Geospatial Analysis for Heavy Metals and Water Quality Assessment in Bugesera Agricultural Wetlands of Rwanda

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Abstract

Agricultural wetlands are crucial ecosystems for provision of food, water purification, soil retention, nutrients cycling, to name few. However, they are more exposed to heavy metals deposition generating ecological concerns. Therefore, spatially explicit study for water quality and heavy metals' contents in wetlands to reveal metal contamination sources are key steps for sustainable utilization of water resources in irrigated wetlands. Water samples were collected from surface water alongside the Gashora river. Three sampling sites (Karugenge, Karumuna and Muzi) were selected as the show high occurrence of flooding in wetland. A Global Positioning System (GPS) was used to obtain positional data where surface water samples were collected. A point (vector) database was developed for the attributes of soil, water, and associated parameters. The Photometric, calcination, titration and atomic adsorption spectrometer machines were used to detect the heavy metals. The application of GIS analysis through interpolation using Kriging was used to generate the predictive maps. Principal Components Analysis techniques was used to correlate water quality parameters for similarities and dissimilarities through cluster analysis. All statistical analyses were performed using STATA 13.0 and ArcGIS 10.5 was used to generate prediction maps. The study findings on water quality analysis shows that the ranges of heavy metals were Ca, Mg, Na, K, Cu, Zn, Mn, Pb, Cd and Cr concentration were 3.9–23; 10–22; 2–11; 10.6 –20.6; -7– 210; 0.63– 0.81; 110–160; 0.37–12; 0.15– 0.78; and 0.23–4.4ppm while for water quality analysis, the ranges for pH, EC, TDS, TH, SAR, MAR, KR and SSP concentration were 7–7.8; 190–300; 130–200; 55 –150; 26– 110; 47– 73; 8.2–72 and 35–60 respectively. The greatest heavy metals show maximum values compared to Rwanda national and international permissible limits for irrigation. Thus, there is a need of water treatment to reduce the harmfulness effect to plant and human being.

Keywords: Factor Analysis, Heavy metals, Principal Component Analysis, Spatial interpolation, Water quality

1. Introduction

Agricultural wetlands are species rich ecosystems performing valuable services such as flood protection, water quality, food chain support, carbon sequestration food provision, water purification, soil retention, and cycling of nutrients cycling (Coates et al., 2013), but are exposed to heavy metals deposition which creates ecological concerns. Nowadays, the problems of heavy metals contamination among various environmental segment including air, water, soil, vegetation and food items are a concern at global scale (Singh et al., 2018). The research conducted by Ali et al. (2016) proved that coastal wetlands are the main sinks for heavy metals due to a variety of physico-chemical processes (e.g., adsorption, ligand exchange, sedimentation) (Ali et al., 2016). Some physico-chemical properties have proved to be the major controlling factors for the stabilization of trace metals (Vareda et al., 2019). The study conducted by Wang et al. (2017) presented that the reduction of dissolved and particulate trace metals is enhanced in soils by the presence of organic matter and divalent iron (Fe) and clays. Heavy metals are mainly pollutants that deteriorate water quality and are often used for irrigation. Environmental pollution from high heavy metal concentration through leaching and seepage processes from industrial services, anthropogenic activities, erosion and mining activities that enter streams, fertilizer and pesticides leaching, sewage discharge, lakes, rivers and groundwater are a major concern by surface runoff (Bradl, 2005; Sharifi et al., 2016; Zhang et al., 2017). According to Mukanyandwi et al. (2019), safe and affordable water is essential for public health. It is used for drinking, food production, domestic use, and recreational purposes. Access to improved water supplies and sanitation, along with better management of water resources, plays a crucial role in developing countries by impacting on communities' well-being and on national development plan. Water is the leading constituent of swamp ecosystems (Biggs et al., 2017) and water quality is not only suggestive of water's fitness for preserving various agricultural purposes, industrial applications and processes, but also a potential factor in supporting biodiversity and ecosystem function (Duan et al., 2016; Xing et al., 2014). Therefore, it is imperative to study spatial distribution of heavy metals and water quality parameters concentrations to protect water resources and reduce its human health impacts. Worldwide, vulnerable farmers become concerned over the potential growth of heavy metals in various ecosystems including the agricultural land due to waste deposition and residues from surface water systems (Wu et al., 2015; Thunqvist, 2003) for instance, copper's availability was between 1000 mg/ liter to 2000mg/liter and concluded that it has antagonistic effects on marine organisms (Perreault et al., 2014). The high-level of copper content in water bodies might disturb human reproduction, physiological growth and behavioral change on a variety of marine organisms. According to Ayers et al. (1994) in FAO guidelines for irrigation water quality, there is a standardization of water quality applied for irrigation as prescribed below: [Ca]:0-20 ppm, [Mg]:0-5 ppm, [Na]:0-40 ppm, [K]: 0-2 ppm, [Cu]: 0.2 ppm, [Zn]:2.0 ppm, [Mn]:0.20 ppm, [Pb]: 5.0 ppm,

[Cd]: 0.01 ppm and [Cr]: 0.1 ppm. In Rwanda, research reports ascertained that expanding wetland reclamation for agriculture development coupled with rapid urbanization and other physical infrastructure development into wetland catchment areas increases the risk of pollution (Nyandwi et al., 2016). It was reported that a well in the Gahanga sector, Rwanda, had extraordinary cadmium content possibly linked to pollution from the landfill located in its neighborhood whereby eighteen percent of the total samples contained maximum limits of WHO standards (Nsengimana et al., 2012). Hydrologically, Surface water flow measurement is an integral part of most water quality monitoring. Stream flow, runoff, transit, and delivery of many nonpoint source (NPS) pollutants have a direct impact on flooding and stream geomorphology. The flow of the river must be known in order to calculate pollution loads (Corsi et al., 2005). Transition Matrix Land Use Land Cover Change from 1990-2018 of Bugesera agricultural wetlands were classified as 26.741% for forest land, 2.60% for glass land, -27.52% for crop land, -3.01% for built – up land, 0.68% for wetlands and 0.504% for water body. In this regards, the geospatial variation has been recognized for many years in water quality analysis where Water characteristics generally showed spatial dependence (Mousavifard et al., 2013). Samples close to each other have similar properties compared with samples distant from each other (Mousavifard et al., 2013). The Kriging interpolation has been adoped to compute the concentration of missing data spatially from the available surrounding data. However, classical statistics, assuming that the measured data are independent, is not able to analyze the spatial dependency of variables (Mousavifard et al., 2013). Spatial variability of nutrients in farmland wetland based on Kriging interpolation indicated that the spatial correlation of wetland's total N, available P and K with random factors (fertilization, soil management and land use) was weak (Zheng et al., 2009). Studies on wetlands' properties analyzed geostatistically in a paddy growing alfisol revealed that the spatial dependencies of wetlands' properties can be used to support spatial sampling for detailed wetlands mapping (Nayanaka et al., 2010). The study further suggested that management practices such as fertilizer application, irrigation and tillage operations can be fine-tuned within the field scale to maximize rice crop production while minimizing the detrimental effects on the environment. Geostatistical methods combined with multivariate statistics have been used to study the spatial variation of heavy metals (Li et al., 2017; Li & Shen, 2016), but few studies have statistically analyzed the prediction map of the heavy metals and water quality components and come up with their intercorrelation profiles. Currently, there is no specific study that has been undertaken to evaluate levels of heavy metals in the Bugesera Agricultural wetland and effects on surface water quality useful in irrigation activities to enable the management of water use and the fertilizer use quantity. For the purposes of this research on the irrigational suitability, the rationale of this study is to assess the geospatial analysis for heavy metals and water quality assessment in Bugesera agricultural wetlands in Rwanda and come up with proper recommended water to be used for a range of beneficial and realistic irrigated cropping patterns for different strata (hillside, marshland).

Therefore, the specific objectives of this study was to conduct a geospatial analysis on heavy metals (Cu, Pb, Cd, Cr, Mn and Zn) and water quality (pH, EC, SAR, TDS, TH, KR, MAR and SSP) at Bugesera in comparison to international standards.

2. Materials and methods

2.1. Description of the study area

Bugesera is one of seven (7) districts comprising Eastern province of Rwanda. It is located in the South west of the Province. It is geographically situated at 02º12´18″ S and 30 º 08´42″ E. The District is developing and have some industrialization sites. However, there are various small industries and workshops such as welding of metals and plating, small tanning industries, mining sites etc., which are mainly located in southeast region. There are several farmland areas like Gashora farms, Kanzenze Agricultural swamp near Akagera river, located also in Upper Akagera Catchment (Figure 1). This research covered three (3) sampling location including Muzi, Karugenge and Karumuna sites. Major crops grown in the catchment are maize, rice, bush beans, and horticultural crops like chilli peper, vegetables and fruits. The water quality of Akagera Upper Catchment where located three sampled locations has deteriorated gradually in recent years, with anthropogenic inputs comprising the dominant source of a variety of contaminants into the lake, including those from metal mining, waste disposal, urban effluent, modernized agriculture (application of fertilizers and pesticides), and sewage sludge. A map indicating three sampled points is shown in figure 1 using Arc GIS 10.5 respectively. In this study, we adopted a buffer zone of 1 Km as the smallest buffer to avoid the soil and water deformation. Critically, the greater buffer zone absorb and reduce rainwater, which recharges ground water supplies and allows storm runoff to be released more slowly in the wetland and thus affect surface water quality and soil properties. This should be taken as much smaller to avoid any associated changes to soil and water properties.

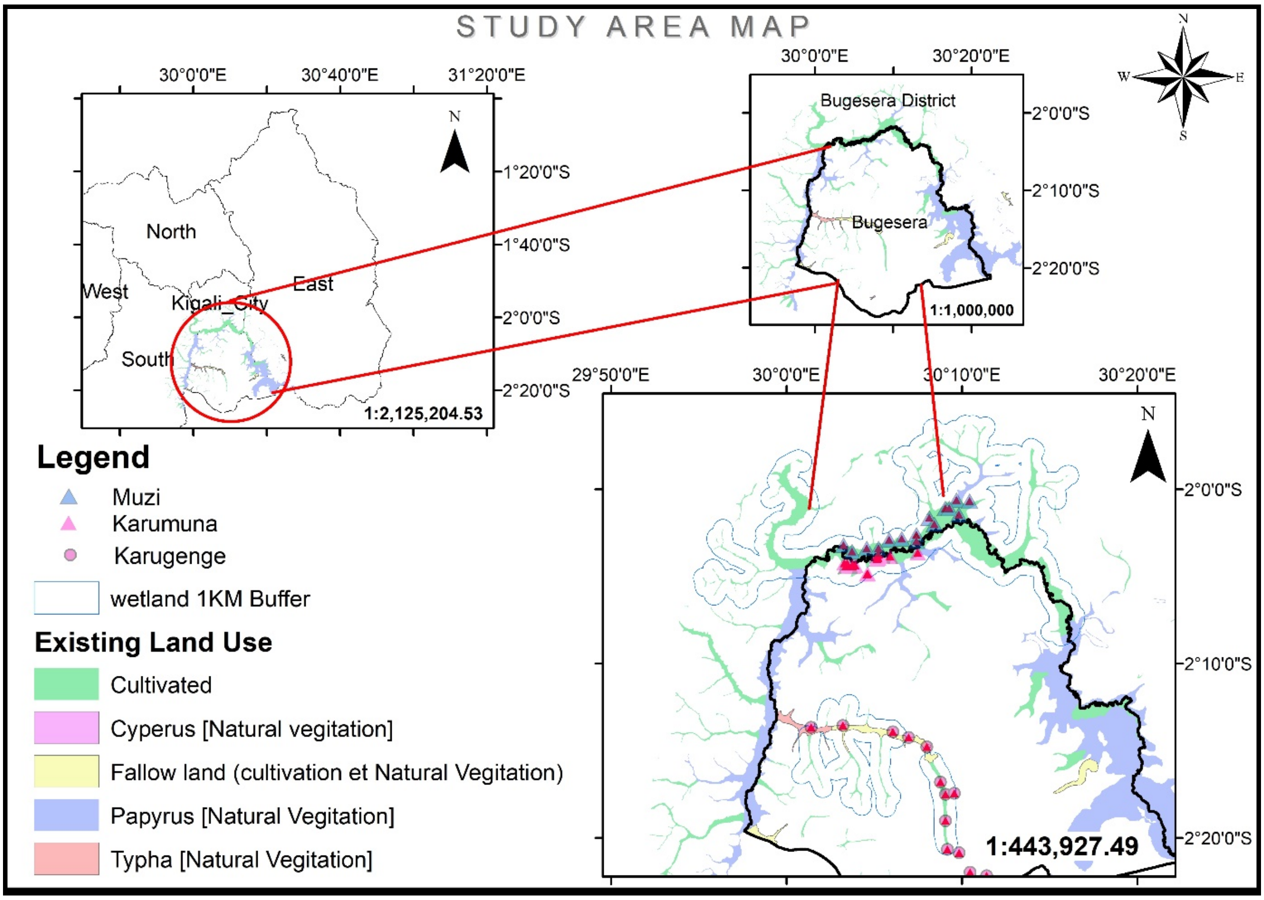

Figure 1: Location of sampling sites

Table 1 shows classification of wetlands which are associated with the selected sites of Bugesera Agricultural wetlands (Karumuna, Muzi and Karugenge). It indicates the names of wetlands, vegetation type, importance and status, management and the area of each wetland in Ha (Table 1 and Figure 2).

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Table 1: Detailed area in ha of the three selected sites (Karumuna, Muzi and Karugenge)

No.	Name of wetland	Vegetation and use	Importance	Status	Management	Area in Ha
22	Rwintare	Cultivation	National		Conditionally exploited	79.1
21	Nyabarongo Amont	Cultivation	National	Proposed RAMSAR site	Conditionally exploited	4849.4
20	Ruboroga	Cultivation	National		Conditionally exploited	198.3
19	Ruhosha-Ayabaraya	Papyrus [Natural Vegetation]	Local		Conditionally exploited	48.9
18	Mwanana-Mulindi-Kanombe	Cultivation	National		Conditionally exploited	243.9
17	Nyabarongo Aval	Cultivation	National	Proposed RAMSAR site	Conditionally exploited	6198.9
16	Cyacika	Cultivation	National		Conditionally exploited	156.8
15	Rwabikwano-Gatare	Cultivation	National		Conditionally exploited	134.4
14	Rugende-Isumo	Cultivation	National	Proposed RAMSAR site	Conditionally exploited	583.7
13	Rubilizi	Cultivation	National		Conditionally exploited	92.1
12	Nyarubande	Cultivation	National	Proposed RAMSAR site	Conditionally exploited	339.0
11	Nyabuhoro – Kiruhura	Cultivation	National		Conditionally exploited	27.3
10	Bigaga-Kibaya	Cultivation	National		Conditionally exploited	92.3
9	Murago-Umurago	Fallow (Cultivation and Natural Vegetation)	National	Proposed RAMSAR site	Conditionally exploited	440.9
8	Mulindi-Kanombe	Cultivation	National		Conditionally exploited	121.5
7	Mbonwa	Cultivation	Local		Conditionally exploited	17.4

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No.	Name of wetland	Vegetation and use	Importance	Status	Management	Area in Ha
6	Kitaguzirwa	Papyrus [Natural Vegetation]	National	Proposed RAMSAR site	Conditionally exploited	290.3
5	Kiruhura 2	Cultivation	Local		Exploitation without special conditions	11.3
4	Kiruhura-Gatare	Cultivation	National		Conditionally exploited	92.1
3	Kiradiha	Cultivation	Local		Exploitation without special conditions	42.4
2	Kazabagarura	Cultivation	National		Conditionally exploited	54.1
1	Kanyetabi	Papyrus [Natural Vegetation]	Local		Conditionally exploited	45.4

Source: RLMUA, 2019

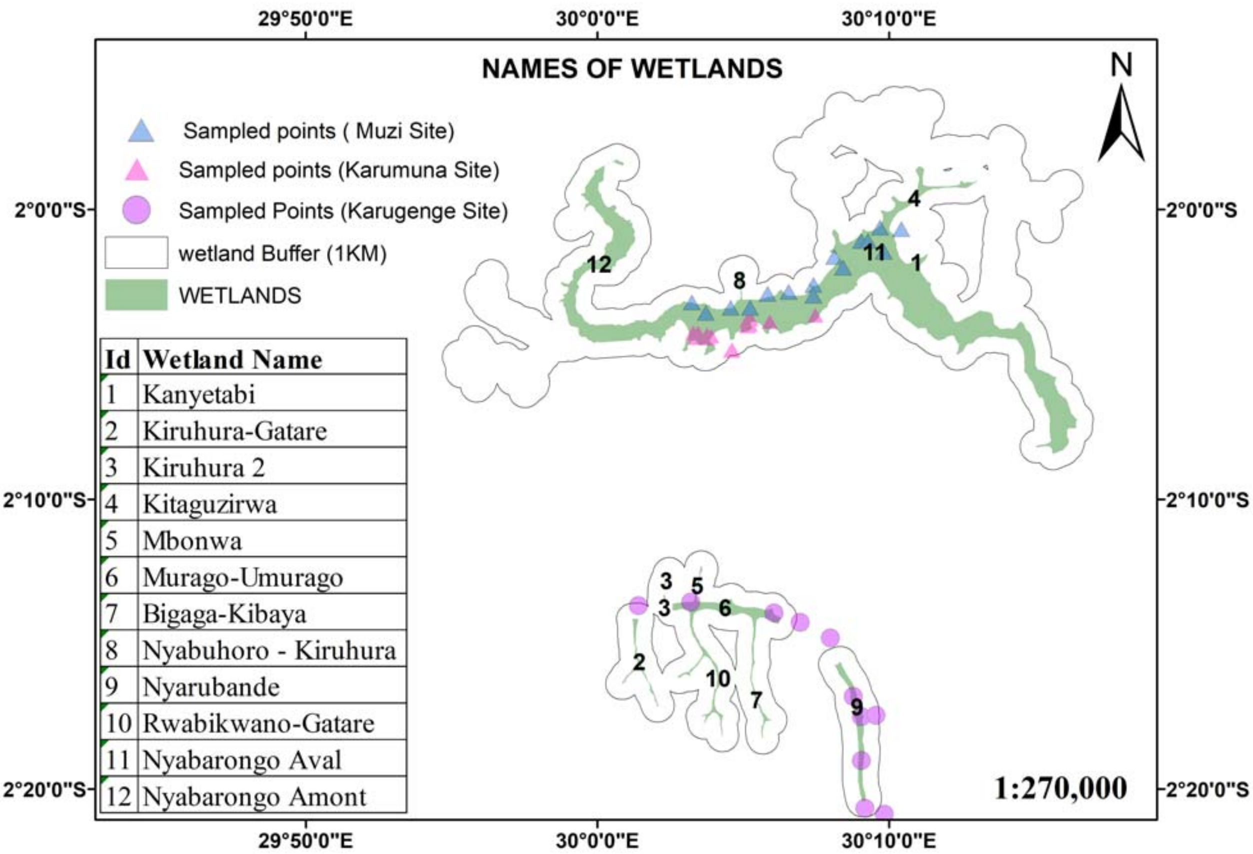

Figure 2: Description of Karumuna, Muzi and Karugenge sampling sites

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2.2. Soil types

In terms of soil texture classification, the greatest part of soil types from the selected sampling sites was classified by > 35% clay and the range of 20 – 35% clay as the smallest (Figure 3).

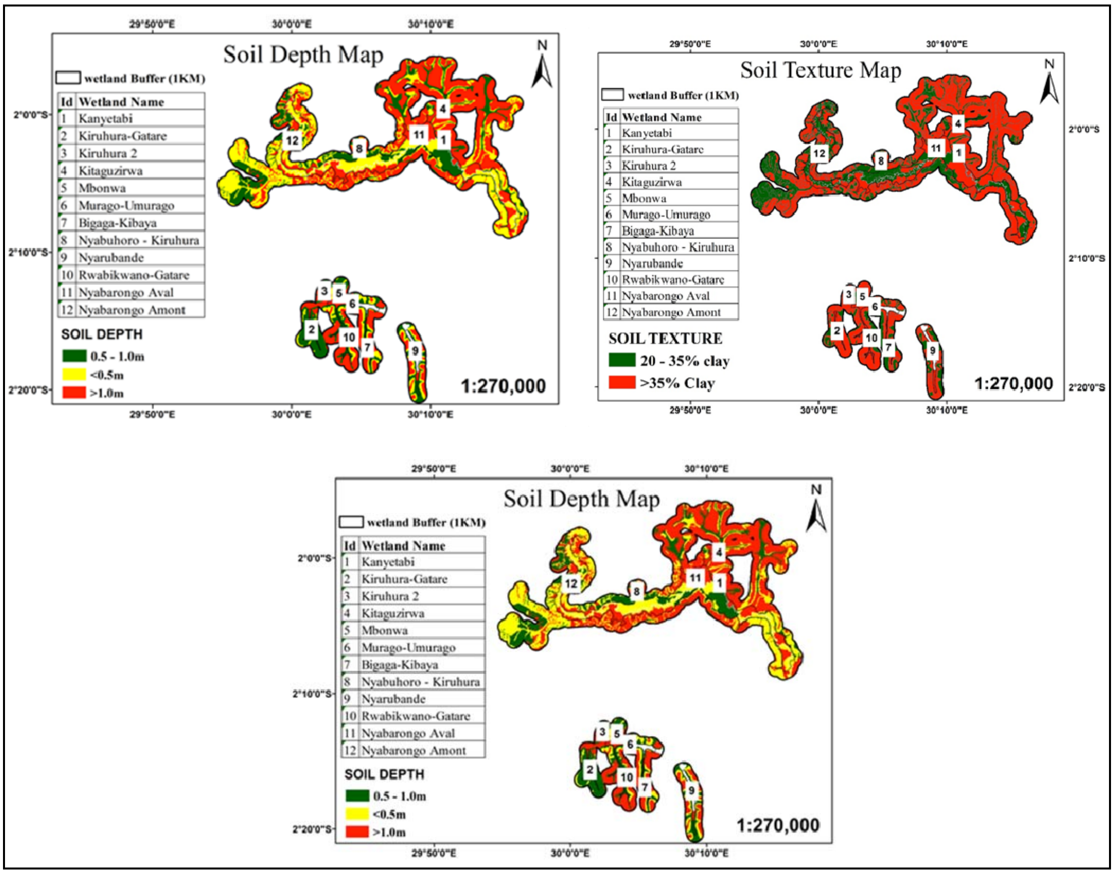

Figure 3: Soil textures for Karumuna, Muzi and Karugenge sites

2.3. Land Cover Land Use (LCLU) change from 1990 to 2018

Land used for different purposes may be disturbed to differing degrees depending on management practice, application rate and timing in the areas of intensive agriculture. The area and percentage of LCLU since 1990 – 2018 in the selected wetlands was 26.74% for forestland, 2.604% for grassland, -27.52% for cropland, -3.008% for built up land, 0.679% for wetland and 0.504% for water body (Table 2 and Figure 4).

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Table 2: Transition Matrix Land Cover Land Use (LCLU) Change from 1990-2018

Vegetation types	Area in Percentage (%)					Land use land cover in percentage (%)		
	1990	2000	2010	2018	1990-2000	2000-2010	2010-2018	1990-2018
Forestland	44.839	42.893	38.597	18.098	1.946	4.297	20.499	26.741
Grassland	10.274	1.108	3.745	7.670	-9.167	-2.637	-3.925	2.604
Cropland	25.961	39.123	38.683	53.480	-13.163	0.440	-14.797	-27.520
Built-up land	12.542	3.137	13.755	15.550	9.405	-10.618	-1.795	-3.008
Wetland	5.192	3.137	4.541	4.513	2.055	-1.404	0.028	0.679
Water body	1.192	0.829	0.679	0.688	0.363	0.150	-0.009	0.504

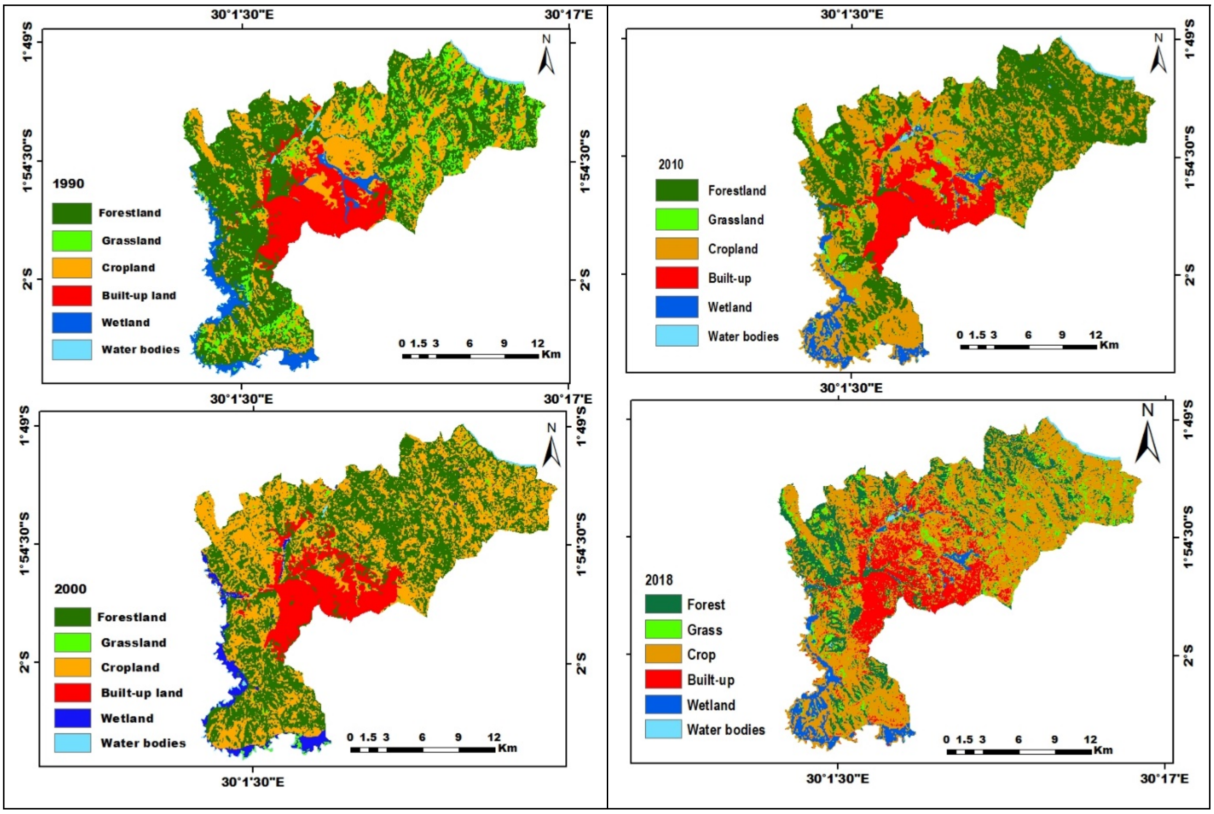

Figure 4: Changes of Land Cover Land Use (LCLU) in the three sites

2.4. Sampling procedures, measurement and digestion

The factors considered for selecting the sampling points were soil erosion rate in site, anthropogenic activities around the river (without consideration of 50 m as buffer zone from the river) and the pre surveying conducted during the year of 2019 aimed to assess the effect of surface water irrigation on crop yield. These statistical findings were key factors to be considered during sampling. The water samples were collected during the short sunny time and long rainy period of 2020. Water sampling points from surface water were identified and followed using the geographical coordinates captured by GPS. First, the 45 samples were taken from surface water primarily used by farmers to irrigate the

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crops in Bugesera Agricultural wetland during the short sunny season and long rainy season. The total of 45 water samples were collected from all three sites of Muzi, Karugenge and Karumuna and then transported in plastic bottles for laboratory analysis. Some water quality parameters like pH and EC were measured in situ while others were analyzed via analytical methods. Water samples were collected in February and April during the year of 2020 and the activity started 8:00 AM. The samples collected were kept in containers that were thoroughly washed to avoid any contamination. One litre of the water collected from Bugesera lakes in the river was first pickled with 1.5 ml of rigorous HNO_3. In addition, 50 ml of the solution was relocated to an evaporating system and removed 20 ml. Then 10 ml containing 8 moles of Nitric acid (HNO_3) concentrated at 98% purity was added to catalyze the reaction and evaporation rate. It was then refrigerated and deionized with distilled water of 50 ml added and then the final solution was filtered. The process was repeated for whole heavy metals detection. The filtrate was quantitatively transferred to a 100 ml volumetric flask with two portions of 5 ml of deionized distilled water. The solution was diluted and mixed thoroughly by shaking. The heavy metals under study were thereafter determined using Atomic Absorption Spectrophotometer (AAS) machine as prescribed in the research conducted by (Chiroma et al., 2014). The photometry methods was also used to obtain the concentration of Ca, Mg, Na and K in the water.

2.5. Analytical methods

2.5.1. Statistical methods

Rudimentary statistics of the raw data were calculated in STATA 13.0. Pearson correlation analysis was performed to assess heavy metals and water quality parameters elementals' associations and evaluated at 5% level of probability. Principal component analysis (PCA) was used to explore associations and identify origins of heavy metal elements. It is based on Eigenvalue analysis of the covariance. According to classification made by Shrestha et al., (2007), Eigen values of 1.0 or greater are considered significant classification of factor loading, thus "strong when $r>0.75$", "moderate when r is between 0.75-0.50" and "weak when r is between 0.50-0.30 respectively (Liu et al., 2003).

2.5.2. Geostatistical methods

Arc GIS 10.5 the geostatistical analysis tools were used for interpolation of point based distribution of measured heavy metals and water quality to the full study areas. The Kriging Interpolation methods was adopted to spatially represent the pattern of heavy metals and water quality in the Upper Akagera Catchment. Spatial prediction to assess the variability of parameters implies the process of estimation of a target quantity's values at un-sampled locations. Ordinary Kriging (OK) interpolation is the geostatistical method employed for the spatial distribution of heavy metals' concentration and water quality analysis. It entails the superior method for the estimation of interpolation weights and can provide error information for the creation of the thematic maps. The following formula was used to estimate the Ordinary Kriging (OK):

$$\hat{Z}(S_0) = \sum_{i=1}^{N} \beta_i Z(S_i) \qquad (1)$$

Where $\hat{Z}(S_0)$ represents the interpolated or predicted value for S_0 point, and β_i is the value for the equivalent weight of the $Z(S_i)$ values, while $Z(S_i)$ indicates the known value to satisfy the condition and $\sum_{i=1}^{N} \beta_i = 1$.

3. Results

3.1. Source of heavy metals

The sources of pollution for these wetlands could be due to the release of partially-treated wastewater effluents from Thohoyandou wastewater treatment plant, runoffs from agricultural soil, landfill sites very close to the river and other non-point sources, like atmospheric deposition. Other relative sources are the discharge of sewage water from Hotel La Pallisse Bugesera and the presence of car wash bus station at Nyamata. The layout's map indicating how they channeled and reached in the selected agricultural wetlands (Heavy metals transport process at catchment level) is shown in figure 5 to indicate the layout of sampled points of the selected sites (Karumuna, Muzi and Karugenge).

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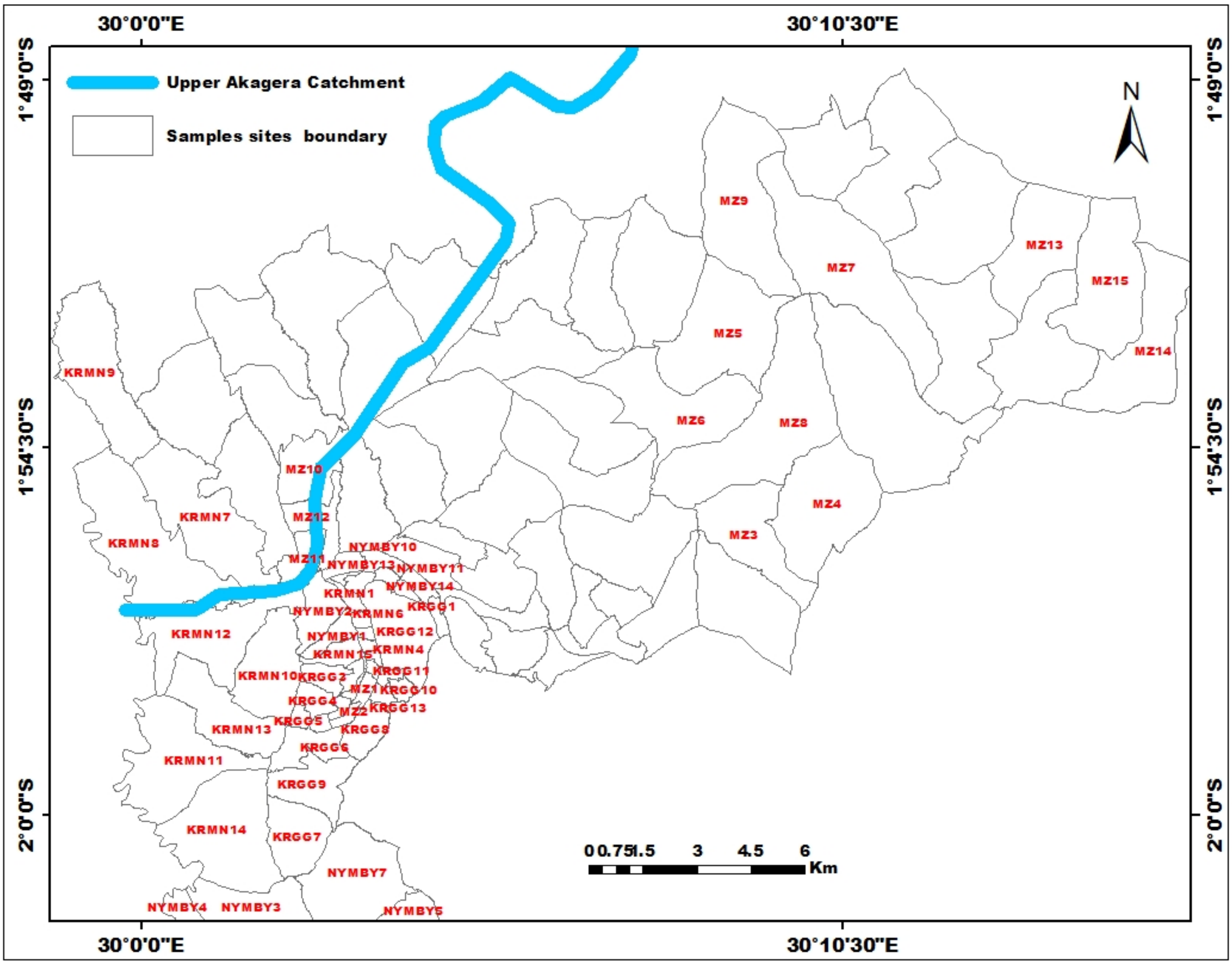

Figure 5: Main sources of heavy metals in the selected Bugesera agricultural wetland

3.2. Basic statistics of the sampled heavy metals

The main drive of this objective is to determine levels of heavy metals present in Bugesera Agricultural wetlands. The heavy metals determined in the irrigation water are Ca, Mg, Na, K, Cu, Zn, Mn, Pb, Cd and Cr which are important parameters during the heavy metals' assessment. The presentation and discussion of heavy metals was performed types of detected heavy metals expressed in ppm (parts per millions) are indicated in table 3. The basic statistical parameters and the measured concentrations of heavy metals in the samples are shown in Table 3. The mean of heavy metals in surface water were as follow: 13.016±9.995 ppm for Ca; 16.014±6.670 ppm for Mg; 7.246±3.597 ppm for Na; 14.781±6.813 ppm for K; 7.493±46.731 ppm for Cu; 0.720±0.183 ppm for Zn; 124.780±43.358 ppm for Mn; 0.821±0.426 ppm for Pb; 0.423±0.284 ppm for Cd and 1.713±1.252 ppm for Cr respectively. Overall, based on FAO sequence of heavy metals in descending order, the research findings showed Bugesera Agricultural wetland has heavy metals ordered as follow: Mn>Mg>Ca>K>Na>Cr>Pb>Zn>Cu>Cd respectively in descending order of concentration 156.534

ppm to 0.744 ppm for Manganese (Mn) to Cadmium (Cd). This classification differs from the heavy metals order done by Kaboosi et al., (2018) and Huong et al., (2008) which confirmed that heavy metals in surface water either for fresh water or waste water is showed as Cd < Ni < Pb < Cr respectively. For example, all sites with higher Cr concentration were artificial wetlands. The excessive Mn may not only be caused by the human disturbance but also by natural factors such as decreased runoff from the Bugesera rivers and the plants in juvenile stage (Bertin et al., 2015). Compared to the background values of heavy metals permissible standards developed by FAO, the actual heavy metals available in surface water from Bugesera Agricultural wetlands were 22.524 ppm for Ca, 23.006 ppm for Mg, 19.290 ppm for K, 0.746 ppm for Cu, 0.863 ppm for Zn, 156.534 ppm for Mn, 1.216 ppm for Pb, 0.744 ppm for Cd, 3.202 ppm for Cr and only 7.654 ppm for Na is within permissible limits for irrigation water.

Table 3: Concentration of heavy metals in selected three sampling locations

Sites	Stats (ppm)	Ca	Mg	Na	K	Cu	Zn	Mn	Pb	Cd	Cr
Karugenge	Mean	10.445	12.262	8.782	13.058	21.175	0.691	122.826	0.834	0.460	1.274
	SE(mean)	2.498	1.300	0.515	0.832	20.916	0.044	12.292	0.072	0.064	0.285
	SD	9.674	5.036	1.996	3.222	81.008	0.170	47.607	0.279	0.248	1.103
	Min	1.360	6.580	5.380	9.360	0.050	0.321	86.370	0.242	0.118	0.147
	Max	30.920	23.741	12.117	21.131	314.000	0.935	278.784	1.321	0.883	4.226
	CV	0.926	0.411	0.227	0.247	3.826	0.245	0.388	0.335	0.538	0.866
	N	15	15	15	15	15	15	15	15	15	15
Karumuna	Mean	8.589	15.432	3.098	13.331	0.459	0.715	133.918	0.976	0.488	1.322
	SE(mean)	2.348	1.906	0.533	2.220	0.072	0.058	13.969	0.037	0.071	0.221
	SD	9.095	7.382	2.063	8.599	0.278	0.223	54.103	0.144	0.276	0.855
	Min	1.170	5.670	0.980	6.110	0.124	0.286	86.550	0.746	0.092	0.847
	Max	36.190	32.420	8.140	34.185	0.941	0.987	257.614	1.352	0.954	4.236
	CV	1.059	0.478	0.666	0.645	0.606	0.312	0.404	0.148	0.567	0.647
	N	15	15	15	15	15	15	15	15	15	15
Muzi	Mean	20.015	20.349	9.859	17.954	0.845	0.755	117.596	0.652	0.321	2.541
	SE(mean)	1.951	1.275	0.526	1.739	0.032	0.041	6.142	0.166	0.081	0.353
	SD	7.557	4.937	2.036	6.734	0.124	0.158	23.788	0.643	0.314	1.367
	Min	2.110	9.170	5.583	8.370	0.586	0.417	95.320	0.106	0.040	0.645
	Max	27.240	30.160	12.940	31.393	0.996	0.945	196.750	1.854	0.971	4.628
	CV	0.378	0.243	0.206	0.375	0.146	0.209	0.202	0.987	0.980	0.538
	N	15	15	15	15	15	15	15	15	15	15
Overall average	Mean	13.016	16.014	7.246	14.781	7.493	0.720	124.780	0.821	0.423	1.713
	SE(mean)	1.490	0.994	0.536	1.016	6.966	0.027	6.463	0.063	0.042	0.187
	SD	9.995	6.670	3.597	6.813	46.731	0.183	43.358	0.426	0.284	1.252
	Min	1.170	5.670	0.980	6.110	0.050	0.286	86.370	0.106	0.040	0.147
	Max	36.190	32.420	12.940	34.185	314.000	0.987	278.784	1.854	0.971	4.628
	CV	0.768	0.416	0.496	0.461	6.237	0.254	0.347	0.519	0.672	0.731
	N	45	45	45	45	45	45	45	45	45	45

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3.2.1. Geostatistical prediction maps of heavy metals in surface water

The geostatistical prediction maps (Fig.6a) of heavy metals show the spatially distributed concentrations of heavy metals in the Bugesera agricultural wetland with surface drainage outlets from Upper Akagera Catchment. Referring to Fig.1a, the ranges for Ca, Mg, Na, K, Cu, Zn, Mn, Pb, Cd and Cr concentration were 3.9–23; 10–22; 2–11; 10.6 –20.6; -7– 210; 0.63– 0.81; 110–160; 0.37–12; 0.15– 0.78; and 0.23–4.4ppm respectively. The mean of Mn concentration (124.780±43.358) was the highest one in ten heavy metals detected in the sample waters collected from Bugesera agricultural wetland due to industrial effluent, sewage and landfill leachate that contributed to local groundwater recharge in the wetlands. Thus these findings are coherent to those previously reported studies (Xie et al., 2016) and (Dai et al., 2018). The geostatistical prediction maps (Fig. 6a) illustrate clearly the patterns of the heavy metals' accumulation and distribution, where red color stands for high concentration values while blue color signifies low concentration in the wetland. It is clear that that high content of Ca, Mg, Na occurred in the North-East; K, Zn , Cr in North, Cu in South, Mn in West while Pb in North- West section of the wetland section of the Bugesera agricultural wetland. Compared to the results in table 4, all the surface water sample concentrations of Ca, Mg and Na (mean concentration is 13.016±9.995; 16.014±6.670 and 7.246±3.597 ppm); the content of K, Zn, Cr (mean concentration is 14.781±6.813 ppm; 0.720±0.183 ppm and 1.713±1.252 ppm); the concentration of Cu (with mean concentration of 7.493±46.731 ppm) were highly concentrated in the wetland. There are also mean concentration of 124.780±43.358 ppm for Mn and 0.821±0.426 ppm for Pb which were higher in the Bugesera Agricultural Wetland, which indicates significantly frequent antagonistic biological effects on several farmed crops in the area. Referring to study background and FAO & RSB standards of heavy metals in irrigation water quality, all the heavy metals are out of permissible limits and there is a need of water treatment for proper use.

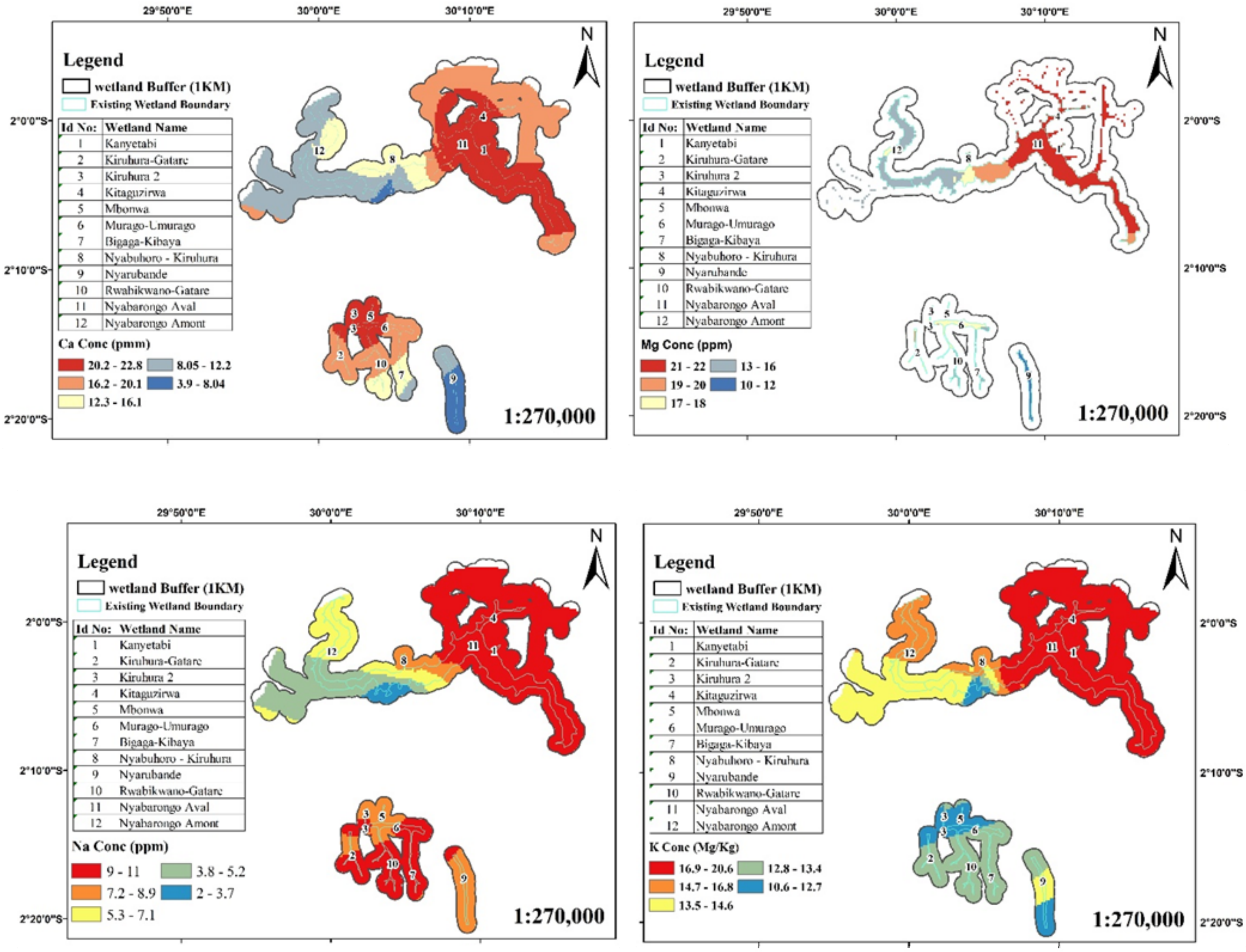

Figure 6.a: Spatial distribution of heavy metals in Karumuna, Muzi and Karugenge wetlands

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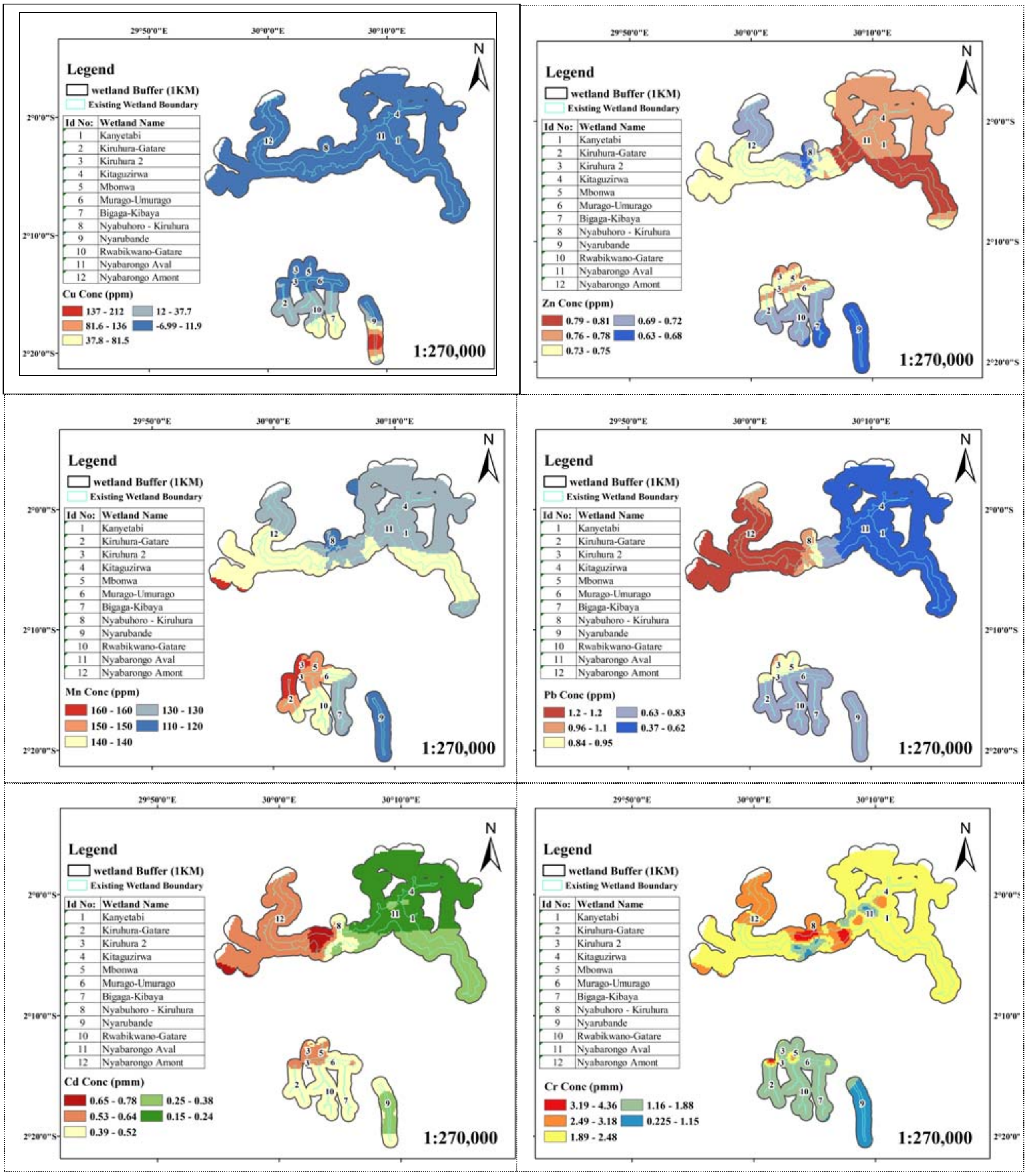

Figure 6.b: Spatial distribution of heavy metals in Karumuna, Muzi and Karugenge wetlands

3.3. Basic statistics of water quality analysis

The objective of this theme is to evaluate the suitability of the irrigation water quality of the Bugesera Water Rivers draining to wetland. The basic parameters to be discussed in water quality are pH, EC, TDS, TH, SAR, MAR, KR and SSP (table 4). The mean concentration in surface water were as follow: 7.309±0.684 for pH; 243.811±87.3µS/cm for EC; 165.402±59.224 ppm for TDS; 98.449±47.539 ppm for TH; 71.181±34.858% for SAR; 60.266±16.781% for MAR; 30.246±19.691% for KR; 44.958±11.596% for SSP respectively. According to Ayers et al., (1994) in FAO and RSB guidelines for irrigation water quality, the surface water quality used for irrigation in moderately out of permissible limits.

Table 4: Basic statistics of water quality analysis

Sites	Stats (ppm)	pH	EC	TDS	TH	SAR	MAR	KR	SSP
Karugenge	Mean	7.044	272.683	184.988	76.576	99.587	60.086	47.808	52.361
	SE(mean)	0.143	22.786	15.458	11.157	6.380	3.884	5.033	2.958
	SD	0.554	88.249	59.868	43.209	24.709	15.043	19.494	11.456
	Min	6.146	150.180	101.882	35.037	61.181	38.036	17.322	27.456
	Max	7.816	421.200	285.742	171.290	149.258	91.288	85.451	72.146
	CV	0.079	0.324	0.324	0.564	0.248	0.250	0.408	0.219
	N	15	15	15	15	15	15	15	15
Karumuna	Mean	7.513	252.047	170.989	84.995	35.481	68.883	17.587	41.444
	SE(mean)	0.233	25.376	17.215	12.478	6.850	4.429	4.273	2.939
	SD	0.901	98.282	66.674	48.327	26.530	17.153	16.550	11.381
	Min	4.964	130.400	88.463	31.290	8.356	39.511	2.850	26.493
	Max	8.543	501.333	340.104	223.872	103.984	93.469	53.133	66.040
	CV	0.120	0.390	0.390	0.569	0.748	0.249	0.941	0.275
	N	15	15	15	15	15	15	15	15
Muzi	Mean	7.371	206.704	140.228	133.775	78.474	51.829	25.342	41.071
	SE(mean)	0.123	16.460	11.167	7.557	3.807	3.729	1.566	2.217
	SD	0.477	63.751	43.249	29.266	14.743	14.444	6.065	8.586
	Min	6.553	49.500	33.581	88.152	41.316	31.244	12.230	26.561
	Max	8.214	260.810	176.934	187.523	104.731	91.677	34.037	56.207
	CV	0.065	0.308	0.308	0.219	0.188	0.279	0.239	0.209
	N	15	15	15	15	15	15	15	15
Overall average	Mean	7.309	243.811	165.402	98.449	71.181	60.266	30.246	44.958
	SE(mean)	0.102	13.014	8.829	7.087	5.196	2.502	2.935	1.729
	SD	0.684	87.300	59.224	47.539	34.858	16.781	19.691	11.596

Sites	Stats (ppm)	pH	EC	TDS	TH	SAR	MAR	KR	SSP
	Min	4.964	49.500	33.581	31.290	8.356	31.244	2.850	26.493
	Max	8.543	501.333	340.104	223.872	149.258	93.469	85.451	72.146
	CV	0.094	0.358	0.358	0.483	0.490	0.278	0.651	0.258
	N	45	45	45	45	45	45	45	45

3.2.1. Statistics of geostatistical prediction maps of water quality analysis

The geostatistical prediction maps (Fig.6b) of water quality analysis for irrigation show the spatially distributed concentrations water quality parameters in the Bugesera agricultural wetland with surface drainage outlets from Upper Akagera Catchment. Referring to Fig. 1b, the ranges for pH, EC, TDS, TH, SAR, MAR, KR and SSP concentration were 7–7.8; 190–300; 130–200; 55 –150; 26– 110; 47–73; 8.2–72 and 35–60 respectively. All units of SAR, MAR, KR and SSP are percentage except pH (Unitless), EC (µS/cm), TDS (ppm) and TH (ppm). Except the mean concentration of MAR with 60.266±16.781% that outweighed the permissible limit of 50% in water for irrigation, other parameters are good to be used for irrigation (Table 5 and Fig 6b). The geostatistical prediction maps (Fig. 6b) illustrate clearly the patterns of pH, EC, TDS, TH, SAR, MAR, KR and SSP accumulations and distribution, where red color stands for high concentration values while blue color signifies low concentration in the wetland. Obviously, the higher concentration of pH and MAR accrued in North-west; EC and TDS from Central-East; TH found in North-East while SAR, KR and SSP accrued highly in South-East sections of the Bugesera Agricultural Wetlands. Based on findings from table 4, all the surface water sample concentrations of pH and MAR (mean concentration is 7.309±0.684 and 60.266±16.781%); the content of EC and TDS (mean concentration is 243.811±87.3 µS/cm and 165.402±59.224 ppm); the concentration of TH (with mean concentration of 98.449±47.539 ppm); SAR, KR and SSP (with mean concentration of 71.181±34.858%, 30.246±19.691% and 44.958±11.596%) were highly concentrated in the wetland (Note: 1dS/m= 1000 µS/cm).

Table 5: Suitability of irrigation water in Bugesera agricultural wetland

Parameters	Conditions	Suitability	Citation
pH	6.5-8.4	Suitable for irrigation	Tak et al. (2012)
EC (dS/m)	<0.7	Good for Irrigation	Westcot et al. (1985)
	0.7-3.0	Slightly to moderate for irrigation	
	>3.0	Restricted (Not useful for irrigation)	
TDS	< 450	Preferred for irrigation	Rawat et al. (2018)
	450-2000	Slightly moderate for irrigation	
	>2000	Unsuitable for irrigation	
TH	0-60	Soft water, fit for irrigation	Rawat, Singh, and Gautam (2018)
	60-120	Moderately hard water to fit for irrigation	
	120-180	Hard water, not fit for irrigation	
	>180	Very hard water, Unsuitable for irrigation	
SAR	<10	Ideal or Excellent water for irrigation	Westcot et al. (1985)
	10 to 18	Good for irrigation	
	18 to 26	Doubtful for irrigation	
	> 26	Unsuitable for irrigation	
MAR	<50	Recommended for irrigation	Rawat et al. (2018)
KR or KI	<1	Recommended for irrigation	Rawat et al. (2018)
SSP	<60	Recommended for irrigation	Rawat et al. (2018)

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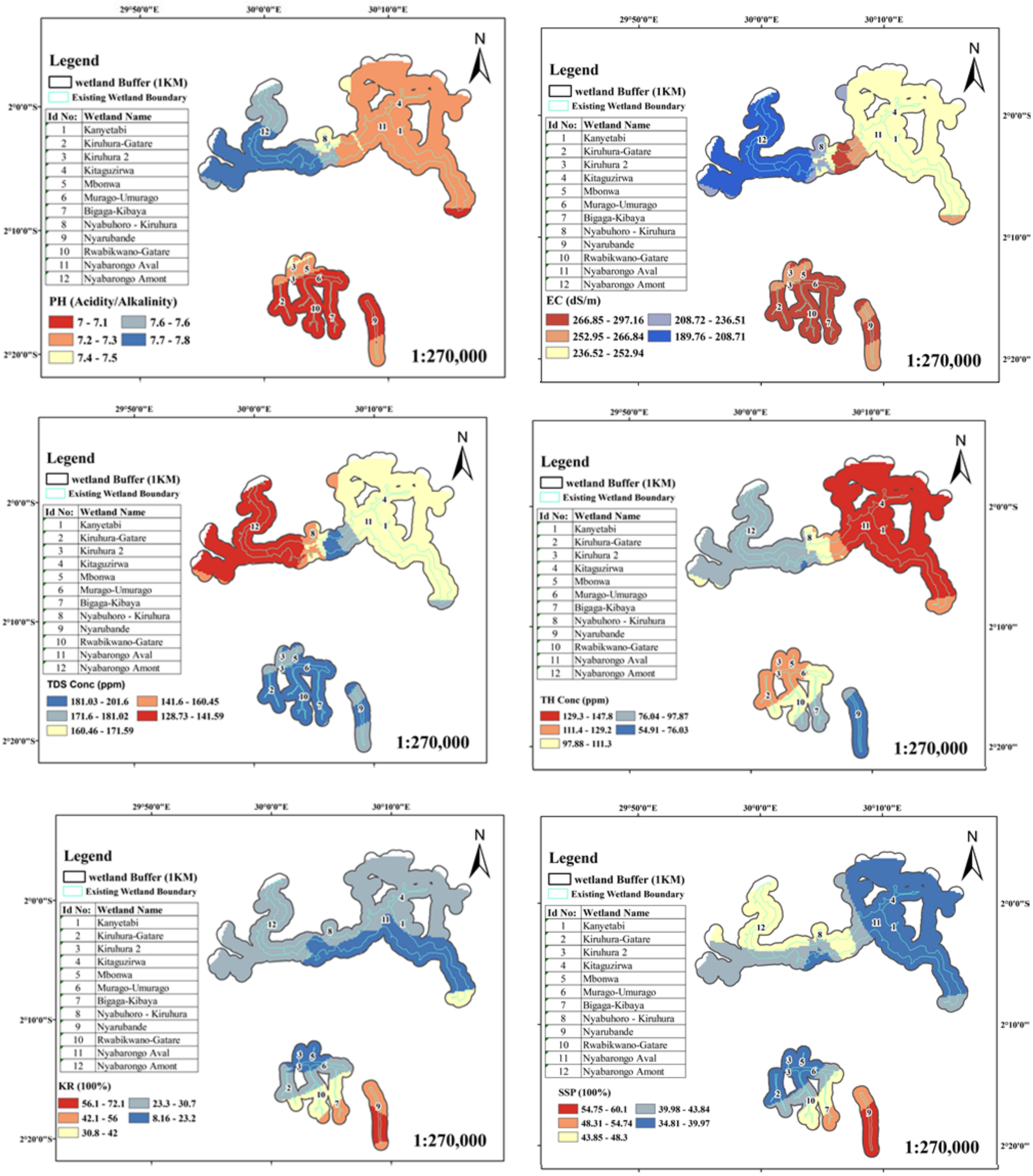

Figure 7: Spatial distribution of water quality analysis for irrigation of Bugesera Agricultural wetland

3.4. Principal component analysis for heavy metals and water quality parameters

Raw data of heavy metals and other water quality parameters were analysed with Principal Component Analysis in Table 6. The principal components are produced in a consecutively well-ordered routine with diminishing charities to the variance, i.e. the first principal component clarifies the greatest of the deviations existing in the original data, and continual principal components account for lessening magnitudes of the variance. After rotation, each variable will only be connected to one of the loading factors and each factor, to be discussed here, will have high correlation and weak correlation for one component with only a small set of variables. This method is suitable for classification of groundwater quality which is why it was adopted as a technical model for water quality evaluation. In this case, according to classification made by Shrestha et al. (2007); Eigenvalues of 1.0 or greater are statistically significant of factor loading identified. If correlation coefficient 'r' < 0.50 then the correlation relationship between variable is weak and if r is between 0.50 to 0.75 then there was moderate relationship among variables else if $r > 0.75$ then there will be strong relationship among variables (Liu et al., 2003). The results for Correlation matrix and Principal Component Analysis combining heavy metals and water quality parameters are shown in the table 2 and table 4. Table 3 shows the correlation matrix for the analyzed heavy metals and water parameters. High positive and/ or negative correlations (above 0.8) were observed between Ca and TH (r=0.897), Ca and MAR (-0.805) and moderate positive and/ or negative correlation between Ca and Mg (-0.600) respectively which are statistically significant at $p<0.001$. It is obviously found that Mg and TH had very high positive correlation (r=0.916) while Na and SAR had a very high positive correlation (r=0.806). In addition, there is also a high positive correlation between SAR and KR (r=0.887) as well as KR and SSP (r=0.817). It is an implication that higher content of Ca, Mg and Na water content will affect the Sodicity, Magnesium hazards, Total dissolved solids, total hardness, Kelly index and the soluble sodium percent which are very important determinants of water quality for irrigation. Correlations matrix indicated that there are no strong association between heavy metals and major water quality parameters, rather there are moderately and weak associated. This may indicate the dissociation of these elements in the agricultural wetland of the area.

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Table 6: Correlation matrix for the analyzed parameters

	Ca	Mg	Na	K	Cu	Zn	Mn	Pb	Cd	Cr	pH	EC	TDS	TH	SAR	MAR	KR	SSP
Ca	1																	
Mg	**0.644**	1																
Na	0.470	0.238	1															
K	0.367	0.493	0.230	1														
Cu	-0.146	-0.211	0.049	0.051	1													
Zn	0.295	0.265	-0.018	0.200	-0.061	1												
Mn	0.233	0.380	-0.152	0.192	-0.042	0.334	1											
Pb	-0.009	-0.121	-0.230	0.054	-0.180	-0.077	0.207	1										
Cd	0.245	0.029	-0.073	0.081	-0.127	0.125	0.274	0.624	1									
Cr	0.537	0.467	0.336	0.358	-0.106	0.329	0.354	0.113	0.222	1								
pH	-0.140	-0.185	-0.257	-0.410	-0.184	0.001	-0.162	-0.032	0.024	-0.309	1							
EC	0.013	0.232	0.053	0.190	0.077	0.029	0.225	-0.138	-0.072	0.025	-0.641	1						
TDS	0.013	0.232	0.053	0.190	0.077	0.029	0.225	-0.138	-0.072	0.025	-0.641	1.000	1					
TH	**0.897**	**0.916**	0.384	0.478	-0.199	0.308	0.342	-0.075	0.146	0.551	-0.180	0.141	0.141	1				
SAR	-0.057	-0.265	**0.806**	0.010	0.272	-0.214	-0.283	-0.184	-0.132	-0.023	-0.203	0.013	0.013	-0.183	1			
MAR	**-0.805**	-0.148	-0.424	-0.198	0.063	-0.228	-0.060	-0.080	-0.246	-0.389	0.040	0.131	0.131	-0.508	-0.092	1		
KR	-0.420	-0.566	0.448	-0.159	0.425	-0.309	-0.294	-0.105	-0.127	-0.288	-0.113	-0.020	-0.020	-0.547	**0.887**	0.179	1	
SSP	**-0.600**	-0.585	0.149	0.174	0.354	-0.307	-0.304	-0.014	-0.103	-0.307	-0.183	0.012	0.012	**-0.653**	**0.619**	0.363	**0.817**	1

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Table 7: Principal Components Analysis of heavy metals and water quality parameters analyzed

Components/ Factors												
Variable	1	2	3	4	5	6	7	8	9	10	11	12
Ca	0.859	0.197	-0.383	-0.028	-0.158	-0.123	-0.112	0.120	0.040	-0.027	0.102	0.010
Mg	0.844	0.134	0.112	-0.238	0.282	0.234	0.182	0.189	0.028	-0.015	-0.027	-0.009
Na	0.162	0.767	-0.538	-0.151	-0.106	0.221	0.055	-0.049	-0.034	0.108	-0.030	-0.011
K	0.445	0.417	0.056	0.274	0.643	-0.036	-0.294	-0.033	0.099	-0.004	-0.056	0.006
Cu	-0.290	0.328	0.029	0.021	0.143	-0.591	0.210	0.281	-0.085	0.068	-0.025	0.000
Zn	0.406	-0.058	0.006	0.030	0.066	-0.219	0.183	-0.316	0.177	0.060	0.004	0.004
Mn	0.446	-0.041	0.248	0.277	0.024	-0.081	0.370	-0.099	0.096	-0.107	-0.011	-0.003
Pb	0.068	-0.252	-0.029	0.730	-0.104	0.189	-0.017	0.136	-0.089	-0.016	-0.046	0.001
Cd	0.247	-0.152	-0.116	0.669	-0.173	0.081	0.092	0.125	0.127	0.102	0.025	0.001
Cr	0.599	0.194	-0.158	0.199	0.067	-0.010	0.188	-0.247	-0.238	0.025	0.025	-0.003
pH	-0.185	-0.616	-0.374	-0.212	0.008	0.039	0.066	0.048	0.284	0.047	-0.023	-0.003
EC	0.181	0.531	0.776	-0.015	-0.276	0.013	-0.064	0.004	0.082	0.023	-0.006	-0.001
TDS	0.181	0.531	0.776	-0.015	-0.276	0.013	-0.064	0.004	0.082	0.023	-0.006	-0.001
TH	0.939	0.181	-0.136	-0.152	0.080	0.071	0.046	0.172	0.037	-0.023	0.038	0.000
SAR	-0.412	0.764	-0.440	-0.009	-0.097	0.147	0.130	-0.025	0.049	-0.024	-0.042	0.022
MAR	-0.531	-0.156	0.539	-0.127	0.334	0.315	0.290	0.068	-0.050	0.058	0.055	0.012
KR	-0.735	0.573	-0.255	0.109	-0.060	0.004	0.185	0.062	0.103	-0.102	0.012	-0.009
SSP	-0.756	0.451	-0.016	0.289	0.316	0.023	-0.115	-0.051	0.080	0.011	0.098	-0.010
Eigenvalue, difference, proportion and cumulative based on Factor analysis/correlation												
Eigenvalue	***5.482***	***3.954***	***2.649***	***1.778***	***1.241***	0.964	0.803	0.636	0.302	0.135	0.057	
Difference	1.528	1.305	0.871	0.536	0.278	0.160	0.167	0.334	0.167	0.079	0.057	
Proportion	0.305	0.220	0.147	0.099	0.069	0.054	0.045	0.035	0.017	0.008	0.003	
Cumulative	0.305	0.524	0.671	0.770	**0.839**	0.893	0.937	0.973	0.989	0.997	1	

Based on PCA, the findings showed five components PC for Ca, PC for Mg, PC for Na, PC for K and PC for Cu accounted for the cumulative value of 0.839 in table 7, which is 83.9% of the total variance of original data set after transformation into factor analysis with Eigenvalues greater than one were statistically significant correlated with other factors from the same clusters. Table 5 shows the principal component analysis application to describe the dispersion of original parameters which implies a five components model, explaining 83.9% of total variance, thinned in eighteen dimensions. This result is in agreement with the works of Helena et al.,(2000) and Simeonov et al. (2003) in which the two to three first generated components explain a great part of the variation of original data (60% to 90%). Table 7

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presents principal components for the heavy metals and water quality parameters in surface water in Bugesera Agricultural wetlands. A matrix rotation was performed and data for components and communalities after transformation are presented in table 7. The first component explains 30.5% of total variance in the data, whereas the second and third factors explain 22.0% and 14.7% respectively. The fourth component accounted 9.9% while the fifth component accounted 6.9% of the total variance. In the first Factor/Component, parameters such as Ca, Mg and TH present a load above 0.80 which indicating the most common composition of the observed parameters in the water for irrigation. It increases with increasing of Ca (0.859), Mg (0.844) and TH (0.939). In the second Factor/Component, parameters Na, SAR show high factor load of above 0.75 and 0.53 respectively to indicate the second and moderate factors for suitability of water. The third factor, parameters like EC and TDS showed higher factorial load of 0.776 while fourth Factor/Component showed Pb and Cd as the element with the load (0.730 and 66.7). The fifth factor displayed K as the components that has the significant load of 0.643 respectively.

3.5. Discussion of results

From a small number of sample data points, interpolation predicts values for cells in a raster. It can be used to forecast unknown values for any type of geographic point data, including elevation, rainfall, chemical concentrations, and soil physical properties. The prediction maps from geospatial analysis of heavy metals indicated that Mn is highly concentrated among the three sites compared to other heavy metals. The mean of Mn concentration (124.780±43.358) was the highest one in ten heavy metals detected in the sample waters collected from Bugesera agricultural wetland due to industrial effluent, sewage and landfill leachate that contributed to local groundwater recharge in the wetlands. It was found that except the mean concentration of MAR with 60.266±16.781% that outweighed the permissible limit of 50% in water for irrigation, other parameters are good to be used for irrigation. The fact that Mn contentment is very higher compared to other trace metals, It is not statistically significant correlated to other heavy metals and differ significantly ($p > 0.01$) with their levels in the river water. They are often not considered to have adverse effects on marine organisms, hence their exclusion from the SQGs (Sediment quality guidelines) (Long et al., 1995). It is an implication that waters from Bugesera agricultural wetlands are polluted by some heavy metals and it needs water treatment before irrigation purposes. For irrigation purposes and domestic use, heavy metals and water quality parameters of all water samples should comply with the guidelines of the Department of Water Affairs and Forestry (DWAF) of South Africa and the World Health Organization (WHO) as prescribed by Edokpayi et al, (2016). It is therefore concluded the prediction maps of heavy metals' concentrations of Cu, Zn, Mn, Pb, Cd and Cr in the water samples exceeded the recommended guidelines of DWAF and WHO for domestic

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water use. Generally, the concentrations of Cu, Zn, Mn, Pb, Cd and Cr in the selected surface water sediments exceeded the corresponding Effect Range Low (ERL) values in the sediment quality guidelines and could have adverse effects on aquatic organisms in selected three Bugesera agricultural wetlands. After Mn, the Cd and Pb contents were almost higher as result of anthropogenic activities near the Bugesera rivers' bank. Additionally, the availability of Pb in Bugesera Agricultural wetlands mainly from "Munguiti" wetland is associated with anthropogenic sources, fertilizers and pesticides, discharge of domestic and industrial water around the wetland transported by run off to downstream that form temporal flooding status in that catchment and thus, once human beings consume the water or fauna from these wetlands, the Pb can be harmful to human health. Based on the surface water environment quality standards of China and referring to FAO and RSB standards for water quality use in Irrigation, the five components PC for Ca, PC for Mg, PC for Na, PC for K and PC for Cu accounted for the cumulative value of 0.839. Those elements are major source of pollutants in the surface water of the agricultural wetland. Thus these findings also are supported by the research done by Khadse et al. (2008) and who confirmed that temporal and spatial variability in the Kanhan river water quality may be attributed to catchment characteristics, agricultural and urban activities in catchment and on the bank of the river. In addition, heavy metals' concentrations displayed distinct variation and these were Ca, Mg, Na, K and Cu with higher Eigen value greater than one while the remained of Zn, Mn, Pb, Cd and Cr were recorded with weak concentration in surface water sediment. It means that the water from Bugesera Agricultural wetland may be used in irrigation purposes effectively and efficiently after water treatment. This higher pollution is especially due to wastewater discharge from industry located by near the river and the overuse of pesticides and inorganic fertilizers. Thus these findings agree with the research conducted by Varol (2011) and Kumar et al., (2016) who confirmed similar findings of water quality. Hence these findings are statistically coherent with the research findings of Morabito et al. (2018) and Bertin and Averbeck (2006) who similarly found that when humans and other fauna ingest water with higher Pb and Cd, they are harmfully contaminated and may get stunted.

4. Conclusion and recommendations

The average concentration of heavy metals in Bugesera Agricultural wetland decreased in the following order Mn>Mg>Ca>K>Na>Cr>Pb>Zn>Cu>Cd. The concentrations of Mn was the highest determined in all three sampled Bugesera Agricultural Wetlands of the Upper Akagera Catchment and this may be related to their relative abundance in the Earth's crust. The pollution for this river is linked to the release of partially-treated wastewater effluents from Bugesera Water Treatment plant which is located in

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Bugesera Industrial park zone, in Kanzenze cell through runoffs from the agricultural soil, landfill sites closed to river and other anthropogenic sources around the wetland. The Cd, Cr, Pb, Zn, Mn and Cu concentrations in the surface water quality could possibly lead to the toxic effects on aquatic organisms in the river, while the concentrations of Pb and Zn are not likely to pose any adverse effects on them. The levels of heavy metals like Cd, Cr, Pb, Zn and Cu in the Bugesera Agricultural wetland differ significantly from their levels in the Karumuna, Karugenge and Muzi wetlands except Mn which is the highest in the complexity. There is a huge need to apply water treatment of some rivers when using surface water for irrigation due to some heavy metals like Magnesium, Potassium, Zinc, Manganese, Cadmium and Chromium that fall out of the permissible range as prescribed in the FAO guidelines. It was found that agriculture crops and vegetables are mostly irrigated with polluted water from the Agricultural wetlands, which increase the level of toxicity effects that may have a harmful effect on humans. Instead, it should be used for non-food crops. We recommend that heavy metal contamination should be studied within the entire catchment and not just some rivers, because these metals affect water soil and crop quality and can cause ground-water pollution. It is also suggested that policy makers, implementers, donors and any funding agencies with various interests in water and natural resources management should take the advantage of scaling up the water treatment facilities for irrigational water in order to realize perfection of agricultural products, and therefore improving the living standards and reduced stunting of remote families surrounding Bugesera agricultural wetland of the Akagera Upper catchment. Further research is needed to assess the concentration of heavy metals in the groundwater, field crops, and their impact on human health in and around the catchment.

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Conflicts of interests

The authors declare that there are no conflicts of interest.

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