD+).

INTRODUCTION

Reducing emissions from deforestation and forest degradation (REDD) was discussed during Conference of Parties to the United Nations Framework Convention on Climate Change (UNFCCC) in Bali (COP 13). But, the idea of REDD+ was first introduced in 2005 by developing countries at the eleventh conference of parties to the UNFCCC as RED (Vijge and Gupta, 2014). The second 'D', referring to forest degradation, emerged later in 2007 (Wertz-Kanounnikoff and Angelsen, 2009). Since then, progresses have been made with regard to REDD+. In 2010, in Cancun, REDD+ emerged to emphasize that developing countries should be encouraged to contribute to mitigation actions in the forest sector by the full scope of REDD+ activities through: (i) reducing emissions from deforestation; (ii) reducing emissions from forest degradation; (iii) conservation of forest carbon stocks; (iv) sustainable management of forests; and (v) enhancement of forest carbon stocks (UNFCCC, 2011).

Some experts argue that the plus sign, such as conservation, sustainable management of forests and enhancement of forest carbon stocks, might deprive the rights of local communities in the long run as REDD+ activities may focus on carbon intensive projects. Additionally, viewing forests only for their carbon sequestration purpose underestimates their non-carbon benefits. Non-carbon benefits are benefits gathered from forest, which can be tangible or intangible. Tangible forest resources include wood, leaves, grasses, forest coffee, forest honey, fruits, medicinal plants, fish, meat from hunting, etc. Intangible forest resources include water that comes from forest, pollen from forest flowers, erosion prevention, nutrient supply, etc. There is assumption that carbon finance alone might not be attractive enough to local communities and forest managers when compared with other land use options. Furthermore, there is high demand for non-carbon forest resources. Incorporating carbon as a component of multiple objectives management alters the economics of forest enterprises (up to 30% increase in revenue) and, thus, acts as a catalyst to create an economic incentive for forest plantation development, but not sufficient to compensate the 70% (Yitebitu et al., 2010). Annual carbon payments in agro-forestry contracts in Mozambique were equivalent to about two months of wage labor. Thus, carbon payments appeared to play a relatively weak role in improving household incomes (Groom and Palmer, 2012).

Tropical deforestation accounts for up to a fifth of global anthropogenic carbon dioxide emissions (Groom and Palmer, 2012). For instance, between 1990 and 2000, some 16 million ha of tropical forests were lost per year (McDermott et al., 2012). Agriculture land expansion and biomass energy consumption have been attributed as the main causes. Worldwide, about 1.6 billion people heavily depend on forest resources for their livelihoods (FAO, 2001). Therefore, the lives of these people are directly affected by forest degradation and deforestation.

REDD+ created a lot of expectations. Local communities, politicians, governments and NGOs are hoping that modest carbon finance might be established to offset parts of the greenhouse gases (GHGs) from the atmosphere as well as mitigate the emissions. Failure to establish carbon finance mechanism and meet the expectations may cause REDD+'s collapse in the future. But if the design considers all benefits from the forestry sector, REDD+ might be successful. To do that, there is a need to establish proper indicators to monitor those non-carbon benefits and link REDD+ to a broader landscape.

Among the various benefits that a landscape in general and forest resources in particular provide to local communities, removal and mitigation of GHGs, biodiversity non-carbon benefits, and tangible and intangible non-carbon benefits are worth mentioning. The Environmental System of Accounting has a system to measure the contribution of such non-carbon benefits to the national economy (Bann, 1998; Lang et al., 2003). Nune et al. (2013) have estimated that the Ethiopian Forest Sector contributed 11 and 9% to the GDP in 1995 and 2005, respectively. However, this contribution did not get the attention of the decision makers until REDD+ emerged. REDD+ incentives currently cover for only small portion of the total value of the forests (only GHG removals and mitigation).

The current negotiation at the international level seems to be focused on the use of forests in reducing CO_2 emission with little attention to their other benefits, which ensure food security to billions of the poor in developing countries. The main argument behind such attitude is that estimating carbon is relatively simple when compared with the other benefits, such as biodiversity and watershed values. Furthermore, the international community is currently more concerned with problems related to GHG emissions. Although, the effort to reduce GHG emissions is commendable, the argument at this stage is that it is possible to consider the biodiversity value while targeting CO_2 levels. When local communities fail to enjoy the benefits of biodiversity and other landscape non-carbon benefits, including the cultural and customary benefits, as a result of weak policies that undermine incentives, they tend to overexploit environmental resources because of lack of sense of ownership. Hence, strategically, it is better to give sufficient emphasis to biodiversity and other non-carbon benefits when REDD+ is implemented.

Many ecological functions associated with the provision of ecosystem non-carbon benefits to agriculture are closely related to the biodiversity in associated semi-natural patches (Burel et al., 2013). Biodiversity and other forest non-carbon benefits might be difficult to maintain or improve unless they are considered as part of the development plan of a country and given equal weight similar to food security or poverty reduction. Tscharntke

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et al. (2012) argued that conventional agricultural intensification often results in contamination by pesticides and fertilizers, which can affect human health and create non-target effects on wildlife and functional agro-biodiversity (Gibbs et al., 2009). When multiple ecosystem non-carbon benefits are considered, more efficient outcomes can be achieved where the net gains of land use change are maximized (Bryan, 2013).

Forest non-carbon benefits are non-carbon benefits that are derived from forests, usually categorized under two main groups, that is, non-carbon benefits that are tangible and monetized easily, and non-carbon benefits that are intangible and difficult to monetize. Tangible non-carbon benefits include firewood collection, timber and grass harvesting, fruits, forest coffee, medicines, and water resources.

Intangible forest non-carbon benefits are those non-carbon benefits a local community gains because of the existence of forests, such as pollination, microclimate adjustment, carbon sequestration, biodiversity and watershed or catchment protection. Forest non-carbon benefits fall either in one or both of the climate change adaptation and mitigation part of the climate change discourse. Incorporating non-carbon benefits in the REDD+ payment scheme would enhance the interest of local community and local government to engage in the implementation of the REDD+ effectively and sustainably.

There are safeguard policies developed by multilateral organizations, such as the Forest Carbon Partnership Facility (FCPF) in the World Bank and the UN-REDD+ as well as private and NGO certification schemes (Voluntary Carbon Standard, Carbon, Community, Biodiversity Alliance and REDD+ Social and Environmental Safeguards), which are designed to be implemented at national and project levels. Multi-lateral funding programs have drawn heavily on existing safeguards for international aid, while private certification schemes have specialized in different niche priorities at the project level. With regard to the substance of safeguard requirements, the involvement of donors and investors appears correlated with a stronger emphasis on carbon and risk mitigation while greater NGO involvement and the decoupling of safeguards design from REDD+ funding appear correlated with greater emphasis on social rights and benefits (McDermott et al., 2012). For FCPF and UN-REDD+ countries, interest is ultimately contingent on serving the central aim of REDD+, that is, reducing forest carbon emissions.

REDD+ methods approved by Voluntary Carbon Standard (VCS) do not address environmental or social safeguards (McDermott et al., 2012). Carbon, Community and Biodiversity Alliance (CCBA), on the other hand, considers social benefits as additionality. CCBA requires that projects should generate measurable and verifiable additional net social benefits that are ‘‘equitably shared among community members and constituent groups’’ (CCBA, 2008; McDermott et al., 2012). CCBA evaluates projects on the basis of whether or not they are pro-poor and benefit more vulnerable households and individuals.

McDermott et al. (2012) have developed a “continuum of safeguards prioritization” from pure carbon to non-carbon values (VCS, FCPF & UN-REDD, CCBA, REDD+SES and Non-REDD). Based on its analysis, VCS considers pure carbon, whereas organizations who oppose the idea of carbon-focused payments altogether, outside of the above-mentioned organizations, consider Non-REDD+ but other benefits. In some cases, a combination of standards is possible, e.g. VCS and CCBA. Under CCBA, co-benefits are considered.

The choice of organizations in the implementation of REDD+ determines what benefits should go to communities. Furthermore, lack of measuring and reporting mechanisms for non-carbon benefits in the safeguards of multilateral funding and VCS may pose a great challenge for future REDD+ implementation. The success or failure of REDD+ will be determined not only by carbon emission reductions, but also by equity for local communities and indigenous peoples (Jaung and Bae, 2012).

The objectives of this study were to: (i) investigate species richness and similarity, diversity, evenness and stand structure of the woody species; (ii) determine the amount of carbon stock stored in the above-ground biomass of woody species; and (iii) establish the relationship between the Shannon diversity indices and carbon stock stored in the above-ground biomass of woody species in the forests of four districts found in the BMER, (iv) identify the most important forest Non-Carbon Benefits obtained by the local communities from the forests; and (v) determine contribution of forest resources to the local economy when compared with other incomes generated from agriculture, including livestock production.

The results from the study are expected to assist government (both federal and regional) and other concerned parties to consider non-carbon benefits prior to any decision or negotiation they make regarding REDD+ since non-carbon benefits are not only crucial for the livelihoods of the communities but also might be determining factors for the success of the REDD+ initiatives.

MATERIALS AND METHODS

Study area

The study was carried out in Bale Mountains Eco-Region (BMER), southeastern Ethiopia. Geographically it is located between latitude 5°16'54"N and 7°52'55"N, and longitude 38°37'52"E and 41°13'0"E (Figure 1). The BMER is found within one of the Afromontane forests. The Afromontane rain forest is mainly distributed in two geographically different and wide apart regions namely South-west and South-East forests (Friis, 1992). Both areas are part of the Eastern Afromontane Biodiversity Hotspot. The two sites are known for their non-carbon resources among which Non-Timber Forest

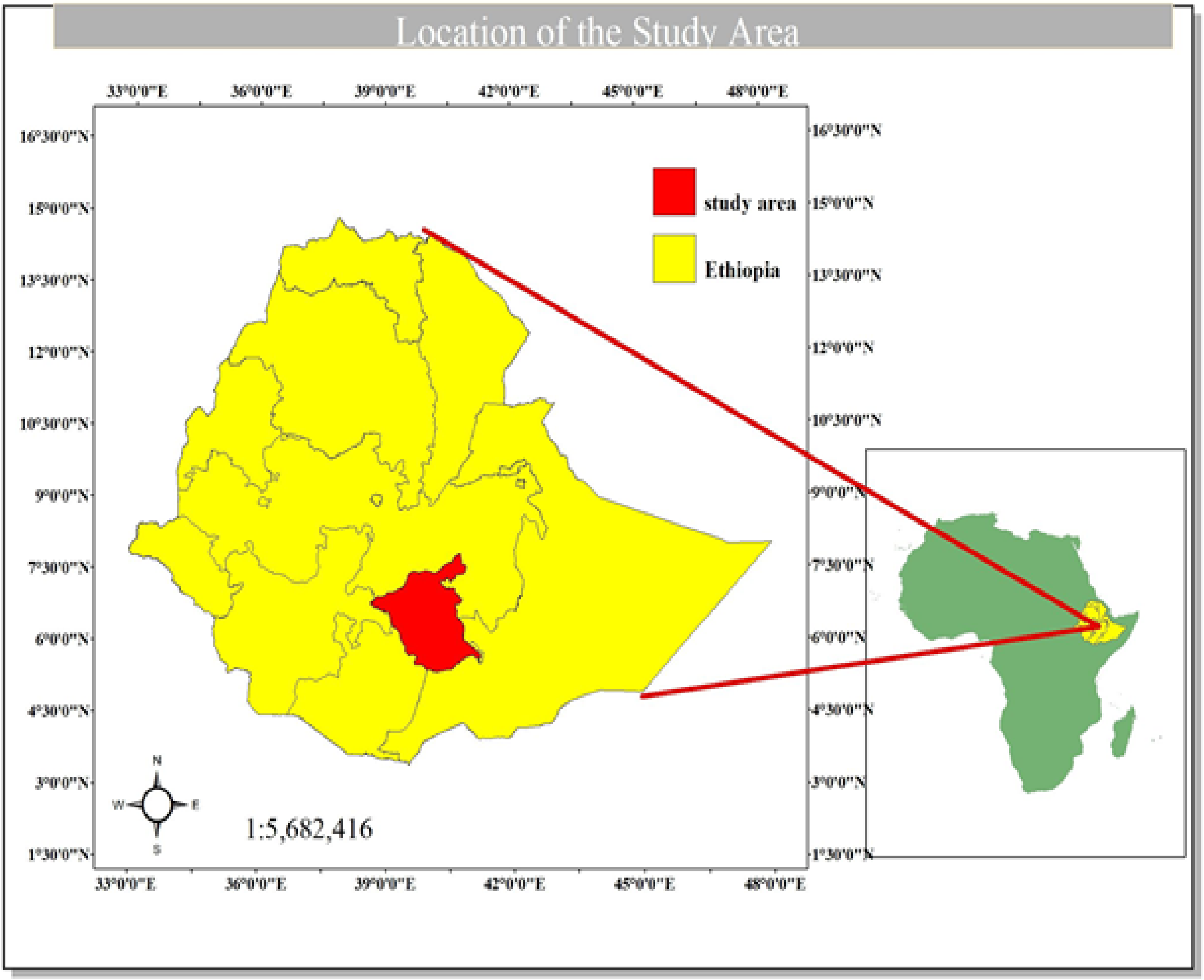

Figure 1. Map showing the location of Bale Mountain Eco-Region and the study districts.

Products (NTFP), where forest dependent communities practice their customary rights, such as collection of wild coffee, honey and spices, which are abundant. In the BMER there is Participatory Forest Management (PFM). There are more than 60 forest user groups who are responsible for the management of this forest area.

Sixteen districts (locally known as *Woredas*), namely Agarfa, Dinsho, Adaba, Dodolla, Goba, Sinana, Gololcha, Gasera, Delo Mena, Kokosa, Berbere, Harana Buluk, Nansebo, Mada Walabu, Goro and Guradhamole form the BMER. The forests in the BMER are mainly high forests composed of six forests formerly designated as "forest priority areas", namely, Aloshe Batu, Goro Bale, Harana Kokosa, Kubayu, Menna Angetu and Adaba Dodolla (EFAP, 1994). According to FARM-Africa (FARM Africa, 2008), the total forest area of the BMER was 690,000 ha in 2011, of which 193,000 ha was covered by the Bale Mountain National Park (BMNP), which was not included in this study.

About 1,904,279 people live in the sixteen districts (CSA, 2013) of which BMER comprises 61.4%. BMNR receives almost eight months of precipitation (March-October). Temperature varies from the lowest less than 7.5°C at the Sannati Plateau to over 25°C in Dolo Mena (WBISPP, 2001).

The Bale Mountains, housing BMNP and surrounded by the priority forest areas, mountains, valleys, grasslands and agricultural land, represent the largest area of Afro-alpine habitat in the African continent (FARM Africa, 2008). It is home of not only the endangered Ethiopian Wolf *(Canis simensis)* but also diverse bird species, Mountain Nyala (*Tragelaphus buxtoni*), the entire population of the Giant Mole Rat (*Trachyoryctes macrocephalus*) and stocks of valuable genetic material, including wild coffee (*Coffea arabica* L.) (OFWE et al., 2014).

The BMER is considered as the water tower of south-eastern Ethiopia, Somalia and Northern Kenya. According to recent studies, the BMER supplies water for some 12 million people in the lowlands of southeast Ethiopia, Northern Kenya and Somalia (OFWE et al., 2014). A total of 40 rivers arise in the area, contributing to five major rivers, namely the Web, Wabi Shebele, Welmel, Dumal and Ganale (FARM Africa, 2008). These rivers are the only sources of perennial water for the arid lowlands of the eastern and southeastern Ethiopia, including the Ogaden and Somali agricultural belt (OFWE et al., 2014).

Table 1. Major forest type, their sizes (ha) and estimated households for interview in the four study districts.

Forest type	Area (ha)*	Representing district	No. of *kebeles*	Representing *kebeles*	No. of households***
Dense conifer	113,702	Dodolla	25	Berisa, Deneba and Bura Chale	124
Dense Mixed Conifer and Broadleaved	657,133	Harena Buluk	13	Shawe, Sodu Welmel, and Angetu	64
Disturbed High Forest	99,062	Nansebo	16	Huro Bero;Korema;Bulga	79
Dense Mixed Conifer and Broadleaved	586,443	Dolo Mena	13	Chiri, Wabero and Irba	64
Total estimate	1456340**		67		331

*Source: WBISPP (2005); ** = Includes the Bale Mountain National Park, which is managed by the Ethiopian Wildlife Conservation Authority; *** = number of households proportionally allocated based on the number of *Kebeles* per district.

Despite its great significance, the BMER is under threat. Deforestation and forest degradation, resulting from immigration of people from other parts of Ethiopia and, hence, population increment, livestock pressure, fire and settlement, have affected the status and future of the forest resources. The projected deforestation for the period of 10 years exceeds 150,000 ha (FARM Africa, 2008), and it has been projected to continue unless proper incentives to the stakeholders in the area are provided. Failure to design attractive incentive system to the communities and the local government as well as restricting communities to access non-carbon benefits may lead to further loss of these invaluable resources. Temperature in BMER varies from the lowest, less than 7.5°C at Sannati Plateau to over 25°C at around Dolo Mena (WBISPP 2005).

The ecoregion consists of conifers and broadleaved species. The large Harenna forest of the Bale Mountains is floristically very closely related to South Western Ethiopian Afromontane forests (Friis 1992). The conifers are mainly *Podocarpus falcatus* and *Juniperes procera*.

Tree species in the area include *Oleaa europea* subsp. *cuspidata, Acacia abyssinica, Acacia negri, Euphorbia abyssinica* and *Apodytes dimidiata, Allophylus abyssinicus, Myrsine melanophloeos* and *Olinia rochetiana. Epiphytes* like orchids, mosses and lichens are also present. The shrub layer is primarily composed of *Myrsine africana, Calpurnia aurea, Dovyalis abyssinica* and *Carissa spinarium.* Climbers include *Smilax aspera, Urera hypselodendron, Embelia schimperi, Jasminum abyssinicum* and various species of the Cucurbitaceae family. The ground is usually covered with grasses, herbs, mosses and ferns.

Other trees that are grouped under broadleaved tree species include *Apodytes dimidiate, Celtis africana, Croton macrostachyus, Ekebergia capensis, Milletia ferruginea, Polyscias fulva, Syzigium guineense, Cassipourea malosana, Elaeodendron buchananii* and *Schefflera abyssinica*. The most frequent small tree species include *Allophylus abyssinicus, Bersema abyssinica, Bridelia micrantha, Ehretia cymosa, Maesa lanceolata, Nuxia congesta, Oxyanthus speciosus, Rothmannia uncelliformis, Teclea noblis* and *Vepris daniellii*. Wild coffee is one characteristic species in the understory between 1000 and 2000 masl.

Non-timber forest products (NTFPs) that are essential for the local economy include Arabica coffee, Gesho (*Rhamnus stado*) and medicinal plants. Grass for domestic animal is another significant NTFP especially during the dry season. Quite a lot of cattle are dwelling in the forest during the hot season.

The main soil types common in the area are Cambisols, Vertisols, Luvisols, Lithosols and Nitosols (FARM Africa, SOS Sahel and OFWE, 2014). The Bale Mountains form part of the Ethiopian highlands system and was formed during the Oligocene and Miocene geological periods, between 38 - 7 million years ago. The area consists of a vast lava plateau with at least six volcanic cones, each more than 4,200 m high, which have been considerably flattened by repeated glaciations (ibid). For this study, four districts are considered. These are Dodolla, Harena Buluk, Kokosa and Dolo Mena districts (hereafter referred to as by their names). The districts housed conifers, mixed conifers, broadleaved and high forests (Table 1).

In the selected districts, sample households were selected using simple random sampling (SRS) method (Moore and McCabe, 2002). Three *kebeles* (the smallest and lowest administrative unit in Ethiopia) from each representative district were chosen. The sample *kebeles* in a district were considered to be representative in terms of wealth status (poor, medium and rich), age (more than 50, less than 50), sex (female and male) and education background (read and write and illiterate) of the interviewees. Accordingly, Berisa, Deneba and Bura Chale *kebeles* in Dodolla, Huro Bero, Korema and Bulga *kebeles* in Nansebo, Sodu, Welmel, Angetu and Shawe *kebeles* in Harena Buluk and Cheri, Wabero and Irba *kebeles* in Dolo Mena were chosen (Table 1). The final analyses were, then, aggregated at the district level.

Methods

Various methods were employed to investigate the relationships between different woody species diversity indices and carbon stock as well as the non-carbon benefits obtained by the local communities from the natural forests in the study area.

Relationships between different woody species diversity indices and carbon stock

To investigate the relationships between different woody species diversity indices and carbon stock, the dataset collected during the forest inventory carried out by FARM Africa (with written permission to use the data from FARM Africa) in the study forest resources in 2013 was used.

To determine species richness, diversity, densities, frequencies, dominance and, hence, important value indices of woody species as well as their carbon stock, a total of 28 square quadrats measuring 100 x 100 m (10,000 m^2) were laid down randomly. In each of the quadrats, the following parameters were recorded: identity of all woody species, number of all live individuals and diameter at breast height (DBH) of individuals with DBH > 2 cm of each woody species. A calliper and graduated measuring stick were used to measure DBH and height, respectively, of the woody species.

Non-carbon benefits

To investigate the types, quantities and values of non-carbon benefits obtained by the local communities from the forest resources, household surveys (HHSs) and focus group discussions (FGD) were undertaken.

Household survey: To determine the number of households for the HHSs, the coefficient of variation (CV) was calculated using data from a study carried out on maize production per household in the BMER in 2013. A total of 223 households were considered to estimate the coefficient of variation (CV) in production. The mean production was about 10 quintals per household. The standard deviation was approximately 11. Using these two figures, the CV was calculated as 91%. Accordingly, the numbers of sample households for this study were determined using the following formula (Moore and McCabe, 2002; Loetsch and Haller, 1973):

$$n = \frac{cv^2 * t^2}{e^2}$$

Where, n = number of sample households, CV = coefficient of variation, t = Student-t and the value of 2 is considered, e = allowable error (10% allowable error is considered). Using the above formula, the total number of sample households required for the HHSs was 331 (Table 1).

According to the Ethiopian Central Statistics Agency (undated publication), there are about 414 *kebeles*, including towns in the BMER, and the number of *kebeles* in each district varies. There are 67 *kebeles* in the four study districts of which 12 (18%) were considered as representative for the study. The 331 sample households were distributed randomly over the 12 *kebeles* proportional to the number of *kebeles* in the four districts (Table 1). However, during the actual visits, some households were found abandoned due to one or the other reason. Hence, the total number of households used in the survey was 321 rather than 331. Accordingly, 99, 77, 76 and 69 households were interviewed in Dodolla, Dolomena, Nansebo and Harena Buluk districts, respectively.

The HHSs were carried out by using a questionnaire developed for the purpose. The questionnaire covered issues pertaining to livelihood situation, annual income of households, their relation with forests, duration of households visit to forests to get products or non-carbon benefits, duration or number of days that livestock feeds in the forest within a year and other relevant information.

During the survey, two major research questions were addressed: (i) what are the most important forest products for local communities? (ii) What is the contribution of forests to the local economy? In this study, local economy refers to the sum of total income obtained by the households in the study area. Hence, the non-carbon benefits of the forests, such as water, watershed protection and other intangible non-carbon benefits were not considered. Values of forage obtained from the forests were estimated roughly.

The volume of forest products and kinds of non-carbon benefits obtained by each respondent household were assessed using semi structured questionnaires. Likewise, an attempt to assess revenue generated from crop production and livestock production was made. Each respondent was asked what non-carbon benefits he/she collects from the forest every day, every week or at any regular interval. The respondent also estimated the harvested or collected forest service and product into monetary value using the local market price.

Focus group discussion: The focus group discussion (FGD) was conducted in addition to the HHS. The FGD was conducted in each sample *kebele*. A FGD has particular advantage to get qualitative data or information. The discussion focused on various issues concerning the environment, REDD+, crop production, livestock production, tangible forest resources and intangible forest resources, for which a list of lead topics/questions were prepared well ahead of the discussions. The discussion on environment focused on situations of forest, land, air, water and wildlife in the study areas or their vicinity. Past and present situations were addressed and the understanding of REDD+ of members of the FGD was captured. The discussion on production of major crops and livestock focused on types of crops grown and animals reared, type of inputs used, costs of production and input as well as market value per unit measurement. The discussion on tangible and intangible forest resources focused on products and non-carbon benefits that the groups get from the forest. Information on the most important forest products for market was gathered.

Data analyses

Species richness, diversity and evenness

Species richnes of the study districts was determined from the total number of woody species recorded in each of the districts. It does not take into account the proportion and distribution of each species at the project sites (Neelo et al., 2013).

Diversity and evenness of all woody species in each district were determined using the Shannon-Wiener diversity index (H) and evenness (E) (Krebs, 1989; Magurran, 2004; Zerihun, 2012). The indices were computed using the following formulas:

$$H = -\sum_{i=1}^{s} Pi \ln Pi$$

Where H = Shannon-Wiener diversity index and P_i = the proportion of individuals found in the i^{th} woody species:

$$E = \frac{H}{H\max} = \frac{H}{\ln s}$$

Where E = evenness, Hmax is the maximum level of diversity possible within a given population, which equals ln (number of species);

Similarity in species composition

Jaccard's similarity coefficient (J) (Krebs, 1989) was used to compute similarity in the composition of woody species between the study districts using the following formula:

$$J = \frac{C}{A + B + C}$$

Where, J = Jaccard's similarity coefficient, C = the number of woody species common to both districts, A = the number of woody species present in one of the districts to be compared and B is the number of woody species present in the other district.

The values of J range between 0 and 1, 0 indicating complete dissimilarity and 1 indicating complete similarity in woody species composition (Krebs, 1989; Kent and Coker, 1992).

Density, frequency and dominance

Density was calculated by converting the total number of individuals of each species to equivalent numbers per hectare (absolute density), and as the percentage of the absolute density of each species divided by the total stem number of all species ha^{-1} (relative density). Frequency distribution of each species was determined from the number of plots in which the species was recorded (absolute frequency), and as a percentage (relative frequency) by dividing the absolute frequency of the species by the sum of the absolute frequencies of all the species. The absolute dominance of woody species with DBH > 2.5 cm was determined from summing the basal area (BA) of all individuals of a species. Relative dominance was calculated as the percentage of the BA of a species divided by the total BA of all species (Neelo et al., 2013, 2015).

Importance value index

The relative ecological importance of each woody species, commonly referred to as important value index (IVI), was determined by summing its relative frequency, relative density and relative dominance (Kent and Coker, 1992).

Carbon stock

Carbon stock is the quantity of carbon in a given pool or pools per unit area (Pearson et al., 2005). In this study, above ground biomass of woody species encountered in the plots was considered as the carbon pool. Carbon stock was estimated using the DBH of all individuals of all woody species having DBH of 2 cm and above. For the estimation of carbon stock, the following algorithms, which are applicable for tropical moist and dry deciduous forests were used (Chave et al., 2005):

$$\text{biomass (kg)} = \text{WD} * \text{EXP}(-1.499 + (2.148 * \text{LN(dbh)} + 0.207 * \text{LN(dbh)}^2 - 0.0281(\text{LN(dbh)})^3))$$

(for moist forests)

$$\text{Biomass (kg)} = \text{WD} * \text{EXP}(-0.667 + (1.784 * \text{LN(dbh)} + 0.207 * \text{LN(dbh)}^2 - 0.0281(\text{LN(dbh)})^3))$$

(for dry forests)

$$\text{Carbon stock} = \text{biomass x } 0.5$$

To see if there were any statistical significant differences among the mean values of carbon stock of the woody species in the forests found in the four study districts of BMER, the data were subjected to analysis of variance (ANOVA). Also, regression analysis was undertaken to test the relationships between the Shannon diversity indices and carbon stocks of woody species. Microsoft excel was used to organize data and MINITAB and SPSS 20 were used to analyze the data.

Household survey

The number of livestock in the surveyed households that stay in the forest was estimated. The number was converted to tropical livestock unit (TLU). Then the TLU was multiplied by 6.25 kg to estimate the amount of forage consumed everyday by the livestock. Mean TLU per household was estimated and it varied from 0.678 to 3.011. This figure refers TLU relevant to forest grazing. Otherwise, Woody Biomass Inventory Strategic Planning Project (WBISPP, 2005) reported that TLU per farmer in Arsi and Bale Zones is 5.4 and 6.1, respectively.

The forest non-carbon benefits considered are fuelwood, construction material, forage, forest coffee and forest honey. Local economy in this context is the aggregated economy of each household in the BMER. Therefore, the contribution of forest non-carbon benefits to each household can be aggregated to the local economy. In each surveyed household, the forest products and non-carbon benefits harvested annually were estimated. The volume harvested was valued using local market price that was given by the respondent. Similarly, production and transport cost of the products and non-carbon benefits were estimated based on the information from the respondent. Then, the difference was considered as net income to the household.

Forage consumption depends on the number of days the cattle stay in the forest. Total forage consumed can be estimated from these numbers of days. Then, the contribution of forests to livestock can be estimated. The households reported the number of days their cattle stay in the forest per year. The dates are grouped into the four districts and, then, ANOVA was undertaken.

To estimate contribution of non-carbon benefits to each household, a rapid appraisal of each product collected from the forest was carried out based on local market prices. Similar accounting was also made to crop and livestock production in the study districts.

Household respondents were also asked to identify the most important forest services. The responses were grouped in to two-way table and the analysis was conducted accordingly. To test the presence of differences in the use of forest non-carbon benefits by the different respondent households in the study areas, a Chi-square test was conducted. Chi-square test was used to determine whether there was a significant difference between the expected frequencies and the observed frequencies in one or more categories (Moore and McCabe, 2002). The share of forest contribution to each household was calculated as:

$$Forest\ contribution\ to\ each\ household = \left(\frac{a}{a+b+c}\right) \text{x } 100$$

Where a = income generated from forest, b = income generated from crop production, c = income generated from livestock. Mean contribution of forest in each household per district was estimated. Confidence interval at 95% for each district was estimated using bootstrap in SPSS 20.

Focus group discussion

Summaries from each FGD were compiled and synthesized to draw conclusions. To estimate the value of forage, getting recent data on price of forage from forest was not possible. Market price is available from 2007 studied by International Livestock Research Institute. This market price covers for *teff* [*Eragrostis tef* (Zucc.) Trotter] straw, barely/wheat straw, sorghum and hay. According to the study, the prices of one kilogram of *teff* straw, barley/wheat straw, sorghum and hay were Ethiopian Birr (ETB) 2.00, 0.6 to 1.00, 0.65 and 1.66, respectively in Sululta (Gebremedhin et al., 2009).

RESULTS

Species richness, diversity and evenness

A total of 125 species of woody species, representing at least 45 families and 77 genera, were recorded from the four study districts. Of these, 70, 73, 40 and 32 were from Nansebo, Harenna Buluk, Dolo Mena and Dodolla, respectively. The Shannon diversity and evenness indices of the woody species ranged between 2.8 (Dodolla)

Table 2. Species richness, density, diversity, evenness and mean values of carbon stocks of woody species in the forests found in the four study districts of BMER.

District	Species richness	Density (ha^{-1})	Shannon's diversity index	Shannon's evenness index	Carbon stock (tons)
Nansebo	70	1590	3.4	0.79	213.13
Harenna Buluk	73	2106	3.5	0.80	185.44
Dolo Mena	40	1512	3.0	0.82	246.27
Dodolla	32	551	2.8	0.80	148.88

Table 3. Similarities in species composition of woody species recorded in the forests found in the four study districts of BMER.

District	Nansebo	Harenna Buluk	Dolo Mena	Dodolla
Nansebo	-	0.45	0.33	0.17
Harenna Buluk	0.45	-	0.83	0.15
Dolo Mena	0.33	0.83	-	0.08
Dodolla	0.17	0.15	0.08	-

to 3.5 (Harenna Buluk) and 0.79 (Nansebo) to 0.82 (Dolo Mena), respectively (Table 2).

Similarity in species composition

The highest and lowest similarities in woody species composition were exhibited by Haranna Buluk and Dolo Mena (0.83 = 83%), and Dodolla and Dolo Mena (0.08 = 8%), respectively (Table 3).

Density, frequency and dominance

The woody species had densities ranging from 550 (Dodolla) to 2106 (Harena Buluk) individuals ha^{-1} (Table 2).

The three densest woody species were (in descending order of density) *Vernonia rueppellii, Lepdotrichillia volkensii* and *Teclea nobilis* in Nansebo, *Maytenus arbutifolia, Cassipourea malosana* and *Lepdotrichillia volkensii* in Haranna Buluk, *Coffea arabica, Croton macrostachyus* and *Filicium decipiens* in Delo Mena, and *Rapanea simensis, Discopodium penninervum* and *Maytenus arbutifolia* in Dodolla (Appendix 1).

The most frequent woody species were (in descending order of frequency) *Croton macrostachyus, Teclea nobilis* and *Polyscias fulva* in Nansebo, *Croton macrostachyus, Ehretia cymosa* and *Vepris dainellii* in Haranna Buluk, *Celtis africana, Elaeodendron buchananii, Filicium decipiens, Olea capensis* subsp. *hochstetteri* and *Podocarpus falcatus* in Delo Mena, and *Rapanea simensis, Hagenia abyssinica, Hypericum revolutum, Maytenus arbutifolia* and *Psydrax schimperiana* in Dodolla (Appendix 1)

The three most dominant woody species were (in descending order of dominance) *Syzygium guneense, Croton macrostachyus* and *Prunus africanum* in Nansebo, *Olea capensis* subsp. *hochstetteri, Croton macrostachyus* and *Vepris dainellii* Haranna Buluk, *Olea capensis* subsp. *hochstetteri, Podocarpus falcatus* and *Syzygium guneense* in Dolo Mena, and *Combretum molle, Juniperus procera* and *Maytenus arbutifolia* in Dodolla (Appendix 1).

Importance value index

The three woody species with the highest IVI and, hence, the most ecologically important species, were (in descending order of density IVI) *Syzygium guneense, Prunus africanum* and *Maesa lanceolata* in Nsnsebo, *Olea capensis* subsp. *hochstetteri, Croton macrostachyus* and *Vepris dainellii* in Haranna Buluk, *Coffea arabica, Olea capensis* subsp. *hochstetteri* and *Syzygium guneense* in Dolo Mena, and *Combretum molle, Rapanea simensis* and *Maytenus arbutifolia* in Dodolla (Appendix 1).

Carbon stock and its relationship with Shannon diversity index

The carbon stock stored in the above-ground biomass of woody species in the forests found in the four study districts ranged between 148.88 (Dodolla) and 246.27

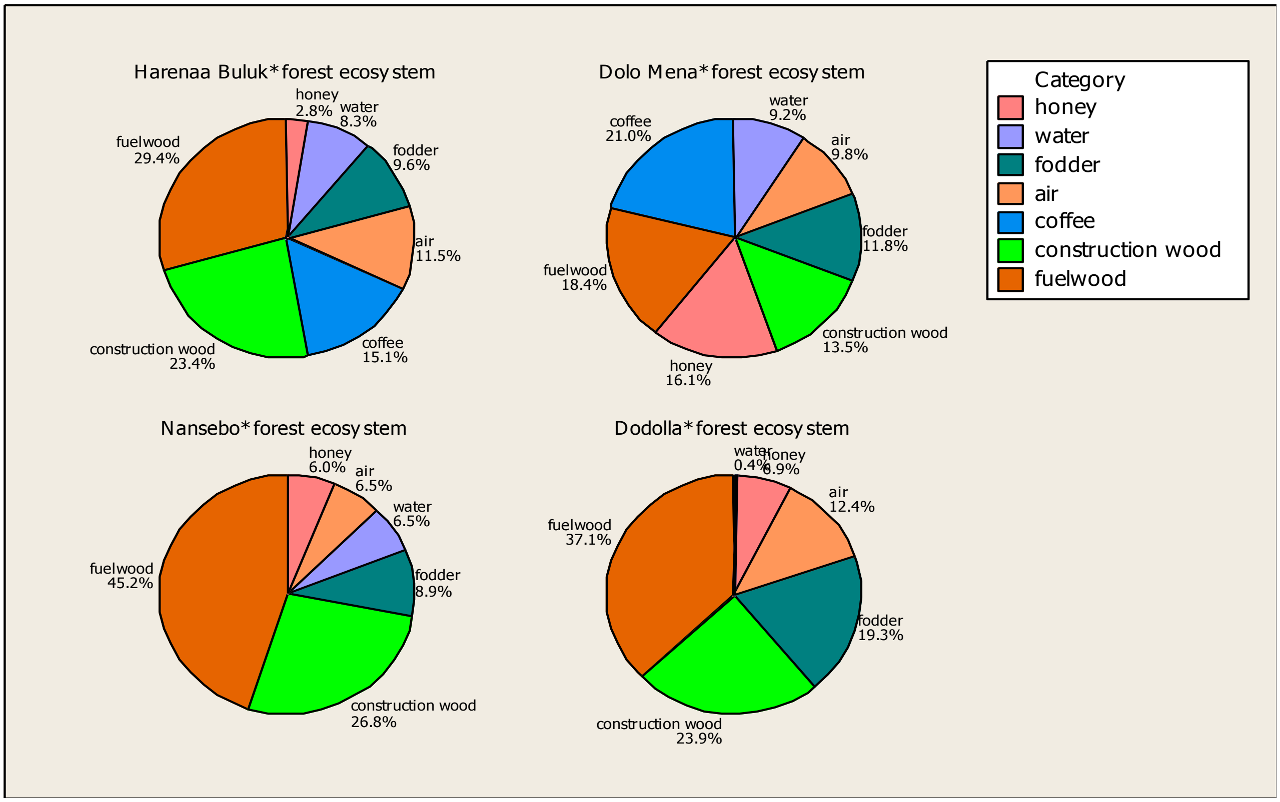

Figure 2. The most important forest non-carbon benefits obtained from forests found in the four study districts of BMER.

(Dolo Mena) tons ha^{-1} (Table 2). No statistically significant differences were found in the mean values of carbon stocks ha^{-1} in forests found in the four study districts [ANOVA $_{(3,\ 24)}$ = 1.34, P = 0.285]. However, Shannon index exhibited statistical difference among the districts [ANOVA $_{(3,\ 24)}$ = 3.93, P = 0.021]. Also, results of the regression analysis showed weak relationship between the Shannon diversity indices and carbon stocks of the woody species (R^2 = 1.5), and the Pearson correlation was 0.268. The correlation coefficient with bootstrapped confidence interval at 95% was between -0.061 and 0.539.

Non-carbon benefits *Household survey*

Various forest non-carbon benefits were mentioned by the respondent households (almost all), such as fuel wood, construction material, coffee, honey and grass (mostly). Also, a few respondent households (less than 13%) mentioned other benefits, such as medicinal plants, shade value, farm implements, rainfall and pure air. According to the respondent households, the most important forest non-carbon benefits were fuelwood, construction wood, coffee, air, fodder, water and honey (Figure 2). The forest service with the highest contributions in Nansebo (45.2%), Dodolla (37.1%) and Harenna Buluk (29.4%) was fuelwood while coffee had the highest contribution in Dolo Mena (21%). Honey, on the other hand, contributed the least in Dodolla (0.4%), Harenna Buluk (2.8%) and Nansebo (6%) while water contributed the least in Dolo Mena District (Figure 2). Construction material, fodder, water, honey were mentioned in all households. Air (clean or pure air) was also mentioned as an important service obtained from forest (contribution of 6.5 - 12.4%). There was evidence of an association between forest non-carbon benefits and districts (X^2= 74.49, df = 18, P < 0.05).

The mean tropical livestock unit (TLU) exhibited statistically significant differences among the districts [ANOVA $_{(3,\ 356)}$ = 13.68, P = 0.000]. Dodolla (0.678) and Dolo Mena (3.011) districts had the smallest and highest TLU values, respectively (Table 4). The mean total number of days per year on which the livestock graze in the forests within the study districts ranged between 34 (Dodolla) and 86 (Harenna Buluk) days with an estimated daily consumption of 6.3 kg dry matter (DM) TLU^{-1}. There was significance differences on the number of days the livestock stayed in the forest year^{-1} in the four study districts [ANOVA $_{(3,\ 354)}$ = 5.44, P = 0.001]. The total annual feed consumption of livestock from the forests in the study districts ranged between 150 (Dodolla) and 1,285 (Dolo Mena) kg DM with an estimated value of ETB300.00 and 2,590.00, respectively (Table 4).

Table 4. Tropical livestock unit (TLU) per household, total annual feed consumption of forage from the forest and the value of feed obtained from the forest per household per year.

District	Mean TLU household^{-1}	Mean number of days year^{-1}	Daily consumption (Kg DM TLU^{-1})	Total annual feed consumption (dry matter in kg)	Estimated value (ETB)*
Harenna	2.0	86	6.3	1084	2,168.00
Dodolla	0.7	34	6.3	150	300.00
Nansebo	1.7	70	6.3	750	1,500.00
Dolo Mena	3.0	68	6.3	1285	2590.00

DM = Dry matter; * = One kg of DM was estimated at ETB 2.00.

Table 5. Contribution (%) of non-carbon forest products to the annum household income in the four study districts.

Sector	Dolo Mena	Dodolla	Nansebo	Harenna Buluk
Forest	51.4	10.0	18.8	40.2
Crops	19	44.5	52.7	23.8
Livestock	31.0	41.0	28.0	35.9

Table 6. Spearman rho for income from forest and total value within each Woreda.

District	Correlation	P-value
Harena Buluk	0.84	0.000
Dodolla	0.32	0.001
Nansebo	0.32	0.004
Dolomena	0.86	0.000

Almost all the surveyed households confirmed that their means of living was from three sectors, namely forests, crops and livestock. The highest and least contributions of forests to the households were found in Dolo Mena (51.3%) and Dodolla (10.0%) districts (Table 5), respectively. Forests contributed 40.2% to the household income in Harenna Buluk District and 18.8% in Nansebo District. The result that Harenna Buluk and Dolo Mena are the highest corresponds with the results from the FGDs. Information obtained from the FGD on contribution of forest varied from 16.5% in Dodolla District to 47.4% in Harenna Buluk District. Contributions of forests to the households in the study area exhibited statistical differences [ANOVA $_{(3,\ 317)}$ = 6.78, P = 0.000]. There is very strong evidence that the four districts do not have the same mean value of forest contribution. Strong correlations were found between contributions of forests and the total household income per annum (Table 6).

Focus group discussion

Within the group, female respondents were more focused and to the point where they reflect their ideas on the non-carbon benefits. Fuelwood and water were the most important products for them unlike men. Free gifts from nature or their surrounding are fuelwood, water, soil, coffee, honey, grass, construction materials, medicinal plants, air, spring water, fruits, sand and stones. The relationship between land, water, forest and other environmental resources was well articulated by the participants of the FGD from the four districts. The concept of landscape for them works very well.

The life of local communities is supported by farming, livestock rearing, beekeeping as well as products and non-carbon benefits that they extract from the forests. Dolo Mena and Harenna Buluk are found within the BMER where forest coffee is well developed whereas Dodolla is located at the agro-ecological zone outside the coffee belt. Hence, the residents are more dependent on forest products of woody nature. Common to all districts are farming, livestock rearing, beekeeping and harvesting of wood. Trade contributes very little, for about 2% of the segments of the communities in Dodolla and Nansebo. Bamboo harvesting and trade were reported from Nansebo. From the FGD, it was learnt that at least one member of a household visits the forest every day to get a product, such as fuelwood.

The most important forest products that a household depends on most were ranked differently in the four study districts. For instance, coffee and honey were ranked in Dolo Mena and Harenna Buluk districts next to fuelwood. In Dodolla district, construction material, water/rain, air and honey were ranked next to fuelwood while water was ranked as number one in Nansebo district. Fuelwood, farm implements, construction materials, including climbers and fences, honey, grass, medicinal plants and furniture were prioritized from most important to least. In general, fuelwood seems to be the most important forest product that the communities harvest from the forest. Water and clean air were very well recognized as important non-carbon benefits from the forest ecosystem. The communities explained the relationship between forests and rainfall. Provision of grasses and thatching grasses from forest for their cattle and house construction, respectively, was discussed as well.

Harvesting, use and sell of medicinal plants were also discussed, but the groups confirmed that sell of medicinal plants is not done by everyone in the communities. It was indicated that only knowledgeable people harvest and trade medicinal plants. In line with this ranking, the most important products for markets were coffee, honey, medicinal plants and bamboo. In Dodolla district, fuelwood, construction material and honey were listed in addition.

It was noted from the FGD that a household sends not less than 10 cattle to the forest for 105 days per year in three of the four districts. Rapid population growth is reported to decrease the available grazing land, hence, use of crop residue as fodder has become a trend in Ethiopia (Mengistu, 2003) as well as the study area. In recent years, crop residue management has become an important intervention of climate-smart agriculture. Leaving crop residue in the field, rather than feeding it to cattle, protects the soil from erosion and limits weed growth throughout the year (IIRR and CTA, 2005). During FGD, the groups from Dodolla, Dolo Mena and Haranna Buluk confirmed that crop residue is used as feed for domestic animals; but, the group from Nansebo claimed that they are managing crop residue in the field and do not fed it to animals or burn it, unlike in the past. It was also noted during the discussion that the products are gathered by different members of the household. However, there was a consensus that most of the products are gathered by women. The interaction between women and the forest is very close.

Access to the forests is regulated by by-laws developed by the community-based organizations (CBOs). There is no prohibition of collecting the products and using non-carbon benefits from the forests as far as permit is secured from the executive committees of the CBOs.

When the groups were asked to explain the most pressing environmental problems, they mentioned coffee wilt disease, rust disease (in Dolo Mena), land degradation, drought as a result of rainfall variability, frost, too much rain, lack of water in the rivers and streams in some months, high and speedy wind uprooting trees, invasive species, such as '*muja'* [*Snowdenia polystachya* (Fresen) Pilg.] and *'ye-wef kollo*' (*Lantana camara* L.) (Dodolla), hailstorms, high speed wind with rainfall, which has not been the case in the old days (recent phenomena, according to the elders).

The FGDs in all districts confirmed that the participants have heard and know about REDD+ (Figure 3). Their expectation is diverse, but they expressed that they expect payment for results they will achieve or have achieved. On the other hand, the participants in the FGD expressed their fear by emphasizing that during the implementation of REDD+, they may lose benefits, that is, the REDD+ initiatives may restrict them from obtaining the benefits that they used to get from the forests, for example, harvesting wood, improvement of coffee stands, etc. since their income is highly dependent on coffee production. In the management of forest coffee, clearing of land and reducing the regeneration and saplings of woody species may be necessary. They fear that implementation of REDD+ initiatives may not approve such activities.

DISCUSSION

The number of woody species in four districts differed. Dodolla being dry tropical forest comprises less number of tree species than the others, and the highest number of woody species was recorded in Harena Buluk. Density of trees per hectare and Shannon diversity index were higher in Harena Buluk, whereas carbon stock was highest in Dolo Mena. But, the number of species registered in Dolo Mena is less than Harena Buluk and Nansebo. Evenness in Dolo Mena was higher than the rest of the three districts, and the highest similarity was found between the forests in Dolo Mena and Harena Buluk districts. Despite the fact that the number of species in Harena Buluk and Nansebo were higher, their similarity in woody species composition was only 45%. The lowest woody species similarity was observed between Dodolla and Harena Buluk.

Forest products and non-carbon benefits that are very important to the communities are highly associated with their livelihoods. Fuelwood was the most important forest benefit in three out of the four study districts. The weighted average of annual per capita energy consumption for all households in rural and urban Ethiopia is 1.16 m^3s or 241 kg of oil equivalent (EFAP, 2004). Each household in the study area collects the specified amount freely. In the absence of fuelwood, it is clear that the rural community in the study area would not have other means for cooking, heating and lighting. However, coffee emerged as the most important benefit in the other district, namely Dolo Mena. In Dolo Mena, communities appreciate the contribution of forest coffee for their annual household income in addition to their daily consumption. In general, forests provide multiple benefits at local to global scales (Agrawal and Chhatre, 2009). In the context of this study, coffee and carbon can be considered as global benefits.

The contribution of forest to local economy is significant when compared with other incomes where non-timber forest products (NTFPs), such as forest coffee, honey and forage for livestock are extracted or harvested by the local people. Still in the absence of the above-mentioned NTFPs, the contribution from forest had positive

Figure 3. Communities expectation from REDD+ implementation.

correlation with total household income. Watson (2007) estimated that a household earns annual income of US$ 1,157.00 from crop production, US$ 228.00 from livestock, and US$ 407.00 from forest products in BMER. In her study, forest coffee was not a major force in income generation as most of her sampled *kebeles* were located at the upper limit of the coffee belt. Also, the income from livestock she considered was selling of live animal only. Unlike the analysis made by Agrawal and Chhatre (2009), this study indicated presence of relationship between carbon stock and benefits to the community in the case of Dodolla and Harena Buluk districts.

Monitoring of biodiversity in tropical forest areas, such as BMER, has significant importance. According to Woods-Schank (1990), extinction of a single plant species in tropical forests means the “demise of as many as 30 animals”. In forests that are managed by thecommunity or through participatory forest management (PFM), more biodiversity implies effective efforts in carbon conservation because of other non-carbon benefits that come as source of livelihoods for communities. For instance, forest communities with more plant diversity provide more honey production that may be related to more pollen source with species having different flowering periods and, hence, continuous provision of pollen throughout the year for bee foraging. Another important benefit of plant diversity conservation, among many others, is decreasing susceptibility to diseases, unlike monoculture plantations. Higher plant diversity in natural forests exhibits good undergrowth and various vertical strata that makes the soil resilient to wind and rain or water disturbance. Soil disturbance may be minimal to affect stable soil carbon stock in this regard. In addition, conservation of biodiversity could ensure the sustainability of contributions of reducing emissions from deforestation and forest degradation (REDD+) to combat global climate change.

The objective of this study was not just to justify the importance of biodiversity. The major aim is to demonstrate that monitoring of biodiversity in addition to carbon stock is crucial for decision makers and practitioners in fighting against climate change and achieving the objectives of sustainable development. Hence, the study provides evidence that monitoring of biodiversity is possible while carbon is monitored.

Although weak statistical relationship between the Shannon diversity index and carbon stock was observed, the results from this study can inform the policy makers that maintaining plant diversity while also conserving/ enhancing carbon in the natural forests is possible/ important. Strassburg et al. (2010) made similar test whether species richness has correlation with carbon stock. Their study covered mammals, amphibians and bird species in the analysis of biodiversity. They have also considered both above- and below-ground biomass in the estimation of carbon stock. They found a strong association between carbon stocks and species richness. Conservation of biodiversity contributes to increased resilience of ecosystems, ecosystem stability and improved habitat (Bann, 1998).

One important achievement from the present study confirms that estimating plant diversity indices can be made while measuring the carbon stock without additional cost. The same data that are collected for the analysis of carbon stock can be used to estimate parameters important for the sustainable management of forests, such as basal area, density, frequency and important value index in addition to biodiversity indices.

Diverse forest ecosystems have diverse values for communities. This was explained by the communities and the non-carbon benefits range from shade during hot sunny days to products, such as honey, medicine and forage. Hence, forest management has to recognize and consider the needs of the local communities to sustain the flow of non-carbon benefits and products from the existing natural forests. REDD+ implementation needs to respond to the needs of the community in this regard. Though fulfilling international commitments are crucial in effecting REDD+ mechanisms, integration of all non-carbon benefits into the negotiation is more crucial for its (REDD+) success. Therefore, considering non-carbon benefits in the design and implementation of reducing emissions from deforestation and degradation (REDD+) is important. Otherwise, acceptance of REDD+ by local communities may be a challenge or completely lacking.

Future research needs to consider plant species less than 2 cm in diameter, seedlings, ferns and mosses. Furthermore, considering other pools in addition to above ground biomass may give different picture.

Conflict of interest

The authors did not declare any conflict of interest.

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REFERENCES

Agrawal A, Chhatre A (2009). Trade-offs and synergies between carbon storage and livelihood benefits from forest commons. (E. Ostrom, Ed.) PNAS 17667-17670.

Bann C (1998). The Economic Valuation of Tropical Forest Land Use Options: A Manual for Researchers. Singapore.

Bryan BA (2013). Incentives, land use, and ecosystem Non-Carbon Benefits: Synthesizing complex linkages. Elsevier, pp. 124-134.

Chave J, Andal, C, Brown S, Cairns MA, Chambers JQ, Eamus D, Yamakura T (2005). Tree allometry and improved estimation of carbon stocks and balance in tropical forests. Springer -Verlag. http://dx.doi.org/10.1007/s00442-005-0100-x

Edwards S, Mesfin T, Hedberg I (eds.) (1995). Flora of Ethiopia and Eriterea, National Herbarium, Addis Ababa University, Addis Ababa and University of Systematic Botany, Uppsala University, Uppsala. 2:2.

Edwards S, Mesfin T, Sebsebe D, Hedberg I (eds.) (2000). Flora of Ethiopia and Eriterea, National Herbarium, Addis Ababa University, Addis Ababa and University of Systematic Botany, Uppsala University, Uppsala. 2: 1.

Edwards S, Sebsebe D, Hedberg I (eds.) (1997). Flora of Ethiopia and Eriterea, National Herbarium, Addis Ababa University, Addis Ababa and University of Systematic Botany, Uppsala University, Uppsala. Vol. 6. .

FAO (2001). How Forests can reduce Poverty. Rome: FAO.

FARM Africa (2008). Bale Mountains Eco-REgion Sustainable Development Plan: Report Phase I and II planning Workshops. Addis Ababa: FARM Africa.

Friis I (1992). Forests & Forest Trees of Northeast Tropical Africa. Birmingham: HMSO.

Gebremedhin B, Hirpa A, Berhe K (2009). improving productivity and market success of Ethiopian farmers project (IPMS). Addis Ababa: International Livestock Research Institute (ILRI).

Groom B, Palmer C (2012). REDD+ and rural livelihoods. Elsevier pp. 42-52. http://dx.doi.org/10.1016/j.biocon.2012.03.002

Hedberg I, Edwards S (eds.) (1989). Flora of Ethiopia, Addis Ababa University, Addis Ababa and Department of Systematic Botany. Uppsala University, Uppsala. Vol. 3.

Hedberg I, Edwards S (eds.) (1995). Flora of Ethiopia and Eritrea, Addis Ababa University, Addis Ababa and Department of Systematic Botany. Uppsala University, Uppsala. Vol. 7.

Hedberg I, Ensermu K, Edwards S, Sebsebe D, Persson E (eds.) (2006). Flora of Ethiopia and Eritrea, Addis Ababa University, Addis Ababa and Department of Systematic Botany. Uppsala University, Uppsala. Vol. 5.

Hedberg I, Friis I, Edwards S (eds.) (2004). Flora of Ethiopia and Eritrea, Addis Ababa University, Addis Ababa and Department of Systematic Botany. Uppsala University, Uppsala. 4(2).

Hedberg I, Edwards S, Sileshi N (eds.) (2003). Flora of Ethiopia and Eritrea, Addis Ababa University, Addis Ababa and Department of Systematic Botany. Uppsala University, Uppsala. 4(1). IIRR and CTA (2005). Conservation Agriculture : A Manual for Farmers and Extention Wokers in Africa. Nairobi: International Institute of Rural Reconstruction, Nairobi; African Conservation Tillage Network, Nairobi.

Jaung W, Bae JS (2012). Evaluating Socio-economic equity of REDD+ in a rights-based apporach: Rapid equity appraisal matrix. ELSEVIER, 1-12.

Kent M, Coker P (1992). Vegetation Description and Analysis. A Practical Approach. England: John Wiley and Sons Ltd.

Krebs CJ (1989). Ecological Methodology. New York: Harper Collins Publishers.

Lang GM, Hassan R, Hamilton K (2003). Environmental Accounting in Action: Case Studies from Southern Africa. Chltenham: Edward Elgar Publishing Limitted.

Loetsch F, Haller K (1973). Forest Inventory (Vol. I & II). Munchen: BLV.
Magurran AE (2004). Measuring Biological Diversity. MA: Blackwell Publishing.
McDermott CL, Coad L, Helfgott A, Schroeder H (2012). Operationalizing Social Safeguards in REDD+: actors, Interests and Ideas. Elsevier pp. 63-72. http://dx.doi.org/10.1016/j.envsci.2012.02.007
Mengistu A (2003). Country Pasture/Forage Resources Profile. FAO. Retrieved January 10, 2015, from FAO: http://www.fao.org/ag/AGP/AGPC/doc/counprof/ethiopia/ethiopia.htm#5.
Moore DS, McCabe GP (2002). Introduction to the Practice of Statistics. New York: W.H. Freeman and Company.
Neelo J, Teketay D, Masamba W, Kashe K (2013). Diversity, Population Structure and Regeneration Status of Woody Species in Dry Woodlands Adjacent to Molapo Farms in Northern Botswana. Open J. For. 3:138-151. http://dx.doi.org/10.4236/ojf.2013.34022
Neelo J, Kashe K, Teketay D, Masamba W (2015). Ethnobotanical survey of woody plants in Shorobe and Xobe villages, Northwest Region of Botswana. Ethnobotanical Research Applications 5: 313-328.
Nune S, Menale K, Mungatana E (2013). Forest Resource Accounts for Ethiopia. In Hassan RM, Mungatana ED (Eds.), Implementing Environmental Accounts, Springer 28: 103-142. http://dx.doi.org/10.1007/978-94-007-5323-5_5
OFWE, FARM Africa, SOS Sahel Ethiopia (2014). Bale Mountains Eco-Region Reduction of Emission from Deforestation and Forest Degradation (REDD+) Project-Ethiopia. Addis Ababa: FARM Africa and SOS Sahel.
Pearson T, Walker S, Brown S (2005). Sourcebook for Land Use, Land-Use Change and Forestry Projects. Winrock International. Retrieved March 7, 2015, from http://www.katoombagroup.org/documents/cds/uganda_2011/Ag%20and%20Land%20Use%20Management/Sourcebook%20for%20LULUCF%20Projects.pdf
Strassburg BB, Kelly A, Balmford A, Davies RG, Gibbs HK, Lovett A, Rodrigues AS (2010). Global Congruence of Carbon Storage and Biodiversity in Terrestrial Ecosystems. Wiley Periodicals, Inc. Retrieved from http://onlinelibrary.wiley.com. http://dx.doi.org/10.1111/j.1755-263x.2009.00092.x
UNFCCC (2011). Report of the Conference of the Parties on its sixteenth session, held in Cancun from 29 November to 10 December 2010: Addendum Part Two: Action taken by the Conference of the Parties at its sixteenth session. UNFCCC. Retrieved May 14, 2014, from http://unfccc.int/resource/docs/2010/cop16/eng/07a01.pdf#page=2
Vijge MJ, Gupta A (2014). Framing REDD+ in India: Carbonizing and centralizing Indian Forest Governance. ELSEVIER. pp. 17-27.
WBISPP (2001). Report of Natural Grazing Lands and Livestock Feed Resources: Oromia Regional State. Addis Ababa: MoA.
WBISPP (2005). WBISPP. A National Strategic Plan for the Biomass Energy Sector: Final Report. Addis Ababa: MoA,
Woods-Schank GG (1990). Protecting the Tropical Forests A high Priority International Task. Bonn: Bonner Universitats - Buckdruckererei, 5300 Bonn.1.
Yitebitu M, Eshetu Z, Sisay N (2010). Ethiopian Forest Resources: Current Status and Future Managment Options in view of Access to Carbon Finance. Addis Ababa: UNDP.
Zerihun W (2012). Environmental and Ecological Data Analysis. Lap Lambert Academic Publishing.

Appendix 1. List of woody species recorded from the four study sites in BMER with their scientific and family names, densities (DE), frequency (FR), dominance (DO) and important value index (IVI).

Species*	Nansebo				Haranna Buluk				Dolo Mena				Dodolla			
	DE	FE	DO	IVI	DE	FE	DO	IVI	DE	FE	DO	IVI	DE	FE	DO	IVI
Acacia albida (Fabaceae)	0	0	0	0	3	14	0	1	0	0	0	0	0	0	0	0
Acacia lahai (Fabaceae)	0	0	0	0	6	14	0	1	0	43	0	2	0	0	0	0
Agave sisalana (Agavaceae)	0	0	0	0	1	29	1	2	0	0	0	0	0	0	0	0
Albizia grandibracteata (Fabaceae)	6	14	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Allophylus abyssinicus (Sapindaceae)	0	0	0	0	12	29	1	2	3	29	0	2	0	0	0	0
Apodytes dimidiate (Icacinaceae)	0	0	0	0	17	14	0	2	16	43	12	8	0	0	0	0
Arundinaria alpina (Poaceae)	118	29	2	4	0	0	0	0	0	0	0	0	0	0	0	0
Balanites aegyptica (Balanitaceae)	0	0	0	0	0	0	0	0	0	0	0	0	36	29	1	11
Bersama abyssinica (Melianthaceae)	13	14	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Brucea antidysenterica (Simaroubaceae)	33	29	1	2	0	0	0	0	0	0	0	0	30	29	0	9
Buddleja polystachya (Buddlejaceae)	0	0	0	0	0	0	0	0	0	0	0	0	0	14	0	2
Calpurnia aurea (Fabaceae)	0	0	0	0	0	14	1	2	0	0	0	0	0	0	0	0
Canthium euryoides (Rubiaceae)	1	14	1	1	15	57	1	4	5	86	3	6	0	0	0	0
Carissa spinarium (Apocynaceae.)	0	0	0	0	22	29	0	2	0	0	0	0	0	0	0	0
Cassipourea malosana (Rhizophoraceae)	20	57	1	4	158	57	4	14	18	71	2	6	6	14	0	3
Celtis africana (Ulmaceae)	15	29	2	3	14	71	3	6	13	100	10	10	0	0	0	0
Coffea arabica (Rubiaceae)	10	14	0	1	117	29	0	7	1298	43	8	91	0	0	0	0
Combretum molle (Combretaceae)	0	0	0	0	0	0	0	0	0	0	0	0	39	14	50	36
Cordia africana (Boraginaceae)	0	0	0	0	12	57	1	4	1	29	2	2	0	0	0	0
Croton macrostachyus (Euphorbiaceae)	65	86	21	26	36	100	11	17	22	71	14	11	0	0	0	0
Discopodium penninervum (Solanaceae)	0	0	0	0	44	14	0	3	0	0	0	0	60	29	0	14
Dombeya goetzenii (Sterculiaceae)	7	14	1	1	0	14	0	1	0	0	0	0	0	0	0	0

Appendix 1. Contd.

Ehretia cymosa (Boraginaceae)	35	29	3	4	121	100	5	15	10	86	2	6	0	0	0	0
Elaeodendron buchananii (Celastraceae)	0	0	0	0	43	43	1	4	10	100	5	8	0	0	0	0
Embelia schimperi (Myrsinaceae)	0	14	0	1	3	14	0	1	0	0	0	0	0	0	0	0
Erica arborea (Ericaceae)	0	0	0	0	0	0	0	0	0	0	0	0	10	14	6	7
Erythrina abyssinica (Fabaceae)	2	29	2	4	0	0	0	0	0	0	0	0	0	0	0	0
Erythrococca abyssinica (Euphorbiaceae)	3	14	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Fagaropsis angolensis (Rutaceae)	7	14	0	1	8	43	0	2	1	43	1	3	0	0	0	0
Ficus exasperata (Moraceae)	0	0	0	0	2	57	2	4	0	29	0	2	0	0	0	0
Ficus sp. (Moraceae)	0	0	0	0	2	43	1	2	5	43	2	3	6	14	0	3
Ficus sur (Moraceae)	0	14	1	2	0	0	0	0	0	14	0	1	0	0	0	0
Ficus vallis-choudea. (Moraceae)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Filicium decipiens (Sapindaceae)	0	0	0	0	68	43	1	6	21	100	20	15	0	0	0	0
Flacourtia indica (Flacourtiaceae)	0	0	0	0	3	14	0	1	0	0	0	0	0	0	0	0
Galiniera saxifraga (Rubiaceae)	37	29	1	3	0	0	0	0	0	0	0	0	0	14	0	2
Gardenia ternifolia (Rubiaceae)	4	29	1	2	1	29	0	1	0	0	0	0	0	0	0	0
Hagenia abyssinica (Rosaceae)	0	0	0	0	0	0	0	0	0	0	0	0	9	43	19	17
Hippocratea africana (Celastraceae)	3	14	0	1	3	29	0	1	0	14	0	1	4	29	0	4
Hypericum revolutum (Hypericaceae)	0	0	0	0	0	0	0	0	0	0	0	0	5	43	3	8
Ilex mitis (Aquifoliaceae)	2	43	3	5	0	0	0	0	0	0	0	0	11	29	1	6
Juniperus procera (Cupressaceae)	0	0	0	0	0	0	0	0	0	0	0	0	7	29	45	29
Lepidotrichillia volkensii (Meliaceae)	138	43	3	6	150	86	4	14	0	0	0	0	0	0	0	0
Linociera latipetala (Oleaceae)	0	0	0	0	1	29	1	2	1	14	1	1	0	0	0	0
Loranthus sp. (Loranthaceae)	10	14	0	1	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 1. Contd.

Maesa lanceolata (Myrsinaceae)	52	29	16	18	10	29	0	2	0	0	0	0	11	29	2	7
Manilkara butugi (Sapotaceae)	6	14	1	2	0	14	0	1	4	71	4	6	0	0	0	0
Maytenus arbutifolius (Celastraceae)	64	29	1	2	183	57	2	12	0	0	0	0	43	43	34	32
Maytenus undata (Celastraceae)	7	14	1	1	0	0	0	0	0	0	0	0	0	0	0	0
Millettia ferruginea (Fabaceae)	23	43	3	5	35	71	4	8	0	14	0	1	0	0	0	0
Mimusops kummel (Sapotaceae)	21	14	0	1	0	0	0	0	0	14	0	1	0	0	0	0
Myrsine africana (Myrsinaceae)	0	0	0	0	0	0	0	0	0	0	0	0	13	14	0	4
Nuxia congesta (Loganiaceae)	0	0	0	0	0	0	0	0	0	0	0	0	4	29	4	6
Ocotea kenyensis (Lauraceae)	0	0	0	0	0	14	0	1	2	29	2	3	0	0	0	0
Olea capensis subsp. *hochstetteri* (Oleaceae)	0	0	0	0	9	57	15	18	12	100	65	34	0	0	0	0
Olea europaea subsp.*cuspidata* (Oleaceae)	0	0	0	0	0	0	0	0	0	0	0	0	1	14	1	2
Olea welwitschii (Oleaceae)	8	29	1	2	22	86	1	5	0	43	0	2	0	0	0	0
Olea sp. (Oleaceae)	23	14	7	8	0	0	0	0	0	0	0	0	0	0	0	0
Olinia rochetiana (Oliniaceae)	0	14	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Osyris quadripartita (Santalaceae)	0	0	0	0	0	0	0	0	0	0	0	0	0	14	0	2
Piliostigma thonningii (Fabaceae)	0	0	0	0	0	14	0	1	0	0	0	0	0	0	0	0
Pittosporum abyssinicum (Pittosporaceae)	12	29	0	2	7	43	0	2	0	14	0	1	0	0	0	0
Podocarpus falcatus (Podocarpaceae)	15	29	7	9	91	43	2	8	11	100	26	17	0	0	0	0
Polyscias fulva (Araliaceae)	9	71	10	14	14	43	5	7	0	0	0	0	0	0	0	0
Pouteria adolfi-fredericii (Sapotaceae)	0	29	2	3	15	57	3	6	0	14	3	2	0	0	0	0
Prunus africanum (Rosaceae)	31	43	20	23	0	29	0	1	0	0	0	0	0	0	0	0
Psydrax schimperiana (Rubiaceae)	53	29	1	2	10	14	0	1	0	14	0	1	32	43	0	11

Appendix 1. Contd.

Rapanea simensis (Myrsinaceae)	3	14	0	1	0	0	0	0	0	0	0	0	120	86	8	36
Rhamnus prinoides (Rhamnaceae)	9	29	0	2	0	0	0	0	0	0	0	0	0	0	0	0
Rhus glutinosa (Anacardiaceae)	0	14	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Ricinus communis (Euphorbiaceae)	0	0	0	0	0	0	0	0	0	0	0	0	3	14	0	2
Rubus steudneri (Rosaceae)	6	14	0	1	3	14	0	1	0	0	0	0	12	29	0	6
Rumex nervosus (Polygonaceae)	0	0	0	0	0	0	0	0	0	0	0	0	0	14	0	2
Rytigynia neglecta (Rubiaceae)	6	14	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Schefflera abyssinica (Araliaceae)	0	14	3	4	0	14	0	1	0	0	0	0	0	0	0	0
Schefflera volkensii (Araliaceae)	1	14	1	2	0	0	0	0	0	0	0	0	3	29	5	7
Schrebera alata (Oleaceae)	9	14	1	1	0	0	0	0	0	0	0	0	0	0	0	0
Syzygium guineense (Myrtaceae)	14	57	50	54	46	86	2	8	14	86	24	16	0	0	0	0
Teclea nobilis (Rutaceae)	134	86	5	10	22	57	1	4	2	14	0	1	0	0	0	0
Trema guineensis (Ulmaceae)	0	0	0	0	1	14	0	1	1	43	1	3	0	0	0	0
Trichilia emetica (Meliaceae)	8	57	6	9	0	14	0	1	0	0	0	0	5	29	0	4
Urera hypselodendron (Urticaceae)	29	29	0	2	0	0	0	0	0	0	0	0	13	29	0	6
Vepris dainellii (Rutaceae)	55	57	3	6	100	100	6	15	2	43	1	3	0	0	0	0
Vernonia amygdalina (Asteraceae)	0	0	0	0	0	0	0	0	7	57	6	6	0	0	0	0
Vernonia rueppellii (Asteraceae)	152	43	2	4	3	14	0	1	0	0	0	0	3	14	0	2
Vernonia schimperi (Asteraceae)	10	29	1	3	0	29	0	1	0	0	0	0	0	0	0	0
Warburgia ugandensis (Canellaceae)	0	0	0	0	2	57	1	4	9	86	12	10	6	14	0	3
Ximenia caffra (Olacaceae)	0	0	0	0	116	71	3	12	2	14	0	1	0	0	0	0
Unidentified 37 species	303				543				13				58			
Total	1592				2094				1503				550			

*Plant nomenclature used in this article follows those in Hedberg and Edwards (1989, 1995), Edwards et al. (1995, 1997, 2000), Hedberg et al. (2003, 2004, 2006)

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Full Length Research Paper

Assessment of cobalt levels in wastewater, soil and vegetable samples grown along Kubanni stream channels in Zaria, Kaduna State, Nigeria

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The concentration of cobalt was determined in wastewater, soil and vegetable (carrot, lettuce, onion, spinach, cabbage, tomato and okra) samples collected on seasonal basis from January, 2013 to September 2014 along Kubanni stream channels in Zaria. The results show cobalt levels in wastewater were in the range of 3.77 - 15.20 mg/L for the year 2013 and 4.74 - 15.20 mg/L in 2014; 0.63 - 3.57 mg/Kg for the year 2013 and 0.99 - 4.07 mg/Kg in 2014 for the soil while the vegetables had concentrations in the range of 1.25 - 8.75 mg/Kg for the year 2013 and 2.76 - 12.45 mg/Kg in 2014. Statistical analysis revealed no significant difference in cobalt levels across the sampling locations whereas significant difference ($p < 0.050$) were observed in seasons for wastewater and vegetables analyzed. Pearson correlation showed substantial ($r = 0.726$) relationship between cobalt levels in wastewater for the year 2013 and 2014, substantial ($r = 0.799$) relationship for soils between these two years and substantial ($r = 0.720$) relationship was also obtained for vegetables cultivated in 2013 to that of 2014, respectively. Cobalt concentrations in this study were higher than maximum contaminant levels set by Standard Organizations such as WHO and FAO in wastewater while below their limits in vegetables.

Key words: Cobalt level, Kubanni River, soil, vegetable, wastewater.

INTRODUCTION

Cobalt is beneficial to human because it is part of vitamin B_{12}. Exposure to high levels of cobalt results in lung and heart diseases and dermatitis. It is a key constituent of cobalamin which is known as vitamin B_{12}, the primary biological reservoir of cobalt as an ultratrace element (Prasad, 2004). Bacteria in the guts of ruminant animals convert cobalt salts into vitamin B_{12}, a compound which can only be produced by bacteria or arches. The minimum presence of cobalt in soils therefore markedly improves the health of grazing animals and an uptake of 0.20 mg/kg a day is recommended for them, as they can obtain vitamin B_{12} in no other way (Schwarz et al., 2000).

Industrial or municipal wastewaters are used for the irrigation of crops in periurban ecosystem, due to its

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availability and scarcity of fresh water. Irrigation with wastewater contributes to heavy metals contents in the soil. Heavy metals are harmful because of their non-biodegradable nature, long biological half-lives and their potentials to accumulate in different body parts (Wegelin et al., 1995). Heavy metals like cobalt are toxic because of their solubility in water. Low concentration of heavy metals has damaging effects on man and animals because there is no mechanism for their elimination in the body (Bahemuka and Mubofu, 1991). Wastewater contains substantial amounts of toxic metals which create problems (Sharma et al., 2009). High accumulation of these metals in agricultural soils through wastewater irrigation may not only result in soil contamination but affect food quality and safety (Mohsen and Seilsepour, 2008).

Soil is known as earth: it is the substance from which our planet takes its name. Soil is a vital resource of sustaining basic human needs, a quality food, food supply and a live able environment. Chemical analysis of soil is important for environmental monitoring and legislation (Catharine et al., 2011). It provides information on the fertility status, index of nutrient availability and bases for fertilizer recommendation (for a given crop) as well as planning of a nutrient management programme. Metals are introduced into aquatic systems as a result of the weathering of rocks and soils. For example, volcanic eruption and also several human activities involving the mining, processing and uses of metals and industrial material contain metal contaminants. Soil whether in urban or agricultural areas represent a major sink for metals released into the environment from a variety of anthropogenic activities (Fraser, 2004).

Vegetables provide accessible sources of essential vitamins (particularly ascorbic acid, niacin, riboflavin and thiamine) and minerals (such as calcium and iron), as well as supplementary protein and calories (FAO, 1988). Vegetables promote intake of essential nutrients from other foods by making them more palatable (Taylor, 1996; Oke, 1980). They provide dietary fibre to improve digestion and health, and they are essential for balanced diets (Koch et al., 1965). In developed countries, average daily consumption of vegetables is estimated to be about 238 g per capita (FAO, 1988). For the developing countries, it is only 135 g per capita. Availability per capita per day is estimated at about 60 g in Southeast Asia and sub-Saharan Africa (AVRDC, 1991) and 90-100 g in Latin America and South Asia. These average levels do not provide adequate amounts of essential nutrients. Moreover, they mask the fact that low income group consumes less than high income group, a pattern that is accentuated in rural areas, where income are lower than in urban areas (AVRDC, 1991).

Analysis of heavy metals found in vegetables from some cultivated irrigated gardens in the Kano metropolis, Nigeria were investigated by Lawal and Audu (2011). From results they obtained, the vegetable samples from Jakara indicated highest mean levels of Co (1.14±0.17 mg/Kg), Cu (7.50±1.08 mg/Kg), Zn (18.89±1.93 mg/Kg) and Cr (0.85±0.10 mg/Kg) while those from Sharada indicated highest levels of Ni (2.02±0.35 mg/Kg) and Pb (1.60±0.53 mg/Kg). They reported increased danger of growing vegetables on soils irrigated with contaminated industrial and domestic wastewater. This study is aimed at ascertaining the extent to which cobalt is accumulated in wastewater, soil and vegetables through man-made activities.

MATERIALS AND METHODS

Sampling

Wastewater samples from Kubanni stream were obtained from five different sampling points on a four month basis along the stream channels for the period of two years giving total number of thirty (30) samples. Sampling was conducted in the harmattan, dry and rainy seasons. Wastewater samples were collected using composite sampling technique in a polyethylene plastic container that were previously cleaned by washing in non-ionic detergent and then rinsed with tap water and soaked in 10% HNO_3 for 24 h and finally rinsed with deionized water prior to usage (Ademoroti, 1996). During sampling, sample bottles used were rinsed with sampled water three times and then filled to the brim at a depth of one meter below the wastewater from each of the five designated sampling points. Wastewater sample bottles were labelled, stored in ice-blocked coolers and transported to the laboratory while in the laboratory; they were stored in the refrigerator at about 4°C prior to the analysis (APHA, 1998). Soil samples were collected at three depths (0-5, 5-10 and 10-15 cm) from both sides of the river banks by using spiral auger of 2.5 cm diameter. Soil samples were randomly sampled and bulked together to form a composite sample from each designated point giving total number of thirty (30) samples. They were then put in clean plastic bags, labelled and transported to the laboratory. The full grown vegetable of [spinach (*Amaranthus hybridus*), lettuce (*Lactuca sativa*), cabbage (*Brassica oleracea*), carrot (*Daucus carota),* okra (*Hibiscus esculentus*), onion (*Allium cepa*) and tomato (*Lycopersicon esculenetum*)] were randomly handpicked from various garden plots along Kubanni stream channels using hand-gloves, bulked together to form a composite sample, wrapped in big brown envelopes giving total of forty-two (42) samples, labeled accordingly and transported to the laboratory.

Sample treatment

Wastewaters used for cobalt determination were acidified at the points of sampling with 5 cm^3 of concentrated HNO_3 as to avoid microbial activities on the wastewaters which might reduce the concentrations of intended cobalt before analysis and they were kept in a refrigerator prior to analysis (APHA, 1998). Soil samples were air-dried, crushed and passed through 2 mm mesh sieve. The soil samples were then put in clean plastic bags, sealed and labelled accordingly (Samira et al., 2009). Each vegetable samples were washed with tap water, followed by deionized water, air dried in the laboratory, grounded to powder and sieved using 250 µm sieve (Munson and Nelson, 1990).

Digestion of Wastewater Samples for Cobalt Determination

1000 cm^3 of each wastewater sample was transferred into a beaker

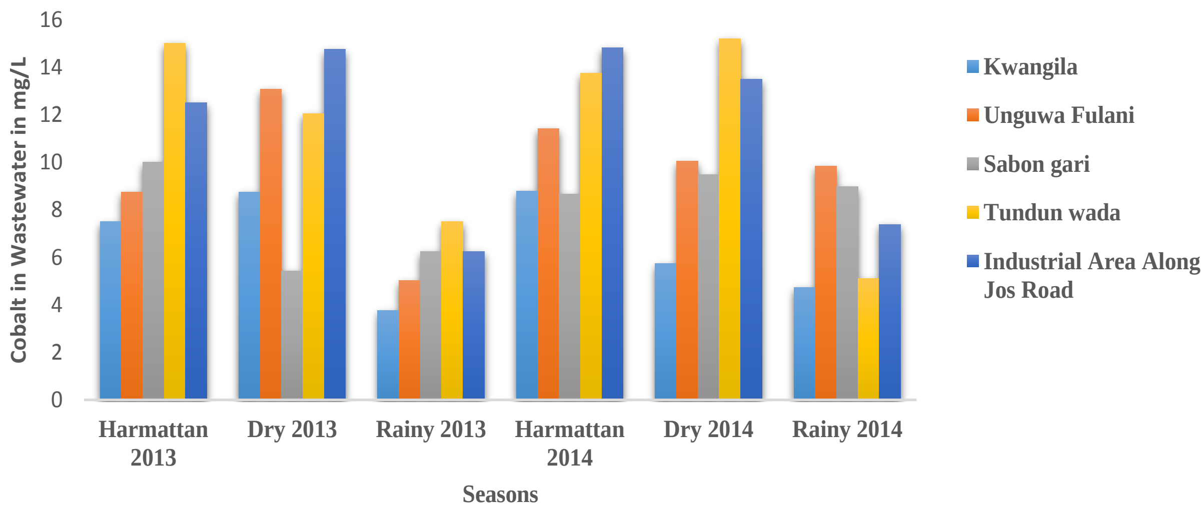

Figure 1. Cobalt Concentrations in Wastewater from Kubanni Stream Channel, Zaria.

and 50 cm^3 concentrated HNO_3 were added. The beakers with the content were placed on a sand bath and evaporated down to about 20 cm^3. The beakers were cooled and another 5 cm^3 concentrated HNO_3 were added to each beaker. The beakers were covered with watch glasses and returned to the sand bath. The heating was continued and then small portion of HNO_3 was added onto each beaker until the solutions appeared light colour and clear. The beakers wall and watch glasses were washed with deionized-water and the samples were filtered to remove any insoluble materials that could clog the atomizer. Each sample volume was made up to 100 cm^3 with deionized water (Ademoroti, 1996). Determination of Co in the wastewater sample was done at 241 nm wavelengths using Alpha-4 Model Atomic Absorption Spectrophotometer (AAS) as described by Association of Official Analytical Chemist (AOAC, 1995).

Determination of cobalt in soil samples

Two grams of each soil sample was weighed into acid-washed glass beaker. Soil samples were digested by the addition of 20 cm^3 of aqua-regia (mixture of HCl and HNO_3 in ratio 3:1) to each soil sample and 10 cm^3 of 30% H_2O_2 were added in small portion to avoid any possible overflow leading to loss of material from the beakers. The beakers were covered with the watch glasses and heated on a water bath for 2 h at 90°C. The beakers wall and watch-glasses were washed with deionized water and the samples were filtered out to separate the insoluble solid from the supernatant liquid. Each soil sample was made up to 100 cm^3 with deionized water to the mark levels. It was then analyzed for Co at 241 nm wavelengths using Alpha-4 Model Atomic Absorption Spectrophotometer (AAS) as described by Association of Official Analytical Chemist (AOAC, 1995).

Digestion of vegetable samples for cobalt determination

Three grams of the dry sample of each vegetable sample was ashed using Muffle furnace that was set at 450°C until a constant weight was obtained. On cooling, the ash was transferred to a decomposition flasks and 1cm^3 of concentrated HNO_3 was added. The content was refluxed on a hot plate for 40 min and on cooling 20 cm^3 of deionized water was added, boiled for 3 min and filtered. 10 cm^3 of 2 M HNO_3 was added to the resulting solutions in a 100 cm^3 volumetric flask. They were made up to the mark with deionized water, cobalt was determined at 241 nm wavelengths using Alpha-4 Model Atomic Absorption Spectrophotometer (AAS) as described by Association of Official Analytical Chemist (AOAC, 1995).

RESULTS AND DISCUSSION

The results of cobalt in wastewater, soil and vegetables analyzed were expressed in form of bar-charts using Microsoft Excel (Window 7 Professional), the results obtained were subjected to one way Analysis of Variances (ANOVA) and Pearson Product Moment Correlations (PPMC) using Statistical Package for the Social Sciences (SPSS) 20.0 version software. Null hypothesis was adopted and this was set at 95% Confidence Mean level to check if there is significant difference in the concentrations of cobalt analyzed. Statistical decision for Pearson Correlation Coefficients (r) was taken as follows;

(i) If $0.05 \leq r \leq 0.20$ there is negligible relationship
(ii) If $0.21 \leq r \leq 0.40$ there is low relationship
(iii) If $0.41 \leq r \leq 0.60$ there is moderate relationship
(iv) If $0.61 \leq r \leq 0.80$ there is substantial relationship
(v) If $0.81 \leq r \leq 1.00$ there is very high relationship (Robert, 1992)

Figure 1 presents cobalt levels in wastewater from Kubanni stream channels. The concentrations determined were in the range of 3.77 - 15.20 mg/L for the year 2013. Highest level of 15.20 mg/L was obtained at Tundun-wada during harmattan season and closely followed by 14.75 mg/L at Industrial area along Jos road in the dry season. High concentrations were also observed at Unguwa-fulani (13.08 mg/L), 12.50 mg/L at Industrial area along Jos road and 12.05 mg/L at Tundun-

Table 1. Analysis of variance for cobalt in wastewater (locations and seasons).

Analysis of variance		Sum of square	df	Mean square	F	Significance
Cobalt in wastewater (locations)	Between groups	110.970	4	27.742	2.937	0.040
	Within groups	236.141	25	9.446		
Total		347.111	29			
Cobalt in wastewater (seasons)	Between groups	46.090	5	9.218	0.735	0.604
	Within groups	301.021	24	12.543		
Total		347.111	29			

Table 2. Summary of Pearson product moment correlation for cobalt in wastewater

Variable	N	$\bar{x}$	SD	r	df	Significance
Cobalt 2013	15	9.107	3.624	0.726	13	0.002
Cobalt 2014	15	9.825	3.374			

wada sampling site all in the dry season whereas least level of 3.77 mg/L was found in rainy season at Kwangila sampling site. High concentration of cobalt in harmattan and dry seasons could be as a result of industrial effluents being discharged to Kubanni River from nearby industries coupled with harmattan-dusts as suggested by Butu (2013) and Nwadiogbu et al. (2013). In the year 2014, concentrations of the cobalt in wastewater were in the range of 4.74 - 15.20 mg/L. Highest level was noted at Tundun-wada (15.20 mg/L) during the dry season and closely followed by 14.80 mg/L from Industrial area along Jos road during the harmattan season. High levels of cobalt were also observed at Tundun-wada (13.74 mg/L) in the harmattan season, 13.50 mg/L during the dry season at Industrial area along Jos road and 11.41 mg/L at Unguwa-fulani in the harmattan season while the least concentration of 4.74 mg/L was found at Kwangila sampling site. High levels of cobalt at Tundun-wada and Industrial area along Jos road could be traced to anthropogenic activities in the sampling sites as suggested by Butu (2013).

Comparing the results of 2013 and 2014 there was gradual increase in the cobalt concentrations from the rainy season 2013 (3.77 - 7.50 mg/L) to that of 2014 (4.74 - 9.84 mg/L). The chart also revealed high levels of cobalt during the harmattan (8.79 - 14.81 mg/L) and dry (5.73 - 15.20 mg/L) seasons of both years however, least concentration for cobalt was obtained in rainy season, 2013 as its concentration was in the range of 3.77 - 7.50 mg/L (Figure 1). All the sampling sites had cobalt levels above permissible limit set by FAO/WHO, 1985 (0.05 mg/L). Akan et al. (2008) reported 2.34 - 5.23 mg/L as cobalt level in wastewater indicating this study had high level of cobalt.

Analysis of variance in Table 1 indicates, $p = 0.040 < 0.050$ shows that there is significant difference in cobalt concentrations from one sampling site to another throughout the periods of analyses. This is reflected from their mean and standard deviation as thus; Kwangila (6.547±2.118), Unguwa-fulani (9.690±2.731), Sabon-gari (8.130±1.850), Tundun-wada (11.433±4.202) and Industrial area along Jos road (11.532±3.770), respectively. ANOVA Table 1 also reveals $p = 0.604 > 0.050$ means there is no significant difference in cobalt levels from one season to season. This indicates cobalt concentration does not change significantly within the period of sampling when harmattan season 2013 compared with that of harmattan season 2014 as it showed from their mean and standard deviation as thus; harmattan season 2013 (10.814±3.631), dry season 2013 (8.246±4.004), rainy season 2013 (8.774±2.693), harmattan season 2014 (11.512±3.132), dry season 2014 (8.450±3.851) and rainy season 2014 (9.002±3.778) respectively.

Pearson Product Moment Correlation (PPMC) was conducted to establish the relationship between cobalt levels in wastewater for the year 2013 and 2014. Statistical data showed mean with standard deviation level for cobalt to be 9.107±3.624 in 2013 while 9.825±3.374 was obtained in 2014. Statistical analysis indicated Pearson correlation ($r = 0.726$), degree of freedom ($df = 13$) and $p = 0.002 < 0.050$ indicates that there is substantial relationship between cobalt levels in wastewater for the year 2013 and 2014 respectively (Table 2). The decision is justified from their mean as they are very close.

Cobalt concentrations in soil from Kubanni stream channels are presented in Figure 2. Concentration range of 0.63 - 3.57 mg/Kg was obtained in the year 2013.

Highest level was found at Sabon-gari (3.57 mg/Kg)

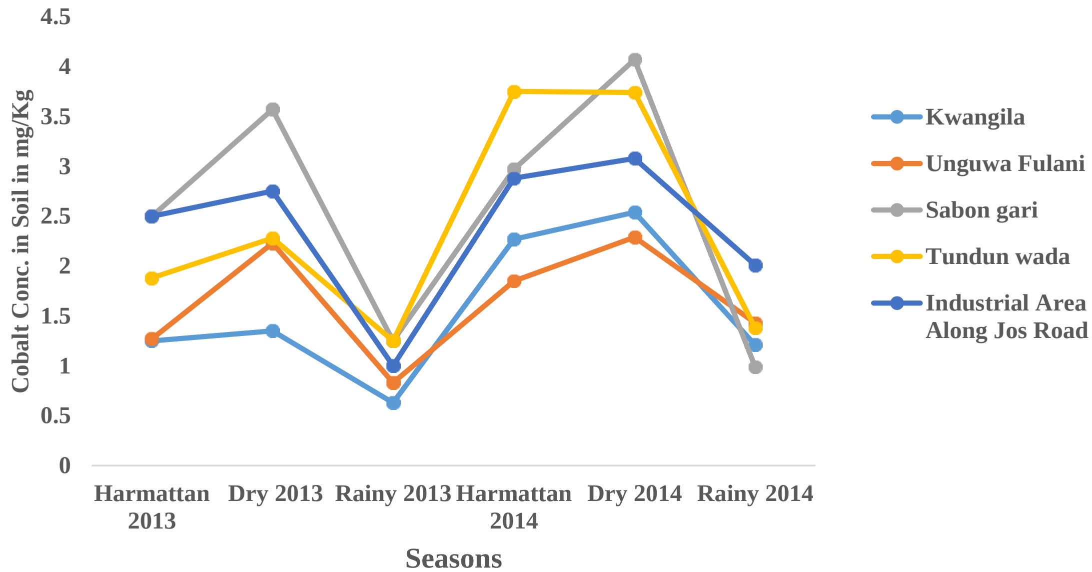

Figure 2. Cobalt concentration in soil from Kubanni Stream Channels, Zaria.

during dry season followed by 2.75 mg/Kg at Industrial area along Jos road during the same season. High levels were also observed at Industrial area along Jos road (2.50 mg/Kg) during harmattan season, 2.28 mg/Kg at Tundun-wada during dry season and 2.23 mg/Kg at Unguwa-fulani during the same dry season while the lowest level of 0.63 mg/Kg was recorded at Kwangila sampling site in the rainy season. High cobalt concentrations during harmattan and dry seasons might be as a result of excessive use of wastewater to irrigate the farmland as suggested by Kumar et al. (2009). Generally, cobalt concentration was drastically reduced during rainy season as it had level ranging from 0.63 - 1.25 mg/Kg. This could be related to dilution effect as suggested by Chapman (1997). In the year 2014, cobalt levels were in the range of 0.99 - 4.07 mg/Kg as determined. Highest concentration was noticed at Sabon-gari (4.07 mg/Kg) during dry season, followed by 3.74 mg/Kg at Tundun-wada sampling site but in the same dry season. This might be as result of anthropogenic sources of contamination from nearby dump-sites as suggested by Srinivas et al. (2009). Other sampling sites with high levels of cobalt were Industrial area along Jos road (3.08 mg/Kg) during the dry season, Sabon-gari (2.97 mg/Kg) during the harmattan season, Kwangila (2.54 mg/Kg) in the dry season and Unguwa-fulani (2.29 mg/Kg) also in the dry season whereas low concentrations were noticed at Kwangila (1.21 mg/Kg) and Sabon-gari (0.99 mg/Kg) sampling sites both in the rainy season. Comparing the results of 2013 to that of 2014, there was a reduction in cobalt level from the dry season (1.35 - 3.57 mg/Kg) to the rainy season (0.63 - 1.25 mg/Kg) in both years however, there was build-up in cobalt levels from the harmattan season (1.85 - 3.57 mg/Kg) to the dry season (2.29 - 4.07 mg/Kg) of both years. Least level for cobalt was recorded in the rainy season of both years although there was build-up in its concentration from rainy season, 2013 (0.63 - 1.25 mg/Kg) to that of rainy season, 2014 (0.99 - 2.05 mg/Kg). This might be connected to high application of manure, herbicides, fungicides and fertilizers in 2014 as these chemicals are rich in Cd, Co, Pb and Zn as suggested by Yasmeen et al. (2010).

Analysis of variance in Table 3 indicates, $p = 0.280 > 0.050$ this means that there is no significant difference in cobalt concentrations among the soil of sampling sites. Their mean and standard deviation clarify these; Kwangila (1.467±0.563), Unguwa-fulani (2.060±1.279), Sabon-gari (2.698±1.168), Tundun-wada (2.188±0.751) and Industrial-area along Jos road (2.254±0.608) respectively. This might be as a result of similar geological formation of soil from the sampling sites as suggested by Butu (2013). Also, Table 3 ANOVA indicates $p = 0.915 > 0.050$ this means that there is no significant difference in cobalt levels from one season to another within the periods of sampling. Their results showed that; harmattan season 2013 (1.764±0.758), dry season 2013 (1.962±1.073), rainy season 2013 (2.066±0.609), harmattan season 2014 (2.386±1.063), dry season 2014 (2.370±1.386) and rainy season 2014 (2.253±1.386), respectively.

Table 4 presents Pearson product moment correlation for cobalt levels in soil between the year 2013 and 2014. Statistical data showed mean with standard deviation level of cobalt to be 1.837±0.831 in the year 2013 while 2.431±0.975 were obtained in the year 2014 with the degree of freedom (df) = 13, Pearson correlation (r) = 0.799 and $p = 0.001 < 0.050$ indicates that there is substantial relationship between cobalt level in soil for

Table 3. Analysis of variance for cobalt in soil (locations and seasons)

Analysis of variance		Sum of square	df	Mean square	F	Signifance
Cobalt in soil	Between groups	4.705	4	1.176	1.351	0.280
(locations)	Within groups	20.891	24	0.870		
Total		25.596	28			
Cobalt in soil	Between groups	1.507	5	0.301	0.288	0.915
(seasons)	Within groups	24.089	23	1.047		
Total		25.596	28			

Table 4. Summary of Pearson product moment correlation for cobalt in soil.

Variable	N	$\bar{x}$	SD	r	df	Signifance
Cobalt 2013	15	1.837	0.831	0.799	13	0.001
Cobalt 2014	15	2.431	0.975			

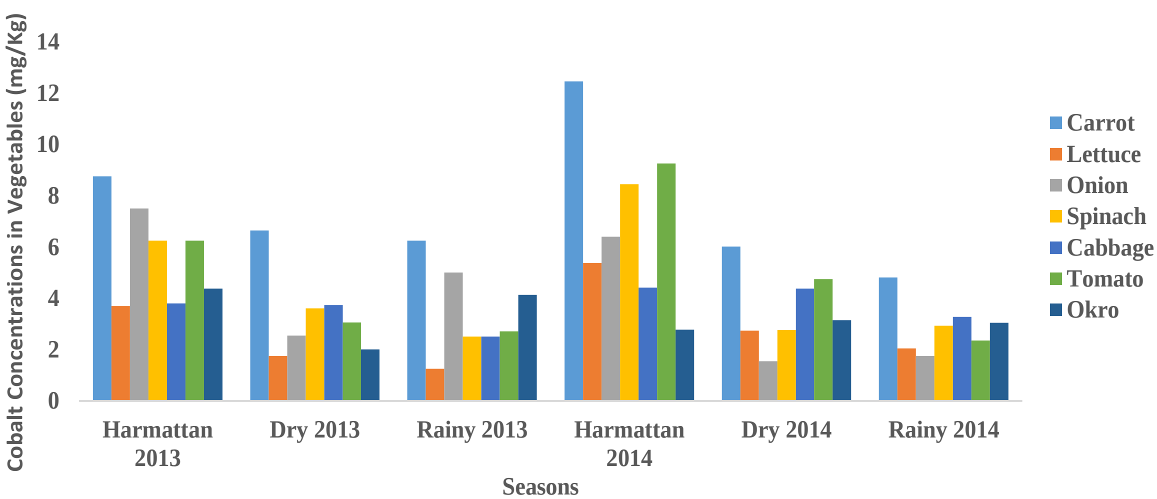

Figure 3. Cobalt Concentration in Vegetables from Kubanni Stream Channels, Zaria.

2013 to that of 2014. This decision is jusified as analysis of variance showed similar results (no significant difference).

Cobalt levels in vegetables collected along Kubanni stream channels is presented in Figure 3. In the year 2013, the concentrations determined were in the range of 1.25 - 8.75 mg/Kg. Highest level was found in carrot (8.75 mg/Kg) followed by onion (7.50 mg/Kg) both in the harmattan season. High level was also observed in carrot (6.64 mg/Kg) in dry season, in addition similar concentration of 6.25 mg/Kg was noticed in tomato, carrot and spinach but in different seasons. Low concentrations of 1.75 and 1.25 mg/Kg were obtained in lettuce during dry and rainy seasons. Harmattan season showed more accumulation of cobalt in 2013 with concentration in the range of 3.70 - 8.75 mg/Kg than other seasons (Figure 3). This could be related to harmattan-dusts and extensive use of wastewater for irrigation as suggested by Kumar et al., (2009). Vegetables analyzed had concentrations in the range of 2.76 - 12.45 mg/Kg for the year 2014. Highest level was found in carrot (12.45 mg/Kg) followed by tomato (9.25 mg/Kg) and spinach (8.45 mg/Kg) all these results were obtained in the harmattan season. High concentrations were also noticed in onion (6.40 mg/Kg), lettuce (5.37 mg/Kg) both in harmattan season and 6.01 mg/Kg was recorded in carrot during dry season. Low level of cobalt was observed in rainy season from lettuce (2.04 mg/Kg) and 1.55 mg/Kg in onion. This might be related to dilution effect as suggested by Chapman (1997). Comparing the

Table 5. Analysis of variance for cobalt in vegetable (varieties and seasons).

Analysis of variance		Sum of square	df	Mean square	F	Signifance
Cobalt in vegetable (among various vegetable)	Between groups	84.445	6	14.074	3.274	0.012
	Within groups	150.474	35	4.299		
Total		234.919	41			
Cobalt in vegetable (seasons)	Between groups	15.901	5	3.180	0.523	0.757
	Within groups	219.018	36	6.084		
Total		234.919	41			
Cobalt among wastewater, soil and vegetable	Between groups	820.047	2	410.023	63.629	0.000
	Within groups	631.509	98	6.444		
Total		1451.556	100			

Table 6. Summary of Pearson product moment correlation for cobalt in vegetables

Variables	N	$\bar{x}$	SD	r	df	Signifance
Cobalt 2013	21	4.357	2.030	0.720	19	0.000
Cobalt 2014	21	4.504	2.759			

results obtained for the year 2013 and 2014, harmattan season 2014 showed more accumulation of cobalt (2.77 - 12.45 mg/Kg) than harmattan season 2013 (3.80 - 8.75 mg/Kg). No much difference was observed in dry season of both years as they showed concentrations in the range of 1.75 - 6.64 mg/Kg for the year 2013 and 1.55 - 6.01 mg/Kg for the year 2014. Carrot showed more accumulation of cobalt than other vegetables analyzed with levels of 4.81 - 12.45 mg/Kg while okra was observed with least concentrations of 2.01 - 4.37 mg/Kg. Lettuce and cabbage were moderate in their levels as they had concentrations between (1.25 - 5.37 mg/Kg) and (2.50 - 3.80 mg/Kg), respectively. The cobalt levels analyzed were below permissible limit set by FAO/WHO, 2001 (50.00 mg/Kg) thereby these vegetables are free of its contamination. The present study had similar level of cobalt in cabbage with reported concentrations by Mohsen and Seilsepour, 2008 (0.10 - 3.18 mg/Kg) but less than reported levels by Lawal and Audu (2011) as they reported 1.14±0.24 mg/Kg for vegetables grown in irrigated garden.

Analysis of Variance in Table 5 shows, $p = 0.012 < 0.050$ this means that there is significant difference in cobalt concentrations from one species of vegetable to another as observed by Clemens (2001). This is more illustrated from their mean and standard deviation as thus; carrot (7.485±2.750), lettuce (2.807±1.517), onion (4.655±2.470), spinach (4.417±2.404), cabbage (3.682±0.719), tomato (4.725±2.657) and okra (3.243±0.878), respectively. The same Table 5 for ANOVA shows, $p = 0.757 > 0.050$ this means that there is no significant difference in cobalt levels from one season to another. This could be explained from their mean and standard deviation as thus; harmattan season 2013 (4.387±3.012), dry season 2013 (3.426±1.690), rainy season 2013 (5.169±2.636), harmattan season 2014 (5.209±3.638), dry season 2014 (4.183±1.313) and rainy season 2014 (4.210±1.634) respectively. In addition, Table 5 reveals $p = 0.000 < 0.050$ means that there is significant difference in cobalt concentrations in wastewater, soil and vegetables of the sampling sites. It implies that each constituent (wastewater, soil and vegetable) accumulates cobalt at different rate as reflected from their mean and standard deviation; wastewater (9.534±3.501), soil (2.308±1.358) and vegetable (4.431±2.394) respectively.

Pearson Product Moment Correlation (PPMC) is presented in Table 6 to show relationship between cobalt levels in vegetables for the year 2013 and 2014. Statistical analysis showed that the mean with standard deviation of 4.357±2.030 were obtained for 2013 and 4.500±2.759 for 2014. It also revealed Pearson correlation (r) = 0.720, degree of freedom (df) = 19 and $p = 0.001 > 0.050$ this means that there is substantial relationship between cobalt level in vegetables for the year 2013 and 2014 respectively.

There is need to find means of removing this heavy metal (cobalt) which might make these vegetables unsuitable for human consumption in future by stop using wastewater to irrigate the farmland in the studied area and stop indiscriminate discharge of refuse on the body of Kubanni River by providing appropriate dumpsites within the vicinity for this purpose.

Conflict of interest

The authors did not declare any conflict of interest.

REFERENCES

Ademoroti CMA (1996). Standard Method for Water and Effluents Analysis. Foludex Press Ltd., Ibadan. pp. 22 - 23, 44 - 54,111 - 112.

Akan JC, Abdulrahman FI, Dimari GA, Ogugbuaja VO (2008). Physicochemical Determination of Pollutants in Wastewater and Vegetable Samples along the Jakara Wastewater Channel in Kano Metropolis, Kano State, Nigeria. J. Am. Sci. 6:78-87.

APHA (1998). Standard Methods for the Examination of Water and Wastewater, 17th edition, Washington D.C. pp. 1269 - 1280.

Asian Vegetable Research and Development Centre (AVRDC) (1991). Vegetables Research and Development in the 1990's (A strategic Plan) Taipei. pp. 4 - 10.

Association of Official Analytical Chemist (AOAC) (1995). Official Methods of Analysis. 14th Edition, Washington DC. pp. 142-158.

Bahemuka TE, Mubofu EB (1991). Heavy metals in edible green Vegetables Grown along the site of the Sinza and Msimbazi River in Dares Salaam, Tanzania. Food Chem. 66: 63 - 66. http://dx.doi.org/10.1016/S0308-8146(98)00213-1

Butu AW (2013). Concentration of Metal Pollutants in River Kubanni, Zaria, Nigeria. J. Nat. Sci. Res. 3:19-25.

Catharine AR, Christine LT, Ann LY, Heather BD (2011). Dietary Reference Intakes for Vitamin D and Calcium. Institute of Medicine, 2011. Retrieved 31 March, 2011 from http://www.nap.edu/caterlog.php?recordid=13050.

Chapman D (1997). Water Quality Assessment. A Guide to the use of Biota, Sediments and Water in Environmental Monitoring, 2nd Edition, E & F Spon, London. File: A//:Hydrology and Water Quality of Lake Merced.htm.

Clemens S (2001). Molecular Mechanisms of Plant Tolerance and Homeostasis. Planta 4:475 - 486. http://dx.doi.org/10.1007/s004250000458

FAO/WHO (1985). Joint/WHO Expert Committee on Food Additives 1999. Summary and Conclusions. Proceedings of the 53rd Meeting, Rome, June 1 - 10, 1999.

Food Agricultural Organization/World Health Organization (FAO/WHO) Standards, (2001). Codex Alimentarius Commission, Rome.

Food and Agricultural Organization (1988). Production Year Book. Vol. 42, FAO, Rome

Fraser PM (2004). What is soil? Retrieved from http://www.compostingvermont.org/artilcles/whatissoil.htm 24th July, 2010.

Koch B, Kota M, Horvath MI (1965). Fodder Crops as Leafy Protein. Agrobotanica 1:19-28.

Kumar NJ, Soni HI, Rita NK, Bhatt IJ (2009). Hyperaccumulation and Mobility of Heavy Metals in Vegetable Crops in India. J. Agric. Environ. 10:10-20.

Mohsen B, Seilsepour M (2008). Investigation of Metals Accumulation in Some Vegetables Irrigated with Wastewater in Shahre Rey, Iran and Toxicological Implications. American-Eurasian J. Agric. Environ. Sci. 4:86-92.

Munson RD, Nelson WL (1990). Principle and Practices in Plants Analysis in "Soil Testing and Plant Analysis" (ed) Westernan, R.L.; Mandison, SSSA. pp. 359-387.

Nwadiogbu JO, Nwankwere ET, Eze KA, Chime CC (2013). Trace Metals in Airborne Harmattan Dust in Ahmadu Bello University Zaria, Nigeria. Arch. Appl. Sci. Res. 5:159-163.

Oke OL (1980). Amaranth in Nigeria. Proceeding of 2nd Amaranths Conference, Emmaus P.A. Rodel Press. pp. 8 - 10.

Prasad MNV (2004). Heavy Metal Stress in Plants, 2nd Edition, Springer, United Kingdom. pp. 484-487. http://dx.doi.org/10.1007/978-3-662-07743-6

Robert J (1992). Elementary Statistics. 6th Edition. PWS Publishers, Wadsworth Inc, USA. pp. 120 - 129.

Samira AB, Elferjani HS, Haroun FA, Abdelnabi FF (2009). Determination of Available Nitrate, Phosphate and Sulfate in Soil Samples. Int. J. PharmTech Res. 3: 598-604.

Schwarz FJ, Kirchgessner M, Stangl GI (2000). Cobalt Requirement of Beef Cattle - Feed Intake and Growth at Different Levels of Cobalt Supply. J. Anim. Physiol. Anim. Nutr. 83(3):121-128. http://dx.doi.org/10.1046/j.1439-0396.2000.00258.x

Sharma RK, Agrawal BM, Marshall FM (2009). Heavy Metals in Vegetables Collected from Production and Market sites of a Tropical Urban area of India. Food Chem. Toxicol. 47:583-591. http://dx.doi.org/10.1016/j.fct.2008.12.016

Srinivas TN, Rao SR, Kumar KS (2009). Trace Metal Accumulation in Vegetables Grown in Industrial and Semi Urban area: A case study. Appl. Ecol. Environ. Res. 7:131-139. http://dx.doi.org/10.15666/aeer/0702_131139

Taylor OA (1996). Potentials of Grain Amaranth Utilization as Food. Proceedings of National Training Workshop on Grain Amaranth Production and Utilization. NIHORT, Ibadan, Nigeria. pp. 17-28.

Wegelin T, Jenka B, Ether R (1995). Heavy Metals in Soils and Plants of Allotment Gardens in the City of Zurich, Switzerland. Soil Environ. 5:269-272. http://dx.doi.org/10.1007/978-94-011-0415-9_69

Yasmeen K, Versiani M, Arain R, Haque Q, Khan N, Ali S, Langha A (2010). Enhanced Metal Levels in Vegetables and Farm Soil Irrigated with Industrial Wastewater. J. Appl. Sci. Environ. Manage. 14:95 - 99.

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Full Length Research Paper

Microbial safety assessment of recreation water at Lake Nabugabo, Uganda

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This study assessed the microbial safety of Lake Nabugabo beaches for recreation. Faecal microbial indicators and physico-chemical characteristics of beach recreational water were determined. Water sampling was done between 10.00 and 11.30 h and 1700 and 18.00 h. Data was analysed using student t-tests, ANOVA and spearman correlation (at 95%). Results were: total coliform (10.5-15.8 CFU/100 ml), faecal coliform (10-12.5 CFU/100 ml), *Escherichia coli* (0-2.63 CFU/100 ml), faecal streptococci (0-1.5 CFU/100 ml), all significantly different (P<0.05) from the control and electrical conductivity (27-32.6 µS/cm), pH (7.1), turbidity (12.6-26 NTU), total dissolved solids (13.2-15.4 mg/l), total suspended solids (12.6 - 13.4), colour (10.3 Pt-Co), alkalinity (29.3 mg/l), hardness ($CaCO_3$) (32.5 mg/l), total nitrogen (1.3 mg/l), ammonium-N (0.6 mg/l), nitrate (0.05 mg/l), total phosphorus (0.8 mg/l), orthophosphates (0.02 mg/l), iron (0.2-0.3 mg/l), calcium (1.2-1.8 mg/l), magnesium (0.4-0.6 mg/l), sodium (1.2-2 mg/l), potassium (1.8-2.6 mg/l), all not significantly different (P > 0.05) from the control. Total coliforms and faecal streptococci exhibited significant correlation with TSS (r = 0.9, p = 0.04). Results indicate that Lake Nabugabo water is safe (WHO, US-EPA) for recreation.

Key words: Lake Nabugabo, microbial safety assessment, recreation water, water quality.

INTRODUCTION

Contamination of water bodies is on the increase and is causing major public health concerns in developing countries where water regulations are lacking. Pathogenic microorganisms are introduced into aquatic ecosystems from the catchment via different agents that include humans, animals and effluents. The microbial composition of aquatic ecosystem depend on the type, nature of the aquatic ecosystem, microbial profile of effluents (Jaiani et al., 2013) and the contaminating agents (for example, humans, wild animals). Organisms of public health concerns in recreational waters include *Salmonella* spp., *Escherichia coli*, *Shigella* spp., *Clostridium* spp.,

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Vibrio spp and various human enteric microbes and protozoa (Wade et al., 2003; WHO, 2005). Therefore, the most significant threat of contamination is autochthonous microorganisms that may be triggered to multiply when the environment is favourable for growth (Jaiani et al., 2013). Water contamination can be assessed by various methods (APHA, 1998; WHO, 2001, 2003) depending on the intended use of the water.

Swimming and bathing in inland waters are recognized forms of full contact recreation activities but due to poor management, waters may easily be contaminated by humans as a result of people defecating in the water and possible sewage discharges or overflows (EPA, 2001). It is therefore useful and necessary to monitor recreational waters continuously for human pathogens as a way to prevent swimming associated infections (Wade et al., 2008).

A study in the USA (Wade et al., 2010) found that gastro intestinal illnesses were associated with swimmers as compared to non- swimmers. Information on microbial safety classification of recreational water is important to the public and managers from public health and economic perspectives (Abbott et al., 2011).

Lake Nabugabo and its wetland system form the second biggest Ramsar site in Uganda after Lake George (Byaruhanga et al., 2006). The lake attracts a number of bird watchers and researchers. Besides research, the lake has for long been used as a site for recreation including parties, picnics, boat rides, swimming and bathing. This has resulted in business developments along the lake shores. Consequently, the lake has experienced transformation from a pristine water source to a more developed recreational site with two beaches and additional sites under development. With the increasing rate of recreational activities in the lake and the physical development (structures and sanitation facilities) at the shores, contamination potential of the lake has increased.

Compared to other Ugandan lakes such as Victoria, Kyoga, Edward and George, Lake Nabugabo has been most preferred for swimming and bathing because it is believed to be safe from Bilharzia due to the absence of snails, the intermediate hosts of Schistosomes (Ogutu-Ohwayo, 2002). There is little information about microbial safety of East African lakes for recreation activities, while most studies concentrated on the suitability of water for drinking (Matano and Anyona, 2013; Olapade, 2013). Although available information is on drinking water quality, results obtained indicate serious contamination with total coliforms, faecal coliform and faecal streptococci, implying that the water is unsafe for use. While a number of studies have been carried out on Lake Nabugabo on aspects such as benthic macro-invertebrates (Efitre et al., 2001), nutrient dynamics (Okot-Okumu, 2004), environmental history of the lake (Stager et al., 2005), there is lack of information on the microbial safety of the lake. The microbial safety of recreational water users of Lake Nabugabo is still unknown. Understanding the lake's microbial safety for recreation is paramount and was the motivation of this study.

The overall objective of the study was to assess the suitability of Lake Nabugabo water for recreation with respect to microbial safety.

MATERIALS AND METHODS

The study was carried out on Lake Nabugabo in Masaka District, Central Uganda (Figure 1). Lake Nabugabo is a shallow ($\bar{x}$= 2.5 m) lake lying near the equator, about 100 km south-east of Kampala City. Lake Nabugabo is a satellite lake of Lake Victoria and is separated from the latter by a sand bar of only two kilometres wide. The lake is about five kilometres long with a surface area of 24 square kilometres. It is situated at an altitude of approximately 1140 m, average minimum temperature for this part of Uganda does not drop below 15°C and the average maximum temperature varies little between 25 and 30°C (Cheng, 2006).

Water samples were collected from two beaches of Lake Nabugabo [Sand Beach (Beach 1) and Holiday Centre (Beach 2)]. For sampling location consistency, coordinates of the sampling sites were obtained using a Garmin GPS within zones of recreation along the beaches and control point in the middle of the lake. Samples were collected once a month for a period of five months covering the last Friday, Saturday and Sunday when the beaches had heightened recreation activities. Sample collection and preservation were done in accordance with Standard Methods for Examination of Water and Wastewater (APHA, 1998).

The water samples were collected just below surface twice a day, in the morning between 10.00 and 11.00 h and in the afternoon between 17.00 and 18.00 h at waist height depth of approximately 0.65 m (near shore) and breast height of approximately 1.0 m depth (offshore). Control samples were collected by boat in waters towards the middle of the Lake, the lake zone that is not normally used for swimming. Samples were kept in an icebox at temperatures of 4°C during the time before laboratory analysis. *In situ* determinations were: temperature (°C) and pH using electrode probe WTW TA 197pH/T, electrical conductivity (μScm^{-1}) and total dissolved solids (mgl^{-1}) using Hach 4460000 conductivity meter, turbidity (NTU) using HACH 2100A turbidity meter.

Laboratory bacteriological analysis was done for total coliforms, faecal coliform, *E. coli* and faecal streptococcus following Standard Methods for Examination of Water and Wastewater (APHA, 1998), sections 9221 B, 9221 E, 9221 F and 9230 C, respectively. Membrane filtration (0.45 µm pores), growth media used, incubation procedure and bacteria enumeration were according to APHA (1998). Physico-chemical parameters: total suspended solids (TSS), colour Ptco, NO_3^-, PO_4^{3-}, total nitrogen (TN), ammonia, total phosphate (TP), Fe^{2+}, Ca^{2+}, Mg^{2+}, K^+, alkalinity and hardness ($CaCO_3$) were all analysed in the laboratory following APHA (1998).

Statistical analysis

Data was analysed in Excel 2010 and SPSS (21st edition). All statistics were computed at a 95 percent confidence level ($p \leq 0.05$). A one sample student t-test was used to compare the recreational water samples with controls, two sample student t-test was used to compare microbial counts between the two beaches, ANOVA was used to compare mean values of all samples collected

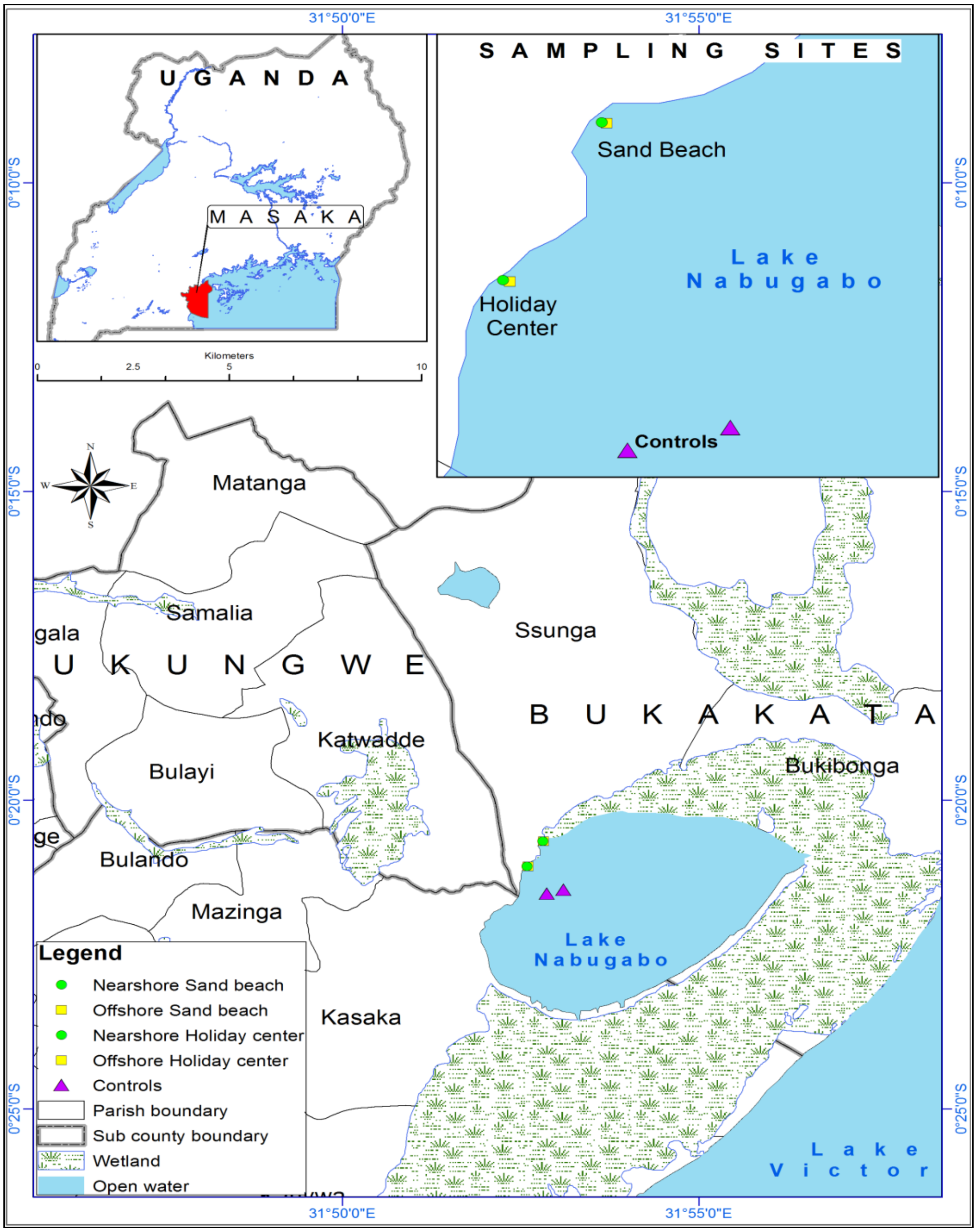

Figure 1. Map of Lake Nabugabo showing sampling sites.

throughout the study period and Spearman correlation analysis 'r' was conducted to determine relationship between microbial and physico-chemical water quality aspects.

RESULTS AND DISCUSSION

The microbial quality (mean values) of Lake Nabugabo water is presented in Figure 2 for the two beaches assessed. Sand beach faecal coliform, total coliform, *E. coli* and faecal streptococci counts were 10-11.5, 10.5-14.8, 2-2.5 and 0.3-1.2 CFU/100 ml, respectively. Holiday Centre beach faecal coliform, total coliform, *E. coli* and faecal streptococci were 10-12, 12-15, 1.7-2.2 and 0.8-1.3 CFU/100 ml, respectively.

Coliform bacteria

Total coliform data was a general indication of the microbial contamination of Lake Nabugabo. According to

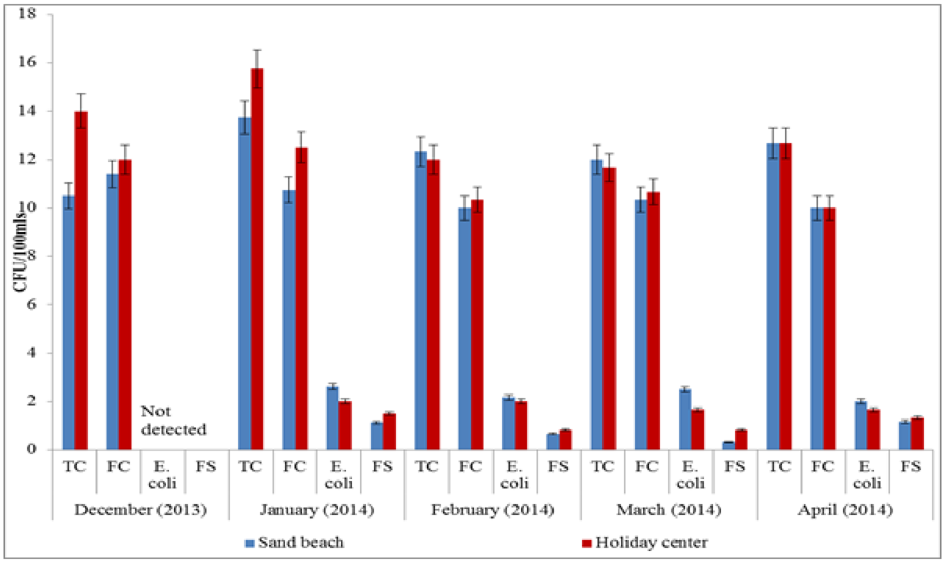

Figure 2. Microbial counts at the beaches of Lake Nabugabo. TC- Total coliforms, FC- faecal coliforms, *E. coli*- *Escherichia coli*, FS- faecal streptococci.

DWA (1996), total coliform gives an indication of the general sanitary quality of water since this group includes bacteria of faecal origin. Lake Nabugabo total coliform counts was low as compared to findings of studies of coastal waters (Abbu and Lyimo, 2007; Mwakalobo et al., 2013) in Tanzania and urban lakes (Shirude et al., 2014) in India. This can be attributed to variation in number of recreational users and the frequency of use of the various lakes/beaches studied.

Faecal coliform bacteria which are more specific indicator of human contamination of water in Lake Nabugabo exhibited counts lower than total coliform that is similar to finding by Mwakalobo et al. (2013) on Pangani, Ruvu and Mzinga creeks along the coast of Tanzania. Faecal coliform is part of the total coliform counts and therefore as expected is lower than total coliform counts taken from the same point of assessment. Faecal coliform counts obtained in Lake Nabugabo were comparable to findings at Rasi Dege in Dar es Salaam, Tanzania (Abbu and Lyimo, 2007) but very low as compared to findings of Lake Kivu in Rwanda (Olapade, 2013). The low values of faecal coliform counts in Lake Nabugabo could be due to low pollution inputs from near shores areas of the lake catchment.

According to information obtained from the beach owners at Lake Nabugabo, the recreational use of the lake was mostly during weekends. The number of recreational water users varied between 50 people during rainy season months (November, March and April) and 600 people during dry and sunny months (December, January and February). The number of recreational water users and frequencies of beach water use was lower at Lake Nabugabo as compared to other water bodies (Abbu and Lyimo, 2007; Mwakalobo et al., 2013), that also had higher faecal bacterial counts. This could be an indication of human population influence on faecal coliform contamination of recreational waters.

Lake Nabugabo is a rural fresh water body where human settlements are approximately 500 m away from the shores implying that direct pollution input from the catchment settlements is very low if any. It is therefore presumed that the recreational water users at the beaches were the main source of bacterial contamination of Lake Nabugabo. Animals like donkeys and cattle although not in very big numbers were observed entering the shallow waters of Lake Nabugabo to drink and waterfowls were also common. According to Choi et al. (2003), although humans or sewage effluents are sources of faecal indicator bacteria in water, wildlife and waterfowl may also contribute to the observed total coliform counts. Results of total coliform and faecal coliform counts indicate that Lake Nabugabo has not yet been exposed to immense faecal contamination.

Escherichia coli

E. coli counts obtained in Lake Nabugabo water were low as compared to findings for other water bodies like Lake Kivu in Rwanda (Olapade, 2013), bathing beaches in Durban, South Africa (Mardon and Stretch, 2004), coastal waters in Greece (Vantarakis et al., 2005) and natural recreation waters of Southern Portugal (Valente et al., 2010). The low counts of *E. coli* in Lake Nabugabo can be attributed to the presumed low contaminant input from the catchment. Although sanitation facilities like septic

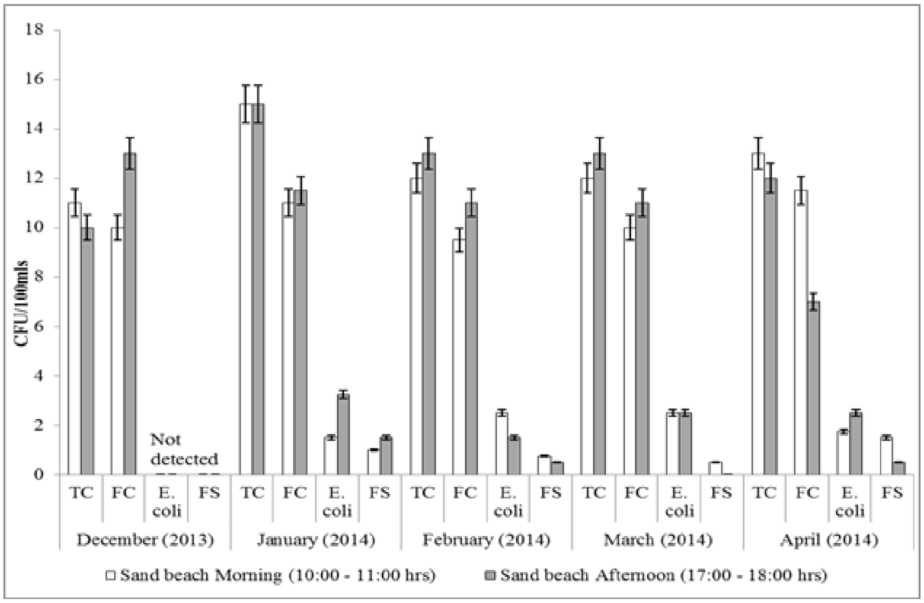

Figure 3. Microbial variations with sampling time in different months at Sand Beach, Lake Nabugabo. TC- Total coliforms, FC- faecal coliforms, *E. coli- Escherichia coli*, FS- faecal streptococci.

tanks and pit latrines are located less than 250 m away from Lake Nabugabo shores, the *E. coli* counts indicated that these facilities currently do not have any significant contamination impact on the lake. However, environmental factors such as high irradiation levels and visible light typical of tropical climate such as at Lake Nabugao, have bactericidal effects (Vermeulen et al., 2008). According to Vermeulen et al. (2008), the proportion of the surviving *E. coli* cells decreases exponentially with increase in radiation dosage at a given wavelength.

Faecal streptococci

Faecal streptococci counts in Lake Nabugabo as in many other water bodies (Mardon and Stretch, 2004; Valente et al., 2010; Olapade, 2013; Mwakalobo et al., 2013), were found to be far lower than any other bacterial indicators. Faecal streptococci is normally low in number in faeces of humans and other warm-blooded animals as compared to other bacteria indicators (Mwakalobo et al., 2013). Faecal streptococci rarely multiply in polluted water and are more resistant to disinfection than coliform organisms (UNESCO/WHO/UNEP).

Temporal variation in microbial contaminants

Microbial counts were also compared with respect to time of sampling to check whether time of sampling contributed to variation in counts of faecal indicator microorganisms. Figure 3 shows variation in microbial counts with sampling time at Sand Beach while Figure 4 shows variation in microbial counts with sampling time at Holiday Centre.

Generally, afternoon sample microbial counts were higher ($p < 0.05$) than morning sample counts. This is due to the fact that afternoon samples were normally collected during and after swimming and other recreation activities. The increased contamination level therefore can be attributed to human contamination of the lake water during the afternoon recreation activities. This observation at Lake Nabugabo is similar to findings of a study in Rwanda (Olapade, 2013).

Spatial variation in microbial contaminants

Total coliforms can naturally exist in open surface water bodies and so are not considered for this comparison. There was a significant difference between faecal coliform counts at Sand Beach and control ($p = 0.01$ for December (2013), $p < 0.001$ for January, February, March and $p = 0.02$ for April in 2014). Similarly, there is a significant difference between faecal coliform counts at Holiday Centre and control ($p = 0.04$ for January, $p < 0.001$ for February, March and $p = 0.01$ for April 2014). There was no significant difference between *E. coli* counts at Sand Beach and control ($p = 0.2$ for January, $p = 0.4$ for February, $p = 0.13$ for March and $p = 0.4$ for

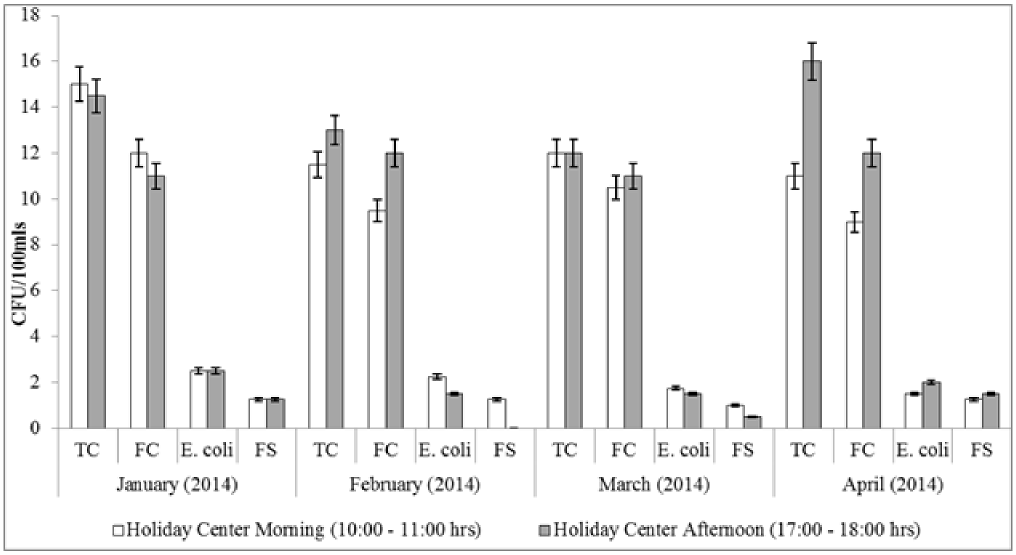

Figure 4. Microbial variations with sampling time in different months at Holiday Centre, Lake Nabugabo TC- Total coliforms, FC- faecal coliforms, *E. coli*- *Escherichia coli*, FS- faecal streptococci.

April in 2014). There was also no significant difference between *E. coli* counts at Holiday Centre and control (p = 0.3 for January, p = 0.4 for February and p = 0.8 for March and April 2014). There was a significant difference between faecal streptococci counts at Sand Beach and control in the months of January and April (p = 0.004 and p = 0.01, respectively) but no significant difference in the months of February and March (p = 0.1 and p = 0.2, respectively). There was a significant difference between faecal streptococci counts at Holiday Centre and the control (p = 0.001 for January, p = 0.04 for February, March and p = 0.01 for April 2014). The observed significant difference in bacterial counts between the control and the beaches indicate the influence of human recreation activities on the level of contamination of Lake Nabugabo water.

Comparing Lake Nabugabo water with recreational water standards

Uganda and East Africa countries do not have recreational water standards, and for purposes of this research therefore, results are compared with internationally recognized standards. Bacteriological counts from Lake Nabugabo recreation water when compared with South Africa, US-EPA, EC and WHO standards indicate that the lake water is 'very good' and 'very safe' for recreation. Table 1 summarizes comparison of our findings with the various international recreational water quality standards.

From Table 1, the bacteriological counts compared favourably with various standards implying that Lake Nabugabo water is safe for recreational activities. Classification of Lake Nabugabo beaches according to EC guidelines indicates that the beaches achieve an overall "excellent" rating based on the *E. coli* counts. Given the controversies attached to many of the faecal indicator microorganisms, faecal streptococci remain the most doubtable microbial indicators of human faecal contamination of any water source.

Since the bacteriological (Total coliform, Faecal coliform, *E*. *coli*, Faecal streptococci) study on Lake Nabugabo has not demonstrated any substantial contamination, the lake therefore probably still has the opportunity for self-purification to maintain water of environmentally insignificant microbial levels with low risk of infection during recreation. This observation however only applies to the current situation and may change if the pollution threshold is exceeded, which will reduce the capacity of the lake to ameliorate the situation and the water will become unsafe for recreational activities.

Physical chemical characteristics of Lake Nabugabo water

Table 2 summarises the physico-chemical parameters determined during the study. The results indicate low ions and nutrient (mesotrophic) and low buffering capacity lake water characteristics as illustrated in Table 2.

Lake water turbidity was lower during calm weather as compared to windy conditions that recorded high turbidity values when water was turbulent. High turbidity reduces

Table 1. Comparison of research findings with recreational water standards.

Institution/Country	Standard value	Sand beach (Average value)	Holiday Centre (Average value)	Comment
Faecal coliforms				
South Africa	≤ 130	10.5 CFU/100 mls	10.7 CFU/ 100 mls	Values fall within acceptable ranges of South African recreational water standards. Lake Nabugabo water is safe for recreation activities in reference to faecal coliforms contamination
Escherichia coli				
US EPA	≤ 126	2.4 CFU/ 100 mls	2 CFU/100 mls	Values fall within acceptable ranges of all standards. Lake Nabugabo water is safe for recreation activities as far as *E. coli* is concerned
EC	≤ 100			
New Zealand	≤ 130			
South Africa	≤ 30			
Faecal streptococci				
WHO	≤ 40	0.8 CFU/100 mls	1.1CFU/100 mls	Values obtained fall within acceptable ranges of all standards. Lake Nabugabo water is safe for recreation activities, in reference to faecal streptococci contamination.
US EPA	≤ 33			
EC	≤ 100			
Australian	≤ 40			
New Zealand	≤ 40			
South Africa	≤ 130			

Table 2. Physico-chemical characteristics of Lake Nabugabo.

Parameter	Average value[+]	Relevance to recreational water
EC (µS/cm)	27.9 ± 0.7	-
pH	7.1 ± 0.0	Eye and skin irritation
TN (mg/l)	1.3 ± 0.0	-
Nitrate (mg/l)	0.1 ± 0.0	-
Ammonia (mg/l)	0.6 ± 0.0	-
TP (mg/l)	0.8 ± 0.1	-
Ortho-P (mg/l)	0.02 ± 0.0	-
Turbidity (NTU)	20.8 ± 1.4	Aesthetics
TSS (mg/l)	13.0 ± 0.4	Aesthetics
TDS (mg/l)	14.9 ± 2.5	-
Colour (Pt co)	10.3 ± 0.6	Aesthetics
Fe^{2+} (mg/l)	0.2 ± 0.0	Aesthetics
Ca^{2+} (mg/l)	1.6 ± 0.1	-
Mg^{2+} (mg/l)	0.5 ± 0.0	-
Na^{+} (mg/l)	1.8 ± 0.1	-
K^{+} (mg/l)	2.3 ± 0.1	-
Alkalinity (mg/l)	29.3 ± 0.8	-
Hardness ($CaCO_3$, mg/l)	32.5 ± 1.1	-

[+]Average values.

aesthetics value of recreational, since the water becomes unsightly and less attractive for swimming and bathing.

The recorded alkalinity of the lake water indicates low buffering capacity of the lake. The buffering capacity of

Table 3. Spearman's rank correlation analysis for water quality parameters of Lake Nabugabo.

Parameter	TC	FC	*E. coli*	FS	pH	EC	Turbidity	TDS
FC	r = -0.4 p = 0.5	1						
E. coli	r = 0.6 p = 0.3	r = 0.0 p = 1	1					
FS	r = 1** p < 0.001	r = -0.4 p = 0.5	r = 0.6 p = 0.3	1				
pH	r = -0.4 p = 0.5	r = 0.1 p = 0.9	r = 0.4 p = 0.5	r = -0.4 p = 0.5	1			
EC	r = -0.05 p = 0.9	r = -0.8 p = 0.8	r = -0.6 p = 0.3	r = -0.05 p = 0.9	r = -0.2 p = 0.7	1		
Turbidity	r = -0.6 p = 0.3	r= 0.2 p = 0.7	r = 0.2 p = 0.7	r = -0.6 p = 0.3	r = 0.9* p = 0.01	r = -0.2 p = 0.7	1	
TDS	r = 0.1 p = 0.9	r = 0.8 p = 0.1	r = 0.3 p = 0.6	r = 0.1 p = 0.9	r = 0.1 p = 0.9	r = 0.8 p = 0.08	r = 0.0 p = 1	1
TSS	r = 0.9* p = 0.04	r = -0.2 p = 0.7	r = 0.3 p = 0.6	r = 0.9* p = 0.04	r = -0.6 p = 0.3	r = -0.05 p = 0.9	r = 0.8 p = 0.1	r = 0.3 p = 0.6

TC = Total coliform, FC = faecal coliform, *E. coli* = Escherichia coli, FS = faecal streptococci, pH = water pH, EC = electrical conductivity, TDS = total dissolved solids, TSS = total suspended solids ** = correlation is significant at 0.01, * = correlation is significant at 0.05, ($r \leq 0.2$) = weak linear correlation, ($r>0.2 \leq 0.6$) = moderate linear relationship, ($r \geq 0.7$) = strong linear relationship.

water is strongly related to pH (UNESCO/WHO/UNEP, 1996). Although Lake Nabugabo alkalinity was low, the average pH was almost neutral, that was, favourable for survival of microorganisms. This means contaminant bacteria could survive well unless impacted by external factors such as strong sunshine (UV light) that kills bacteria. Lake Nabugabo had low ions contents. The physico-chemical characteristics of the lake water (Table 2) were all comparable to Okot-Okumu's findings in 1999, which is an indication that the lake has been fairly stable for more than ten years as regards physico-chemical characteristics.

Physico-chemical characteristics of Lake Nabugabo water were studied to understand lake phenomena and determine any significant relationship between physico-chemical and microbial components of the water and also to aid in future reference studies. According to Maipa et al. (2001) survival of most bacteria in water is also dependent on temperature, pH, solar radiation and other factors, all of which have to be taken into consideration when interpreting results. The lake water pH is 7.1 which is recommended for recreational water use (Raibole and Singh, 2011). According to WHO (2003), pH has a direct impact on the recreational users of water only at very low or very high values, which may have effects on the skin and eyes. There are no specific guidelines for physico-chemical parameters for recreational waters. However, parameters such as TSS, turbidity and colour that are visible, certainly do affect aesthetics value of the water. Iron at certain concentrations may cause colouring of the water hence its aesthetic value.

Correlation between physico-chemical and microbial parameters

Spearman's rank correlation analysis (Table 3) shows that among all physico-chemical parameters, TSS was significantly correlated with microbial contaminants [total coliform: (r = 0.9, p = 0.04); faecal streptococci (r = 0.9, p = 0.04)]. According to Muirhead et al. (2006), the strong relationship between microbial contaminants and TSS is reasonable because bacteria are likely to attach to fine suspended particles. Faecal streptococci was also significantly correlated with hardness (r = 0.9, p = 0.005), total phosphorus (r = 0.9, p = 0.005) and total coliforms (r = 1, p < 0.001).

Faecal coliform has exhibited a significant negative correlation with colour (r = -0.9, p = 0.01). There are also significant relationships between physico-chemical parameters like pH and turbidity (r = 0.9, p = 0.01), hardness and colour (r = -0.9, p = 0.005), colour and total phosphorus (r = -0.9, p = 0.005), hardness and total phosphorus (r = 1, p < 0.001). Although not significant, faecal coliforms and *E. coli* was also positively correlated with TSS.

The correlation analysis (Table 3) was done to establish relationships and understand the interaction between individual microbial contaminants and physico-chemical parameters of Lake Nabugabo. This was done to possibly aid future studies to use as dummies, water physico-chemical parameters that demonstrate strong correlation with microbial contaminants. Caution should however be taken when using physico-chemical parameters to explain microbial contamination status of a given water resource because it may not always be the case, since many factors both internal and external (Maipa et al., 2001) interact to determine the survival of bacteria in water.

Conclusions

It has been demonstrated that Lake Nabugabo water has low microbial contamination levels. Although microbial counts within the recreational zones were higher than microbial counts for non-recreational zones of the lake, all microbial populations fall within acceptable limits for recreational water standards implying that Lake Nabugabo water is microbially safe for recreation. Physico-chemical parameters of Lake Nabugabo were found at permissible levels of recreational water quality standards which further contribute to the assertion that Lake Nabugabo is safe for recreation. Notwithstanding, there is need for national guidelines for managing risks in recreational water in Uganda. Guided use of recreational water will create confidence among swimmers and ensure that the water users are safe from contamination.

Conflict of interest

The authors declare that there is no conflict of interest.

REFERENCES

Abbott B, Lugg R, Devine B, Cook A, Weinstein P (2011). Microbial risk classifications for recreational waters and applications to the Swan and Canning Rivers in Western Australia. J. Wat. Health. 9: 70 - 79.

Abbu AA, Lyimo TJ (2007). Assessment of fecal bacteria contamination in sewage and non-sewage impacted mangrove ecosystems along the The coast of Dar es salaam. Tanz. J. Sci. 33: 27-40.

APHA (1998). Standard Methods for the Examination of Water and Wastewater. 20th ed., American Public Health Association, Washington, D.C.

Byaruhanga A, Opige M, Mafabi P (2006). A paper on the role of International Conventions in protection of species, A Case of Ramsar sites in Uganda.

Cheng DNK (2006). Weather Information for Entebbe. World Meteorological Organisation(http://www.worldweather.org).

Choi S, Chu W, Brown J, Becker SJ, Harwood VJ, Jiang SC (2003). Application of enterococci antibiotic resistance patterns for contamination source identification at Huntington Beach, California. Mar. Pollut. Bull. 46: 748-755.

Department of Water Affairs and Forestry (DWA) (1996). South African Wter Quality Guidelines (second edition), Volume 2: Recreational Use. elines+-+recreational+water+use [Accessed October 30, 2014].

Efitre J, Chapman LJ, Makanga B (2001). The inshore benthic macro-invertebrates of Lake Nabugabo, Uganda: seasonal and spatial patterns. Afr. Zool. 36:205-216.

EPA (2001). Report to Congress- Implementation and Enforcement of the Combined Sewer Overflow Policy. United states Environmental Protection Agency. Washington, DC.. EPA 833- R - 01 - 003.

Jaiani E, Kokashvili T, Mitaishvili N,Elbakidze T, Janelidze N, Lashkhi N, Kalandadze R, Mikashavidze E, Natroshvili G, Whitehouse CA, Huq A, Tediashvili M (2013). Microbial water quality of recreational lakes near Tbilisi, Georgia. J. Wat. Health. 11:333- 345.

Maipa V, Alamanos Y, Bezirtzoglou E (2001). Seasonal fluctuation of bacteria indicators in coastal waters. Microbial. Ecol.Health Dis. 13:143-146.

Mardon D, Stretch D (2004). Comparative assessment of water quality at Durban beaches according to local and international guidelines. J. Wat. S. Afr. 30: 317-324.

Matano A, Anyona D (2013). Effects of Land Use Types on the Levels of Microbial Contamination Based on Total Coliform and *Escherischia coli* counts on the Mara River, East Africa. Afr. J. Trop. Hydrobiol. LVFO. 13:5 - 11.

Muirhead RW, Collins RP, Bremer PJ (2006). Interaction of *Escherichia coli* and soil particles in runoff. Appl. Environ. Microb. 72: 3406-3411.

Mwakalobo SL, Namkinga L, Lyimo TJ, Lugomela C (2013). Assessment of Faecal Bacteria Contamination in Selected Coastal Waters of Tanzania. J. Biol. Life Sci. 4: 63-82.

Ogutu-Ohwayo R (2002). The Effects of Predation by Nile Perch, Lates niloticus L., on the Fish of Lake Nabugabo, with Suggestions for Conservation of Endangered Endemic Cichlids. Conserv. Biol. 7:701-711.

Okot-Okumu J (2004). Primary production and decomposition of *Loudetia phragmitoides* (A. Peter) in the littoral wetland of a small satellite lake (L. Nabugabo, Uganda). Afr. J. Ecol. 42: 108-113.

Okot-Okumu, J., 1999. Interaction between a littoral wetland and open lake (Lake Nabugabo) with special reference to phosphorus dynamics. PhD Thesis. Makerere University, Kampala, Uganda.

Olapade O (2013). Anthropogenic Pollution Impact on Microbial Contamination of Lake Kivu, Rwanda. West Afr. J. Appl. Ecol. 20: 23-31.

Raibole M, Singh YP (2011). Impact of physico-chemical parameters on Microbial diversity: seasonal study. Curr. World Environ. 6: 71-76.

Shirude M, Gupte A, Nabar B (2014). Assessment of water quality of urban lakes for recreational purpose in thane district. IOSR J. Environ. Sci. Toxicol. Food Technol. 8:46-50.

Stager JC, Westwood J, Grzesik DA (2005). A 5500-year environmental history of Lake Nabugabo, Uganda. Palaeogeography, Palaeoclimatology, Palaeoecology 218: 347-354.

UNESCO/WHO/UNEP (1996). Water Quality Assessments - A Guide to Use of Biota, Sediments and Water in Environmental Monitoring - Second Edition. Chapman D (ed). University Press, Cambridge. ISBN 0 419 21590 5 (HB) 0 419 21600 6 (PB).

Valente MS, Pedro P, Alonso MC, Borrego JJ, Dionísio L (2010). Are the defined substrate-based methods adequate to determine the microbiological quality of natural recreational waters? J. Wat. Health. 8:11-19.

Vantarakis AC, Tsibouxi A, Venieri D, Komninou G, Athanassiadou A, Papapetropoulou M (2005). Evaluation of microbiological quality of coastal waters in Greece. J. Wat. Health. 3:371-380.

Vermeulen N, Keeler WJ, Nandakumar K, Leung KT (2008). The Bactericidal effect of ultraviolet and visible light on *Escherichia coli*. Biotechnol. Bioeng. 99:550-556.

Wade T J, Pai N, Eisenberg J N S, Colford J M (2003). Do U.S. Environmental Protection Agency water quality guidelines for recreational waters prevent gastrointestinal illness? A systematic review and meta-analysis. Environ. Health Perspect. 8: 1102-1109.

Wade TJ, Calderon RL, Brenner KP, Sams E, Beach M, Haugland R, Wymer L, Dufour AP (2008). High sensitivity of children to swimming-associated gastrointestinal illness: results using a rapid assay of recreational water quality. Epidemiology 19: 375-383.

Wade TJ, Sams E, Brenner KP, Haugland R, Chern E, Beach M, Wymer L, Rankin CC, Love D, Li Q, Noble R, Dufour AP (2010). Rapidly measured indicators of recreational water quality and

swimming-associated illness at marine beaches: a prospective cohort study. Environ. Health 9: 66.
WHO (2001). Water Quality: Guidelines, Standards and Health: Assessment of risk and risk management for water-related infectious disease. (L. Fewtrell & J. Bartram, eds). IWA Publishing, London, UK.
WHO (2003). Guidelines for Safe Recreational Water Environments. Volume 1. Coastal and Fresh Waters. Geneva, Switzerland.
WHO (2005). Water Recreation and Disease: Plausibility of Associated Infections: Acute Effects, Sequelae and Mortality. IWA Publishing, Alliance House, 12 Caxton Street, London SW1H 0QS, UK.


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