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Assessment of Soil Quality along the Proposed Main Road through Ngorongoro and Northern Serengeti, Tanzania

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Abstract

A new road through northern Serengeti National Park is proposed to be built. The purpose of this study was to collect baseline data on soils along the route of the proposed road before its construction. The physicochemical properties were used to characterize the soil before the construction of the proposed road. Levels of soil macro-elements mainly potassium (K), calcium (Ca), magnesium (Mg) and sodium (Na), and physicochemical properties: electrical conductivity (EC), pH, organic carbon (OC), soil organic matter (SOM), total nitrogen (TN), cation exchange capacity (CEC), phosphorus (P), aluminium (Al) were determined. Also, heavy metals: cadmium (Cd), chromium (Cr), copper (Cu), iron (Fe), lead (Pb), manganese (Mn), mercury (Hg), nickel (Ni) and zinc (Zn) were analyzed. This study was done on the eastern (Ngorongoro District) and western (Serengeti District) segments of the proposed road. The ranges in average values obtained for the physicochemical parameters and metal concentrations in the soils were: 0.05–0.57 mS/m for EC, 6.5–7.9 for pH, 0.71–1.23% for OC, 0.30–0.74 g/kg for TN, 1.23–2.12% for SOM, 20.6–79.7 mg/kg for available P, 0.27–2.08 meq/100-g for available K, 9.89–30.3 meq/100-g for available Ca, 0.29–0.67 meq/100-g for available Mg, 0.06–1.35 meq/100-g for available Na, 11.04–33.12 meq/100-g for CEC, 46702.9–63963.3 mg/kg for Al, BDL for Cd, 24.70–101.55 mg/kg for Cr, 27.31–34.96 mg/kg for Cu, 32390.8–42439 mg/kg for Fe, 18.06–22.19 mg/kg for Pb, 957.1–1458.9 mg/kg for Mn, BDL for Hg, 20.24–32.52 mg/kg for Ni and 96.09–124.14 mg/kg for Zn. These observed levels indicate that the soils before road construction are unpolluted, moderately fertile and within the specifications of good agricultural soil. On the western segment of the proposed road, the soil will need application of fertilizers for better agricultural usage.

Keywords: Physicochemical properties, soil quality, total nitrogen, macro-elements, heavy metals.

Introduction

A project to obtain baseline data for the conservation of the northern Serengeti ecosystem with respect to the construction of a proposed new all-weather road to pass through Ngorongoro and Serengeti Districts was undertaken. The road, a much-needed infrastructure for the development of the people of these areas, has been a subject of much controversy (Dobson et al. 2010, Fyumagwa et al. 2013, NTNU 2013). From the baseline data an understanding of the dynamics and effects of the proposed road on the conservation of the Serengeti-Mara ecosystem may be obtained. In other words, the project's goal was to establish benchmark data for three phases of construction, the before-construction phase, and later compare data to during- construction phase and then the after-construction phase of the new road. This article is the result of the assessment of the status of soils (soil physical and chemical properties) at different locations along the proposed road before construction and it documents the 'before-road- construction' background data. Future monitoring exercises will use the data for comparison. Baseline data at this stage of the planned new road will establish the main points of reference for evaluating any changes on the conservation status of the northern Serengeti-Mara ecosystem.

Soils are the unconsolidated minerals on the surface of the earth that serves as a natural medium for plant growth (Imran et al. 2010). Because of soils being sensitive ecosystems, conducting an ecological sensitivity evaluation of a project area before consolidation of engineering is very important for reducing unnecessary human interference. It is expected after road construction that the soil will show variations in characteristics arising from any changes or increases in use by human population, road traffic (van der Ree et al. 2011), animals (Fahrig and Rytwinski 2009), agriculture (Lokesha and Mahesha 2016) and any other environmental usage (Leviäkangas 2015, Bevanger et al. 2017) thus allowing researchers to assess any benefits or damages to this ecosystem by activities due to the new road. Soil quality (SQ) is the capacity of a soil to function within the ecosystem and land-use boundaries to sustain productivity, maintain environmental quality and promote plant and animal health (Doran and Parkin, 1994). SQ integrates the physical, chemical and biological components of soil and their interactions. Therefore, to capture the holistic nature of soil quality or its health, all soil parameters should be measured.

Soil parameters assessed included levels of exchangeable macro-elements, potassium (K), calcium (Ca), magnesium (Mg) and sodium (Na), cation exchange capacity (CEC), the physicochemical properties: electrical conductivity (EC), pH, organic carbon (OC), soil organic matter (SOM), total nitrogen (TN), concentration of available phosphorus (P), aluminium (Al) and heavy metals: cadmium (Cd), chromium (Cr), copper (Cu), iron (Fe), lead (Pb), manganese (Mn), mercury (Hg), nickel (Ni) and zinc (Zn). Exchangeable macro-elements are very important plant nutrition and soil fertility parameters (Haby et al. 1990). Aluminum is the most abundant metal in the earth's crust, even though it isn't an essential element for either plants or humans (Lindsay 1979). Heavy metals content indicates the levels of pollution of the soil by these toxic elements. Plants growing on polluted soils show a reduction in growth, performance, and yield (Chibuike and Obiora 2014).

This article is based on a baseline study of the physicochemical data and pollutant levels of soils along the proposed northern Serengeti road at Nyiberekera and Mbirikiri on the western segment of the road and at Ololosokwan and Maaloni on the eastern segment of the road before the construction of the proposed new road.

Materials and Methods

Study area

The proposed road is administratively in Serengeti and Ngorongoro Districts (Figure 1). In these districts, the road shall be constructed in two segments. The western segment, made up of the Makutano to Mugumu tarmac section (going through Nyiberekera, Masongo and Maburi villages) and the Mugumu to Tabora B gravel section (passing through Mbirikiri, Koreri and Nyamirama villages) and the eastern segment from the Kleins Gate to Wasso gravel segment and the Wasso to Mto wa Mbu tarmac segment (Røskaft et al. 2012).

Mbirikiri and Nyiberekera were selected as sampling sites along the western segment and Maaloni and Ololosokwan were selected as sampling sites along the eastern segment. Rivers and streams also flow close to these sites. Tobora River flows through Mbirikiri, Tirina stream passes through Nyiberekera, Maaloni River flows through Maaloni village and Isinyaa stream passes through Ololosokwan. The physicochemical properties of the waters of these rivers and streams have been reported (Kaswamila et al. 2014, Othman et al. 2016).

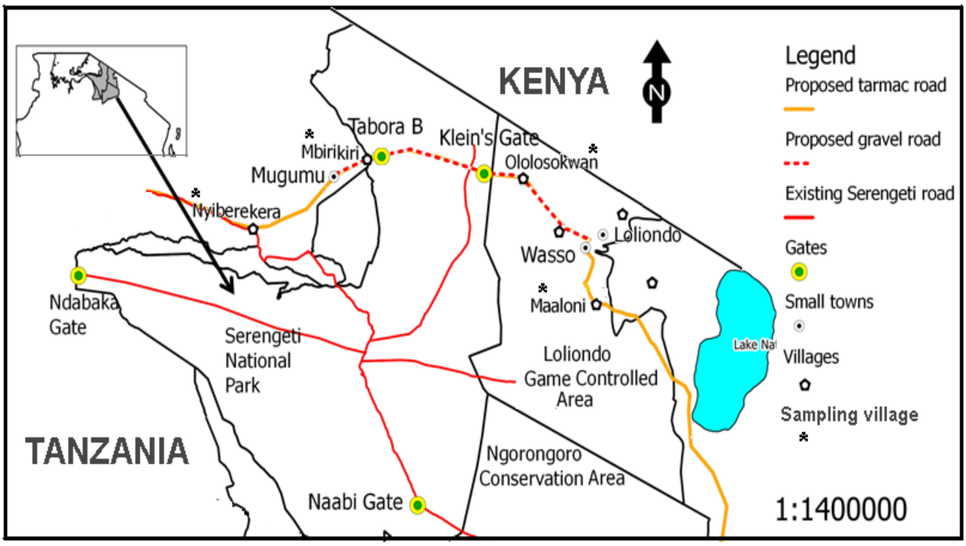

Figure 1: The study area and proposed highway (adopted from Røskaft et al. 2012)

Sampling of soil

Maximum environmental effects arising from activities on a road are seen at distances 0–10 m from the roadside (Luilo and Othman 2006, Nachana'a 2019). Soils were, therefore, dug vertically at the four selected sites, Ololosokwan, Maaloni, Mbirikiri and Nyiberekera, about 1.5–2 m near the proposed road in each road segment to obtain soil profiles and soil samples at various depths. Examples of the soil profiles from the sampling sites are shown in Figure 2. The data for the profile were collected based on the soil profile description guidelines of FAO (1990). The soil samples from the different horizons were collected using clean stainless-steel tools, sterile bagged, labeled and sent to the Chemistry laboratory of University of Dar es Salaam for relevant analyses following the methods of Carter (1993).

Soil analysis

The soil samples from the different sites and from the various depths were analyzed for pH, TN, OC, EC, CEC, SOM, P, macro-elements Na, K, Mg, and Ca and metals Al, Cd, Cr, Cu, Fe, Pb, Mn, Hg, Ni and Zn. Standard published methods were used for determination of these soil parameters (Sparks 1996, VDLUFA 1991) and metal levels. Table 1 summarises the measured soil quality parameters and the methods used for their determination.

The pH of the soils was measured onsite with a digital pH-meter (Hanna Instruments - model HI 99121) with combination glass membrane bulb electrode after a 1:1 soil/water suspension was prepared (ISO 2005). The electrical conductivity of soil was measured onsite using a digital conductivity meter (Mettler Toledo Conductivity meter) by dipping the conductivity cell into the 1:5 soil/water suspension and measuring at units of mhos/cm (ISO 1995a). Exchangeable Na, K, Mg and Ca content of the soil samples were determined in the laboratory using Atomic Absorption Spectrophotometry after extracting the soil elements with 1 M ammonium acetate at pH 7 (a reference method approach) (Thomas 1982, ISO 2018). For this method, standard curves were initially prepared, and the elements measured with respect to these curves. The total nitrogen (TN) content was determined by using the modified Kjeldahl method (ISO 1995b) for sample extraction followed by colorimetric measurement at 660 nm.

Table 1: Soil quality parameters and methods of measurement

Parameter	Unit	Measurement	Standard method
pH	–	Soil:H_2O (1:1) suspension	ISO 2005
EC	mS/cm	Soil:H_2O (1:5) suspension	ISO 1994a
OC	%	Walkley and Black	ISO 1995b
SOM	%	OC% x 1.724	Walkley and Black 1974
TN	g/kg	modified Kjeldahl method	ISO 1995a
Available P	mg/kg	Kjeldahl-Olsen Method	ISO 1994b
Exchangeable K	meq/100 g	1 N NH_4OAc extract pH = 7	EPA 1986
Exchangeable Ca	meq/100 g	1 N NH_4OAc extract pH = 7	EPA 1986
Exchangeable Mg	meq/100 g	1 N NH_4OAc extract pH = 7	EPA 1986
Exchangeable Na	meq/100 g	1 N NH_4OAc extract pH = 7	EPA 1986
CEC bases	meq/100 g	Sum of exchangeable cations	Rengasamy and Churchman 1999
Al	mg/kg	EDTA back titration	AOAC 2016
Fe	mg/kg	Atomic Absorption Spectrophotometry	Khan and Cornfield 1968
Cd, Cr, Pb, Mn, Cu, Ni, Zn	mg/kg	Atomic Absorption Spectrometry	TBS 2020a
Hg	mg/kg	Direct Mercury Analyzer DMA-80	Elhag et al. 2015

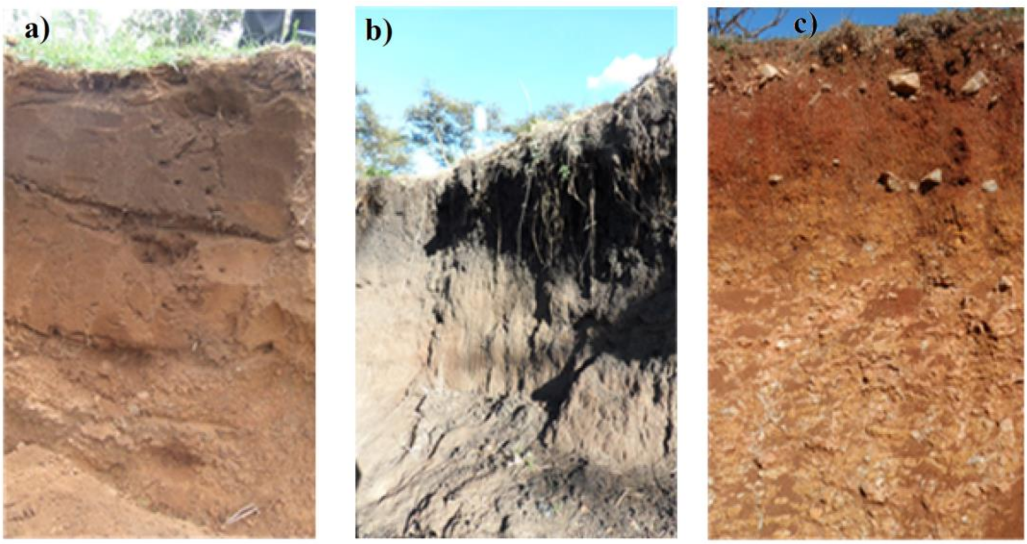

Figure 2: Soil profiles from study sites at: a) Mbirikiri village b) Ololosokwan village and c) Maaloni village.

Phosphorus content was determined by converting various P forms to phosphate using Kjeldahl digestion followed by Olsen extraction (Olsen and Sommers 1982) and subsequent spectrophotometric measurements of the coloured phosphomolybdenum complex. The OC in soil was determined after extraction and direct dichromate oxidation of organic matter in sulfuric acid (Walkley-Black procedure) followed by titration of excess $Cr_2O_7^{2-}$ with a standard solution of ferrous ammonium sulfate using a potentiometric endpoint detection (Sparks 1996, APHA/AWWA/WEF 2017). Soil Organic Matter (SOM%) was calculated as (Walkley and Black 1974): SOM% = OC% x 1.724. Exchangeable amounts of Na, K, Mg and Ca were measured using Method 9080 of 1986 of the Environmental Protection Agency (EPA). Cation Exchange Capacity (CEC) was calculated as the sum of exchangeable amounts of Na, K, Mg and Ca (Hendershot et al. 2008). Mercury was analyzed using a Milestone's Direct Mercury Analyzer DMA-80 (Elhag et al. 2015). Al levels were determined by EDTA back titration (AOAC 2016) and heavy metals Cd, Cr, Fe, Pb, Mn, Cu, Ni, Zn were determined by Atomic Absorption Spectrophotometry after extracting of the soil elements with aqua regia (TBS 2020a).

Quality assurance

Quality control tests were conducted on all samples to evaluate the experimental procedures and efficiency of the AAS and other methods. All reagents and chemicals used were of analytical grade or high purity. All analysis values reported are averages of triplicate determinations. Two sets of soil samples were analyzed, the original soil samples and the spiked soil samples to obtain the recovery and concentrations of the elements. The spiking was done using diluted solutions of metal-standard solution (e.g., 20 µg/kg of Ca, Mg, Na and K) prepared from several dilutions of the 1000 µg/g stock analytical grade standard solutions. All samples were preserved as per literature (Scott and Nancy 2000). The spiked samples and the original natural samples were then digested, extracted and analyzed using the same procedures to obtain the recoveries and results presented in the tables below. From these measurements the acceptable recovery for the macro-nutrients Ca, Mg, Na and K was 93 ± 10%. The detection limits at the 95% confidence limits, determined using methods of AOAC (2016), were 0.05 g/kg for TN, 0.05% for OC, 0.086% for SOM, 0.01 mS/cm for EC, 5 mg/kg for available P, 0.005 meq/100-g for Ca, 0.01 meq/100-g for K, 0.005 meq/100-g for Mg, 0.01 meq/100-g for Na, 0.1 mg/kg for Hg and 0.01 mg/kg for Al, Cd, Cr, Fe, Pb, Mn, Cu, Ni, Zn.

Results and Discussion

The quantitative measurement results for the different soil quality parameters of the soil samples from the different horizons are presented in Tables 2 to 5. For the eastern segment of the proposed road, the results are presented in Tables 2 and 3 while results presented in Tables 4 and 5 are for the two sites from the western segment of the proposed road. Table 6 presents the results of toxic metals contents of the top soils of the sampled sites.

Soil pH

Soil pH is a measure of the concentration of hydrogen ions $[H^+]$ in the aqueous soil solution, i.e., a measure of soil acidity or alkalinity. The measurement is important because all chemical and biological reactions in soil are influenced by soil pH. Soil pH affects nutrient solubility and rates of decomposition in soil and thereby has a profound effect on the availability of nutrients to plants. A slightly acidic pH of between 6 and 7 appears to provide optimal nutrient availability to plants (Thungngern et al. 2017). All eastern road segment soils had pH higher than 7 implying that their soils were moderately alkaline while the western road segment soils had a slightly acidic pH range of 6.5 to 6.7. These pH levels were within the specification for potential agricultural soil therefore considered appropriate (FAO 1990).

Table 2: Soil quality parameters results for Ololosokwan village soil

	Soil depth/cm (n = 3)						
Parameter	0–8	8–14	14–29	29–38	38–54	>54	Average
TN (g/kg)	0.4	0.4	0.5	0.2	0.2	0.1	**0.30**
OC %	0.81	0.80	0.99	0.66	0.54	0.49	**0.71**
SOM%	1.40	1.38	1.71	1.14	0.93	0.85	**1.23**
EC (mS/cm)	0.16	0.15	0.14	0.15	0.13	0.06	**0.13**
pH (aq. Soln)	7.7	7.7	7.3	8.1	8.2	8.2	**7.9**
P (mg/kg)	62	63	42	95	106	110	**79.7**
Na (meq/100 g)	0.08	0.08	0.08	0.11	0.29	0.19	**0.14**
K (meq/100 g)	0.28	0.46	0.20	0.28	0.26	0.14	**0.27**
Ca (meq/100 g)	26.4	27.1	29.4	35.4	37.0	36.9	**30.3**
Mg (meq/100 g)	0.73	0.78	0.60	0.71	0.63	0.59	**0.67**
CEC (meq/100 g)	27.49	28.42	30.28	36.50	38.18	37.82	**33.12**

Table 3: Soil quality parameters results for Maaloni village soil

	Soil depth/cm (n = 3)				
Parameter	0–6	6–15	15–45	45–57	**Average**
TN (g/kg)	0.8	0.5	0.3	0.2	**0.45**
OC %	1.34	0.99	0.77	0.65	**0.94**
SOM%	2.31	1.71	1.33	1.12	**1.62**
EC (mS/cm)	0.90	0.69	0.44	0.24	**0.57**
pH (aq. soln)	7.1	7.4	7.7	8.0	**7.55**
P (mg/kg)	24	42	58	79	**50.7**
Na (meq/100 g)	1.27	2.61	1.06	0.44	**1.35**
K (meq/100 g)	2.39	2.80	1.67	1.45	**2.08**
Ca (meq/100 g)	17.9	18.8	23.5	30.9	**21.3**
Mg (meq/100 g)	0.30	0.40	0.40	0.56	**0.41**
CEC (meq/100 g)	21.86	24.61	26.63	33.35	**26.61**

Table 4: Soil quality parameters results for Mbirikiri soil

	Soil depth/cm (n = 3)					
Parameter	0–6	6–42	43–82	83–104	>104	Average
TN (g/kg)	0.8	0.9	0.7	0.7	0.6	**0.74**
OC %	1.30	1.37	1.18	1.18	1.12	**1.23**
SOM%	2.24	2.36	2.03	2.03	1.93	**2.12**
EC (mS/cm)	0.04	0.05	0.06	0.04	0.04	**0.05**
pH (aq. Soln)	6.5	6.6	6.5	6.5	6.5	**6.5**
P (mg/kg)	20	20	21	21	21	**20.6**
Na (meq/100 g)	0.05	0.06	0.08	0.05	0.05	**0.06**
K (meq/100 g)	0.38	0.59	0.41	0.27	0.35	**0.40**
Ca (meq/100 g)	11.4	11.7	11.5	11.7	11.7	**11.6**
Mg (meq/100 g)	0.53	0.56	0.49	0.53	0.51	**0.52**
CEC (meg/100 g)	12.36	12.91	12.48	12.55	12.61	**12.58**

Table 5: Soil quality parameters results for Nyiberekera soil

	Soil depth/cm (n = 3)				
Parameter	0 –13	13 –51	51– 67	67– 97	**Average**
TN (g/kg)	0.9	0.7	0.3	0.2	**0.52**
OC%	1.54	1.06	0.84	0.80	**1.06**
SOM%	2.66	1.83	1.45	1.38	**1,83**
EC (mS/cm)	0.14	0.10	0.05	0.04	**0.08**
pH (aq. soln)	6.6	6.5	6.7	6.5	**6.6**
P (mg/kg)	17	21	25	26	**22.0**
Na (meq/100 g)	0.16	0.07	0.16	0.14	**0.13**
K (meq/100 g)	1.00	0.89	0.56	0.45	**0.72**
Ca (meq/100 g)	9.24	9.81	10.2	10.3	**9.89**
Mg (meq/100 g)	0.34	0.29	0.27	0.27	**0.29**
CEC (meq/100 g)	10.74	11.06	11.19	11.16	**11.04**

Organic Carbon (OC)

Organic Carbon (OC), the carbon stored in soil organic matter (SOM), is partly responsible for many soil characteristics such as colour, nutrient holding capacity (cation and anion exchange capacity), nutrient turnover, water retention, aeration and workability (Pluske et al. 2021). The average OC content of 0.71–1.23% for soils of both the segments show that the soils along the proposed road are of fairly good quality, not contaminated and very suitable for plant growth.

Total Nitrogen (TN)

The TN assessment of soils is important because nitrogen is often the most limiting nutrient in soil. Nitrogen is one of the major elements required for vegetation growth. It will stimulate above-ground growth, and it produces the rich green colour that is the characteristic of healthy plants. The average TN level of 0.3–0.74 g/kg in soils indicates that the soils of both segments are relatively fertile and useable for agricultural production.

Electrical Conductivity (EC)

Soil electrical conductivity indicates the amount of soluble salt in the soil and its influence on plant growth and productivity. Soil salinity affects crop growth and soil structure and is estimated from measurement of soil electrical conductivity. The soil average EC values were 0.13 mS/cm at Ololosokwan, 0.57 mS/cm at Maaloni, 0.08 mS/cm at Nyiberekera and 0.05 mS/cm at Mbirikiri. The eastern segment soils had relatively higher levels of soluble salts than the soils from the western segment of the proposed road. As the levels recorded were lower than 2 mS/cm, it can be concluded that there is no soil salinity problem affecting plant growth in the entire study area.

Total Phosphorus (P)

Phosphorus was determined by the Olsen P method (ISO 1994b) which is suitable for slightly acidic to moderately alkaline soils. Low P soils have P values less than 35 mg/kg while high P soils have P values greater than 60 mg/kg. The average P values were 20.6 mg/kg at Mbirikiri, 22.0 mg/kg at Nyiberekera, 50.7 mg/kg at Maaloni and 79.7 mg/kg at Ololosokwan. The results show that the eastern segment of the road has high phosphorus content while the western segment has medium to low phosphorus levels. This suggests necessary application of phosphate-fertilizers to soils of the western road segment for agricultural purposes.

Macro-elements Na, K, Mg and Ca

The concentrations of the above cations are determined in an aqueous soil solution extract of soil (Hendershot et al. 2008). K, Mg, Ca are primary ions for crop management. Potassium is the third essential fertilizer element and essential for photosynthesis, protein synthesis, translocation of sugars, grain formation, tuber development and starch formation. All root crops generally give response to application of potassium (Swapnil et al. 2011). The average K levels in the soils were 0.72 meq/100-g at Nyiberekera, 0.40 meq/100-g at Mbirikiri, 2.08 meq/100-g at Maaloni and 0.27 meq/100-g at Ololosokwan. These levels are appropriate for healthy development of crops at the sites.

The Ca and Mg, known as secondary nutrients (Vitosh et al. 1994) are very important elements for plants life. They are the most abundant mineral elements in soil but are required, however, in comparatively small amounts. The average Ca levels in the soils were 9.89 meq/100-g at Nyiberekera, 11.6 meq/100-g at Mbirikiri, 21.3 meq/100-g at Maaloni and 30.3 meq/100-g at Ololosokwan. The average Mg levels in the soils were 0.29 meq/100-g at Nyiberekera, 0.52 meq/100 g at Mbirikiri, 0.41 meq/100-g at Maaloni and 0.67 meq/100-g at Ololosokwan. The secondary nutrients in these soils were therefore present at healthy levels.

Sodium plays a critical role in soil health even though it is not considered a plant nutrient. High sodium level reduces soil permeability, resulting in drainage and compaction problems that cause a decline in grass vigor. A healthy soil sodium concentration must be within 0–5 % (Carrow et al. 2002). The average Na levels in the soils of the study sites were 0.13 meq/100-g at Nyiberekera, 0.06 meq/100-g at Mbirikiri, 1.35 meq/100-g at Maaloni and 0.14 meq/100-g at Ololosokwan. These levels were all within the healthy soil Na level for an agriculture soil.

Cation Exchange Capacity of soils varies according to the clay %, the type of clay, soil pH and amount of organic matter. Pure sand has a very low CEC of less than 2 meq/100-g. Sandy, low organic matter soils can range below 5 meq/100-g whereas finer textured soils and those high in organic matter usually have over 15 meq/100-g. Average CEC of the soils studied ranged from 11.04 to 12.58 meq/100-g for soils of the western segment of the road while average CEC for the eastern segment ranged from 26.61 to 33.12 meg/100-g. We note that all soils have fine texture properties and exhibited high organic matter contents making them appropriate for good agriculture.

Levels of toxic metals in the soils

The results of toxic metals contents of the top soils of the sampled sites are presented in Table 6.

Table 6: Metal levels (mg/kg) in top soil (0–13 cm, n = 3)

	Village				
Metal	Ololosokwan	Maaloni	Mbirikiri	Nyiberekera	TBS 2020b
Al	63963.3 ± 107.1	52083.4 ± 95.2	50695.7 ± 81.9	46702.9 ± 86.6	NS
Cd	BDL	BDL	BDL	BDL	2.0
Cr	24.70 ± 2.75	29.51 ± 1.89	46.55 ± 2.28	101.55 ± 3.65	150.0
Cu	27.31 ± 2.42	34.96 ± 1.25	33.07 ± 0.67	30.15 ± 2.59	36
Fe	39144.7 ± 71.9	42439.0 ± 75.8	32390.8 ± 36.4	38304.1 ± 40.6	NS
Pb	19.54 ± 0.52	18.06 ± 0.36	22.19 ± 0.60	21.06 ± 1.04	80.0
Mn	957.12 ± 15.74	1458.97 ± 32.12	1025.34 ± 16.87	1358.83 ± 15.96	1800
Hg	BDL	BDL	BDL	BDL	2.0
Ni	32.52 ± 1.89	28.29 ± 1.46	20.24 ± 1.83	27.44 ± 1.16	100
Zn	124.14 ± 1.73	117.53 ± 1.66	96.09 ± 1.57	101.85 ± 1.03	150

BDL = Below Detection Limit, NS = Not Specified. The levels are presented as mean ± standard deviation.

Aluminium (Al) is the most abundant metal in the earth's crust. The typical range of aluminium in soils is from 1 percent to 30 percent (10,000 to 300,000 mg-Al/kg) (Lindsay 1979, Dragun 1988) with naturally occurring concentrations varying over several orders of magnitude. The average Al levels in the soils of the study sites were 46702.9

mg/kg at Nyiberekera, 50695.7 mg/kg at Mbirikiri, 52083.4 mg/kg at Maaloni and 63963.3 mg/kg at Ololosokwan. These levels were all within the healthy soil Al level for an agriculture soil (Dragun 1988).

Cadmium (Cd) and ***mercury*** (Hg) were below measurement detection limits in the studied soils indicating clearly the soils were not contaminated with these heavy metals.

Chromium (Cr) is a naturally occurring element in rocks and soil. Natural soil typically contains between 10 and 50 mg of chromium for every kg of soil. The Canadian Soil Quality Guidelines (CSQG) for the protection of environmental and human health recommends that soil in residential areas and parklands should contain less than 64 mg/kg of total chromium (CSQG 2007). The average total Cr levels in the soils of the study sites were 101.5 mg/kg at Nyiberekera, 46.5 mg/kg at Mbirikiri, 29.5 mg/kg at Maaloni and 24.7 mg/kg at Ololosokwan. TBS (2020b) specifies that for a good agricultural soil, the level of chromium must not exceed 150 mg/kg. The measured levels of Cr in all the study sites were, therefore, within the healthy soil Cr level for an agriculture soil.

Copper (Cu) is a micronutrient in plants and an important constituent, in small amounts, of the human diet. Copper plays a range of roles in plants. It facilitates respiration and photosynthesis and is important for plant metabolism. It is a component of a variety of enzymes and plant cell walls, so it is important for plant strength. Copper also affects the flavour, sugar content and storage life of fruits (Wade 2019a). TBS (2020b) specifies that for a good agricultural soil, the level of copper must not exceed 36 mg/kg. The average total Cu levels in the soils of the study sites were 30.15 mg/kg at Nyiberekera, 33.07 mg/kg at Mbirikiri, 34.96 mg/kg at Maaloni and 27.31 mg/kg at Ololosokwan. Therefore, the measured levels of Cu in all the study sites were within the healthy soil Cu level for an agriculture soil.

Iron (Fe) is the fourth most abundant element found in soil, though it is largely present in forms that cannot be taken up by plants. Iron, in small amounts, is essential for healthy plant growth and is classed as a micronutrient. It is important for the development and function of chlorophyll and a range of enzymes and proteins. It also plays a role in respiration, nitrogen fixation, energy transfer and metabolism (Wade 2019b). A normal iron level in soil will be between 0.2% to 55% or 20,000 to 550,000 mg/kg (Bodek et al. 1988). The average total Fe levels in the soils of the study sites were 38304.1 mg/kg at Nyiberekera, 32390.8 mg/kg at Mbirikiri, 42439.0 mg/kg at Maaloni and 39144.7 mg/kg at Ololosokwan. TBS (2020b) does not specify the acceptable levels for Fe in soil, but the measured levels of Fe at all the study sites were within the healthy soil Cu level for an agriculture soil (Bodek et al 1988).

Lead (Pb) is a naturally occurring heavy metal that is however, toxic to plants and humans. Pb in soil has been recognized as a public health problem, particularly among children and pregnant women. Soil naturally contains lead concentrations less than 50 mg/kg. At concentrations of 10000–40000 mg/kg, lead can kill soil bacteria and fungi (Wade 2019c). TBS (2020b) specification for maximum acceptable lead level in agricultural soil is 80 mg/kg. The average total Pb levels in the soils of the study sites were 21.06 mg/kg at Nyiberekera, 22.19 mg/kg at Mbirikiri, 18.06 mg/kg at Maaloni and 19.54 mg/kg at Ololosokwan. The measured levels of Pb in all the study sites were low confirming that there was no Pb pollution in the soils by the roadside of the proposed new road.

Manganese (Mn) is a plant micronutrient that fulfils a number of roles and is used in photosynthesis, synthesis of chlorophyll and nitrogen absorption as well as the synthesis of riboflavin, ascorbic acid and carotene (Wade 2019d). A good soil should have a Mn level higher than 10 mg/kg, but not the exceeding the TBS (2020b) threshold of 1800 mg/kg. The average total Mn levels in the soils of the study sites were 1358.83 mg/kg at Nyiberekera, 1025.34 mg/kg at Mbirikiri, 1458.97 mg/kg at Maaloni and 957.12 mg/kg at Ololosokwan. Therefore, the measured levels of Mn in all the study sites were within the healthy soil Mn level for an agricultural soil.

Nickel (Ni) is a plant micronutrient that contributes to nitrogen fixation, the metabolism of urea, and is important for seed germination. Nickel is also important for bacteria and fungi, which are both important for good plant growth. Ideally, for healthy and productive soil the concentration of 1–20 mg-Ni/kg is needed (Wade 2019e). Excess nickel, higher than 400 mg/kg can impede the uptake of other essential nutrients especially iron and inhibit seed germination as well as shoot and root growth (Wade 2019e). The average total Ni levels in the soils of the study sites were 27.44 mg/kg at Nyiberekera, 20.24 mg/kg at Mbirikiri, 28.29 mg/kg at Maaloni and 32.52 mg/kg at Ololosokwan. The specification for maximum acceptable nickel level in agricultural soil is 100 mg/kg (TBS 2020b). Consequently, all study sites had good nickel levels, very suitable for agriculture.

Zinc (Zn) is an essential plant micronutrient, important for production of plant growth hormones and proteins, and is involved in sugar consumption. Good root development as well as carbohydrate and chlorophyll formation are also dependent on zinc. Zinc is also involved in the synthesis of auxin, a plant hormone that helps plants determine whether to focus on growing tall or becoming bushy (Wade 2019f). Ideally, for healthy and productive soil the concentration of zinc should be between 1 and 150 mg/kg, the maximum acceptable zinc level in agricultural soil (TBS 2020b). The average total Zn levels in the soils of the study sites were 101.85 mg/kg at Nyiberekera, 96.09 mg/kg at Mbirikiri, 117.53 mg/kg at Maaloni and 124.14 mg/kg at Ololosokwan. Hence, the measured levels of Zn in all the study sites were within the productive and healthy soil Zn level for an agriculture soil.

In summary, we can conclude that the soils in all the study sites were not polluted and fulfilled the requirements for a good, healthy, productive agricultural soil.

Conclusion

The physicochemical properties such as EC, pH, OC, SOM, available P, TN, macro-elements K, Ca, Mg and Na concentrations, CEC levels and metal elements Al, Cd, Cr, Pb, Mn, Cu, Ni, Zn, Fe and Hg concentrations in the soil samples collected close to the proposed northern Serengeti Road at Nyiberekera, Mbirikiri, Maaloni and Ololosokwan in Ngorongoro and Serengeti Districts were determined. When compared to the specification of soil quality (Fact Sheets 2021, TBS 2020b), the soils in all the sampling sites were evidently unpolluted, had fine texture, high organic matter content and were, therefore, healthy and moderately fertile. The need of fertilizer applications for agricultural purposes is only necessary for soils of the western road segment. Therefore, at the present time, the soils alongside the proposed road are good, clean, clearly not contaminated, fertile, having physicochemical properties and levels of soil macro-elements and metal elements including heavy metals that are within the specifications of good agricultural soil.

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