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Assessing the Impact of land-use types on the groundwater quality: a case study of Mid River Njoro Catchment, Kenya

Valutazione dell'impatto generato da diverse classi di uso del suolo sulla qualità delle acque sotterranee: il caso studio del medio bacino del fiume Njoro, Kenya

Halake Guyo Rendilicha, Patrick Home, James M. Raude, Charles M. M'Erimba, Stellamaris Muthoka, Jacqueline Wanjala

Riassunto: Il presente studio ha valutato l'impatto sulla qualità delle acque sotterranee di diversi tipi di uso del suolo nel medio bacino del fiume Njoro (Kenya). Campioni di acque sotterranee sono stati raccolti da 8 pozzi nel periodo compreso tra ottobre 2017 e febbraio 2018; in questi campioni sono stati analizzati pH, temperatura dell'acqua, conduttività elettrica, ossigeno disciolto, nitrati, ammonio e fosforo totale. Questi parametri sono stati usati per calcolare l'indice di qualità delle acque sotterranee (GQI) per l'area di studio. Le mappe di concentrazione ("mappe primarie I") sono state realizzate per i sette parametri di qualità delle acque sotterranee utilizzando un'interpolazione Kriging tramite il programma ArcGIS. Le "mappe primarie I" sono state standardizzate con i valori limite dell'OMS e del KEBS per realizzare le "mappe primarie II" al fine di facilitare l'integrazione in un ambiente SIT. Le "mappe primarie II" sono state successivamente valutate e pesate tramite una funzione polinomiale al fine di generare "mappe di rango" prima di calcolare il GQI, usando lo strumento "spatial analyst" di ArcGIS. La mappa di uso del suolo è stata generata da immagini satellitari ad alta risoluzione ottenute da Google Earth. Sono stati calcolati e confrontati tra loro, tramite tecniche SIT, i valori medi di GQI per i diversi poligoni a differente uso del suolo. I valori di GQI variano da 68.38 a 70.92, indicando una buona qualità delle risorse idriche sotterranee presenti nel medio bacino del fiume Njoro. Le principali classi di uso del suolo identificate includono insediamenti, foreste, terreni agricoli e aree miste. Le aree agricole dominano l'area di studio, seguite dagli insediamenti, dalle foreste e infine dalle aree miste. Il valore medio di GQI in ogni classe di uso del suolo varia di poco e questo può essere relazionato al fatto che queste sono distribuite in maniera diffusa nell'area di studio. Gli insediamenti hanno un basso GQI, seguiti dalle aree agricole e dalle aree miste; le foreste hanno il valore medio di GQI più alto, che corrisponde ad una buona qualità delle acque sotterranee. Anche se la variazione è insignificante in questo particolare caso studio, questa in qualche modo indica gli effetti negativi dei diversi usi del suolo sulla qualità delle acque sotterranee.

Keywords: *Groundwater, Groundwater Quality Index, Land use types, GIS.*

Parole chiave: Acque Sotterranee, Indice di Qualità delle Acque Sotterranee, Classi di Uso del Suolo, GIS.

Halake GUYO RENDILICHA ✉
Patrick HOME, James M. RAUDE
Department of Soil, Water and Environmental Engineering
Jomo Kenyatta University of Agriculture and Technology
P.O. BOX 62000-00200, Nairobi, Kenya. Tel: +254 710 953 283.
hguyo@jkuat.ac.ke; pghome@jkuat.ac.ke; ramesso@jkuat.ac.ke

Charles M. M'ERIMBA
Department of Biological Sciences, Egerton University
merimba2000@yahoo.com

Stellamaris MUTHOKA
Department of Human Nutrition, Egerton University
P. O. Box 536, 20115 Egerton, Kenya
smuthoka@egerton.ac.ke OR skaveni@yahoo.com

Jacqueline WANJALA
Ministry of Agriculture, Livestock and Fisheries
P.O. Box 34188 – 00100, Nairobi, Kenya

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Abstract: : *The study assessed the impact of land-use types on the groundwater quality of the mid River Njoro catchment, Kenya. Groundwater samples were collected from eight boreholes between the period of October 2017 to February 2018 and analyzed for pH, temperature, electrical conductivity, dissolved oxygen, nitrate, ammonium, and total phosphorus. These parameters were used to calculate the Groundwater Quality Index (GQI) value of the study area. The concentration maps ("primary maps I") were constructed using Kriging interpolation of ArcGIS software from the seven groundwater quality parameters. The "primary maps I" were standardized with the KEBS and WHO standards to the "primary maps II" for ease of integration into a GIS environment. The "primary maps II" were then rated and weighted using a polynomial function to generate "rank maps" before calculating the GQI using spatial analyst tools of ArcGIS software. The land use map was prepared from a high-resolution Google earth satellite imagery of 2015. The mean GQI values for the different land use polygons were calculated and compared using GIS techniques. The GQI ranged from 68.38 to 70.92, indicating a high groundwater quality of mid River Njoro catchment. The major land-use types identified include settlement area, forest cover, agricultural land and mixed area. The agricultural land dominated the study area, followed by settlement area, forest cover and finally mixed area. The mean GQI value in each land use type varied minimally and this could be because of the diffuse nature of the land use types of the study area. Settlement area had low GQI, followed by agricultural land, mixed area and the forest cover had the highest mean GQI value, which corresponds to good quality of groundwater. Even though the variation is insignificant in this particular study, it somehow indicates the adverse effects of different land use on the quality of groundwater.*

Introduction

Groundwater is the world's valuable and renewable natural source of fresh water. It contributes about 95% of the total freshwater resource found on our planet Earth (Foster et al. 2013; Kaur 2011). Sustainable development of this resource is the biggest challenges facing water resource managers worldwide (Foster et al. 2002; Goonetillike and Vithanage 2017). Naturally, the groundwater is free from artificial impurities, caused by human activities, because of the natural filtration processes occurring in the subsurface, which eliminates contaminants before it reaches groundwater aquifers (Karanth 1989; Balke and Zhu 2008).

However, when the decontamination capacity of the subsurface media is subdued by wastes generated over the years, then the groundwater becomes vulnerable to contaminations (Civita 2010; Obot and Edi 2012). Once the groundwater is contaminated, remedial measures and processes are too expensive and time-consuming to undertake in most of the developing countries (Agbaire and Oyibo 2009; Yin et al. 2013). Besides, polluted groundwater resource is a major impediment to the future economic growth as well as poses high risks to public health and environment (Pius et al. 2012). Hence, the best option is to prevent contaminants from reaching the groundwater system through frequent monitoring and quality assessments (Sanaa et al. 2016; Saleem et al. 2016).

Balancing human development with the sustainable use of groundwater is a major problem in the water sector. Over-abstractions, excessive use of fertilizers, improper wastes disposals and leakage from septic tanks have adversely affected groundwater quality and quantity (Wen et al. 2005; Gautam et al. 2015). Land use patterns, development trends and populations characteristics have also impacted negatively on the watershed and recharge health (Mishra et al. 2014). Therefore, it is very important to study the impact of land use and other human activities on the quality of groundwater every two to three years, to ensure clean and safe water are consumed by people.

There are several groundwater quality parameters to be studied to ascertain the safety of any drinking water. These parameters can be combined to generate a Groundwater Quality Index (GQI), which is used to describe the overall groundwater quality status of a given area. The GQI values help communicate groundwater quality status as wells as inform the groundwater quality programs and protection strategies (Singh et al. 2011).

The groundwater quality assessment has been made easier by the GIS technology and many researchers have applied it in generating solutions to water quality assessment problems (Ishaku et al. 2009; Yue et al. 2010; Khan et al. 2011; Khan et al. 2017). Geostatistical methods are one of the advanced techniques used for interpolation of groundwater quality data and provide a number of methods base, which are frequently used to estimate the value of a spatially measured variable at the unsampled locations. Kriging is one of the best and most widely-known techniques used in spatial linear predictions. This study, therefore, evaluates the GQI of Mid River Njoro catchment, Kenya, using a GIS-based approach. The study further assessed the impact of land-use types on the groundwater quality of the study area by comparing the mean GQI value in each land use type using the spatial analyst tools of ArcGIS software.

Study Area

Mid River Njoro catchment is located in Nakuru County, Kenya. It lies southwestern Rift valley and covers approximately 55.5 Km^2. The area stretches between latitudes 0° 30' S and 0° 18' S and longitudes 35° 46' E and 35° 55' E. The area experiences a trimodal precipitation pattern with long rains occurring from April to May, short rains occurring from November to December, and an additional small peak occurring in August. The rainfall ranges from 800mm to 1700mm and potential evaporation is in the ranges of 1200mm to 1500mm. Average annual minimum and maximum temperatures are 9° C and 24°C respectively (Sombroeck 1982). The location map of the study area is shown in Figure 1.

Land Use Patterns

Over the years the area has experienced drastic land-use changes from forest cover to an intensive agricultural field. Important centres such as Kenya Agricultural Research Institute (KARI), Njoro canning factories, Njoro town and Egerton University have been established in the mid-zone of the River Njoro catchment. The main economic activities in the study area are agricultural-based industries including vegetable and milk processing, large-scale wheat and barley farming. Light manufacturing industries such as timber milling and quarrying are also the mainstay of the economy (Olang et al. 2011).

Geological and Hydrogeological Characteristics

The area is covered by well-drained red volcanic soils (latosolic) and imperfectly drained loam soil covering volcanic rocks. Predominant rocks are agglomerates, sediments and phonolites on mountains; Pumice, ciders, basaltic tuffs and black ashes on hills; plateau and upland plains are alluvium, lacustrine and fluviatile derived from them (Sombroeck 1982). The geology of the study area comprises a succession of Miocene–Pleistocene volcanics, primarily phonolites, trachytes and basalts, with pyroclastics and intervening lacustrine beds being more widespread in occurrence during the Pleistocene (McCall 1967; Baker et al.1988). Much of the rift floor area is draped by Holocene pyroclastic, basalt flows, and volcanic soils (McCall 1967); grid faults that occur in this section of the rift (Baker 1986; Schlüter 1997; Woldegabriel et al. 2016) are masked by the superficial materials. As assessment of borehole geo-logs in the study areas indicate that the top brown soils and sediments are on the order of 10 m thick or more. Below them are lava flows of rhyolites, basalts, trachytes or phonolitic trachytes, with varying thicknesses,

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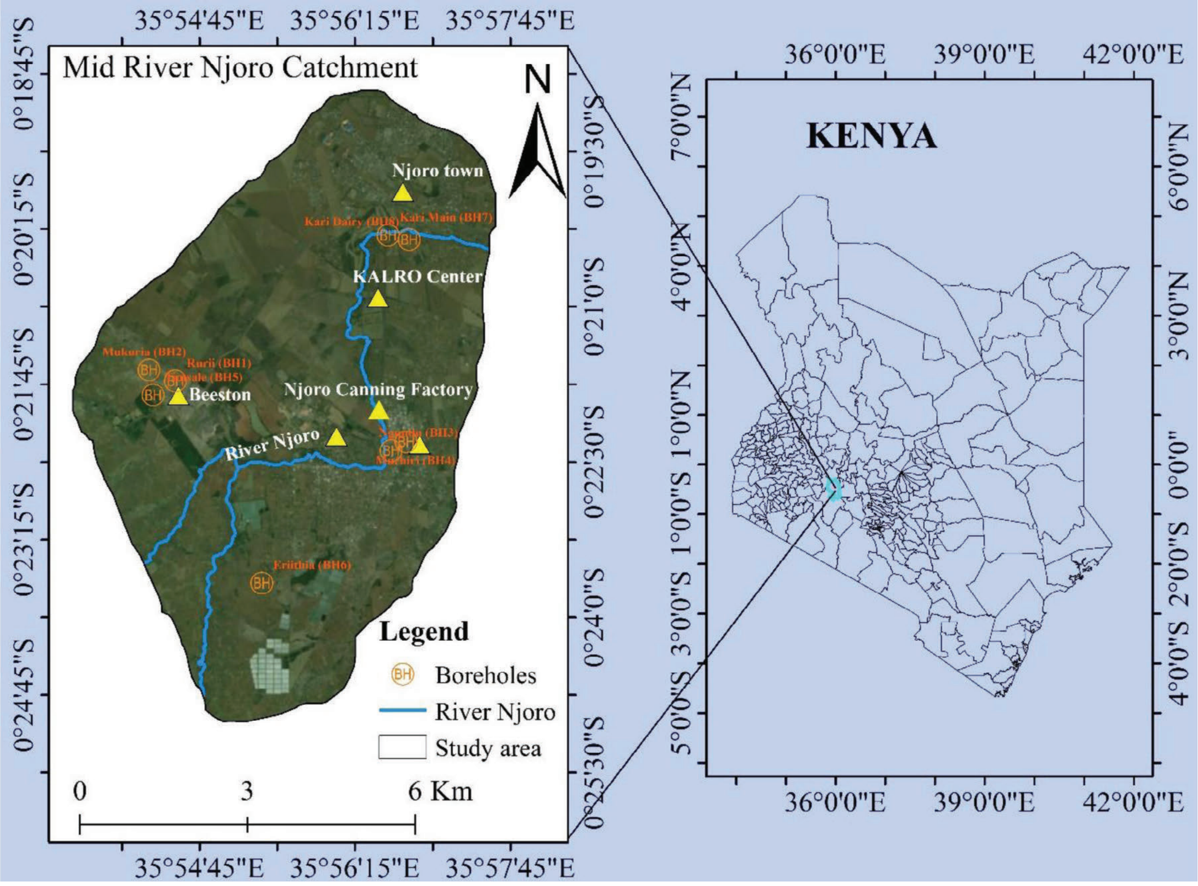

Fig. 1 - Location of study area.

Fig. 1 - Area di studio.

from thin (10 m or less) to thick (sometimes 30–40 m), that alternate with consolidated pyroclastic materials such as tuffs, agglomerates, ashes and their derivatives comprising loose tuffaceous sands or pumiceous gravels. These also comprise layers that are thin (5 m or less) to thick (>50 m). This series occurs up to depths exceeding 200 m (Mogaka 2010). The mid River Njoro catchment is within the bigger rift valley aquifer with the static water levels being shallower that the than depth at which water was initially struck suggesting the presence of confined shallow aquifers (Isaac K and Janet S 2013). The depth at which groundwater samples were collected ranged from 22 m to 126 m. Aquifer lithological studies identified three types of aquifer media; sediments (including volcaniclastics), trachyte and tuffs. Sediment units intercalated in the volcanic formation forming the main sources of groundwater.

Materials and Methods

Groundwater quality data

The present study used groundwater quality data collected between the period of October to February 2018 from eight boreholes found in the mid River Njoro catchment. A total of 168 groundwater samples were collected from 8 boreholes to analyzed for pH, temperature, electrical conductivity, dissolved oxygen, nitrate, ammonium, and total phosphorus. The pH, water temperature, EC and DO of the collected water samples were measured in situ by Hach HQ40D portable multimeter. Extra samples were carried in sampling bottles, preserved as prescribed in America Public Health Association manual (APHA-2320 1999) and taken to Egerton University laboratory to analyze nitrate, ammonium and total phosphorus. The nitrate and ammonium were determined using the sodium-salicylate method (ALPHA 1995). The TP was determined by digesting and reducing the forms of phosphorus present in the water into free ortho-phosphate form (SRP) using persulphate digestion and then analyzed using the ascorbic acid method (APHA 1995) on filtered papers.

The EC estimates the concentration of dissolved salts and indicates the potential chemical contaminants (Gali et al. 2012), while the pH, temperature and DO influences the chemical composition of the groundwater. The nitrate, ammonium and total phosphorus are chemical parameters derived from human activities and nutrient content of manure used in agriculture, hence indicators of possible contaminations from the surface activities (Bohlke et al. 2006). The results obtained were compared with the standard values prescribed in Kenya Bureau of Standards (KEBS, 2004) and WHO standards and guidelines for drinking water.

Spatial data analysis

In order to capture the spatial variation of groundwater quality of the mid River Njoro catchment, the spatial analysts tool of ArcGIS software was employed. The location of groundwater samples and elevation were captured using a handheld Garmin 64 GPS receiver and coordinate recorded in geographic coordinate system in an Excel sheet. The location data (point shapefile) were then linked to the attribute table of the groundwater quality data obtained from the field and laboratory analysis using GIS techniques. The geographic longitude-latitude coordinates were converted to the metric coordinate system using the Universal Transverse Mercator projection for better spatial analysis and interpolation of geospatial groundwater quality data.

A raster model of GIS is used in manipulation of the spatial data because it is suitable for overlay analysis, has simple data structure, easy and efficient overlaying process and provides unified grid cells for several spatial attributes. However, large computational storage, inefficient projection transformations and loss of information when using large cell size discourages its uses.

Kriging Interpolation Technique

Kriging is a multistep process which includes exploratory statistical analysis of the data, variogram modeling, creating the surface, and exploring a variance surface. In order to create a predicting surface map, Kriging tool goes through two-step process: it creates the variograms and covariance functions to estimate the spatial autocorrelation values that depend on the model of autocorrelation and predicts the unknown values. Kriging estimates are calculated as weighted sums of the adjacent sampled concentrations and this means that the values closer to those estimated receive higher weights than those farther away (Ersoy et al. 2004).

The main challenge of the kriging interpolation is the controversy in the number of sampling points used for estimation. Webster and Oliver (1992) recommended the sampling points for interpolation using kriging to be at least 30 or more. However, the extents to which a single data point is interpolated is not clear and as such many researchers have used points greater than 30 but within a bigger spatial area with single point interpolated more than a distance of 3km. For example, Derakhshan et al. (2015) assessed the groundwater quality of Yazd-Ardakan plain with an area of 4117 km2 using GIS and GQI with 80 samples from the wells. Shawgar et al. (2017), also assessed and modelled the groundwater hydrogeological quality parameters via Geostatistical approaches in southeast of Tehran, Iran, with an area of 1535 km^2 using 78 well samples. Augustina et al. (2017), also assessed the spatial variation of groundwater quality in a Mining Basin using GIS-based groundwater quality index (GQI). The catchment covers an area of about 6336 km^2 and 90 boreholes were used.

Calculation of Groundwater Quality Index, GQI

The GQI of the mid River Njoro catchment was calculated following a four-step procedure proposed by Babiker, et al., (2007), outlined here:

i Construction of Concentration Maps- "Primary Map I"

The concentration map for each groundwater quality parameter representing the "Primary Map I" was constructed using the Ordinary Kriging interpolation tool of ArcGIS software. The Kriging interpolation technique was preferred over other interpolation techniques because it was built on statistical procedure which is more accurate and provides reliable output. The concentration maps become raster format of the original point data of groundwater quality parameters. The raster format is usually preferred because it provides a simple data structure and provides easy and efficient overlay analysis as compared to vector format.

ii. Normalizing the Primary Maps I.

Using a normalized difference index function (Equation 1), the primary maps I were standardized to a common universal scale by relating the primary maps I to the KEBS and WHO maximum desirable standards. The resultant maps, referred to the "primary maps II', display for every pixel a contamination index (CI) values ranging from -1 and 1. The normalized difference indexing therefore, provides a fixed upper and lower limits for the levels of contamination in primary maps II.

$$CI = \frac{X' - X}{X' + X} \tag{1}$$

Where CI is the contamination index, X' is the measured concentration and X is the desired KEBS/WHO standards.

iii. The Rank Maps

The primary maps II were then rated between 1 and 10 to generate the "rank maps" using the polynomial Equation 2. The rate 1 indicates least impact on groundwater quality and the rate 10 indicates the highest impact.

$$r = 0.5 * CI^2 + 4.5 * CI + 5 \tag{2}$$

Where CI is the concentration index value for every pixel in the "primary map II" and 'r' the corresponding ranking value.

iv. The GQI

The seven "rank maps" were summed up to generate GQI using raster calculator of ArcGIS software. This GQI value represents linear combination of factors rated and weighted as shown in Equation 3.

$$GQI = 100 - \{(r_1 w_1 + r_2 w_2 + \cdots r_n w_n) / N\} \tag{3}$$

Where 'r' is the rate of the rank map (1-10); 'w' is the relative weight of the parameter which corresponds to the "mean" rating value (r) of each ranking map. The "mean" rating value (r) for the parameters that have potential risks to human health, such as nitrate, is calculated by adding the value 2 (r+2). N is the total number of parameters used for suitability analysis. The 100 value in Equation 3, is the reflection of high water quality and those values close to 100 reflect the high quality of water and those far below 100 reflect the low quality of water.

Preparation of Land use map

The Google Earth satellite provides high-resolution images that could be used to create a land-use map of an area. In this study, Google earth satellite imagery of 2015 was used to generate land use map of the study area. The Google earth digitizing tools such as polygons, lines and points were utilized to construct the various land use types present in the study area. Several polygons were constructed for settlement area, forest covers and mixed area. These polygons were then imported into ArcGIS software and converted into layers. The layers were joined using the union tool of ArcGIS software. The joined layer was then erased from the study area using the erase tool of ArcGIS software and the remaining area assigned to the agricultural land. These four major land-use types formed the land use map of the study area. This map was then employed to assess the impact assessment of land use types on the groundwater quality.

Results and Discussion

The groundwater quality data for the seven selected parameters for the 8 boreholes are presented in Table 1. These are mean values of data replicated three times for each parameters. Table 2 displays the basic statistics of the seven groundwater quality parameters used in generating the GQI and the corresponding KEBS/WHO standards. From the results the observed pH readings varied between 7.53 to 8.70, with the overall mean value of 8.01. The mean pH value of the study area exceeds the KEBS and WHO recommended value of 6.5 to 8.5. Since the mean pH is more than the neutral value of 7, the groundwater of the study area can be described as ‘slightly’ alkaline. The EC of the study area ranged from 389.50 µS/cm to 902.00 µS/cm, with mean value of 631.19 µS/cm. The observed EC is below the threshold value of 2500 µS/cm set by KEBS and WHO standards.

All the groundwater samples had observed DO varied between 1.53 mg/l to 9.01 mg/l, with overall mean of 5.38 mg/l. This value slightly exceeds the maximum desired threshold recommended by KEBS and WHO standards. The temperature readings varied between 17.58 °C to 24.50 °C. The overall mean was 21.34 °C, which is below the threshold recommended in KEBS standard and WHO standards. Nitrate concentration range between 0.05 mg/l to 60.86 mg/l. Except for KARLO dairy borehole (which showed extremely high nitrate value of 60.86 mg/l) the observed nitrate values in other boreholes were lower than maximum acceptable level. ThThis extreme observation (as compared to KEBS of 10mg/l) is probably a case of point source pollution caused by fecal matters which might have directly flushed into the groundwater. This extreme value was corrected in interpolation by dropping and replacing it with the mean of the group data.

The observed ammonium concentration in the study area was between 0.03 mg/l to 0.12 mg/l and these values

Tab. 1 - Results of the groundwater quality analysis.

Tab. 1 - Risultati delle analsi della qualità delle acque sotterranee.

Location	pH	EC (µS/cm)	DO (mg/l)	Temp. (°C)	NO$_3$ (mg/l)	NH$_4^+$ (mg/l)	TP (mg/l)
Rurii (BH1)	8.47	766.00	5.49	20.43	0.44	0.0910	0.08
Mukuria (BH2)	7.53	538.00	3.34	21.07	1.99	0.0713	0.11
Ngondu (BH3)	8.70	623.00	5.85	24.5	0.05	0.0305	0.06
Muchiri (BH4)	8.64	738.00	6.82	24.65	3.36	0.0223	0.06
Timsales (BH5)	7.94	902.00	9.01	17.58	1.72	0.0883	0.05
Eriithia (BH6)	7.78	389.50	7.8	19.4	1.15	0.1248	0.02
KALRO Main (BH7)	7.71	591.50	4.67	22.75	3.56	0.1003	0.10
KALRO Dairy (BH8)	7.96	501.50	1.53	23.65	60.86	0.0927	0.11

Tab. 2 - Basics parameter statistics used in calculating GQI and their standards.

Tab. 2 - Parametri statistici di base delle variabili chimiche usate per calcolare il GQI e relativi limiti normativi.

Parameters	KEBS/WHO	Min	Max	Mean	Std. Dev
pH	6.5 - 8.5	7.53	8.70	8.01	0.43
EC (µS/cm)	1500	389.50	902.00	631.19	153.49
DO (mg/l)	4	1.53	9.01	5.38	2.41
Temperature (°C)	25	17.58	24.50	21.34	2.56
NO$_3$ (mg/l)	10/45	0.05	60.86	9.14	22.29
NH$_4$ (mg/l)	0.5	0.03	0.12	0.09	0.03
TP (mg/l)	2	0.02	0.11	0.08	0.03

are below the maximum desired limits for safe drinking water. The total phosphorus concentration ranged between 0.02 mg/l to 0.11mg/l and the overall mean concentration was 0.08 mg/l. Compared to the desired value of 2 mg/l (KEBS 2014), the observed concentration lower than maximum acceptable level.

Figure 2 represents the groundwater quality index map of the study area. The GQI range from 68.38 to 70.92 and the spatial mean is 69.65. The blue shade in the central area shows high GQI value and the green shade in the northern area shows the low GQI value. The northern part of the study area, occupied by the human settlement shows low values of GQI, while the central part, covered by patches of forest remnants and mixed area (forests, settlement and cropland) show high values of GQI, which correspond to good groundwater quality.

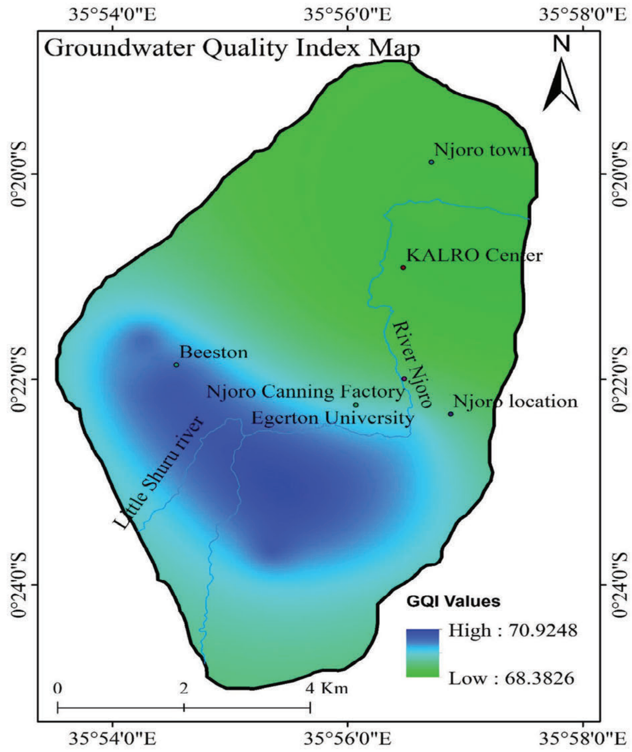

Fig. 2 - Groundwater quality index of the study area.

Fig. 2 - Indice di qualità delle acque sotterranee per l'area di studio.

Figure 3 displays land use map of the study area constructed from google earth imagery of 2015. Four major land-use types believed to have potential adverse effects on the groundwater resources were identified which include: settlement area, forest cover, agricultural land and mixed area.

The land-use types listed here are those that are capable of polluting the groundwater resources. As displayed in Figure 4 the agricultural land dominated the study area at 72%, followed by built-up areas (14%), forests areas (11%) and agroforestry areas (3%).

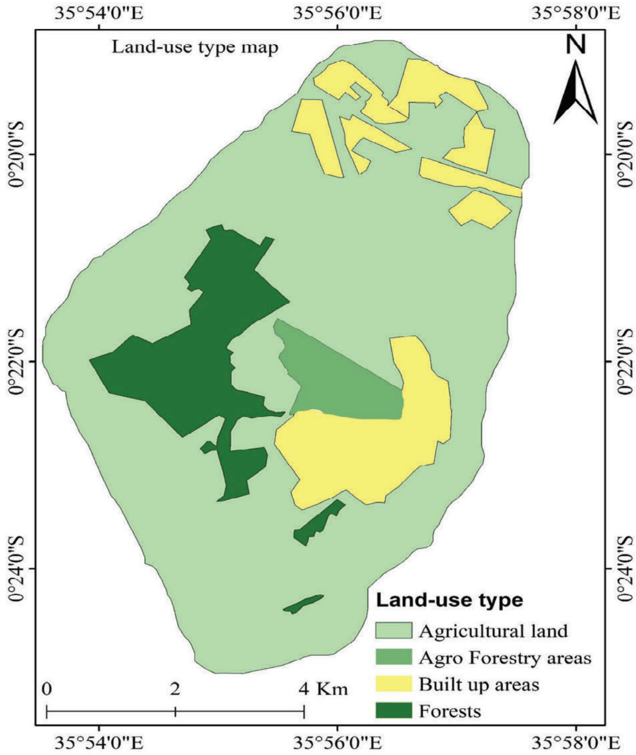

Fig. 3 - Land use map of the study area using Google Earth imagery of 2015.

Fig. 3 - Mappa dell'uso del suolo dell'area di studio realizzata da immagini satellitari del 2015 di Google Earth.

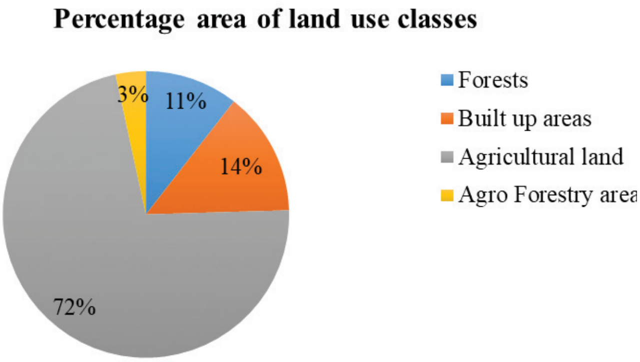

Fig. 4 - Percentage area of each land use type.

Fig. 4 - Estensione percentuale di ciascuna classe di uso del suolo.

GQI and land use correlation

The best approach to assess the impact of land use types on groundwater quality is by measuring the acreage of the nearby land-use types and correlating it with the overall groundwater quality of the borehole. However, in this study, it is difficult to do this because it is hard to establish the extent of a particular land-use type that is impacting on the groundwater quality of a given borehole, due to the spatial variability of the boreholes and the dynamic nature of land use type.

The alternative to this approach is to generate continuous GQI values of the study area and correlate it with land-use types using GIS zonal statistics tool of ArcGIS software (Khan et al. 2017). This approach assumes that the ground surface level is relatively flat and the surface run off from the nearby land use type collects and percolates into ground surface beneath it. The polygons of each land use type were overlaid on the GQI map and the mean and the standard deviation of the GQI values within each land use type calculated and compared using spatial analysts tool of ArcGIS software.

Table 3 shows the GQI statistical results of each land-use type. From the statistics (Tab. 3) it is evident that the mean GQI value varies among the different classes of land use present in the study area. The forest areas have high GQI value corresponding to good groundwater quality, while the built-up areas have low GQI value hence poor groundwater quality as compared to the former. This confirms that land use types of the mid River Njoro catchment has bearing on the quality of the groundwater and the intensity of it depends the type of land use.

Tab. 3 - GQI statistics for each land-use type.

Tab. 3 - Statistiche relative al GQI per ciascuna classe di uso del suolo.

Land use type	Groundwater quality index	
	Mean	Std. dev.
Forest areas	70.82	0.40
Agricultural land	69.15	0.68
Built-up areas	68.48	0.34
Mixed areas	70.03	0.44

For instance, it has been researched and confirmed that the forest cover and grassland have significant positive impact on the quality of surface water and by extension the groundwater, while the built-up/settlement areas and agricultural land with intensive application of agricultural chemicals have negative influencing on the quality of the groundwater (Bullard 1966; Huang et al. 2016). These variations are depicted in the results obtained from this study as shown in Table 3 above.

The mean value of GQI in each of the land use type differed. Forest cover has high GQI value while the built-up/settlement area registered low GQI, confirming the finding of previous studies. A high standard deviation is seen in agricultural land and this simply means a greater spatial variation of groundwater quality. This could be attributed to the systems of farming and intensity of agricultural chemicals used in agricultural production. Such a great spatial variation of groundwater quality and overall contamination index is not desired since it will lower the groundwater resource sustainability.

Conclusion

Assessing the impact of land use on the underlying groundwater quality is not an easy and straightforward task. It involved generation of continuous groundwater quality index values from a point data obtained at the specific locations of the boreholes. The land-use type prepared from the Google Earth satellite imagery is also a spatially varying parameter, which can be linked to the spatially varying GQI values. The mean GQI value for each land use type was extracted using GIS, spatial analyst tools. The GQI of the study area ranges from 68.38 to 70.82, with spatial mean of 69.65, suggesting an average groundwater quality.

The northern part of the study area shows low GQI values, which corresponds to a relatively poor quality of groundwater. The central and towards the southern part shows high GQI values and hence good groundwater quality. The mean GQI value differed from one land-use type to the other, with forest covers showing the highest value and the settlement area, the lowest. This implies that the human settlements have a significant negative impact on the quality of groundwater, hence there is need to monitor the growth of the settlement and assess the potential types and sources of contaminants emanating from these land-use types. This study, therefore, provides a better insight into the impact of land use type on groundwater quality of an area and the need for continuous assessment and monitoring of both land-use type and groundwater quality for the sustainable development of groundwater resources.

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