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Monitoring of the Physicochemical and Bacteriological Quality of the Water of the Gounti-Yéna Basin and Assessment of the Impact on the Health of the Populations

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Abstract

The Gounti Yéna valley is the main watercourse that divides the left bank of the city of Niamey into two unequal parts. The area of its watershed is estimated at about 62 km^2. The objective of this study is on the one hand to evaluate the current state of the physico-chemical and bacteriological quality of the water of the Gounti Yéna basin and on the other hand to define the risks of water pollution and its origin in the face of the phenomenon of the rise in the water table of this basin by defining some health risks linked to these impacts. In order to properly carry out this work, we carried out a study of the evolution of the physicochemical and bacteriological parameters of the water of the Gounti Yéna basin during the period from November 2020 to October 2021, at three sampling points chosen from upstream to downstream of the basin then entomological surveys and among the health centers of the capital. The results obtained showed that the physico-chemical quality of water in the Gounti Yéna basin is influenced by climatic factors (precipitation and temperature) and anthropogenic actions. This study also highlighted the presence of faecal contamination in the water of the Gounti Yéna basin with a greater degree during the rainy season. This contamination remains worrying and constitutes a health risk causing waterborne diseases. The stagnation of the various bodies of water is also a favorable place for the development and spread of vector-borne diseases.

Keywords

Pond, Resurgence Point, Flooding, Health Impact, Urban Environment

1. Introduction

In the current context of climate change and urbanization, the two components of flood risk (hazard and vulnerability) are amplified, and the resulting flood risk increases [1]. Climate change is defined as a shift in the mean values of climate parameters or in the intensity of climate variability. In the Sahel, the most palpable example is the drought of the 1970s [2]. This drought, which is characterized by a 40% drop in regional rainfall [3], is responsible for a decrease in recharge which accentuated a lowering of the water table, which began at the end of the 20th century (from the 0.5 m per year) and a decrease in recharge estimated at 30%, also with consequences on the transformation of certain perennial streams into temporary streams [3] [4]. Since groundwater recharge is estimated at 10% of average annual precipitation, the repercussions of these climate changes on groundwater are then significant [5], groundwater recharge could thus decrease by 30% during the 21st century [6]. In addition to their direct effect on water resources, the droughts of 70 - 80 had an effect on mainly rural populations [7], causing them to move to urban centers in search of water subsistence, which further complicates the management of the already precarious Sahelian urban environment.

The good rainfall observed towards the end of the 1980s initiated a trend of rising groundwater levels. Three phenomena then come together to promote a rapid rise in the water table [8] which causes flooding depending on the level of outcrop, geology and geomorphology of the environment. First, there is an improvement in the climate with a return, if not to the situation of the 1950s-60s, at least to favorable rainfall from the beginning of the 1990s. This improvement in rainfall will contribute to strengthening the conjunction of two other phenomena [8] that are often linked: the cessation or reduction of pumping and anthropogenic actions such as deforestation and population growth.

Currently, cities are experiencing exponential population growth, a phenomenon that is linked to the growing complexity of urban systems [9]. The origin of the floods in these areas is therefore closely linked to the hydrogeological context characterized by a water table at a flush static level [10]. Sahelian cities like Dakar, Saint-Louis, Nouakchott, and more recently Niamey are constantly affected by this phenomenon. In Niamey, all year round, part of the Gounti Yéna watershed is then saturated with water by the outcropping of the water table on the surface of the ground, thus limiting infiltration [11]. They consist above all of cracks in buildings, damage to road networks, civil engineering works, etc. Beyond that, this situation leads to public health problems because the permanent water table is in direct contact with the accumulations of garbage and mixed with domestic wastewater from septic tanks, hence the proliferation of mosquitoes and numerous pathologies in certain districts. These floods therefore cause many environmental, social, economic and health impacts. The set of pressures exerted by the city on the water resource causing the disruption of the water cycle, flows, physico-chemistry of water, shows the interest to review the governance in terms of urban groundwater management hence the need for regular monitoring of the physicochemical and bacteriological quality of water and the evolution of the population of mosquitoes in the various urban centers in order to better prevent the impacts on the lives of people in general and their health in particular.

2. Materials and Methods

2.1. Presentation of the Site

The Gounti Yéna basin is located in the first 3 municipal districts of the 5 that make up the city of Niamey. The name of Gounti Yéna, which means "cool bottom" in Djerma, was given to this valley by the first inhabitants of the district in reference to the wooded valley with a cool microclimate. The Gounti Yéna watershed has an area of 61 km^2. It has an elongated shape (compactness index of Gravilius KG = 2.13) in a North-South direction where fruit gardens, market gardens (vegetable garden) and flower gardens have gradually developed [12]. The watershed has an altitude of 258 meters in its upstream part and an altitude of 179 meters in its downstream part at the level of its outlet which is located between the congress center and the Gaweye hotel, with a hydraulic path of about 25. The slope of the Gounti Yéna basin is generally low except in the main thalweg, downstream of Dar Es Salam where there are slopes of 10 m to 30 m/km, with a tendency to erosion and sinking of the bed which lasted until the relatively recent developments of the bed.

The Niamey region is subject to a semi-arid, Sahelian-type climate and is characterized by two very distinct seasons [13]: a short rainy season (June to September) and a dry season, from long duration (October to May) with average annual precipitation ranging from 350 to 750 mm and average annual potential evapotranspiration of 200 mm [14]. However, [15] states that in recent years, rainfall (annual total) rarely exceeds 600 mm/year.

2.2. Surface Water

Niamey is located in the valley of the Niger River, a river which constitutes the primordial element in environmental, economic and sociological terms and also in terms of risks for the surrounding populations. However, the Niger River is not the only flow vector and numerous Koris (generally temporary watercourses) mark the hydrography of the sector. Indeed, the Niger River with a maximum flow of 2340 m^3/s, crosses the city of Niamey over a length of more than 15 km. However, it experiences a disturbance of its regime due to the phenomena of silting, sedimentation and water erosion.

On the hydrological level (**Figure 1**), the city of Niamey [16]:

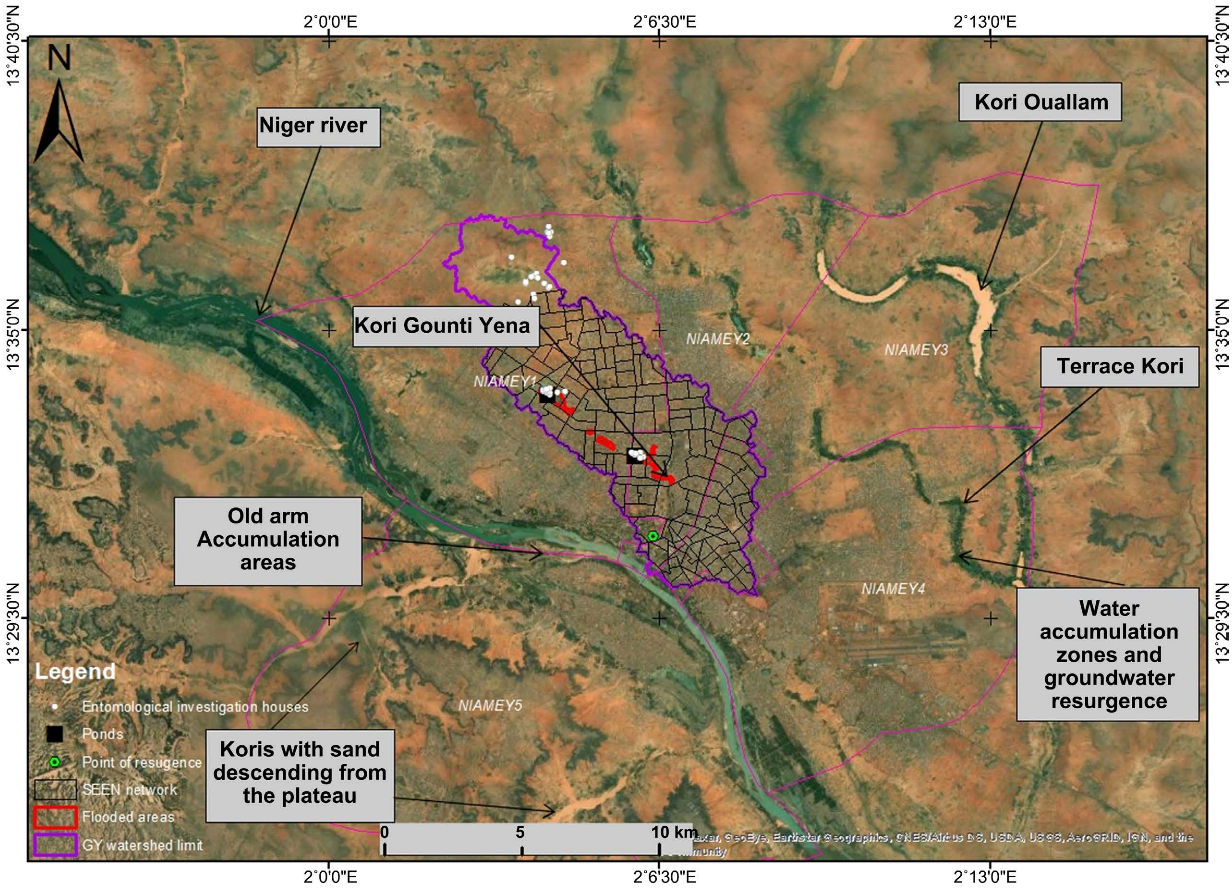

Figure 1. Location of the study area and distribution of sampling points and surface water.

- is bordered to the north and east by the Kori Ouallam and the Kori de Goudel Gourou;
- is crossed by the Kori Gounti Yena, which is the most important Kori crossing the city;
- is also at the crossing by the kori of Tondibia-Goudel, which has its source on a rocky outcrop to the north and which sands up the district of Goudel, and the kori of Yantala which is born on a rocky outcrop not far from the hospital national [17];
- present on the left bank, on the edge of the terraces overlooking the river, many very localized Koris, in particular towards the industrial area and the Saga district;
- present on the right bank of the Koris which descend from the plateau and some of which lead directly to the urbanized area.

2.3. Groundwater

Groundwater is the preferred water resource for drinking water, as it is safer from pollutants than surface water [18]. They are groundwater, layers of permeable land saturated with water.

The first water table encountered under the ground is the water table located less than 50 meters deep and generally separated from the surface by a few layers of permeable soil in certain places. To capture this water, wells, boreholes and springs are used according to the depth of the water table and rarely according to the needs.

2.4. Geology of the Study Area

The geology in the Gounti Yéna basin is made up of three (3) geological entities (Figure 2): at depth, the Meta-Liptako basement of lower Proterozoic age consists of plutonic (granites, granulites) and metamorphic (gneiss, quartzites, greenschists) in different states of alteration; this basement is covered by the Continental Terminal of Middle Eocene to Pliocene age and made up of alternating more or less clayey sandstone and versicolored clays with intercalations of levels of ferruginous oolites, these are the outcrops in the region at the west of Niamey belong to a vast quasi-horizontal sandy-loamy spreading reinforced by sandstone or lateritic levels and crowned by an armored plateau [19]. However, Niamey being located on the extreme southwestern edge of the Iullemmeden basin, it has only one layer known as CT3 [20]. Finally, near the Niger River and at the level of the koris are the Quaternary alluvia which are composed of coarse sands that are not very compacted.

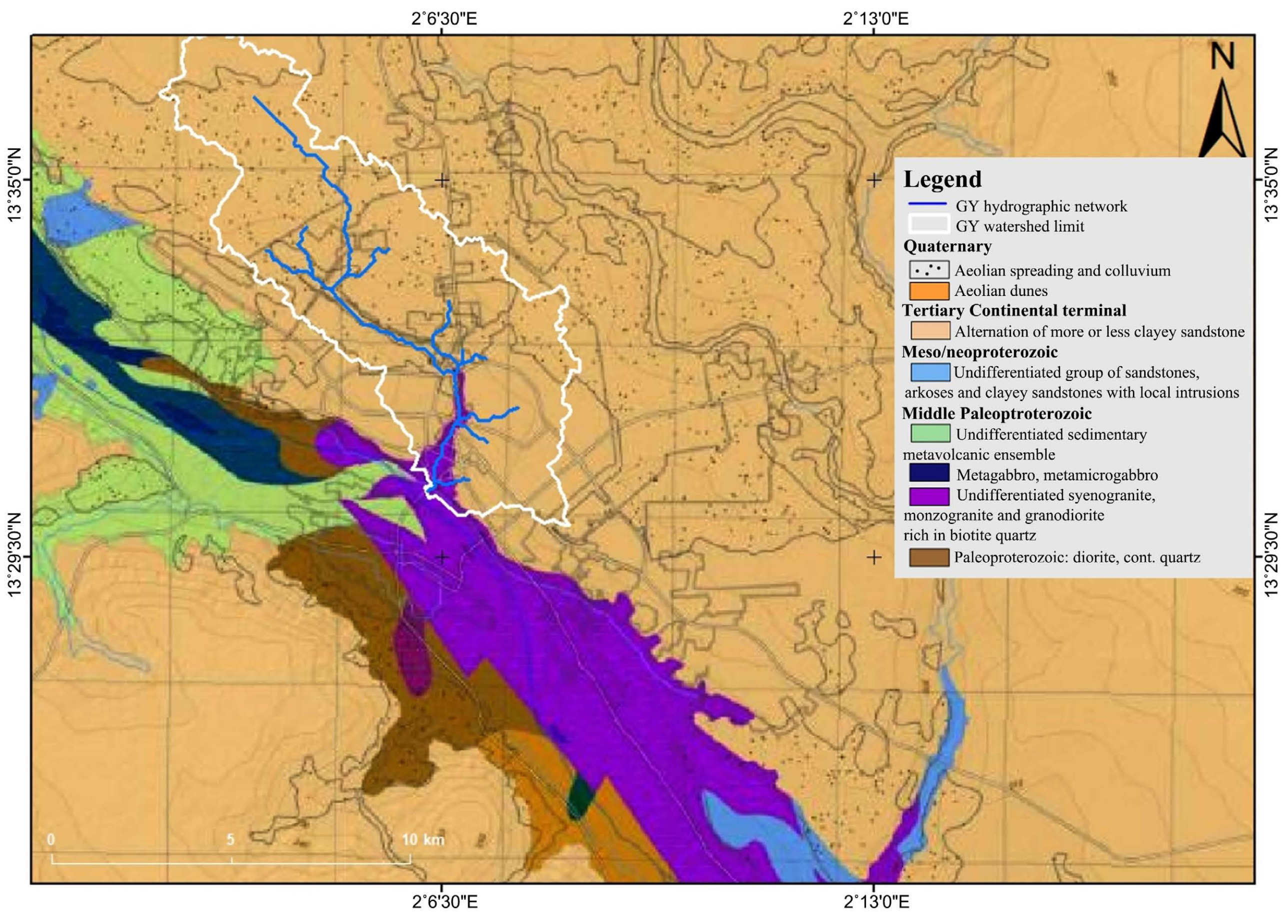

Figure 2. Geology of the Gounti Yéna basin (ABN-BGR, 2015; modified).

2.5. Study Area Hydrogeology

The three geological formations give rise to different aquifers: the bedrock aquifer captured by deep boreholes, the Continental Terminal 3 (CT3) aquifers and the alluvial aquifer captured by surface wells and sumps. The piezometric levels measured in 2020 and 2021 confirm an underground flow which takes place mainly from the NNW towards the South [21] towards the river and drainage towards the Gounti Yéna which is superimposed on this main axis of flow [22]. The hydrogeological functioning of the Continental Terminal water table has been studied and detailed by [23].

2.6. Setting up a Follow-Up Network

2.6.1. Water Quality

The monitoring network is made up of two ponds and a resurgence point (**Figure 1**). The two ponds are bodies of water that emerged following the rise and stagnation of groundwater on the surface and these water are often used in market gardening and nursery production. The results of the various analyses of the physicochemical and bacteriological parameters will be correlated with the rainfall records (daily and monthly). The analysis of these different ponds is above all linked to the fact that they are water from the underground environment by rising from the water table. In addition, this water can be used for human consumption by a phenomenon resulting in its return to the drinking water distribution network (**Figure 1**) of the Société d'Exploitation des Eaux du Niger (SEEN). Indeed, the pipes of this company are located at 80 cm in the city of Niamey, and in places just below these ponds where we sometimes observe their outcrop. In the dry season, during the low water period of the river, there are many water cuts in certain sectors of the capital, hence the probable return of this water from the ponds to the SEEN pipeline network. This then justifies the choice of these ponds.

2.6.2. Rainfall Records

The rainfall readings are taken from two direct-reading rainfall gauges set up as part of this work in the upstream flooded sector (within the FAZA school) and the downstream flooded sector (in the secondary education center of Dar_Es_Salam).

2.6.3. Entomological and Sanitary Surveys

Entomological surveys took place in three districts of the capital, namely SONUCI, Dar_Es_Salam and Karsamba, all based on the Gounti Yéna basin (**Figure 1**). The first two are located in areas that are permanently flooded all year round due to the combined phenomena of the rise in the water table and rainfall flooding. SONUCI is located in the upstream flooded zone, Dar_Es_Salam in the downstream flooded zone and Karsamba constitutes a non-flooded control site, located upstream of the Gounti Yéna watershed. In the context of this study, the collection method makes it possible to capture adult individuals. These are the method of capturing adult mosquitoes by sprinkling insecticide inside the rooms and the method of capturing using CDC-type light traps [24].

The health surveys concerned the different health centers (6) in constantly flooded places in order to collect information on the different diseases that are most often diagnosed, their frequency and the age groups exposed. The distances separating these health centers from the flooded areas vary from 300 to 800 meters.

2.7. Measurement Frequency

Two types of measurement were carried out within the framework of this study with regard to laboratory measurements of water quality: these are physico-chemical and bacteriological (*E. coli*) parameters.

For the physicochemical analyses, major ions and some heavy metals were measured, these are: Calcium, Magnesium, Sodium, Potassium, Bicarbonates, Chloride, Sulphates, Nitrates, Lead, Ammonium, Cadmium, Copper, Nickel, Chromium, Zinc, Phosphorus and Iron. These elements were measured and monitored in the different samples mentioned above at monthly measurement intervals for one year during the period from November 2020 to October 2021.

The microbiological characterization was carried out on the contents of faecal contamination indicators described by [25] [26] [27]. The contents of indicators of faecal contamination were focused on the determination of the rate of *E. coli*. These levels were determined and their evolution followed in the same samples. This time, for three periods: the rainy season, the cold dry season and the hot dry season.

The entomological survey took place during the period from October 2020 to June 2021 in order to cover all seasons of the year: rainy season; cold dry season and hot dry season. Each of the three study sites was subject to three visits due to one visit per season, considering 24 concessions, including 20 for indoor spraying and 4 for light traps.

2.8. Sampling Campaigns

As part of this study, campaigns were carried out in order to take samples which are then analyzed at the Quali-Control-Lab laboratory, at the Faculty of Agronomy of the University of Niamey and at the IRD representation in Niger. These samples are intended for physicochemical and bacteriological quality control.

The water is taken from two different, sterilized 500 ml bottles. The vial intended for physicochemical analyzes is filled to the top to avoid the formation of air bubbles. For the determination of the bacteriological parameters, the bottle is not completely filled in order to allow the bacteria to develop well. Both vials are kept in a cooler and transported to the laboratories.

2.9. Tools for Measuring Physicochemical and Bacteriological Parameters, Rainfall and Entomological and Health Surveys

For the determination of the physicochemical parameters, the materials used are: the HACH digital titrimetry, the HACH DR/3800 spectrophotometer and the JENWAY PFP 7 brand flame photometer.

For microbiology, we needed several tools such as 2 pipettes: 1 ml and 9 ml, 1 pipette with 8 tips, 4 trays, 4 sterile 15 ml bottles, sterile tips, lactate ringers, 1 marker, gloves, a support for flasks and a waste bin.

The rainfall data used come from FAZA and Dar_Es_Salam schools rainfall survey station.

For the entomological survey, the tools consist of white sheets, aerosol insecticide, light traps and petrie dishes.

Survey forms were developed and administered directly to the managers of the various health centers.

2.10. Methodological Approach

⌧ **Physicochemistry**

The different analytical techniques for chemical parameters are as follows:

- **Volumetry:** The chemical parameters determined are: Calcium, Magnesium (EDTA test), Bicarbonates (sulfuric acid test), Chloride (silver nitrate test).
- **Spectrophotometry:** The parameters determined by this technique are Nitrites, Nitrates, Iron, Sulphates, Zinc, Phosphorus, Copper, Cadmium, Ammonium, Nickel and Chromium.
- **Flame photometry:** For this technique, the apparatus used is the flame photometer allowing the determination of Sodium and Potassium.

⌧ **Microbiology**

Drinking water must be free of pathogenic microorganisms and must be free of any bacteria indicative of faecal contamination. Bacteria belonging to the coliform group as indicators of faecal contamination define the reference bacteria with *Escherichia coli* (indicators of recent pollution) as the main representative of this group of bacteria.

For the enumeration of *Escherichia coli*, the microplate technique using MUG has been recognized as being more specific, more precise, more accurate and faster than the methods used previously. It represents an important evolution compared to the usual techniques for *Escherichia coli* which, among the micro-organisms indicating faecal contamination, is of particular interest.

The aim here is to carry out a qualitative and quantitative characterization of the micro-organisms (*Escherichia coli*: indicator of faecal contamination) of the various water samples along the Gounti Yéna basin.

The plates have 96 wells including 12 rows of 8 wells. The manipulation consists in developing the micro-organisms of the water sample in an incubator, after it has gradually undergone several successive dilutions (4 in our case), brought into contact with ringers lactate which will nutrient function for micro-organisms then put in the 96 wells of our plate and closed with plastic to prevent evaporation and any other contamination. The incubator should ideally be at a temperature of 44˚C, because Escherichia are thermo-tolerant and this will already allow a kind of filtration to be carried out by eliminating other types of micro-organisms that cannot tolerate such heat. Incubation can be done at 44.0 ± 0.5˚C for a minimum of 36 hours and up to a maximum of 72 hours, in the context of this study, it is carried out at 44˚C and for 48 hours. After incubation, the wells showing blue fluorescence under UV at 366 nm are considered positive and later the Most Probable Number (MPN) is calculated. The most probable number represents the statistical estimate of the concentration of microorganisms sought in the sample analyzed. This estimate follows Poisson's law. The lower and upper limits correspond to a 95% confidence interval. The detection limit is 75 MPN/100 ml.

The different results for the physicochemical and bacteriological parameters will be presented in correlation with rainfall.

3. Results and Discussion

3.1. Water Facies

To compare the water, we represented the chemical analyzes in the form of triangular (Piper) and semi-Logarithmic (Schoeller-Berkaloff) diagrams.

⌦ **Piper diagram**

The Piper diagram [28] can be used to demonstrate the hydrochemical facies of the water samples analyzed. This diagram provides a convenient method for displaying, classifying, and comparing water types based on the ionic composition of different water samples [29]. The report of the annual averages of the results of the chemical analyzes of the water samples on the Piper diagram (**Figure 3**) shows: 1/3 of the samples are located at the sodium and potassium pole, 1/3 at the calcium pole and and 1/3 in the mixed enclosure at the level of the cation triangle. All the samples (100%) are found at the bicarbonate pole against at the level of the anion triangle.

The projection of these samples on the diamond diagram gives two types of facies (**Figure 3**); this is the sodium and potassium bicarbonate facies for two samples (W_FAZA pond and Deyzeibon resurgence point) and another type of calcium and magnesium bicarbonate facies for the Oriba station pond.

The concentration of the anions follows the following decreasing order: HCO_3^--Cl^--SO_4^{2-}-NO_3^- and that of the cations decreases following this order: Na^+-Ca^{2+}-Mg^{2+}-K^+.

Nitrates make up most of the anions when mineralization is high, while bicarbonates are more significant when mineralization is low [30], so when faced with relatively low mineralization, bicarbonates dominate over nitrates.

⌦ **Schoeller Berkaloff Diagram**

The Schoeller Berkaloff diagram is a semi-logarithmic diagram which allows to graphically represent the results of chemical analyses. Thus, the annual average of the results of the chemical analyzes of the three (3) water samples from the study area reported on the Schoeller Berkaloff diagram (**Figure 4**) show that the peak obtained at the bicarbonate pole and at the level of the sodium pole and potassium in Shoeller Berkaloff's Digram, confirm the name of the facies, it is of

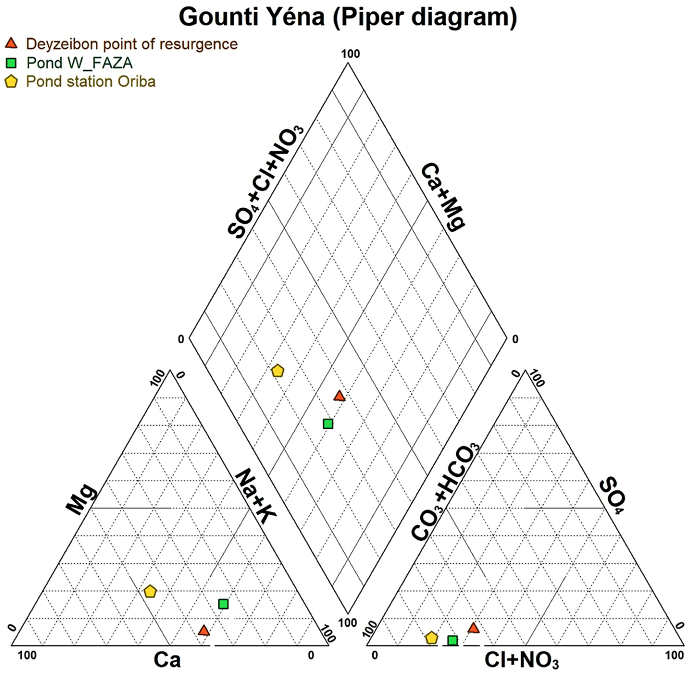

Figure 3. Piper diagram of water in the study area.

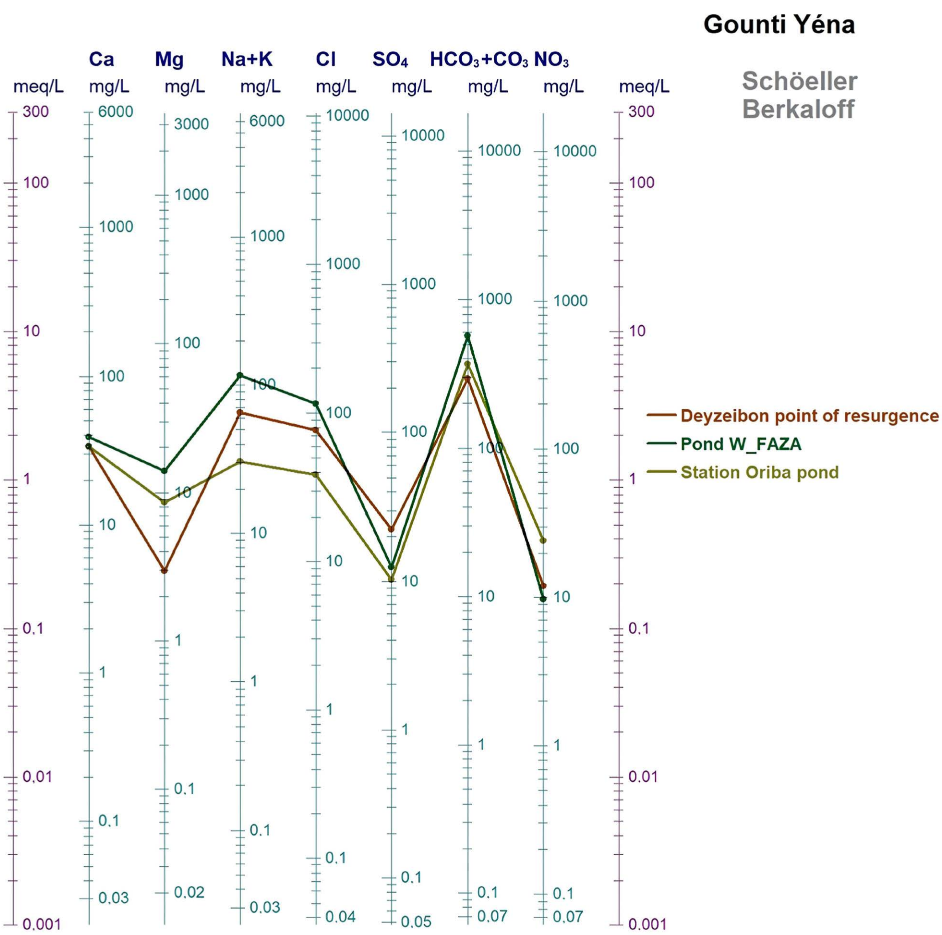

Figure 4. Schoeler Berkaloff diagram of water in the study area.

the sodium bicarbonate and potassium type. The parallelism of the curves representative of the samples implies that they are of the same origin (Figure 4).

3.2. Chemical Parameters

A total of 612 measurements were taken, *i.e.* 204 measurements per sample on the three sampling points chosen.

➢ **Major elements**

1) Calcium

Calcium is an alkaline earth metal extremely widespread in nature and in particular in limestone rocks in the form of carbonates. It is the major component of water hardness. The arrival of water therefore corresponds to a drop in the calcium content. We notice through Figure 5 that as soon as there is a rainfall the Calcium contents drop. These contents vary from 18 to 64 mg/l (Figure 5). All these values are below the standards set by the WHO.

2) Magnesium

Magnesium is the second significant element of water hardness after calcium. A maximum content of 59 mg/l is obtained (Figure 6).

3) Sodium

Sodium salts (eg sodium chloride) are present in virtually all foods (the main source of exposure) and in drinking water. Although sodium concentrations in drinking water are generally below 20 mg/l, they can be much higher in some countries. Levels of sodium salts in the air are normally low compared to levels measured in food or water. In surface water, it is difficult to establish a relationship with rainfall, the variation in these levels remains heterogeneous at the sampling points (Figure 7).

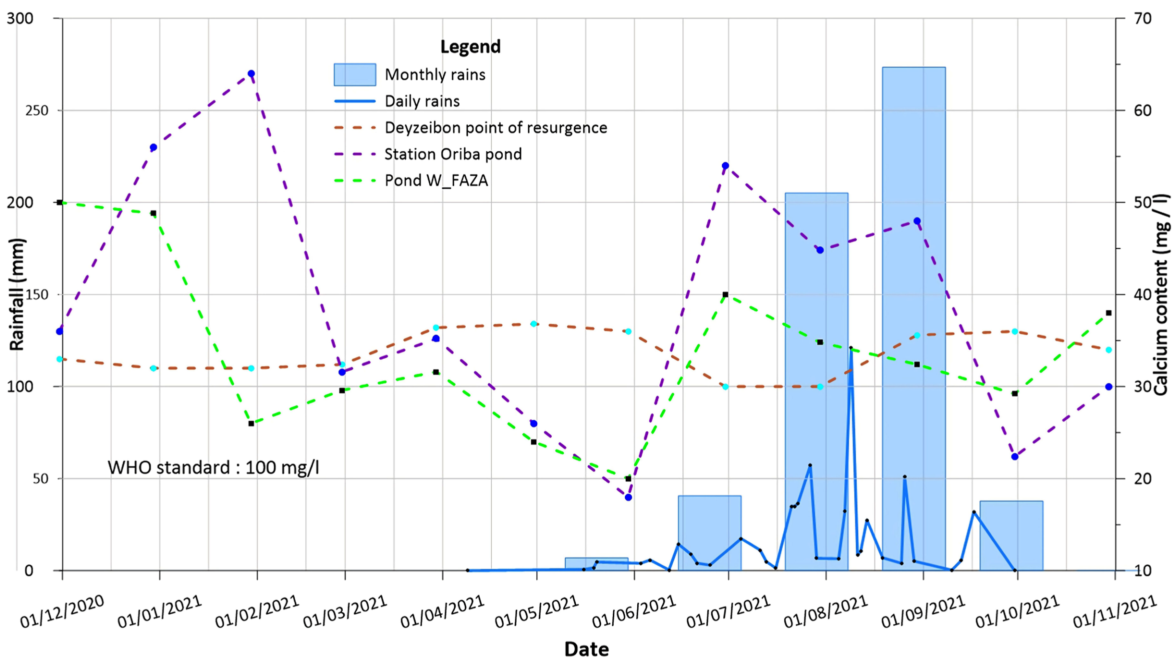

Figure 5. Variation in the calcium content of GY surface water according to rainfall.

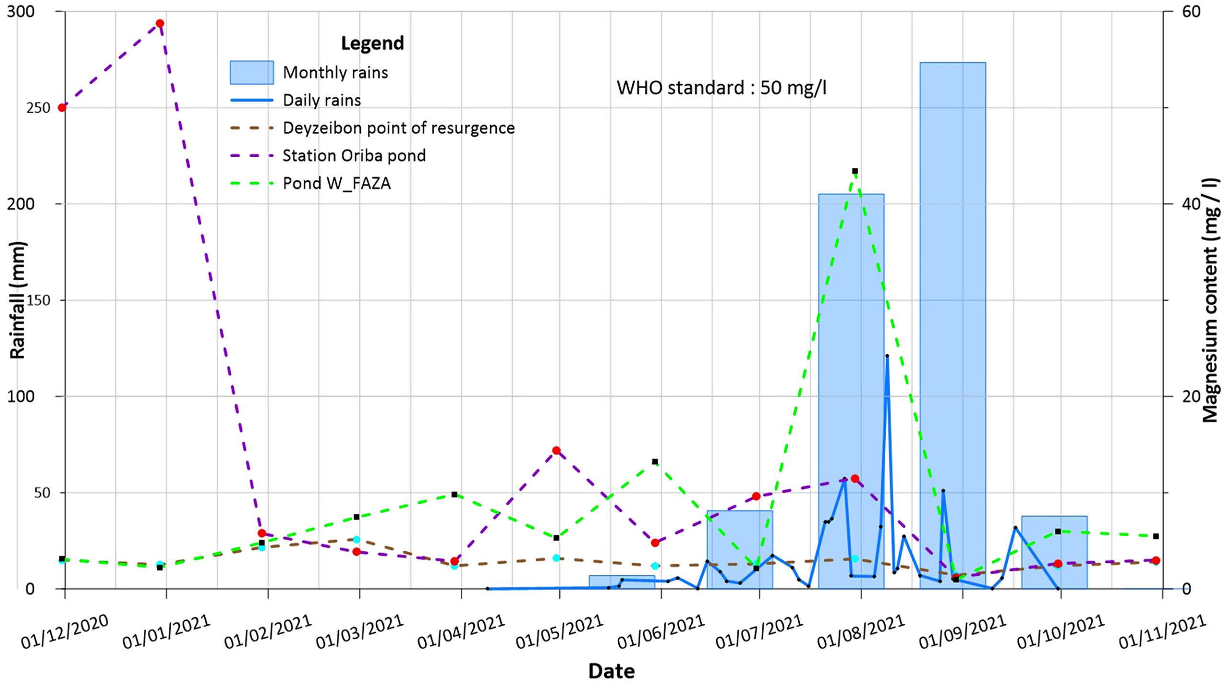

Figure 6. Variation in the magnesium content of GY surface water according to rainfall.

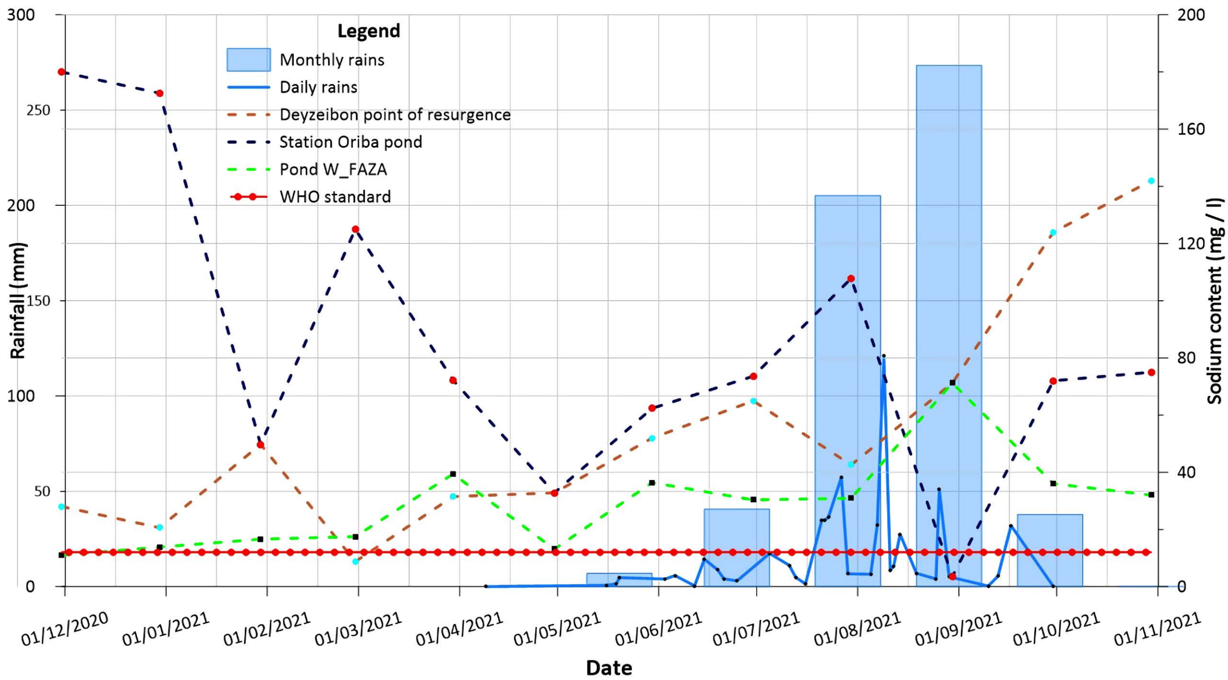

Figure 7. Variation in the sodium content of GY surface water depending on rainfall.

The sodium absorption rate (SAR) of the different samples and their conductivities (**Figure 8**) show that the latter have a low alkalizing power through the Riverside diagram, which implies that these water can then be used on n' any type of soil in the context of irrigated crops without danger of alkalinization of the soils used.

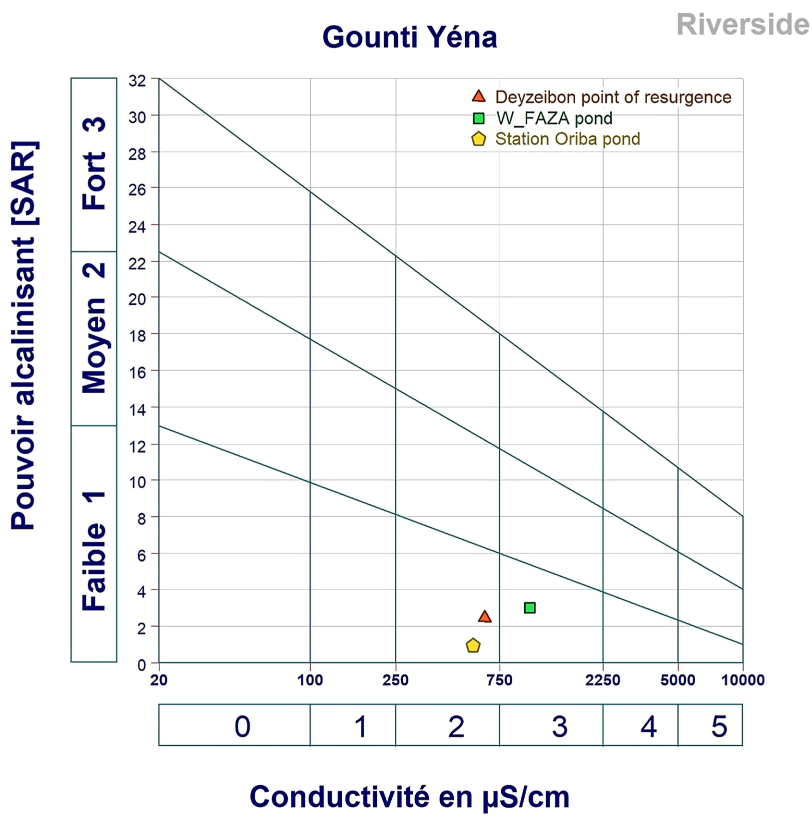

Figure 8. Suitability of water for irrigation.

4) Nitrite

Nitrites come either from an incomplete oxidation of ammonia, or from a reduction of nitrates under the influence of a denitrifying action. Water that contains nitrites is to be considered suspect. The nitrite ion (NO_2^-) is usually not detected in significant concentrations except in reducing environments, because nitrate represents the most stable oxidation state. Nitrite can be formed by microbial reduction of nitrate and, in vivo, by reduction of ingested nitrate.

In general, the largest source of human exposure to nitrates and nitrites comes from vegetables (nitrites and nitrates) and meat foods (nitrites are used as preservatives in many deli meats). Since the WHO standard is 3 mg/L, all the values measured remain below this standard (Figure 9).

5) Nitrates

The nitrate ion (NO_3^-) occurs naturally in the environment and is an important nutrient for plants. It is present in varying concentrations in all plants and is one of the links in the nitrogen cycle. The absorption of nitrates by ingesting vegetables, meat or water is rapid and greater than 90%; they are eventually excreted in the urine. In humans, nearly 25% of ingested nitrates end up in the saliva, 20% of which are converted into nitrites by the action of bacteria in the mouth. All forms of nitrogen are likely to be the source of nitrates by a process of biological oxidation. The contents are higher in the dry period than in the rainy one. This temporal evolution of NO_3 was also observed in the work of [31].

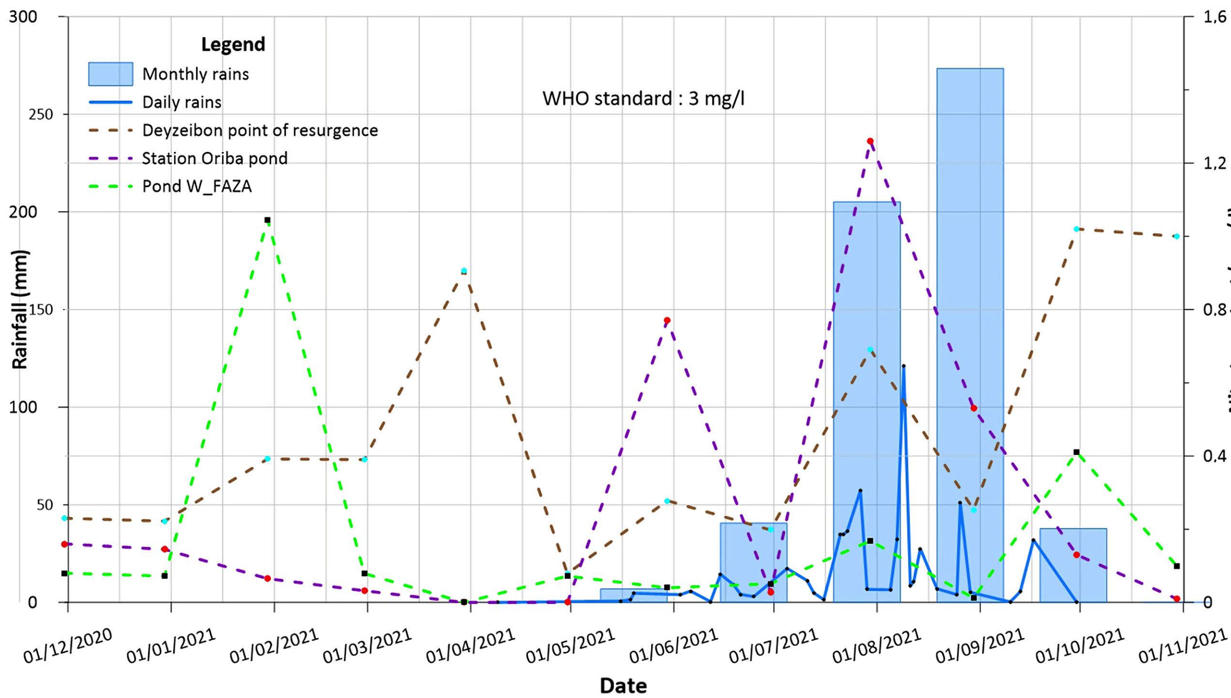

Figure 9. Variation in the nitrite content of GY surface water depending on rainfall.

The nitrate inputs could be linked to the leaching of agricultural soils upstream of the catchment area and the discharge of wastewater from the city into the plans of water.

The levels show pollution of organic origin linked to contact with water from the cesspools (Figure 10).

The distribution of Nitrates remains very variable in space and time, despite factors favorable to the enrichment of water in nitrates, it appears that most water points have a concentration below the drinkability limit set by WHO [32] throughout the monitoring period except in September for the Oriba station pool and October and November for the W_FAZA pool.

6) Potassium

It is a mineral salt that plays an essential role for the proper functioning of the body. On the other hand, a very high potassium level in the blood can be dangerous and have serious consequences (for example serious heart problems). Potassium is widely distributed in the environment, especially in all natural water.

The levels of this element are higher at the start of the rainy season (Figure 11). The fact that these levels are higher at the start of the season means that the external inputs (atmospheric and anthropogenic) are greater during this period. Concentrations exceeding WHO standards are noted, especially during the rainy period.

7) Bicarbonates

There is no WHO standard for this element, but a high concentration of bicarbonates gives a salty flavor to the water. These levels are probably explained

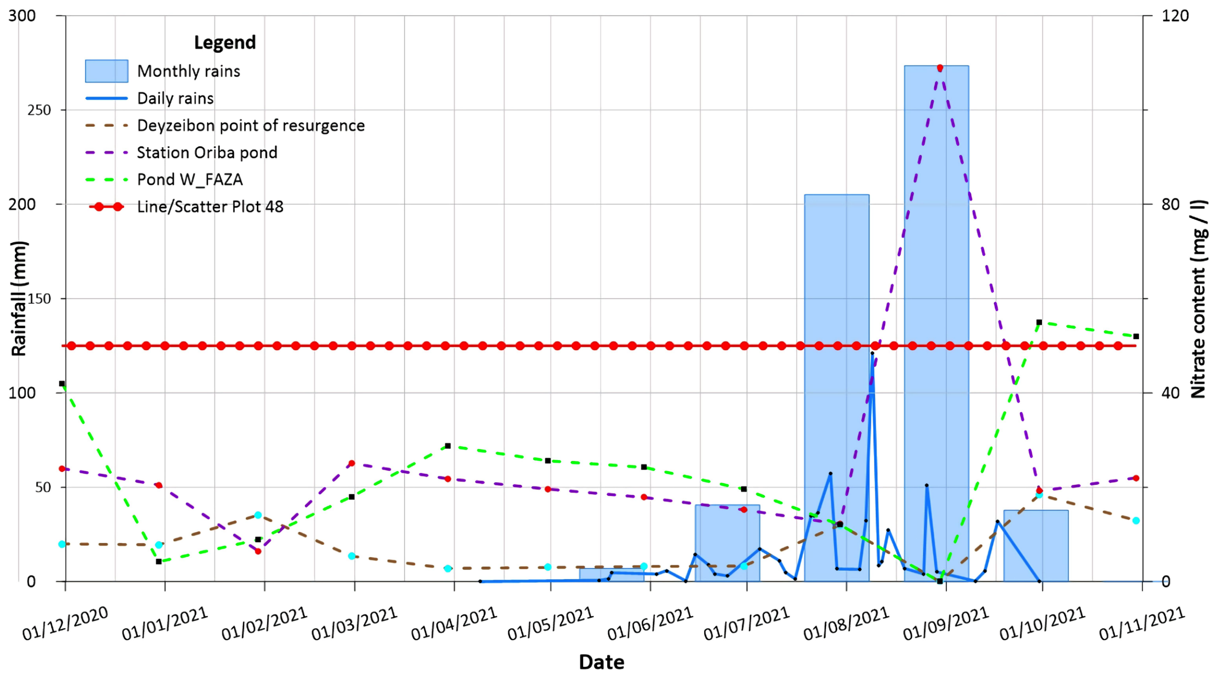

Figure 10. Variation in the nitrate content of GY surface water according to rainfall.

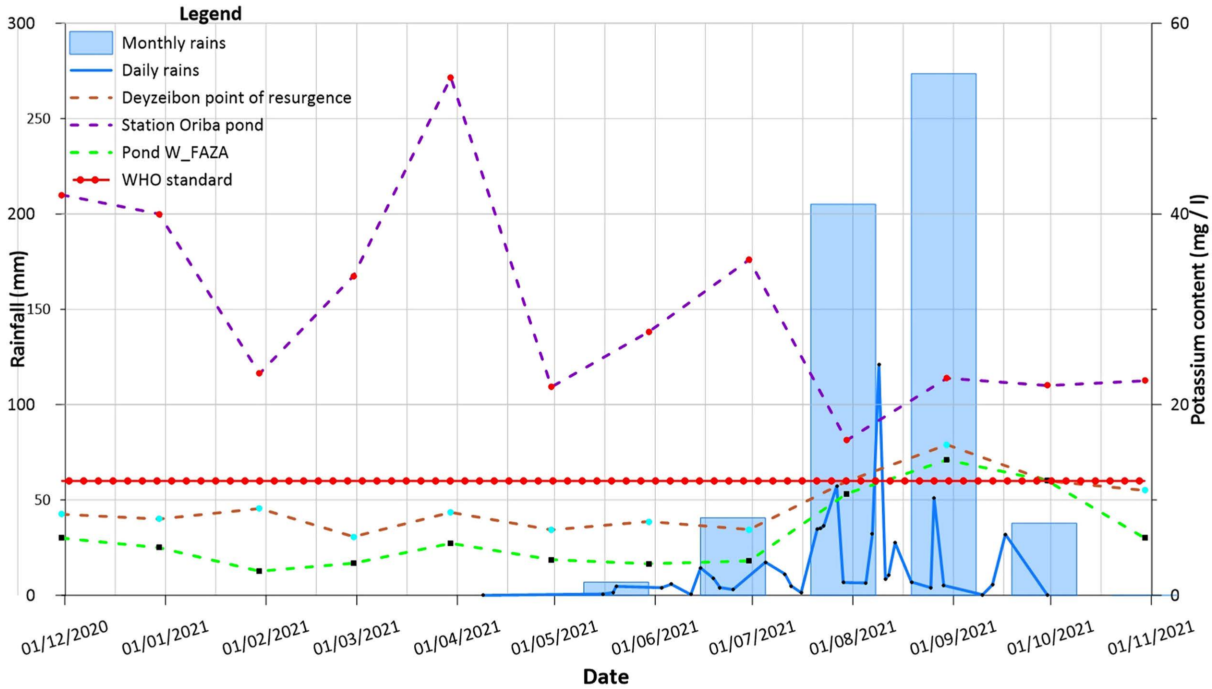

Figure 11. Variation in the potassium content of GY surface water according to rainfall.

by the low dissolution of carbon dioxide at ground level. They are lower during the hot dry period, particularly in February, March, April and May (Figure 12).

8) Sulphates

The sulfate anion is one of the least toxic anions. A laxative effect has been observed in people who consumed drinking water containing more than 600

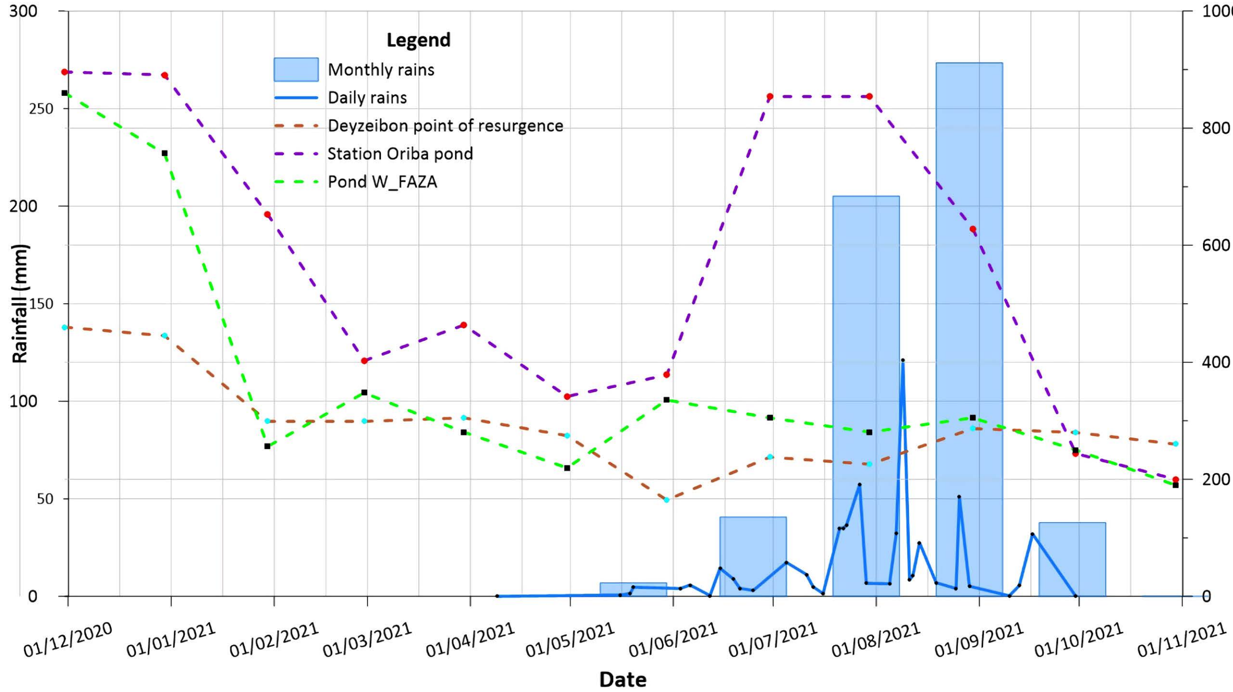

Figure 12. Variation in the bicarbonate content of GY surface water depending on rainfall.

mg/L of sulphates. Sulfates occur naturally in many minerals and are marketed primarily for the chemical industry. Their presence in water comes from industrial waste and atmospheric deposits. In general, the average daily ingestion of sulfates from drinking water, air, and food is about 500 mg, with food being the major source. In accordance with the work of [33], there are few sulphates. The levels recorded throughout the study period do not exceed the limited standard [34] (**Figure 13**).

9) Chlorides

They are often used as a pollution index [35]. Chloride in water comes from natural sources, sewage and industrial effluents, urban discharges containing road salt, and saline water intrusion. No guideline value based on health arguments is proposed for chloride in drinking water.

The chloride ion is never absorbed by geological formations, it is a special element. High concentrations of chlorides are linked to water pollution. The concentrations of this element are homogeneous with a good correlation between rainfall and chloride content (**Figure 14**).

➢ **Heavy metals**

Heavy metals likely to be found such as lead, cadmium, cyanides, mercury, etc...are dangerous, even in trace amounts.

1) Lead

The presence of lead in tap water is rarely due to its dissolution from natural sources. The standard set by the WHO is 0.01 mg/L and no trace of lead was detected in the various analyses.

2) Ammonium

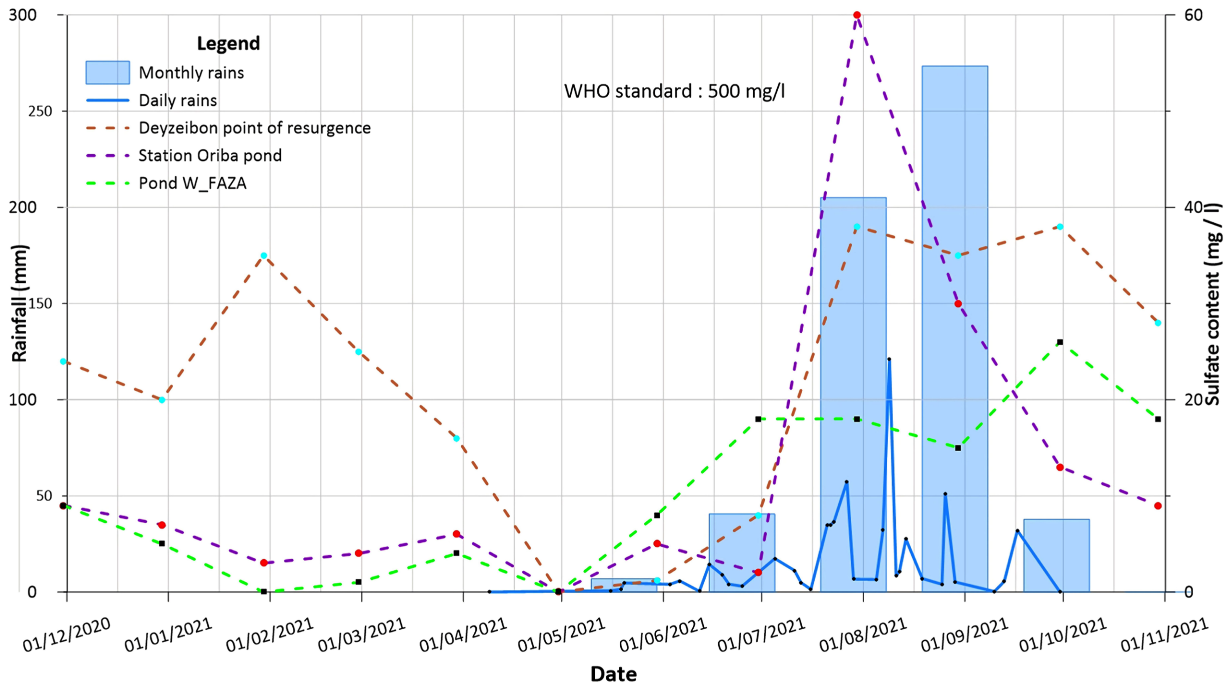

Figure 13. Variation in the sulphate content of GY surface water according to rainfall.

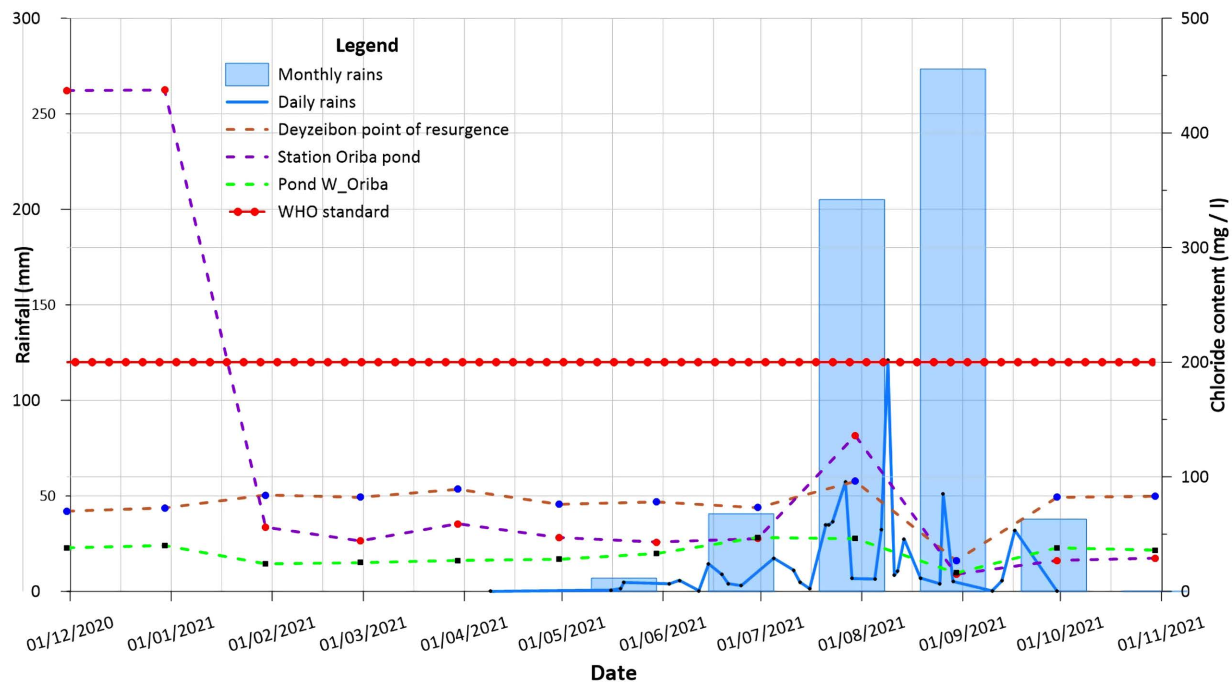

Figure 14. Variation in the chloride content of GY surface water according to rainfall.

The term ammonia includes non-ionized (NH_3) and ionized (NH_4^+) species. Ammonia in the environment is generated by metabolic, agricultural and industrial processes; it can also come from disinfection by chloramine. Intensive farming of farm animals can cause much higher levels in surface water. Ammonia contamination can also come from the interior lining of cement mortar pipes.

Ammonia in water is an indicator of possible bacterial contamination or pollution from sewage or animal waste. According to WHO, concentrations should not exceed 0.003 mg/l.

Figure 15 shows contents exceeding this limit for all the sampling points and throughout its period with an increase in these contents especially in the rainy season. We note an increase in these levels in proportion to the rainfall in surface water. This increase in this period would be related to the bacterial decomposition of nitrogenous organic matter due to the slight decreases in dissolved O_2 levels recorded during these periods. These results agree with the work of [35] [36]. Ammonium is preferentially absorbed when algae simultaneously have NH_4^+ and NO_3^- [37], which explains the low levels measured in the dry season, without neglecting the part of nitrification because the environment is well oxygenated.

According to [38], the dosage of ammonia gave very high results in surface water (Gounti-Yéna and pond). This ammonia pollution has also already been highlighted by [39] on a well in a garden in Gounti Yéna.

3) Cadmium

Cadmium enters the environment through wastewater; diffuse pollution is due to contamination by fertilizers and local air pollution.

The absorption of cadmium compounds depends on their solubility. Cadmium accumulates mainly in the kidneys and has a long half-life in humans (10 to 35 years). Cadmium has been shown to be carcinogenic when inhaled and the IARC has classified cadmium and its compounds as Group 2A (probably carcinogenic to humans). However, there is no evidence for the carcinogenicity of

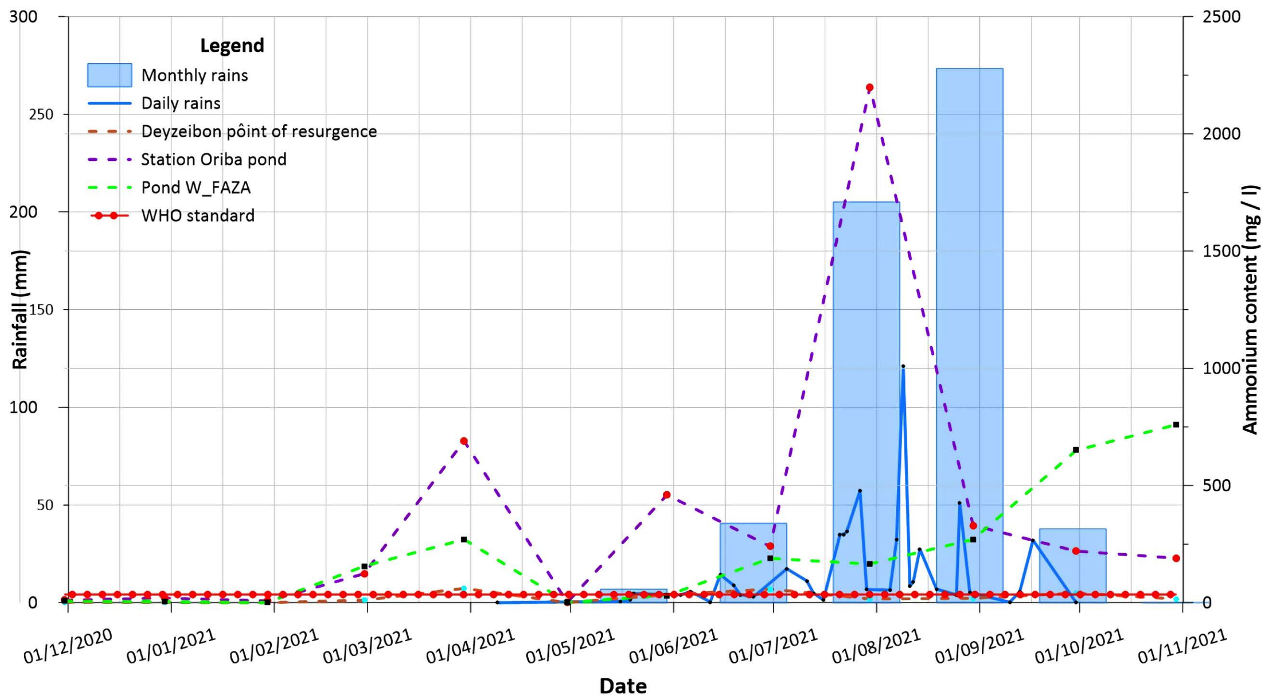

Figure 15. Variation in the ammonium content of GY surface water depending on rainfall.

oral cadmium and no clear evidence of its genotoxicity. The kidney is the main target organ for cadmium toxicity. All measurement values are above WHO standards except for two measurement points. These are the W_FAZA pond and the oriba station pond, respectively recording levels of 0.008 and 0.004 mg/l in April (Figure 16).

4) Copper

Copper is both an essential nutrient and a drinking water contaminant. Levels in running water or after complete flushing tend to be low whereas in standing water samples (Figure 17) concentrations are more variable and can be significantly higher (frequently above 1 mg/l). Drinking standing water can significantly increase total daily copper exposure.

5) Nickel

The contribution of water to nickel exposure can be significant when, for example, the level of pollution is high. The most commonly observed effect of nickel in the general population is allergic contact dermatitis. The WHO standard is 0.07 mg/l and the levels measured for surface water exceed the WHO standards for the two ponds in the hot dry season, particularly in February for the Oriba station pond and in April for the W_FAZA pond (Figure 18). These levels drop during the rainy season.

6) Chromium

Chromium is widely distributed in the earth's crust. It has a range of valences from +2 to +6. Chromium (III) is an essential nutrient. The maximum value accepted by the WHO is 0.05 mg/l. All the measurements are heterogeneous and for a very large part exceed the WHO standards (Figure 19).

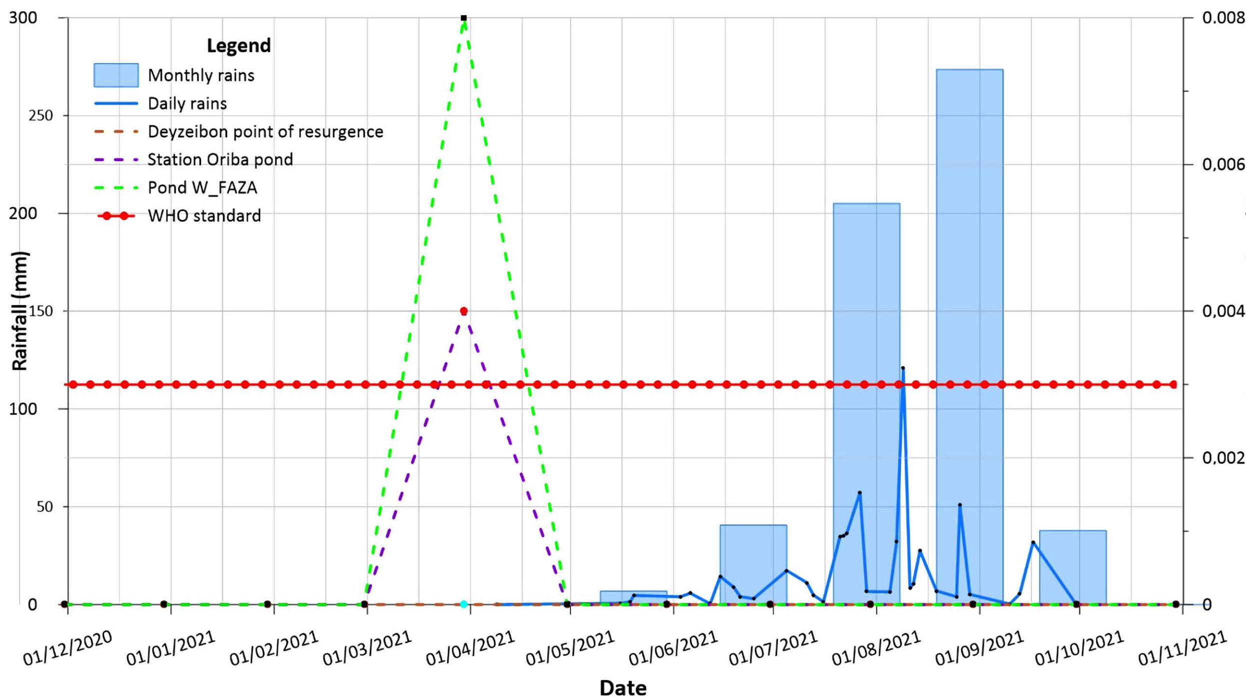

Figure 16. Variation in the cadmium content of GY surface water depending on rainfall.

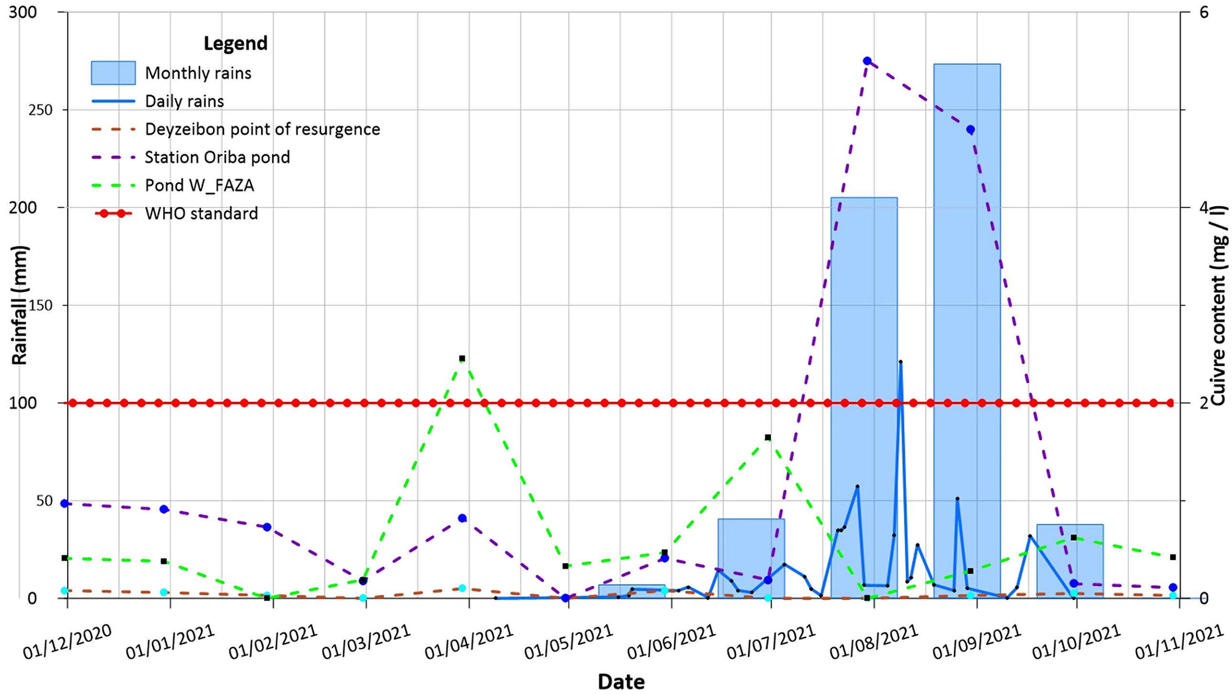

Figure 17. Variation in the copper content of GY surface water depending on rainfall.

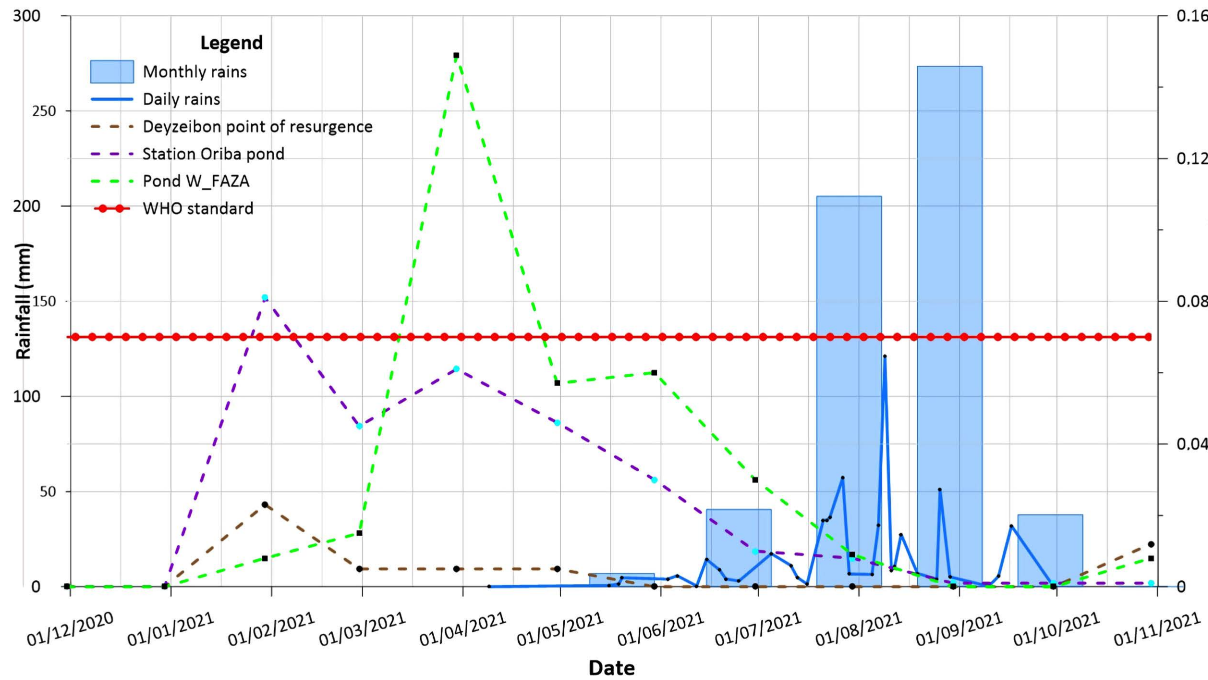

Figure 18. Variation in the nickel content of GY surface water depending on rainfall.

7) Zinc

Zinc is an essential trace element found in virtually all foods and drinking water in the form of salts or organic compounds. Zinc levels in surface water usually do not exceed 0.01 and 0.05 mg/l. The standard set by the WHO is 3 mg/L, this standard is exceeded for the Oriba station pond during the rainy season (Figure 20).

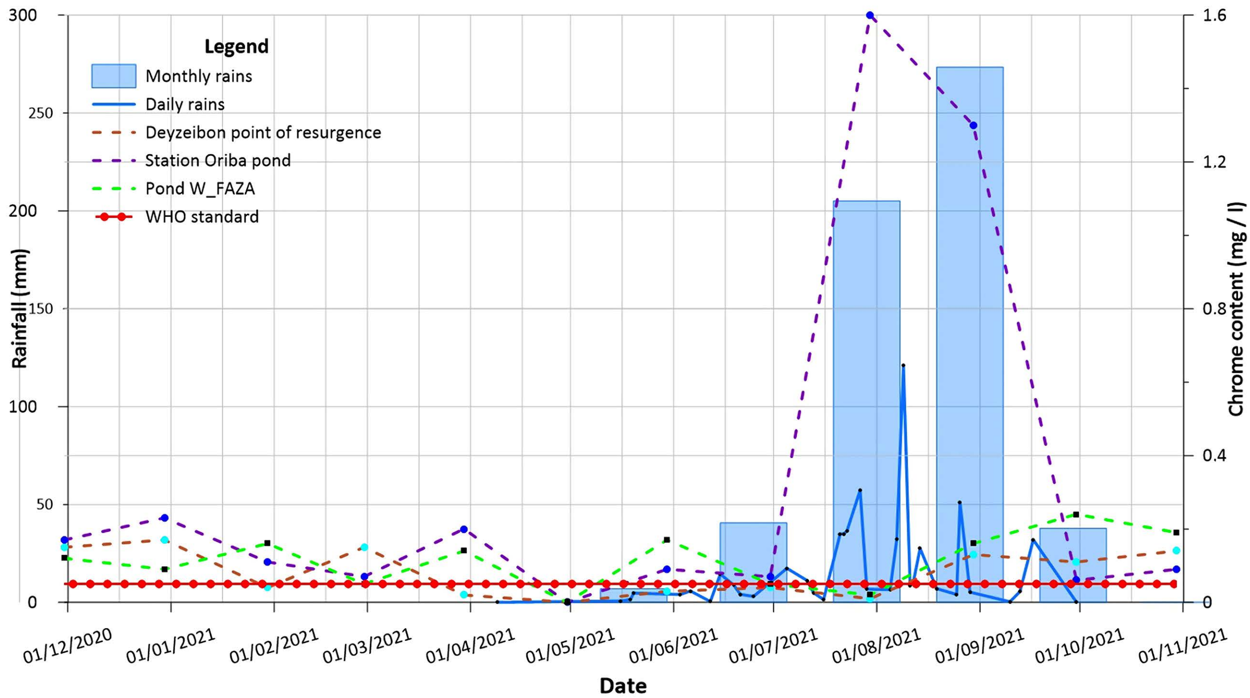

Figure 19. Variation in the chromium content of GY surface water depending on rainfall.

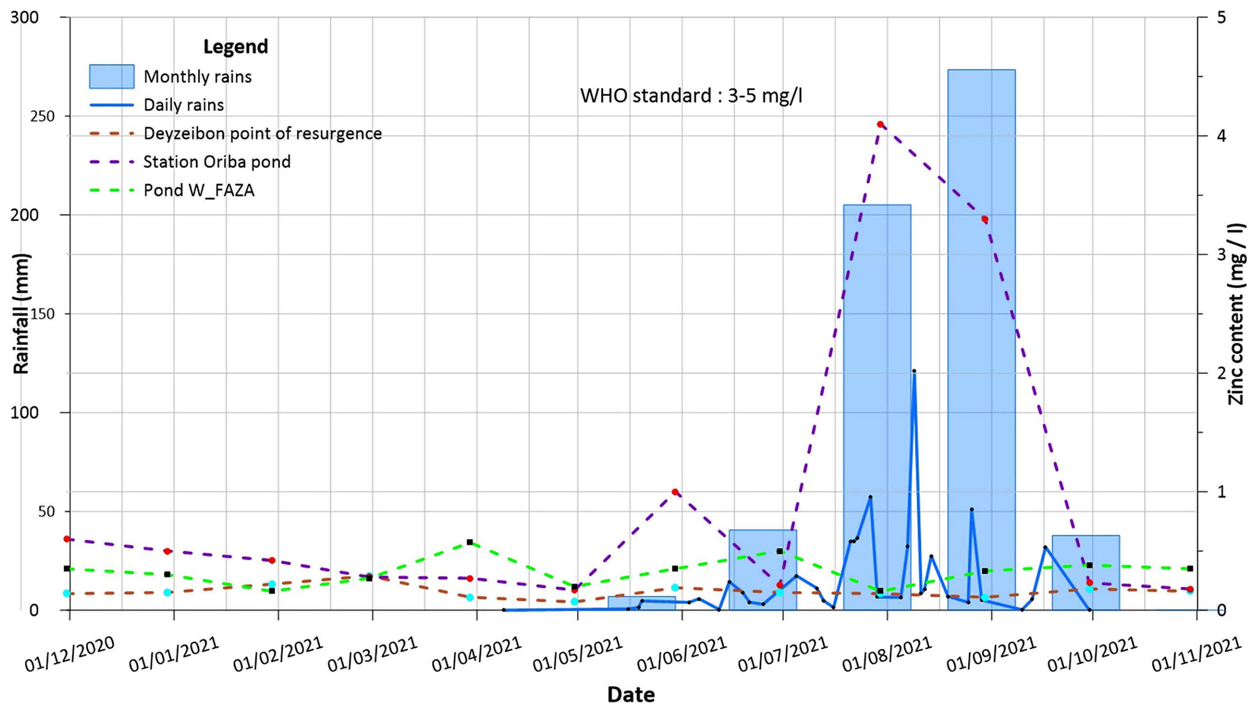

Figure 20. Variation in the zinc content of GY surface water depending on rainfall.

8) Phosphorus

Regarding phosphorus materials, the main indicator is the concentration of total phosphorus, which must not exceed 0.2 mg/L. Phosphorus flows have three origins: collective domestic sanitation, discharges from livestock buildings and phosphorus departures by soil erosion. This last parameter is very difficult to assess and depends not only on the type of soil, its richness in phosphorus, but also on land use and spatial planning. In surface water, phosphorus is essential for plants, but, in excessive quantities, it mainly contributes to modifying the biological balance of aquatic environments by causing eutrophication phenomena.

For all the analyses, high levels are observed in March (Figure 21). This increase in the concentration of phosphorus in the water of the Gounti Yéna basin during this period is due to the increase in organic compounds in the water, which promotes very advanced mineralization of organic matter.

9) Iron

It is soluble in the Fe^{2+} ion state (ferrous ion) but insoluble in the Fe^{3+} state (ferric ion). It is present in natural fresh water at levels between 0.5 and 50 mg/l. The presence of iron in water can promote the proliferation of certain strains of bacteria that precipitate iron. The WHO standard is 0.3 mg/L. The ponds of the oriba and W_FAZA station all have concentrations greater than or equal to the WHO standard throughout the monitoring period (Figure 22).

Observation: Depending on the time of year and the dosed parameter, the different measurement points have levels exceeding the standards set by the WHO, the return of this water to the drinking water distribution pipes of the SEEN remains a worrying fact as to the health of the population for whom this water is intended (Table 1).

3.3. Microbiological Parameters (*E. coli*)

The bacterial load is a little high in the hot dry season for the W_FAZA pond and the Deyzeibon resurgence point (Figure 23); this load decreases during all

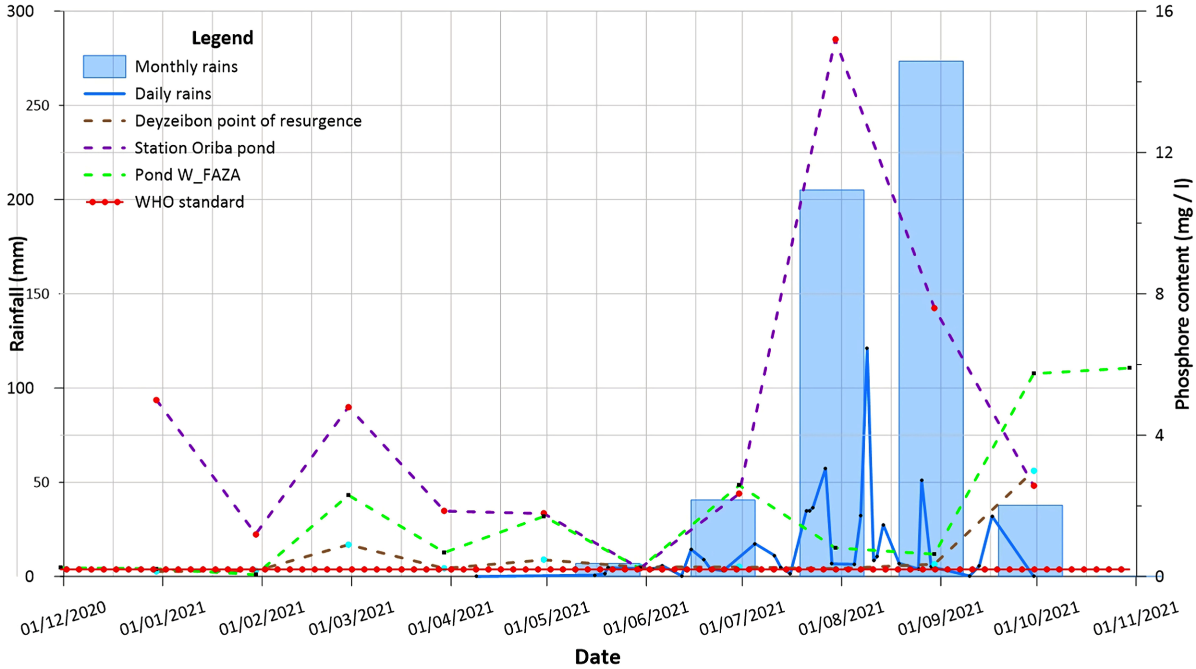

Figure 21. Variation in the phosphorus content of GY surface water according to rainfall.

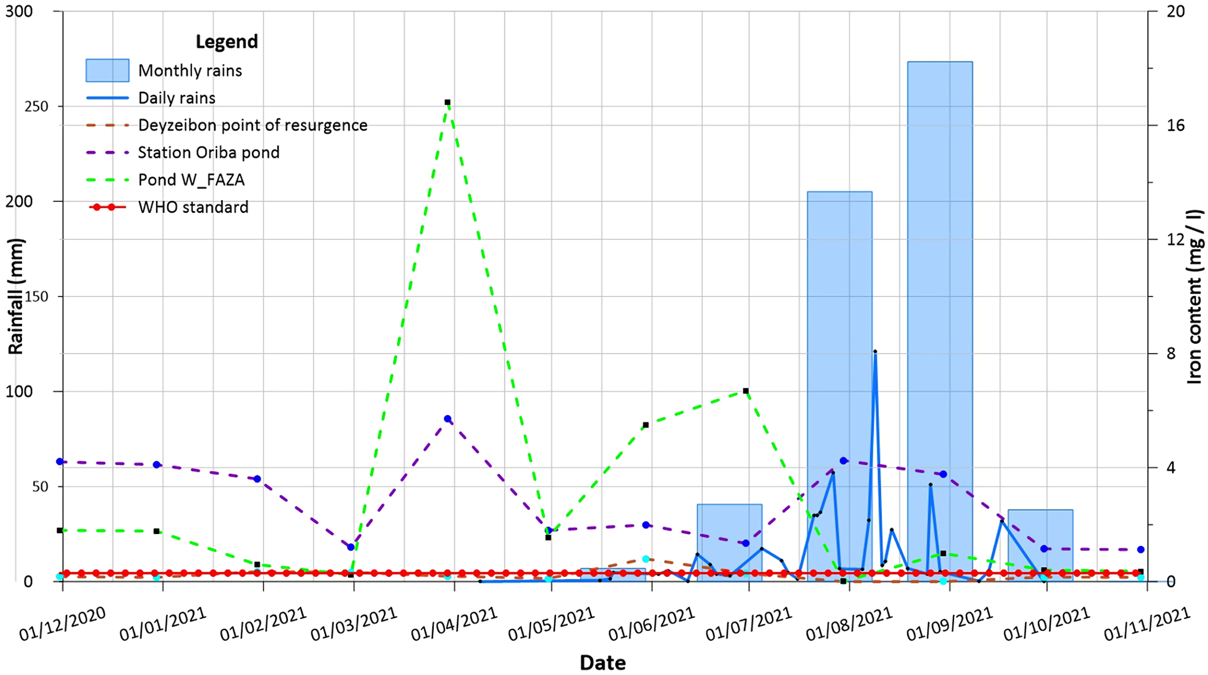

Figure 22. Variation in the iron content of GY surface water according to rainfall.

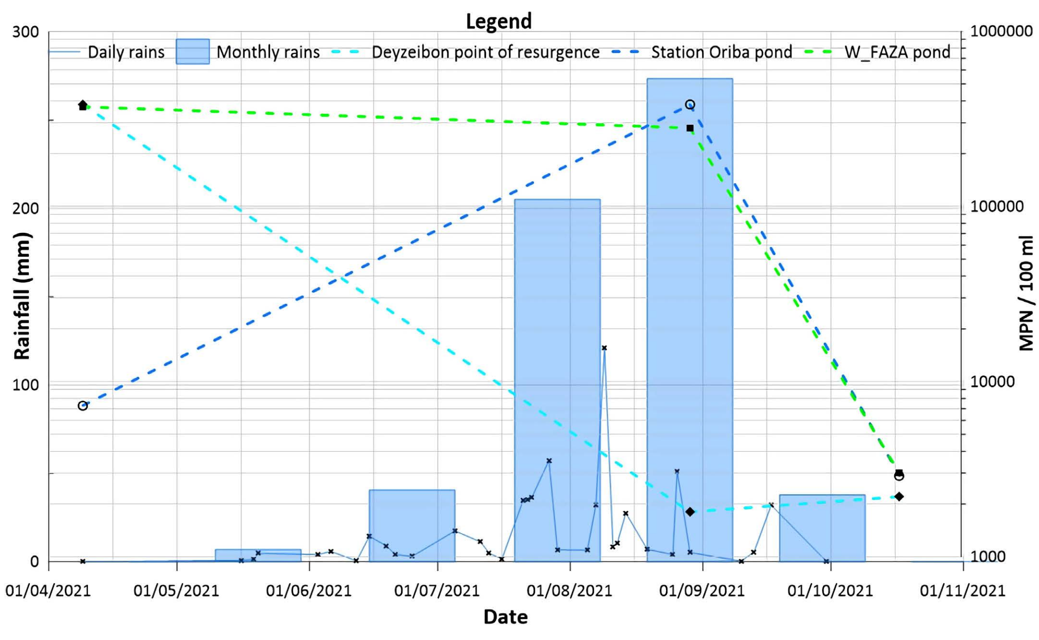

Figure 23. Variation in *E. coli* populations in the water of Gounti Yéna depending on the time of year in 100 ml.

Table 1. Sampling points exceeding WHO standards depending on the period.

Sampling point	Element	Date
Deyzeibon point of resurgence	Sodium	June
Station Oriba pond	Sodium	All the year except September
Station Oriba pond	Nitrate	September

Continued

Pond W_FAZA	Nitrate	October and November
Station Oriba pond	Potassium	All the year
Deyzeibon point of resurgence	Potassium	September
Pond W_FAZA	Potassium	September
Station Oriba pond	Chloride	December and January
Station Oriba pond	Ammonium	All the year except January, February and May
Pond W_FAZA	Ammonium	All the year except January, February and May
Station Oriba pond	Cadmium	April
Pond W_FAZA	Cadmium	April
Pond W_FAZA	Cuivre	April
Station Oriba pond	Cuivre	August and September
Station Oriba pond	Nickel	February
Pond W_FAZA	Nickel	April
Station Oriba pond	Chromium	All the year except May
Pond W_FAZA	Chromium	All the year except and august
Deyzeibon point of resurgence	Chromium	All the year except April, May, June, July and August
Station Oriba pond	Chromium	All the year except May
Station Oriba pond	Zinc	August and September
Station Oriba pond	Phosphorus	All the year
Pond W_FAZA	Phosphorus	All the year
Deyzeibon point of resurgence	Phosphorus	All the year
Pond W_FAZA	Iron	All the year
Station Oriba pond	Iron	All the year

the other two periods of the year for these sampling points. It is much higher in the rainy season at the Oriba station pond, then in the hot dry season and finally in the cold season (Figure 23). This can be explained by the fact that the Oriba station pond receives water from everywhere, therefore very heavy, in addition to that of the aquifer, while the W_FAZA pond receives almost only rainwater combined with rising water, of the aquifer as well as the Deyzeibon resurgence point whose nature characterizes it.

All sampling points are contaminated with agents of faecal origin. The quantity of micro-organisms presents in water increases with rainfall, although no study has so far been able to establish a simple law formally modeling these two parameters. Microorganisms are very common in surface water (Figure 23).

They are the group of pollutants that cause the most disease. It should be noted that the survival time of pathogens (bacteria) is shorter in acid soils (pH 3

- 5) than in basic soils.

3.4. Origin and Factors of Pollution of Water for Domestic Use

The origin of water pollution can be natural or anthropogenic [40]. The main factors that control the physico-chemical and bacteriological quality of water are human activities, the hydrogeological context and the climate [41]. [42], 1996 and Kenfaoui, 2008 clarify that the main sources of anthropogenic pollution are agriculture, which applies diffusely to the territory; industries which are the source of very diversified and often localized discharges and domestic activities via waste water discharges or landfills. [43] distinguished four sources of pollution in the city of Niamey, including domestic sources, industrial sources, hospital sources and agricultural sources.

The presence of nitrites and nitrates in the water comes from deficient septic systems [44]; fertilizers, wastewater, landfills, runoff water, soil leaching by precipitation and nitrogen oxidation, oxidation of nitrites by bacteria following exchanges with wastewater.

3.5. Mosquitoes Captured

3.5.1. Specific Identification of Mosquito Populations Collected

The identifications made on captured individuals are essentially morphological. They are carried out by means of a binocular magnifying glass based on the different determination keys, making it possible to identify the genus, the species and the sex [45] and also with the Xper2-Identification software using bases data that combine both the distinctive criteria of the species and the description of each species.

3.5.2. Population Distribution of Captured Species

From October 2020 to June 2021, the three capture sessions carried out on the study sites (Dar es salam, sonuci, karsamba) made it possible to collect 3635 individuals belonging to six species of the vector entomofauna, including 5 from the family of Culicidae (Mosquitoes) and a single species in the family Psychodidae (Sandfly) (**Table 2**). All six species were found in SONUCI, four of the six in Dar es Salaam, and three in Karsamba (**Table 2**).

Culex sp is the species for which the abundance value is higher. This value is 69.2% with 2517 individuals, followed by that of *Anophele gambiae* which is 29.5% with 1071 individuals and the lowest value is for *Anophele rufipes* with 0.1% and only 5 individuals (**Figure 24**).

3.5.3. Relative Abundances of Species by Site

Relative species abundance values vary from site to site. At all sites, the highest AR% value was noted for *Culex sp* or 83.3% with 1431 individuals in Dar es Salaam; 51.48% with 798 individuals in SONUCI and 78.5% in Karsamba with 288 individuals. Followed by that of *An. gambiae* which is 16.0% and 275 individuals in Dar es Salaam; 46.39% in SONUCI with 719 individuals and 21.0% in

Table 2. Overall list of species encountered at the 3 sites.

Species	Site		
	Dar Es Salaam	Sounuci	Karsamba
An. gambiae/arabiensis	1	1	1
An. rufipes	1	1	0
Culex sp	1	1	1
Ah. aegypti	0	1	1
Mansonia sp.	1	1	0
Sandfly sp.	0	1	0

1: Presence; 0: Absent.

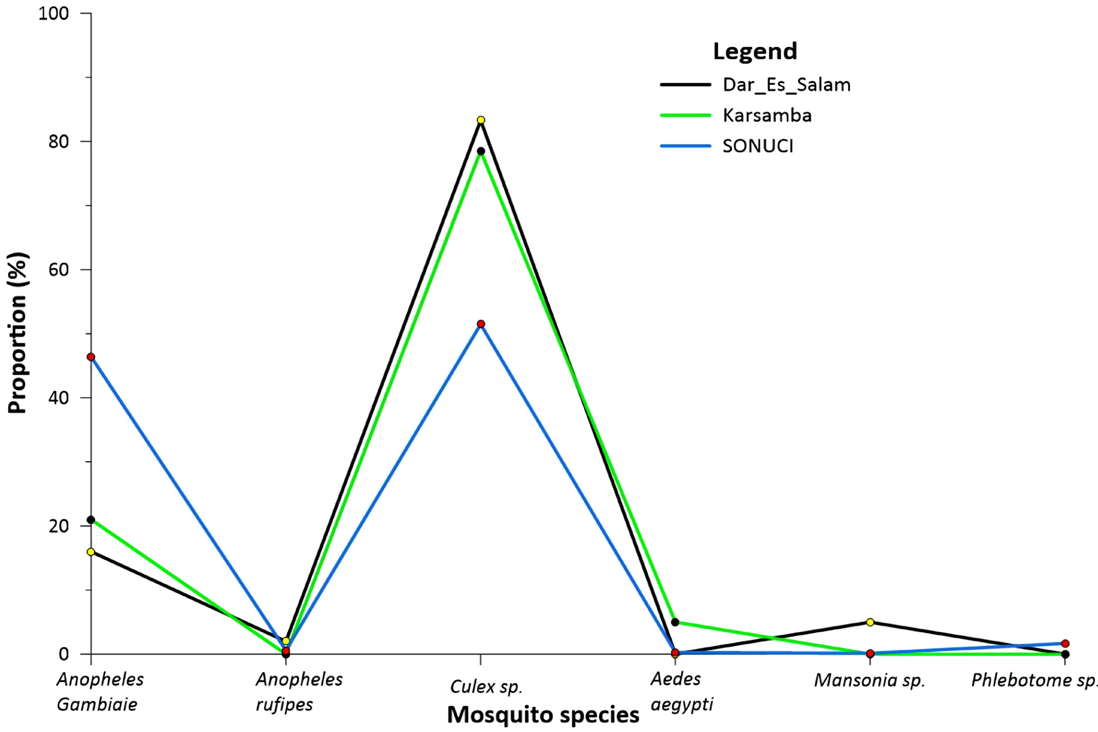

Figure 24. Abundance of species captured by site.

Karsamba with 77 individuals (**Table 2**). The Phlebotomien species is found only in SONUCI with 26 individuals and *Anopheles rufipes* and *Mansonia sp* were found only in Dar es Salaam and SONUCI with respectively (4 individuals in Dar es Salaam and 1 individual in SONUCI) and (8 individuals in Dar es Salaam and 2 individuals in SONUCI). The *Aedes aegypti* species was found in Karsamba and SONUCI with 2 and 4 individuals respectively (**Figure 24**).

3.6. Characteristics of Health Centers

3.6.1. Degree of Diagnosis of Diseases

The most diagnosed diseases have been ranked. According to previous information, malaria ranks first among the most diagnosed diseases with 54%. Diarrheal

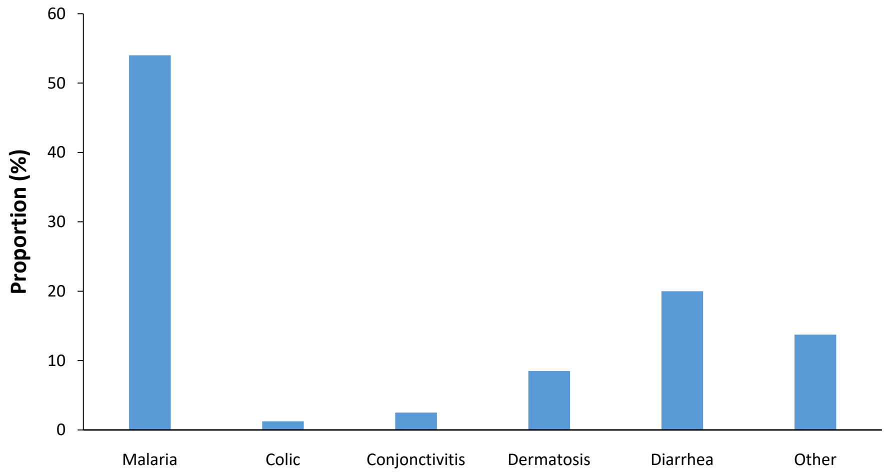

Figure 25. Most diagnosed diseases.

Table 3. Types of diseases according to age.

Diseases	0 - 5 years old	5 - 15 years old	20 - 35 years old	40 years and over
Malaria	*****	**	*	*
Diarrhea	**	***		
Others	***	**		
Dermatosis	*	*	**	
Colic		*		

*bit disastrous; **less disastrous; ***disastrous; ****very disastrous; *****exceptional.

diseases come second with 20%. Then in third position we note the existence of various diseases called others (14%) with a low percentage of diagnosis for each, these are: acute respiratory infections (ARI), sexual infections, pneumonia, etc. Then come dermatosis, conjunctivitis and colic with proportions of 9%, 3% and 1% respectively (**Figure 25**).

3.6.2. Age groups at Risk

Young people are the age groups most affected by these diseases. For example, children from 0 to 5 years old are the most affected by malaria, pneumonia, dermatosis (just behind the age group of 20 to 35 years) and diarrhea after the age group of 5 to 15 years. This age group (5 to 15 years) follows the first age group for all the other diseases, to add also colic which is observed only at this level. The 20 to 35 years old class is much more confronted with dermatosis (**Table 3**).

4. Conclusions

Communication between these surface water leads to the transfer of certain parameters relating to water quality. This monthly monitoring study over a period of one year is carried out with the aim of characterizing, for the first time, the water quality of the Gounti Yéna basin in the face of the new phenomenon of flooding due to the water table. This work provides important information based on physico-chemical and bacteriological descriptors.

Wastewater discharges and the interconnection between septic tanks and groundwater in this area are therefore largely the cause of all bacterial and chemical pollution of groundwater. The communication "SEEN drinking water distribution network and contaminated water bodies" makes the water distributed potentially polluted, constituting a source of waterborne diseases.

The water has a relatively constant content of various elements, but this can change rapidly when the first rains arrive. The results obtained show that the spatio-temporal variation of the bacterial load of the water of Gounti Yéna is much higher in the hot dry season, relatively high in the rainy season and lower in the cold dry season.

This water pollution has a direct impact on the health of the populations of Gounti Yéna where various waterborne and vector-borne diseases have been determined, foremost among which is malaria where the youngest are the most vulnerable. A high population of mosquitoes was highlighted in the capture sites with a peak in the rainy season. The correlation between the mosquitoes captured in the flooded areas and the control site (not flooded) shows a significant difference resulting in a strong colony in the flooded areas compared to the control site.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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