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# Land Use and Water Pollution along the Altitudinal Gradient of the Likii River, Laikipia County, Kenya

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**Abstract** The study aimed at documenting the key land cover and land use types along the Likii River from the upstream to downstream and establishing the presence or absence of heavy metals (arsenic, mercury, lead) and pesticide residue (atrazine, β-endosulfan-isomer, mirex) along the altitudinal gradient. Land cover and land use analysis were undertaken through field missions conducted within the 2km zone on both sides of the river while water quality was based on surface water samples from 32 water sampling points along the altitudinal gradient from 2014 m to 1852 m. Heavy metal detection was done through Inductively Coupled Plasma Mass Spectrometry (ICP-MS) while the pesticide analysis was undertaken through the Solid-Phase Microextraction (SPME) and Gas Chromatography-Mass Spectrometry (GCMS). The land cover and land use analysis established that the river system was characterized by over ten zones along the altitudinal gradient. Arsenic was detected in the river between 1893-1938 m, with the highest concentration of 1.23 µg As/L at 1910 m, near the Likii low-income residential area. The mean lead concentration was 2.72 mgPb/L with the highest mercury concentration at 7.1µgHg/L between 1938 m and 1893 m in the Likii low-income residential area. The presence of atrazine was detected from below 2018 m near the Kariki Flower Farm after which the level increased downstream to a maximum of 76 µg/L at 1864 m. The maximum concentration of β-endosulfan-isomer at 56.7 µg/L was well above the WHO tentative limit of 20 µg/L in most sections of the river below 2015 m. The mean level of Mirex was 49.7 µg/L with two distinguishable peaks near the Kariki Flower Farm and the Likii low-income residential area. The findings indicated that the water in the Likii River was largely unsafe for human consumption below 2018 m because of the presence of heavy metals (below 1910 m for lead and mercury) and pesticide residue (1934 m for atrazine, 1938 m -2018 m for mirex and 2015 m for β-endosulfan-isomer).

***Keywords:*** *Tropical River, land use, heavy metals, pesticides, Mount Kenya region, Laikipia county*

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## 1. Introduction

Water quality is one the most important environmental attributes in a river ecosystem because it determines the suitability of water for societal, livestock and wildlife use. The water quality eventually controls the river ecology, including the state of aquatic biodiversity and primary productivity. The state of river water quality around the world is increasingly changing in a negative way due to the widespread encroachment of the riparian environments by a wide range of human land uses, including subsistence agriculture, horticulture, livestock husbandry, rural settlements, urbanization, industrialization, quarrying and mining. Any negative transformation of water quality will often lead to increased water scarcity because river water is no longer suitable and available for human use especially in Africa where people usually draw untreated raw water directly from rivers. Contaminated water will also lead to a wide range of public health issues and increase the mortality rate while also straining national healthcare budgets as a result of increased waterborne diseases. It is therefore necessary and important to regularly take stock of the water quality situation in rivers in order to understand the emerging water pollution issues especially with regard to toxic heavy metals and pesticide residues which are known to have serious public health implications.

Heavy metals and pesticide residue are usually released into the rivers from a wide range of sources. Thereafter, they pose a big threat to society because the contaminants are usually consumed either directly or indirectly, without people’s knowledge either through direct consumption of polluted water or eating of contaminated food crops, fish or meat which contains the toxins. In recent times, lead poisoning, for example, has been reported in the Owino Uhuru slums in Mombasa, Kenya leading to the death of three people and endangering 3,000 others [1]. In addition to heavy metals, water quality is seriously affected by the introduction of pesticide residue from agricultural fields along rivers where agrochemical use can usually be very intensive especially in irrigation farms. The pesticides (insecticides, fungicides, herbicides, nematicides, rodenticides, acaricides and molluscides) are usually applied in order to kill problematic insects, fungal pests, weeds, nematodes, rats, mice, ticks and snails, but most are also poisonous to humans. Although, the use of such chemicals is desirable for increased crop production the negative health implications can be enormous and the risk is usually unknown to the general public.

In Kenya, the available information on river pollution by arsenic, lead and mercury is quite limited and yet these are very toxic heavy metals. Similarly, the available data and knowledge on pesticide poisoning is inadequate within the region as indicated by the East Africa Pesticide Network (EAPN) and reported by Ngowi & Partanen [2]. This study was intended to address this knowledge gap.

Arsenic, lead and mercury are known to exhibit extreme toxicity in the environment even at trace levels [3]. They are usually mobilized into the environment through a combination of natural processes such as rock weathering and volcanic emissions. Natural sources, such as hot springs and geysers, can also contribute to elevated levels of arsenic in the environment [4]. However, the dominant source is through a range of anthropogenic activities especially mining, combustion of fossil fuels, use of arsenical pesticides and livestock feed, particularly poultry feed. Arsenic is also used in alloys to increase metallic strength and is common in battery grids as well as some electrical devices [5]. The use of arsenic containing glass, ceramics and wood preservation is also quite common. In many cases, the wastes of these products can find their way into waterways unless good measures are in place for well regulated solid waste and sanitation management.

Arsenic is considered as a slow poison which kills people gradually and in most cases without any suspicion by the victims. Long-term exposure to arsenic as a result of drinking contaminated water is known to have carcinogenic effects reflected mostly through lung and skin cancers but is also associated with other health problems such as skin lesions, dermatitis, cardiovascular complications, anemia, and diabetes. It is also associated with lung ailments such as chronic bronchitis and liver diseases like non-cirrhotic portal fibrosis [5,6]. Arsenic pollution has affected people in different parts of the world including USA, Latin America (especially Chile, Mexico, El Salvador, Nicaragua, Peru and Bolivia), China, India, and Bangladesh. Both Bangladesh and India especially West Bengal, have suffered enormously from arsenic water pollution with over 40 million victims. In 2001, the World Health Organization estimated that about 130 million people in the word are exposed to high arsenic concentrations above 50 µgAs/L [7]. Consequently, the WHO set the standard limit for arsenic in drinking water sources at 10 µgAs/L [8]. National governments are expected to ensure that this limit is not exceeded. Africa is considered as one of the continents with the least effort towards the monitoring and documentation of arsenic water pollution and its impact on the society. Reliable research on this problem has only been conducted in a few countries such as Botswana, Burkina Faso, Ethiopia, Ghana, Nigeria and South Africa [8].

Lead on the other hand is a toxic metal which has been used in the world since ancient times. The major consumer of lead is the automobile industry especially the production of lead battery and also as gasoline additive. It is also associated with military equipment and ammunition waste as well as medical waste. It is also common in the manufacture of ceramic glazes and roof paint [9]. According to the International Persistent Organic Pollutants Elimination Network (IPEN), Kenya is one of the countries in the world where lead-based decorative paints especially for house roofs are still in the market [10]. Lead is also used in the production of water pipes and corrosion preventing vehicle fillers. In agriculture, lead arsenate is common in the production of pesticides. The negative health impacts of lead poisoning is associated with a wide range of ailments including anemia, gout, kidney failure, high blood pressure and renal cancers [5]. It is also known to cause damage to the central nervous system including brain damage [11].

Mercury is generally introduced in river water from a wide range of common products such as fluorescent bulbs, dental fillings, textiles, medical equipment, antiseptics, contraceptives, paints, paper, corks, rubber, thermostats and switches [12]. Just like lead it is also contained in some types of pesticides. A common source of mercury in the environment is the casual disposal of expired radio and flashlight batteries which is common practice in most developing countries including Kenya. Mercury poisoning has been associated with gastrointestinal disorders including ulcers, gastritis and diarrhea. It is also associated with Parkinson disease, renal failure, anemia and central nervous system disorders [5]. The health implications of mercury are well illustrated in some countries such as Japan which has suffered from Minamata disease as a result of mercury poisoning. The disease was first discovered in Minamata City within the Kumamoto Prefecture in 1956 [13]. The cause of this was the release into the Minamata River and Bay of methyl mercury contaminated industrial wastewater from the Chisso Corporation's chemical factory between 1932 to 1968 [14,15]. The toxic mercury in water was eventually assimilated in fish and later transferred to society because the area is a fishing hub.

The problem of pesticide residue in rivers is closely associated with the intensification of agriculture around the world. Cultivation along the rivers usually involves substantial use of agrochemicals especially pesticides which can eventually find their way into the water with serious negative consequences [16,17,18]. More than 500 different pesticides formulations are common throughout the world with India ranking tenth in the world in pesticide use with an annual total consumption of about 500 million tonnes. India is also the largest manufacturer of basic pesticides for the African market [19].

In Kenya, approximately 8,370 tonnes of pesticides are imported each year [20]. Heavy use of pesticides is common especially in the horticulture and floriculture sector which is usually operating close to rivers and lakes. In Lake Naivasha, for example, over 40 large flower farms are operating around the lake which creates a high risk of pesticide leakage into the aquatic ecosystem. Pesticide ingestion by humans is usually associated with a wide range of health problems such as leukemia, brain, prostate and breast cancer, asthma, diabetes, renal complications, neurological problems including Alzheimer's and Parkinson's diseases [21,22]. According to the WHO, in 1990 there were around 3 million pesticide poisoning cases are reported annually in the world leading to about 220,000 deaths [21]. The World Health Organization has classified pesticides according to their oral toxicity as shown in Table 1.

**Table 1. Classification of pesticides by toxicity hazard level [22]**

| Pesticide category | Hazard level | Oral toxicity* | |
|---|---|---|---|
| | | +Solids | +Liquids |
| I | Extremely hazardous | <5 | <20 |
| II | Highly hazardous | 5-50 | 20-200 |
| III | Moderately hazardous | 50-5000 | 200-2000 |
| IV | Slightly hazardous | >500 | >2000 |

* - Toxicity based on LD 50 for the rat (mg/kg bodyweight); + - The term solids and liquids refer to the physical state of the product or formulation.

Atrazine, α-endosulfanisomer and mirex are some of the agro-pesticides which are commonly used in the developing world although their use, in the developed world, is either banned or highly controlled. Atrazine (2-chloro-4-ethylamino-6-isopropylamino-s-triazine) is classified as a Class III substance by the WHO classification and is considered to be carcinogenic. It is widely used to control broadleaf weeds and grasses [21,23]. Atrazine has a half-life of 20-50 days at 20-25°C with the half-life increasing at lower temperatures to over 60 days in fresh water environments [21].

Endosulfan α-isomer ($C_9H_6Cl_6O_3S$) is a broad spectrum organochlorine cyclodiene insecticide which is used in the control a wide variety of insects and mites and is commonly traded under the name of Thiodan. It is classified as a Class Ib pesticide [24]. Endosulfan is genotoxic and neurotoxic and is known to cause convulsion and death. It is also known to be an endocrine disruptor and a reproductive toxicant. Epidemiological studies have provided evidence of birth defects, intellectual and behavioral impairment, and disrupted sexual development due to endosulfan poisoning [25]. Acute endosulfan poisoning can also cause brain oedema, impaired memory, epilepsy and paralysis. The pescticide is also associated with breast cancer. Endosulfan has contributed towards 55% of the total agro-pesticide poisoning cases in the Sudan [21]. Because of its threats to human health and the environment, a global ban on the manufacture and use of endosulfan was negotiated under the Stockholm Convention in 2011. More than 80 countries, including the European Union, Australia, New Zealand, the United States of America, Brazil, and Canada and several West African nations, had already banned the use of the pesticide by the time the Stockholm Convention ban was agreed upon. However, the pesticide is still used extensively in India, China, and Africa [24].

Mirex is a fire resistant organochlorine insecticide which is classified as a Class I pesticide. The high degree of chlorination in the pesticide makes it degrade very slowly in the environment leading to chemical persistence. When mirex is introduced in rivers and lakes, it tends to accumulate in the bottom sediments which contaminate the ecosystem for a long period. The pesticide is capable of bioaccumulating and biomagnifying at all trophic levels along the food chain up to the human level where it is known to be carcinogenic. Because of this, the use of the pesticide was discontinued in the 1970s [5]. According to the Kenya National Implementation Plan for the Stockholm Convention on Persistent Organic Pollutants (POPS), mirex was supposed to be listed for banning [20].

The fact that atrazine, endosulfan and mirex are either banned or used under severe restriction in the developed world raises great concern over their continued use in the developing world. The 4$^{th}$ Schedule (Regulation 16) of the Environmental Management and Coordination Act (EMCA 1999, Cap 387) of Kenya prohibits the unlicensed disposal of wastes containing the three pesticides as well as arsenic, lead and mercury because they are classified as hazardous substances [26]. Despite their dangerous character, the fate of these substances in the environment especially highly valued streams and rivers has not been a priority in scientific research hence the justification for this study. The progressive encroachment of the Likii River by human settlements and farming activities including horticulture and floriculture raises the need to establish whether land use along the river system is creating a problem of heavy metal and pesticide pollution.

The study was aimed at documenting the impact of different land uses along the river way and determining how they affect water quality. The key objectives were to: a) assess the key land cover and land use types along the altitudinal gradient of the Likii River from the upstream to the downstream, b) establish the presence or absence of arsenic (As), mercury (Hg) and lead (Pb), and c) establish the presence or absence of atrazine, β-endosulfan-isomer and mirex along the altitudinal gradient. The findings of the study are expected to provide knowledge on the state of water quality in the rivers of Kenya which are experiencing rapid encroachment by a wide range of land use including horticulture, urbanization, informal settlements and quarrying.

## 2. Study Area and Methods

The Likii River which is located in Laikipia County (Nanyuki and Segera Wards, Laikipia East Sub-County) has a catchment area of 184 km$^2$, which stretches from above 2,500 m on Mount Kenya (5199 m) and flows downstream through Nanyuki town before joining the Nanyuki River at an altitude of approximately 1850 m to form the south-eastern tributary of the Ewaso Ngiro River [27]. This stretch of about 5 km constituted the altitudinal gradient of interest for the study was characterized by ecological zones I, II, III and IV which are associated with very humid, humid, semi-humid and savannah conditions, respectively.

The annual rainfall is around 1,000-3,500 m for zones I and II within the high altitude to less than 800 mm in zone III and IV in the downstream. The rainfall distribution is bi-modal with two rain seasons, namely the long rains between April-June and the short rains between October to

December [27]. On average, the longest dry period is approximately four months during which the local people depend almost entirely on the river as the only source of water. The lower part of the river, below Nanyuki town, is dominated by pastoralists who permanently depend on the river for their livestock watering. Water pollution in the river is therefore likely to affect people in distant areas through the consumption of toxic livestock products.

The high altitude upstream section of the river to the south and east is dominated by small-scale farmers with land parcels of between 1-4 acres while the downstream low altitude section to the north crosses through the Likii low-income residential area which was previously a slum [27]. In recent years, the continued deterioration of water quality in the river is creating some tension between upstream and downstream stakeholders. Figure 1 shows the location of the study area while Figure 2 shows the general characteristics of the river system within the foot zone and savanna. The study was based on the main stretch of the river from Mount Kenya near the Kangaita farm through the Likii low-income residential area to just below the Likii horticulture farm in the east of Nanyuki Town (Figure 2). Table 2 shows the population characteristics in the study area.

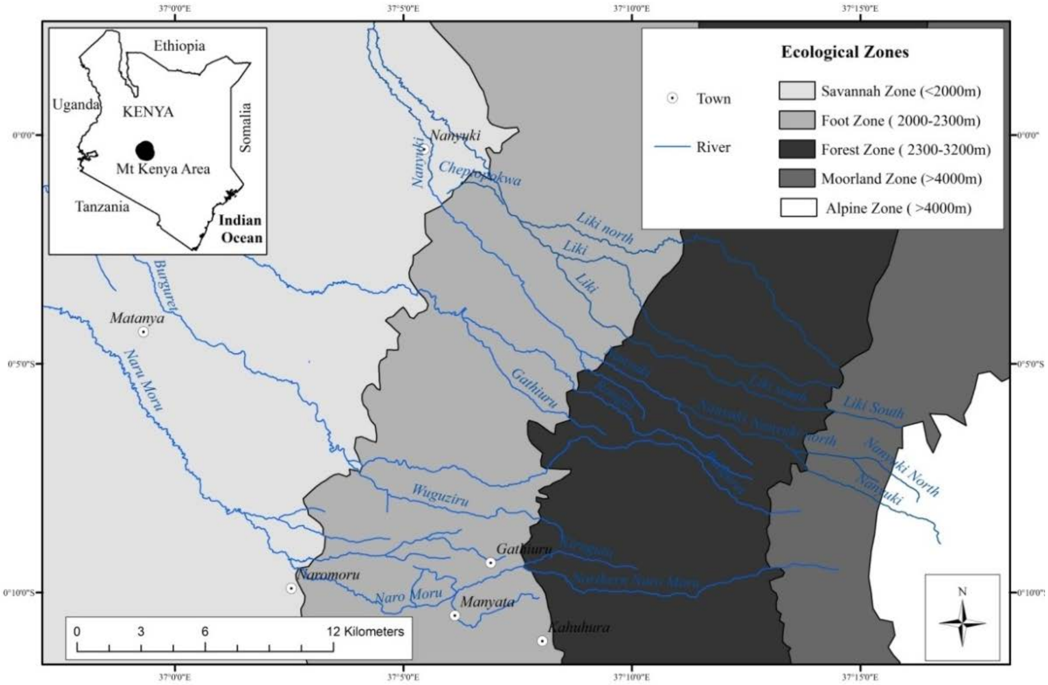


**Figure 1.** The location of Likii river catchment in the Ewaso Nyiro (North) drainage basin

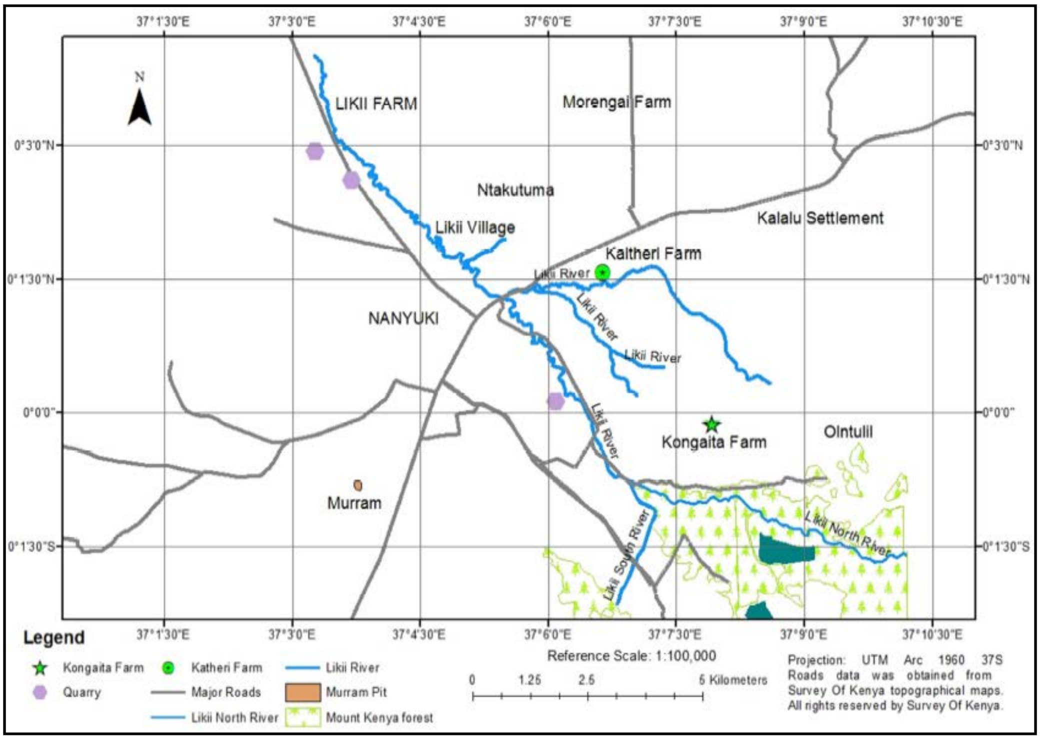


**Figure 2.** General characteristics in the Likii catchment

**Table 2. Population of the study area and the projections**

| Administrative area | Area and population size | | | |
|---|---|---|---|---|
| **Sub-location** | **Land (km$^2$)** | **1999** | **2009** | **2025 Projection** |
| **Laikipia East Sub-county, Central Division, Daiga and Nturukuma Locations** | | | | |
| Rugutu | 129.8 | 1,413 | 2,030 | 3,077 |
| Nturukuma | 19.5 | 3,694 | 5,308 | 8,043 |
| Likii | 5.3 | 6,891 | 9,901 | 15,005 |
| Sub Total | 154.6 | 11,998 | 17,239 | 26,125 |
| **Buuri Sub-county, Timau Division, Ontulili Location** | | | | |
| Sub Location | | | | |
| Kangaita | 11.0 | 2,628 | 4,130 | 7,531 |
| Katheri | 18.7 | 5,080 | 5,448 | 14,558 |
| Sub Total | *29.7* | *7,708* | *9,578* | *22,089.1* |
| **Total** | **184.3** | **19,706** | **26,814** | **48,214.1** |

Source: KNBS [28].

Land cover and land use analysis was undertaken through field missions conducted along road-based inspection transects using the motorable roads and tracks within the 2km buffer zone on both sides of the river from 2014 m in the upper catchment to 1852 m in the lower catchment. The analysis involved a rapid identification of land cover and land use types at random observation points along each transect. The elevation at each observation point was recorded using a Garmin GPS unit. The land cover and land use classes were eventually mapped using ArcGIS.

Water sampling was undertaken after the short rains in December 2013 from 32 water sampling points along the altitudinal gradient (Figure 3). The sampling sites were selected purposively depending on terrain navigability and river accessibility. The sampling interval was generally between 0.5-1.5 km from one point to another along the altitudinal gradient. Water samples were collected at 15-30 cm depth below the water surface using high density polyethylene containers. All the containers were cleaned using deionized water prior to the water sampling. The clean containers were labeled in relation to each sampling site and also geo-referenced according to elevation using a GPS.

The water samples were stored in a cool box during transportation to the laboratory and analyzed at the Kerio Valley Development Authority (KVDA) in Eldoret after 2-5 days.

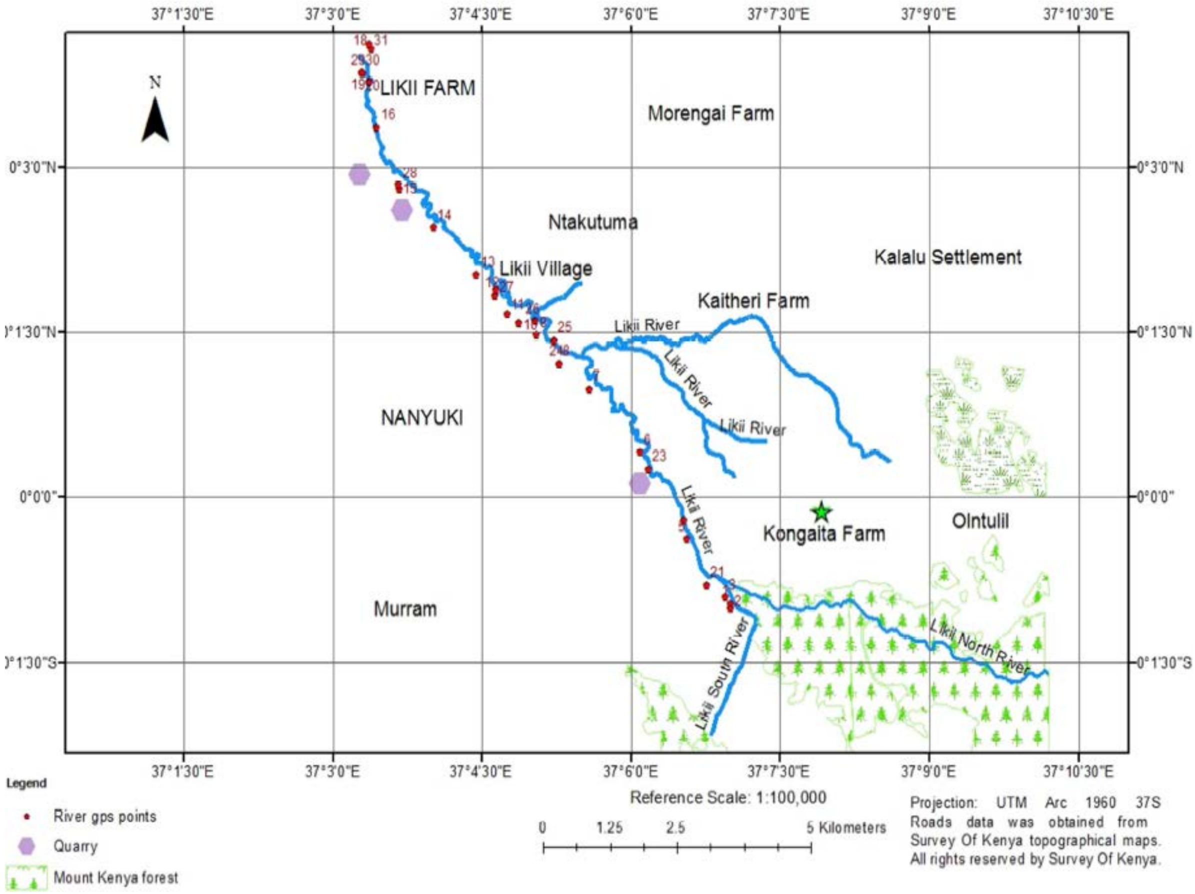


**Figure 3.** Location of sampling sites

Water pH was tested on site using a portable water analyzer (HI 9828 multiparameter meter) in order to determinate the general quality. Arsenic, lead and mercury were analyzed through inductively coupled plasma mass spectrometry (ICP-MS) [29]. The arsenic samples were digested using concentrated nitric acid and high-purity water replenished to 20 mL. From this solution, 2.5 mL was removed and placed in a 15 mL test tube, to which 5mL of pre-reduction solution was added. Following a reaction time of 2 hours, 2.5 mL of high-purity water (5.2.1) was added. After being shaken briefly, 10 mL of sample solution was diluted by a 1:4 ratio. The samples, reference samples, stock solution for standards and ICP-MS tune solution (as solution 5 µg/L) were then treated according to the standard procedure [29]. The accuracy of the ICP-MS performance for water analysis was assessed using external standards which were prepared by diluting the ICP Multi-Element Mixed Standard III (Perkin Elmer) into a series of concentrations with the same acid mixture used for sample dissolution. The analysis was performed using ICP-MS ELAN 9000 (Perkin Elmer) equipped with a Meinhard Concentric Quartz Nebulizer, Cyclonic Spray Chamber, Nickel Sampler and Skimmer Cones.

Pesticide analysis was undertaken through the Solid-Phase Microextraction (SPME) and Gas Chromatography-Mass Spectrometry (GCMS) using the Agilent Technologies 6890N Network GC System in accordance with FAO and IAEA procedures [30]. The sample vial was agitated with a magnetic stir bar and stirrer. Once the SPME fiber had cooled, it was exposed directly into the water sample while still stirring for 15-20 minutes. For the first sample set, ~.70 g of NaCl was added to the samples in order to salt out any possible organochlorine pesticides in the sample. After the adsorption time, the fiber was removed from the sample and immediately inserted back into the GC-MS for about five minutes to analyze for the organochlorine pesticides. This was repeated for each sample vial. The resulting peaks from the GC-MS analysis were identified and the limits of detection found by first creating a standard mixture by spiking of 0.010 mL of a pesticide mix standard solution (Supelco) into 4 mL of deionized water. The standard was contained in a methanol: methylene chloride mix (98:2). The SPME fiber was then exposed to the mixture in the same manner as the sample vials and the areas generated for each compound used to roughly establish the limits of detection for each pesticide as well as providing an estimate of the pesticide concentrations in the water samples. The quantification limits were set to 100 ng/L forβ-endosulfan; and 10 ng/L for atrazine and mirex.

The data was analyzed using the Statistical Package for Social Science (SPSS) and Excel platforms. The two platforms were used in the computation of descriptive summary statistics which was followed by correlation and regression analysis to examine the relationships between heavy metals and pesticide residue on one hand and altitudinal gradient on the other.

## 3. Findings

The river profile had an overall altitudinal gradient of 182 m stretching from 2034 m in the foot zone (Mount Kenya Forest) to 1852 m in the lower catchment savanna at the confluence with Nanyuki River. The land cover analysis established that the river system had over ten different types of land cover zones along the altitudinal gradient.

The high altitude catchment was characterized by pristine forest as part of the Mt. Kenya ecosystem which is a national park and forest reserve. It is also part of the Mount Kenya Biosphere Reserve and UNESCO World Heritage Site. This section is located near the world famous Fairmont Mount Kenya Safari Club and the Kenya Defence Forces (KDF) military camp. The rest of the river was characterized by woodland, bush land, agroforestry and agro-ecosystems with majority of the people practicing mixed farming and irrigation along the Likii River. Figure 4 shows the land cover types along the altitudinal gradient.

The land use analysis established that the Likii catchment is hosting about 25,000 persons with the upstream section consisting of the Kangaita and Oluntulili settlements while the middle section consisted of the Nturukuma settlement, Nanyuki Municipality and Kalalu settlement scheme. The lower section of the river was dominated by the Likii low-income residential area and Morengai villages. The population density along this section of the river was approximately 79/km$^2$. Table 3 and Figure 5 show the and use and land cover zones in the riparian environment**.**

**Table 3. Land use zones along the Likii River**

| Altitude (m) | Dominant land use/landcover zone |
|---|---|
| 2018-1944 | Agro-forestry |
| 2021-1864 | Floriculture and horticulture |
| 2034-1855 | Forestry |
| 1922-1856 | Horticulture and quarrying |
| 2015-1893 | Informal settlement |

The water pH along the entire altitudinal gradient from upstream to downstream was 7-9.8 with neutral pH (pH 7) in the high altitude section of the river inside the Mount Kenya forest at 2034 m. The highest pH at 9.8 was recorded in the section between 1912 and 1910 m which was dominated by the Likii low-income residential area . Many households in the informal settlement discharge their raw sewage directly into the river.

Arsenic was found to exist in the river with the major concentration peak in the altitudinal section between 1893-1938 m where the level was 1.23 µgAS/L at 1910 m within the Likii low-income residential area. The overall mean level at 0.15 µgAs/L was below the WHO limit of 10 µgAs/L. The landuse appeared to indicate the source of arsenic as originating from waste disposal into the river within the informal settlement. Figure 6 shows the spatial pattern of arsenic along the altitudinal gradient of Likii River. The presence of arsenic in the river was alarming given that communities along the river usually draw untreated water for domestic use and including drinking. A lot of livestock especially in the downstream section of the river below Nanyuki town also depend heavily on the river as the source of water.

The mean lead concentration in the river was 2.72 mgPb/L but the heavy metal was undetectable in the high altitude sections of the river above 1934 m in Mt. Kenya forest.

The river was found to have two lead peaks. The first peak along the gradient was recorded at 1950 m, in a river section associated with horticultural and quarrying activities, with the highest concentration at 13.3 mgPb/L This peak was also located below the KDF military base below the pristine forest cover zone. The second peak of 12.5 mgPb/mg was located at 1950 m in a section of the river below the Likii low-income residential area. There was a slight increase of 1.7% in lead concentration along the altitudinal gradient from the upstream to the downstream as indicated by the coefficient of determination ($r^2$= 0.017). The lead levels in the river were above the NEMA and WHO limit of 0.01 mgPb/L for drinking water. Figure 7 shows that two lead peak concentration sections.

The mercury analysis manifested as similar altitudinal pattern to arsenic and lead with two distinguishable peaks. The first peak concentration at 7.1 µgHg/L was located in the altitudinal section between 1938 m and 1893 m which was in the Likii low-income residential area. The second peak at 6.9 µgHg/L was recorded at 1938 m below the Likii low-income residential area (Figure 8). Like arsenic, there was a slight increase of 10% in mercury concentration along the altitudinal gradient from the upstream to the downstream as indicated by the coefficient of determination ($r^2$= 0.1). The landuse analysis appeared to indicate the source of mercury as originating from waste disposal into the river within the Likii low-income residential area to the east of Nanyuki town.

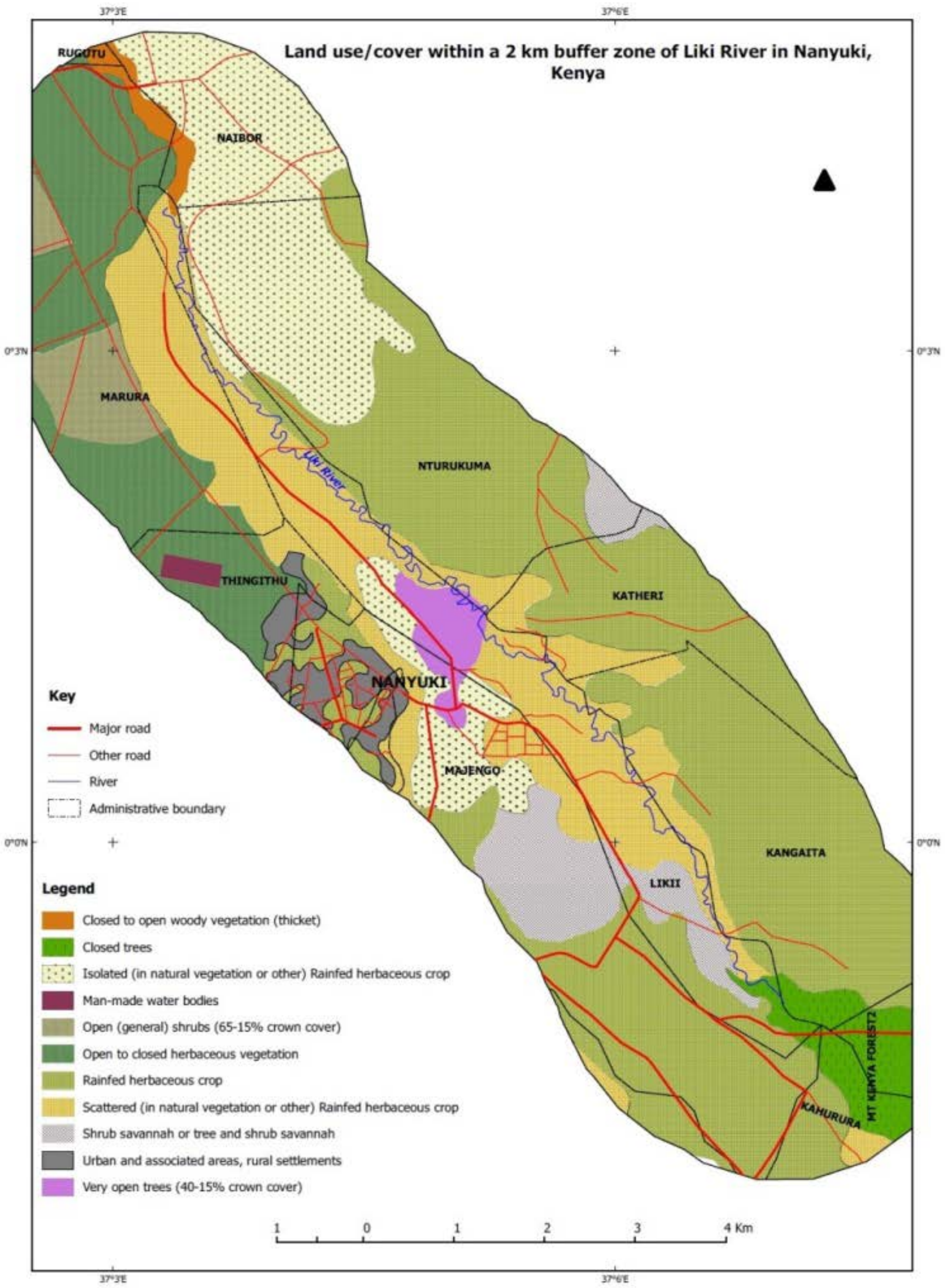


**Figure 4.** Land cover types along the Likii River

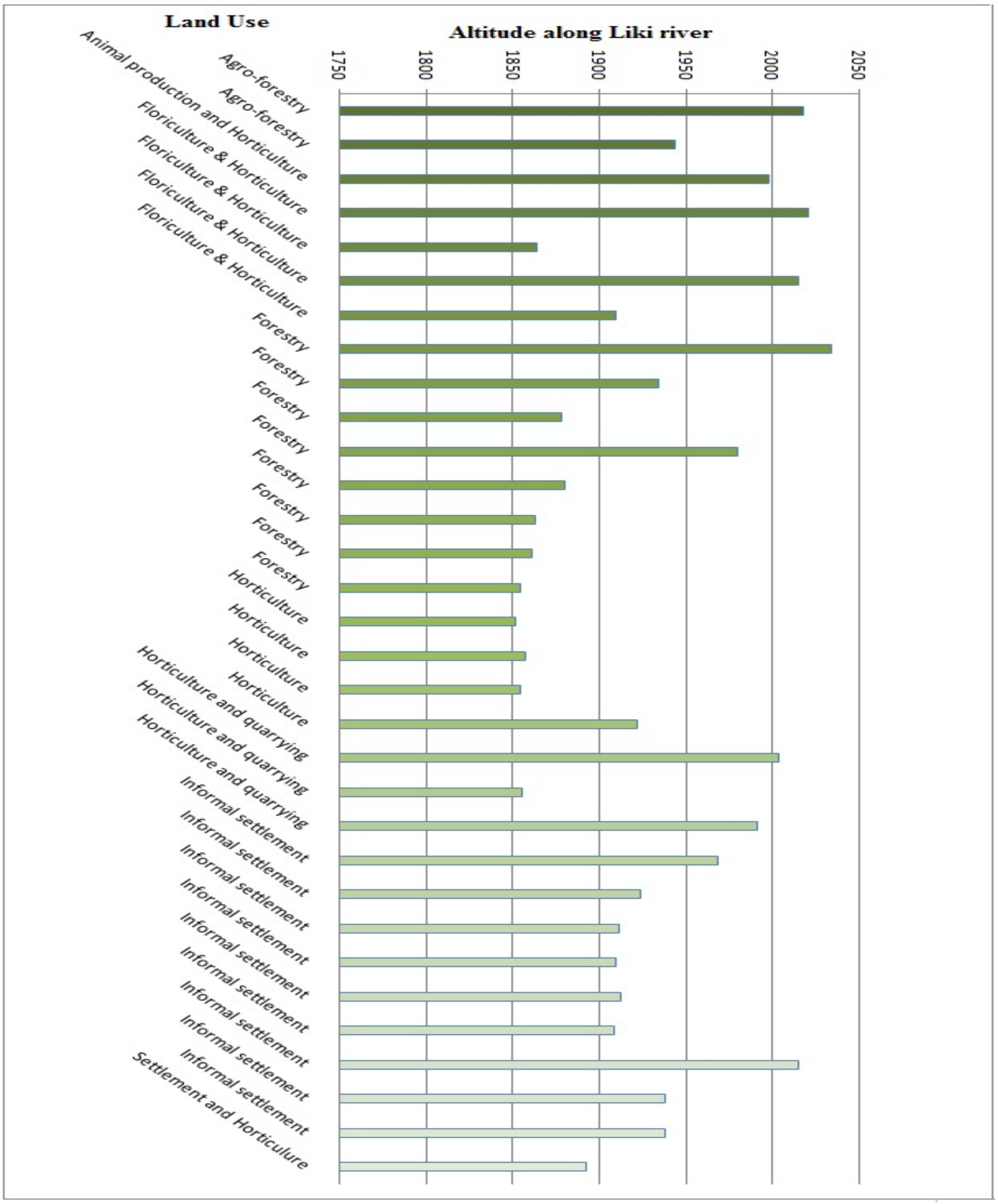


**Figure 5.** Variation in land use types along the altitudinal gradient of the Likii River

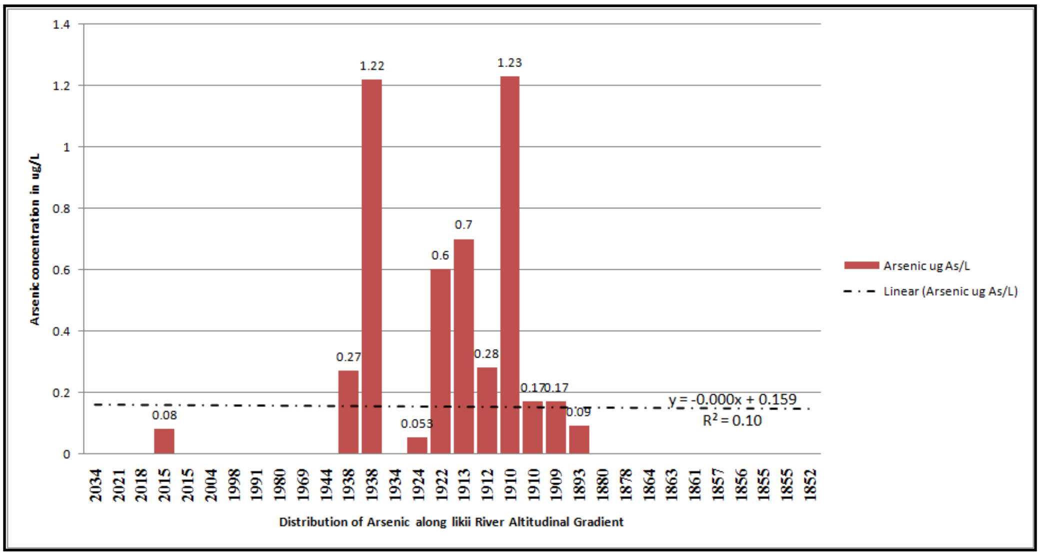


**Figure 6.** Arsenic concentration in Likii River

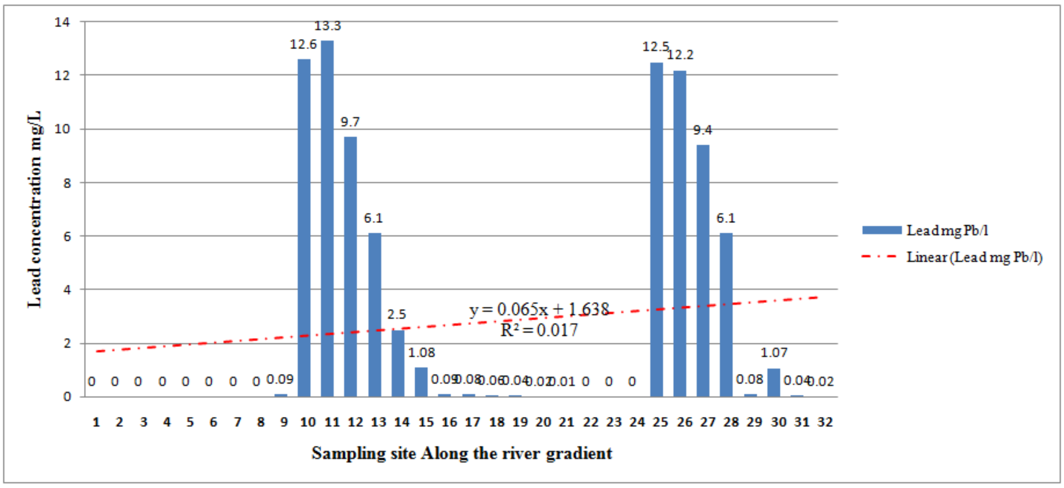


**Figure 7.** Lead concentration in Likii River

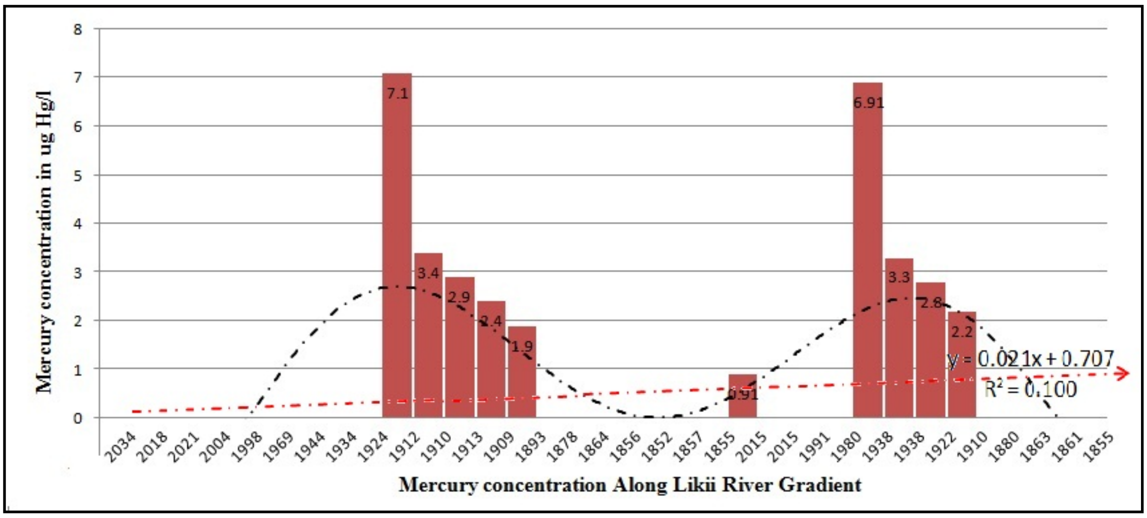


**Figure 8.** Trend in mercury concentration in Likii River

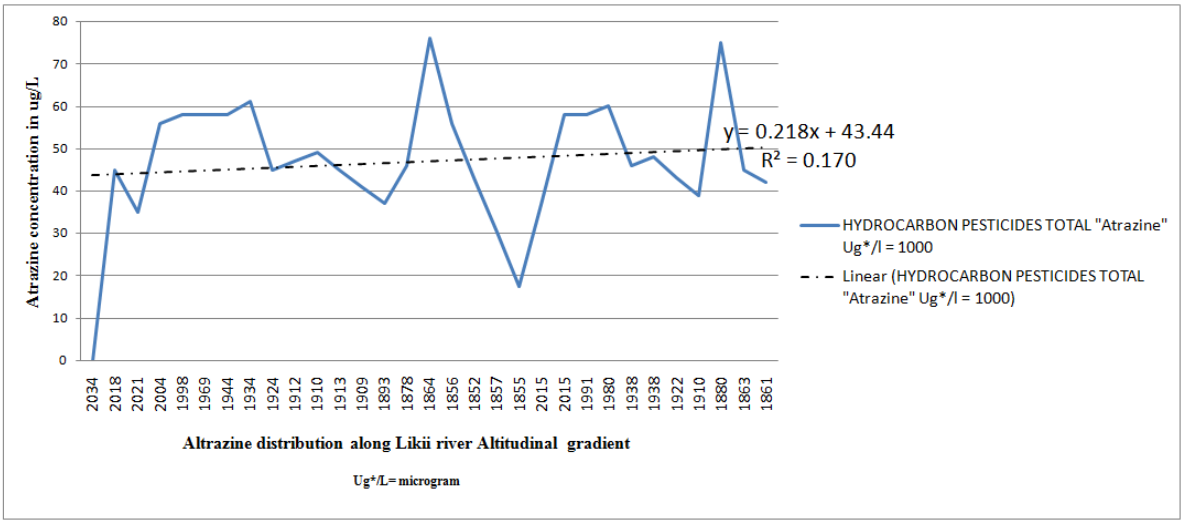


**Figure 9.** Atrazine concentration in the Likii River

The concentration of atrazine in the river was undetectable at 2034 m in the high altitude catchment zone inside Mt. Kenya forest. The mean level for this pesticide along the gradient was 46.9 µg/L with three peaks. The first peak of 62.1 µg/L was recorded at 1934 m and the second peak of 76.2 µg/L which was the highest at 1864 m which were both below the Kariki flower farm in the upper catchment. The third peak of 75.1 µg/L was recorded below the Likii low-income residential area and Likii flower farm. Figure 9 shows the variation in the concentration of atrazine along the altitudinal gradient.

Figure 9 shows that there was a consistent build-up of atrazine in the river with a 17% increase along the altitudinal gradient from the upstream to the downstream as indicated by the coefficient of determination ($r^2$ = 0.17). Given that the sampling was done after short rains it was possible that atrazine flushing by runoff from horticulture fields to the river was taking place. The pattern strongly suggested that the primary source of the pesticide was agricultural activities. The concentration of the pesticide, on the overall, was above the WHO limit of 0.002 mg/L or (2 µg/L). Apart from the upstream sections of the river above Kariki flower farm, the water in the rest of the river was unsafe for human consumption due to the high atrazine concentration.

Just like atrazine, the concentration of β-endosulfan-isomer in the river was undetectable at 2034 m in the high altitude zone within the upper catchment but the overall mean level was 24.1 µg/L with three peaks along the altitudinal gradient. The first and second peaks of 37.5 µg/L was recorded in the section between 2015 m and 1944 m in the Likii low-income residential area while the third and highest peak of 56.7 µg/L was recorded at 1863 m below the other two peaks after the Likii horticulture farm. Figure 10 shows the variation in the concentration of β-endosulfan-isomer along the altitudinal gradient. Figure 10 shows that there was a consistent build-up of β-endosulfan-isomer in the river just like the case for atrazine. The statistical analysis indicated a 30% increase in the concentration of β-endosulfan-isomer along the altitudinal gradient as reflected by the coefficient of determination ($r^2$ = 0.30). Although the concentration of β-endosulfan–isomer was slightly lower than atrazine, the levels were well above the WHO tentative limit of 20 µg/L in most sections of the river gradient with only 25% of the river gradient having β-endosulfan–isomer levels below 14 µg/L. The similar altitudinal trend in atrazine and β-endosulfan–isomer concentrations was an indication that the two were originating from agricultural sources.

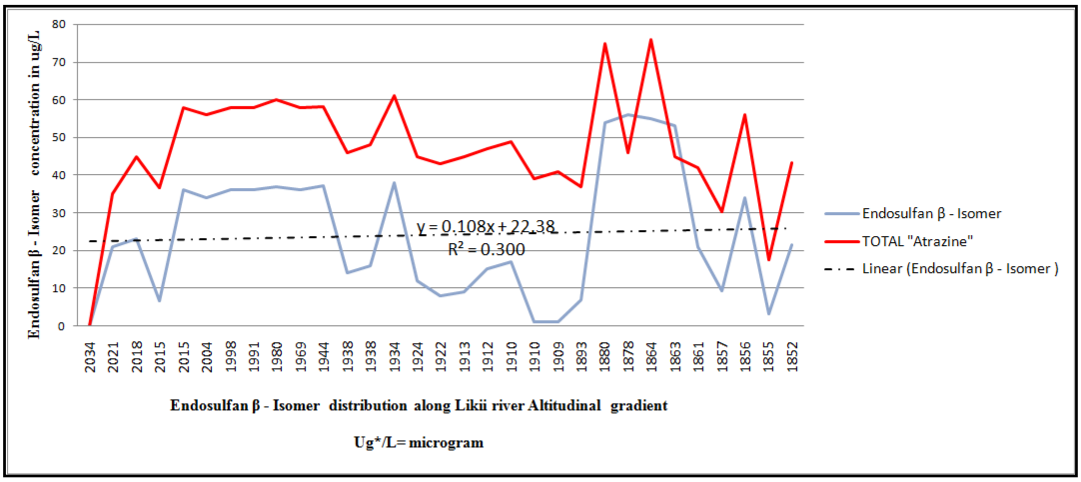


**Figure 10.** Comparative altitudinal trend of β-endosulfan–isomer and atrazine along Likii River

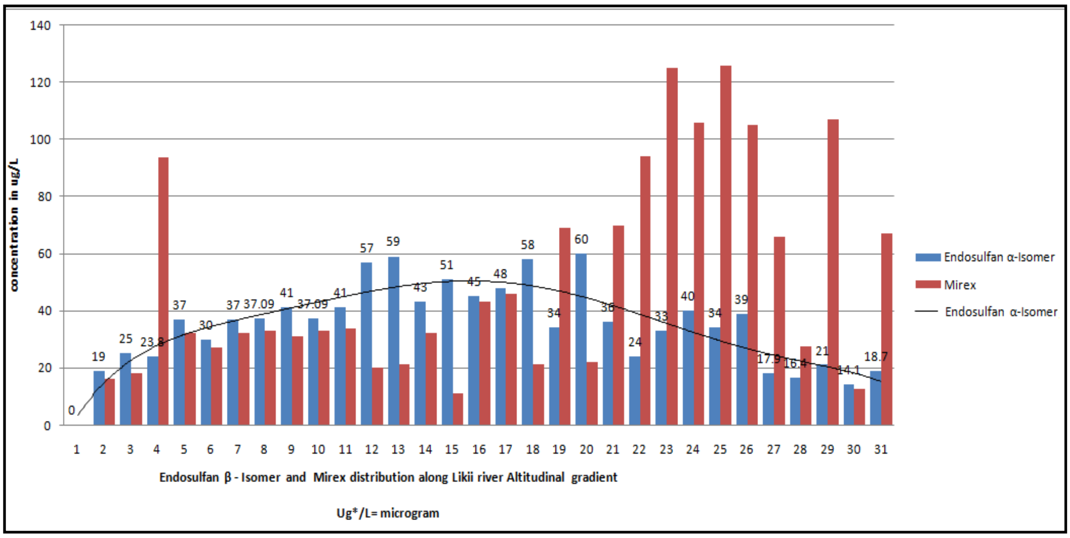


**Figure 11.** Comparative altitudinal trend of Mirex and Endosulfan α-Isomer along Likii River

In the case of mirex, the pesticide, just like β-endosulfan-isomer, was undetectable at 2034 m in the high altitude upper catchment forest zone. However, the mean level along the altitudinal gradient was 49.7 µg/L with two distinguishable peaks. The first peak of 91.5 µg/L was recorded upstream below Kariki flower farm while the second and highest peak of 125 µg/L was recorded downstream in the Likii low-income residential area and also next to Likii horticulture farm. Figure 11 shows the variation in the concentration of mirex in comparison with β-endosulfan-isomer along the altitudinal gradient.

The WHO does not have a clear limit for this pesticide but in the USA the EPA has set a limit of 1 part of mirex per trillion parts of surface water (1ppt). Figure 11 clearly shows that this threshold has been exceeded in the case of the Likii River which means that the water is unsafe for human consumption.

## 4. Discussion

The highest concentration of arsenic in the river was 1.23 µgAs/L which was below the NEMA and WHO limits of 0.02 mgAs/L (20 µgAs/L). However, the presence of the heavy metal in the river water at 1910 m within the Likii low-income residential area means that the water is not safe for human consumption below that point. Comparative studies of arsenic pollution in the rivers of Kenya are quite rare. However, the study Nyamasaria River in Kisumu near Lake Victoria showed that arsenic content was much lower with the peak concentration at 0.01 µgAs/L [30]. Similarly, the arsenic levels in the Likii River were quite low compared with the levels reported for other African rivers. In the Limpopo Province in South Africa, for example, a high concentration of arsenic 13.7 µgAs/L has been recorded of in rivers [31]. But a study in the Northern Cape has reported severe arsenic poisoning with levels as high as 1000 µgAs/L which has been attributed to the use of chromated-copper-arsenate in the preservation of timber. Most of the other arsenic pollution studies in Africa have concentrated on groundwater resources. A study of arsenic water pollution in 12 wells in southern Nigeria, and recorded concentrations of up to 6.88 µg/L which was attributed to groundwater contamination wastes from garages and panel beaters workshops [32]. A similar study in Obuasi area and Ashanti region of Ghana reported high arsenic levels of up to 64-141 µgAs/L [8]. In Ethiopia, it has been reported that out of 138 samples from wells in the Rift Valley only 9 or 6.5% showed arsenic above the WHO limit of 10 µg/L [33].

Although the arsenic levels in the Likii River are below the NEMA and WHO maximum tolerable concentration, the mere presence of the heavy metal is a serious issue. The evidence from this study should make it necessary for efforts to be made of tracking the source of this toxic element and identify strategies for ensuring zero-arsenic in the river for public health reasons. This is important because studies have clearly shown that contaminated water used for human consumption, irrigation of food crops or livestock production poses the greatest threat to public health from arsenic. On average, an adult drinking 2 l/day of water containing 10 g/L of arsenic would accumulate upto 20 g/day of inorganic arsenic from drinking water alone.

The mean concentration of lead in the Likii River at 2.7 mgPb/L with a maximum of 13 mgPb/L was above the minimum NEMA and WHO limit of 0.01 mgPb/L for human consumption. This means that the water in terms of the tolerable lead level is unsuitable for human consumption below 1910 m. Lead in water was quite high in the river especially above Nanyuki town and also below the Likii low-income residential area compared to the levels in other rivers in Kenya. The high lead levels within the informal settlement might be associated with the use of lead-based paints as well as improper disposal of other lead containing solid wastes (discarded batteries and garage waste) into the river. Higher lead levels were common near the horticulture and floriculture production areas which indicated the possible application of lead arsenate pesticides in the farms. This study was not able to establish whether military equipment and ammunition waste from military installations in the area are contributing towards the lead pollution in the Likii River.

The high levels of lead in the Likii River water are not common in other parts of Kenya even within the highly urbanized environments. The of the Nairobi river sections in Kikuyu, Kawangware, Chiromo, Eastleigh, Njiru and Fourteen Falls established that lead levels were mostly below detectable limit except in Kikuyu and Njiru [34]. In Kisumu, lead has previously been recorded at 0.65 mgPb/l in Nyamasaria River [30]. A study in Lake Naivasha, which is a hub for horticulture and floriculture, has recently recorded the lead concentration at 0.01-0.36 mgPb/L [35]. Similarly, a low and safe levels of lead at 0.23 and 0.004-0.009 mgPb/L have, respectively, been recorded in the rivers feeding into the Sasumua Dam in the south eastern zone of the Aberdare Ranges [36] and Masinga reservoir which is part of the Tana River [37].

In other parts of Africa, a study of River Challawa, in Kano City, Nigeria recorded lead level at 1.051 mgPb/L which was attributed to the improper disposal of industrial effluent [38]. In South Africa, the highest level of lead recorded in the Limpopo province was 0.8 µgPb/L in a typical rural area where people are mostly practicing subsistence farming [31]. Elsewhere in South Africa, lead concentration in Dzindi, Madanzhe and Mvudi rivers in Thohoyandou was recorded in the range of 0.01-0.02 mgPb/L [39]and attributed to the effluent from a nearby sewage treatment plant and a waste dumping site.

The highest concentration of mercury in the Likii River at 7.1 µgHg/L within the Likii low-income residential area was way above the NEMA and WHO limit which should be less than 0.005 mgHg/L (5 µgHg/L). This means that the river water is again unsafe for human consumption below 1910 m. However, higher levels of mercury have been reported in other parts of Kenya. A study of Nairobi for example, established that mercury was as high as 10 µgHg/L in Kawangware which is a high population density and low-income informal settlement just like the Likii settlement [34]. This means that a lot of mercury toxic wastes (medical waste, expired radio and flashlight batteries) in informal settlements are disposed into the rivers thereby endangering the lives of the people who rely on rivers as a source of water, fish or irrigated crops. Elsewhere, the study of mercury in river Naka and Irigu in Chuka which is in the foot slopes of Mt. Kenya established that the level was below the detection limit just like in the upstream sections of the Likii River which are forested [13]. In other parts of Africa, the highest level of mercury recorded in the Limpopo province at 2 µgHg/L was found to be safe compared to a level of level 300 µgHg/L in the Ngwabalozi river of Southern Zimbabwe which was dangerously high due to the impacts of gold mining [40].

In the case of pesticide residue, the findings indicated the presence of atrazine from below 2018 m near the Kariki flower farm after which the level increased downstream to a maximum of 76 µg/L at 1864 m. The interim maximum acceptable concentration for atrazine in drinking water is 0.002 mg/L (2µg/L) on the basis of which it was clear from this study that the river water was unsafe for human consumption below 2018 m. There are limited studies with which to compare this finding.

Just like atrazine, the maximum concentration of β-endosulfan-isomer at 56.7 µg/L in the Likii River was well above the WHO tentative limit of 20 µg/L in most sections of the river below 2015 m. The concentration appeared to increase near the horticultural and floricultural irrigation farms especially the Kariki flower farm in the upstream and the Likii horticulture farm in the downstream. It was again clear from the β-endosulfan-isomer that the river water was unsafe for human consumption below 1934 m. A similar study in Lake Naivasha basin which is a hub for horticulture, established that the mean concentration for endosulfan was 0.13 µg/L in 2010 [41] while another reported the highest level at 1.03 µg/L [35] but the two cases were within the WHO limit of 2 µg/L.

In the Western Cape in South Africa, endosulfan levels of upto 0.83 µg/L and 3.16 µg/L have been reported in the farming areas of Hex River Valley and a reservoir in Grabouw, respectively [42] . Endosulfan water pollution is widespread in West Africa. In Côte d'Ivoire, high endosulfan levels was detected in 85% of community shallow wells within agricultural areas which exceeded the recommended level of 0.1 µg/l for drinking water [25]. The maximum endosulfan concentration was 25.3 µg/l. In Bénin, a study undertaken in the Pendjari reserve recorded the pesticide at 0.5µg/L [25] while a similar study in Oyansia River which crosses through the city of Accra in Ghana recorded endosulfan at 0.46- 0.04 µg/kg [29]. According to IPEN , endosulfan is considered as a highly toxic insecticide which is under consideration by the Persistent Organic Pollutants Review Committee for inclusion in the Stockholm Convention on Persistent Organic Pollutants [25].

There are limited studies with which to compare the findings on mirex pollution in the Likii River. However, the water pollution by this pesticide was very surprising because it was contrary to the Government of Kenya position that the pesticide is not in use in the country [20]. The finding indicates that some pesticides are probably being used illegally in the country especially in the horticulture sector which is one of the most important foreign exchange earners after tea and tourism.

The production of export cut flowers, fruits and vegetables in Kenya increased from a cumulative 99,700 metric tonnes in the first half of 2012 to 111,892 metric tonnes in 2013 [35]. The total value of these exports was Ksh43.5 billion in 2013, compared to Ksh40.5 billion in 2012 [35].

The key challenge in Kenya's horticulture sector is ensuring compliance with safety standards with respect to maximum pesticide residual level requirements [43]. The Government of Kenya has put in place two bodies, namely, the Pest Control Product Board (PCPB) and the Kenya Plant Health Inspectorate Service (KEPHIS) to ensure compliance with the required standards. KEPHIS which commenced its operations in 1997 is expected to establish laboratories to monitor the quality and levels of toxic residues in plants, soils and crop and animal produce including pesticide residue in the environment. It appears like the capacity for field inspections in the two institutions should be strengthened in order to ensure effective protection of river ways from pesticide pollution.

The local people in the Likii catchment, especially those within the Likii low-income residential area and below, need to be urgently trained on the cheap methods of treating the river water, before use, in order to remove the waterborne heavy metals and pesticide residues which will affect their health in the long run. Studies have shown that conventional water treatment processes, specifically coagulation–flocculation, sedimentation and conventional filtration, are not very effective in removing heavy metals and pesticides from drinking water [44]. Traditional water treatment plants, for example, rarely exceed 10–20% removal of atrazine [45]. However, the removal of heavy metals and pesticides from the drinking water can be conducted by cheaply through activated carbon filtration [46,47].

## 5. Conclusion

The water in the Likii River is not safe for human consumption, especially below 2018 m in the altitudinal gradient, because of the presence of pesticide residue (2018 m for mirex and 2015 m for β-endosulfan-isomer). The bigger problem begins from 1938 m downwards due to the presence of both pesticide residue and heavy metals (1934 m for atrazine, 1938 m for mercury, 1934 m for lead and 1910 m for arsenic).

The priority short term intervention for this problem is public awareness for people to know the risks associated with consuming water from the contaminated river. This can easily be undertaken through the Likii River Water Resources Users Association (LRWRUA) which was formed in 2001 with the aim of tapping into the social and economic benefits of the river users, while addressing the conflicts between the various interests and stakeholders. LRWRUA need to be facilitated in order to raise awareness among their members who are the most likely victims of the negative impacts of water pollution in the river. The LRWRUA should also be empowered with the capacity to undertake water quality surveillance along the river in order to know how the state of water quality is changing from time to time and take action. The other short term intervention is for LRWRUA members to be urgently trained on the use of activated carbon filtration for the removal of heavy metals and pesticide residue which cannot be removed through the boiling of water before consumption. Cheap activated carbon filters for household use can be made from charcoal, sand and bones in order to remove a broad spectrum of chemical residues including heavy metals and pesticides from the drinking water. The County Government of Laikpia can take lead in these interventions. There is need for the national and county governments to ensure that slum settlements such as the Likii low-income residential area situated next to the rivers are provided with proper sanitary infrastructure in order to alleviate river pollution through improper waste disposal.

On the long term, there is need for more serious inspections and prosecutions by the PCPB in order to ensure that the distribution of dangerous pesticides is properly regulated. It is also necessary that the KEPHIS is adequately funded and equipped to inspect horticulture and floriculture farms more effectively to ensure that leakage of dangerous pesticides into the water ways is prevented. The National Environment Management Authority (NEMA) should also undertake impromptu environmental inspections and control audits in horticulture farms in order to ensure the protection of the neighboring environments especially rivers from which people can suffer long term and irreversible health damages. At the same time, further research is necessary to establish the environmental impacts of the military installations which are located along rivers.

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