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Dynamics Of Intestinal Helminth Eggs And Larvae In Shallow Groundwater Of Yaounde (Cameroon): Influence Of Abiotic Factors

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Abstract: A study was conducted from February 2026 to July 2026 with the aim of investigating the dynamics of the spread of intestinal helminths in groundwater in Yaoundé. Monthly sampling was carried out at six springs and six wells in the districts of Mokolo, Nkomkana, Melen 1, Melen 7, Etoug-ébé and Obili. The results of the morphometric and hydrological analyses showed that the springs and wells studied are poorly managed and shallow. Physico-chemical analyses showed that the water from the springs and wells studied is slightly acidic (6.04 ± 0.49 U.C) and moderately mineralised (533.70 ± 346.18 µS/cm). Certain parameters (temperature, colour, turbidity, electrical conductivity and TDS) exceeded the recommended standards for water. Observation of helminth eggs and larvae was carried out using an Olympus CK2 inverted microscope with a 40× objective lens, following concentration of the samples using the formalin-ether and Kato-Katz concentration techniques. The results revealed the presence of helminth eggs and/or larvae belonging to the species Ascaris sp., Enterobius vermicularis, Ancylostoma duodenale, Strongyloides sp., Taenia sp., Hymenolepis sp., Diphyllobothrium latum, Fasciola hepatica in spring and well water. In general, the highest densities of parasitic elements in spring and well water were recorded during the PSP (224 ± 69 parasitic elements/L) compared with those observed during the PSS (138 ± 33 parasitic elements/L). Statistical analyses reveal positive and significant correlations ($p < 0.05$) between the density of these parasitic organisms and physico-chemical parameters such as suspended solids, colour, dissolved oxygen and electrical conductivity.

Keywords: Biodynamics, Forms of dissemination, helminths, groundwater, Yaoundé.

1. Introduction

Sustainable access to drinking water remains a key issue in the rapidly growing cities of sub-Saharan Africa. In the city of Yaoundé (Cameroon), recurrent failures in the public water supply network force a large proportion of the peri-urban population to rely on nearby groundwater – mainly open wells and springs – to meet their basic domestic needs, often without first considering whether the water is safe to drink (Nola *et al.,* 1998; Ticha *et al.,* 2021). Owing to the shallow depth of the water table, the high permeability of ferrallitic soils and the acute shortage of on-site sanitation infrastructure, these shallow aquifers are particularly vulnerable to chemical and microbiological contamination (Mbawala *et al.,* 2018; Kamdem *et al.,* 2023). When consumed or used for domestic purposes without effective prior treatment, this unsafe water harbours a wide range of pathogens with epidemic potential, foremost among which are the eggs and larvae of parasitic helminths (Ahmed *et al.,* 2013; Ajeagah *et al.,* 2018; Djeunang *et al.,* 2022). The persistence, viability and spatio-temporal distribution of these stages of infestation in the aquatic environment are closely dependent on the morphometric characteristics of the structures and variations in the abiotic variables of the environment (Mbonde *et al.,* 2020).

The present study aims to assess the dynamics of the dissemination patterns of parasitic helminths in the groundwater of several neighbourhoods in the city of Yaoundé. Specifically, the objectives were: to measure the physico-chemical and morphometric parameters of the water sources studied (wells and springs); Identify, morphologically characterise and count the helminth eggs and larvae present in these water resources; Assess the influence of abiotic physico-chemical factors on the observed variation in parasite load.

2. Materials and methods

2.1. Geographical setting of the study site

Our study was carried out from January 2026 to July 2026 and took place in two phases. The first phase, from January to early February 2026, consisted of a survey of the study site, which enabled us to select the various sampling stations based on a number of factors, the most decisive of which were: the importance of the water source to local communities, landowners' consent and the water table level. In total, twelve (12) sampling stations were selected, comprising six (6) springs and six (6) wells spread across six (6) sectors, namely: Mokolo, NKomkana, Melen 1, Melen 7, Etoug-Ebe and Obili. The second phase took place from February to July 2026 and involved, on the one hand, the measurement of morphometric and hydrological parameters and, on the other hand, the measurement of physico-chemical parameters and the sampling of water and sediment for biological analysis, carried out on a monthly basis. The monthly data obtained were then grouped by season.

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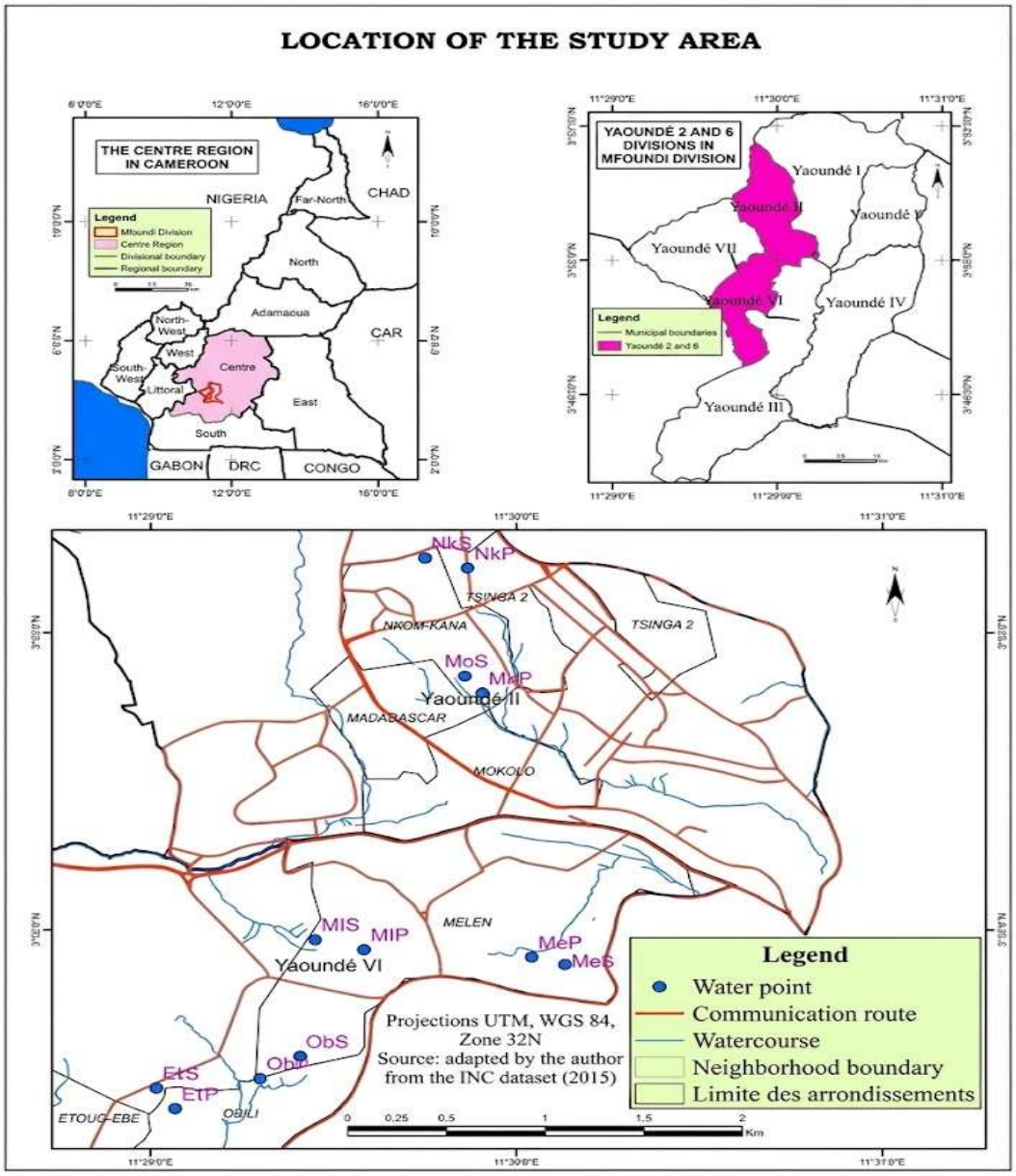


Figure 1: Map of sampling stations

2.2. Sampling

Samples for physico-chemical analysis of the water were taken prior to the collection of fauna using a 5-litre bucket and then transferred to 250-millilitre and 1,000 millilitre polyethylene bottles with double-sealed caps. To carry out the parasitological analyses, 1 litre of water was collected and then mixed with 10% formalin to fix the organisms present in the water. The samples were then transported back to the laboratory in a refrigerated container.

2.3. Physico-chemical Analyses

The physico-chemical analyses were carried out both in the field and in the laboratory in accordance with the recommendations of Rodier *et al.* (2009). In the field, temperature was measured using an alcohol thermometer, whilst pH, electrical conductivity, TDS and dissolved oxygen were measured using a HANNA HI 9829 multi-parameter meter. Dissolved CO_2 was also determined.

In the laboratory, suspended solids (SS), turbidity, colour, nitrates and orthophosphates were measured by colorimetry using a DR/3900 spectrophotometer. Dissolved CO_2, alkalinity and oxidisability were measured by volumetric analysis.

2.4. Biological analyses

Back in the laboratory, the water samples were left to stand at room temperature for 24 hours to allow sedimentation. After decanting, the supernatant was poured off and the volume of the pellet collected was measured. The concentration of parasitic organisms was then carried out using the Kato-Katz and formalin-ether techniques, followed by observation under an Olympus CK2 inverted microscope at 40× magnification. With regard to the Kato-Katz technique, a sample of the pellet obtained from centrifugation at 500 rpm for 5 minutes was taken and placed in the centre of a microscope slide. The slide was covered with a rectangle of cellophane paper moistened with glycerol and, using a test tube, the pellet was spread between the slide and the cellophane to form a smear. The preparation thus obtained was examined directly under an optical microscope to identify hookworm eggs and, at least 30 minutes later, to identify other enteropathogens.

For the formalin-ether concentration technique, we added the following to a 10 ml test tube: 5 ml of the sample pellet, 2 ml of formalin and 3 ml of ether. We then shook the tube and centrifuged it (the contents of the tube separated into four layers: an upper layer of ether, a plug of fatty debris, a layer of formalin and the sediment). Using a glass rod, we dislodged the plug of fatty debris and discarded the three upper layers in one go. We then added two or three drops of staining solution (Lugol's solution or cresyl violet) and transferred a drop of the suspension onto a slide to examine it under a cover slip.

2.5. Identification and Counting of Parasitic Elements

The parasitic elements listed were identified using the WHO charts (1994); the number (X) of parasitic elements in 1 L of sample was calculated using the following formula proposed by Ajeagah *et al.* (2010):

$$X = y \times Vx / 2Vy$$

Where: Vx = volume of sediment in 1 litre of sample; Vy = volume of sediment used for observation; y = number of eggs observed in Vy.

2.6. Statistical analysis of the data

The data collected were processed using appropriate software: graphs were produced using MS Excel 2007, whilst SPSS version 20.0 enabled us to determine Spearman's correlation coefficient 'r' to establish the degree of association between the parameters studied, and to use the Kruskal–Wallis test combined with the Mann–Whitney test to compare the means of these different parameters. The results of these tests were assessed at a 95 per cent confidence level.

3. Results

3.1. Spatial and seasonal variation in physico-chemical parameters

The seasonal mean water temperatures range from 23.50 ± 0.71 °C to 26.25 ± 0.65 °C. The lowest average is recorded at the Etoug-ebe well station (EtP) during the PSS, and the highest average at the Obili well station (ObP) during the PSP. Overall, the highest temperature values are observed during the PSP at all stations except the Melen 1 spring station (MeS). TSS concentrations, meanwhile, range from 0 mg/L at the Nkomkana spring station (NkS) during both seasons to 44.75 ± 41.57 mg/L at the Nkomkana well station (NkP) during the PSP. The pH of the water samples, on the other hand, varies very little. The lowest average (5.13 ± 0.06 U.C) was observed at the Nkomkana spring (NkS) during the PSS, and the highest (6.65 ± 0.15 U.C) at the

Etoug-ébé well (EbP) during the same season. With the exception of the Nkomkana spring (NkS) and Melen 7 well (MlP) stations, where these values are slightly lower during the PSP than during the PSS.

With regard to electrical conductivity, the variation profile shows a maximum of 1242.50 ± 262.34 µS/cm at the Mokolo well station (MoP) during the PSS and a minimum of 135.00 ± 0.00 µS/cm at the Obili well station (ObP) during the same season. Oxidisability values range from 0.33 ± 0.10 mg/L of $KMnO_4$ to 10.76 ± 2.77 mg/L of $KMnO_4$. The highest average was recorded at the Melen 7 spring (SMl) station during the PSP, and the lowest at the Nkomkana spring (NkS) station during the PSP.

Nitrate concentrations ranged from 17.2 ± 0 mg/L of NO_3^- at the Nkomkana well (NkP) station during the PSS to 0.75 ± 0 mg/L of NO_3^- at the Obili well (ObP) station during the PSP, with an average value of 5.76 ± 3.54 mg/L.

As for orthophosphates, concentrations ranged from 0.03 ± 0.00 mg/L of PO_4^{3-} at the Obili Well (ObP) station during the PSS to 2.56 ± 0.00 mg/L of PO_4^{3-} at the Obili Spring (ObS) station during the PSP. These results are recorded in Table I.

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Table I: Spatial and seasonal variation in physico-chemical parameters

Stations	Seasons	**Temperature (°C)**	**MES (Mg/L)**	**pH (U.C)**	Electrical conductivity **(µS/cm)**	Oxidisability **(mg/L)**	**NO_3^- (mg/L)**	**PO_4^{3-} (mg/L)**
MoS	**PSP**	24,38 ±0,95	12,00±2,83	6,03±0,48	642,50±241,31	4,45±1,14	5,85±6,15	2,18±2,91
	PSS	24,25 ±0,35	7,50 ±5,07	6,17±0,10	532,00±48,08	3,36±1,12	4,50±0,00	0,24±0,00
MoP	**PSP**	25,38 ±2,93	26,50±6,36	6,56±0,35	841,25±222,72	5,98±5,23	3,45±0,07	0,36±0,20
	PSS	24,75 ±0,35	24,75±16,50	6,62±0,10	1242,50±262,34	3,46±1,53	3,70±0,00	0,41±0,00
NkS	**PSP**	26,23 ±0,63	0,00±0,00	5,17±0,67	418,25±65,58	0,33±0,10	5,50±1,70	2,13±2,28
	PSS	25,25 ±0,35	0,00±0,00	5,13±0,06	484,50±13,44	0,45±0,49	9,80±0,00	1,94±0,00
NkP	**PSP**	25,13 ±0,25	44,75±41,56	6,09±0,67	406,75±85,92	8,15±2,92	8,30±8,34	2,19±1,45
	PSS	24,30±0,42	8,50 ±2,12	6,65±0,42	302,00±2,83	4,84±0,42	17,20±0,00	1,54±0,00
MeS	**PSP**	23,88±1,03	16,25±16,40	6,32±0,47	844,50±49,82	8,63±8,43	4,80±0,00	1,78±2,28
	PSS	24,25 ±0,06	8,50±2,12	6,52±0,11	818,00±1,41	3,36±2,79	4,30±0,00	2,26±0,00
MeP	**PSP**	25,38 ±0,95	18,00±19,70	5,96±0,18	823,50±104,55	7,55±4,47	5,00±1,98	1,17±1,23
	PSS	24,50 ±0,71	17,00±2,83	6,03±0,11	780,00±0,00	2,67±0,98	12,10±0,00	0,70±0,00
MlS	**PSP**	25,88 ±0,63	10,25±9,88	6,58±0,51	985,75±324,43	10,76±2,77	4,15±4,17	1,20±1,29
	PSS	24,00 ±0,00	2,50 ±0,71	6,58±0,91	1 213,00±19,80	6,23±1,82	1,80±0,00	1,39±0,00
MlP	**PSP**	25,88 ±1,03	17,00±15,56	5,83±0,69	635,75±329,56	4,84±1,57	7,15±9,12	1,04±1,18
	PSS	24,00 ±0,00	8,75±9,60	5,78±0,07	470,50±0,71	2,47±1,26	6,40±0,00	1,36±0,00
EtS	**PSP**	24,25 ±0,29	11,25±2,63	5,31±0,99	216,50±16,60	6,36±2,84	3,50±2,40	1,91±0,45
	PSS	24,25 ±0,35	12,50 ±7,78	5,54±0,30	205,50±89,80	2,28±0,70	6,70±0,00	0,27±0,00
EtP	**PSP**	24,75±0,50	42,75±17,21	6,57±0,13	196,75±23,03	6,36±2,84	6,40±6,79	1,59±0,00
	PSS	23,50±0,71	13,50 ±6,36	6,65±0,15	178,00±2,83	2,28±0,70	2,60±0,00	0,65±0,00
ObS	**PSP**	26,13±1,31	9,00 ±10,80	5,41±0,08	148,25±6,08	5,43±2,18	5,10±6,79	2,55±3,27
	PSS	25,00 ±0,71	6,50±0,71	5,66±0,11	144,00±2,83	1,19±1,39	7,30±0,00	0,33±0,00
ObP	**PSP**	26,25±0,65	17,75±13,89	5,92±1,02	144,00±9,83	4,74±2,27	0,75±0,92	0,86±0,95
	PSS	25,50±0,71	4,00 ±1,41	6,02±0,88	135,00±0,00	1,88±0,70	1,90±0,00	0,03±0,00

Legend: MoS= Mokolo source; MoP= Mokolo puits; NkS= Nkomkana source; NkP=Nkomkana Puits; MeS= Melen 1 source; MeP= Melen Puits; MlS= Melen 7; MlP= Melen 7 puits; EtS= Etoug-Ebe source; EtP= Etoug-Ebe puits ; ObS= Obili source; ObP= Obili puits; PSP= Short rainy season; PSS= Short dry season; pH = hydrogen ion concentration; MES= suspended solids; NO_3^- =nitrates and PO_4^{3-} =orthophosphates.

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3.2. Forms of resistance in the identified intestinal helminths

Biological analyses of the water samples collected during this study revealed parasitic agents belonging to nine (09) genera of helminths. These include the eggs of Ascaris, Enterobius and hookworms (Necator americanus and/or Ancylostoma duodenale), Strongyloides larvae, and the eggs of Taenia, Hymenolepis, Diphyllobothrium, Fasciola and Schistosoma. The sizes of these parasitic agents range from 40 to 200 µm for the eggs and from 100 to 600 µm for the larvae.

3.3. Spatio-temporal variation in the density of the dispersal forms (eggs/larvae) of intestinal helminths.

In terms of space and time, the lowest density of helminth eggs and larvae was recorded at the Melen 7 Wells (MlP) station during the PSS (45 ± 9 parasitic elements/L) and the highest at the Melen 1 Spring (MeS) station during the PSP (224 ± 69 parasitic elements/L). The highest densities of helminth eggs and larvae were recorded during the PSP (Figure 2). However, no form of helminth dissemination was observed at the Nkomkana source (NkS) station during either season. Statistical tests revealed significant differences ($P < 0.05$) between the stations.

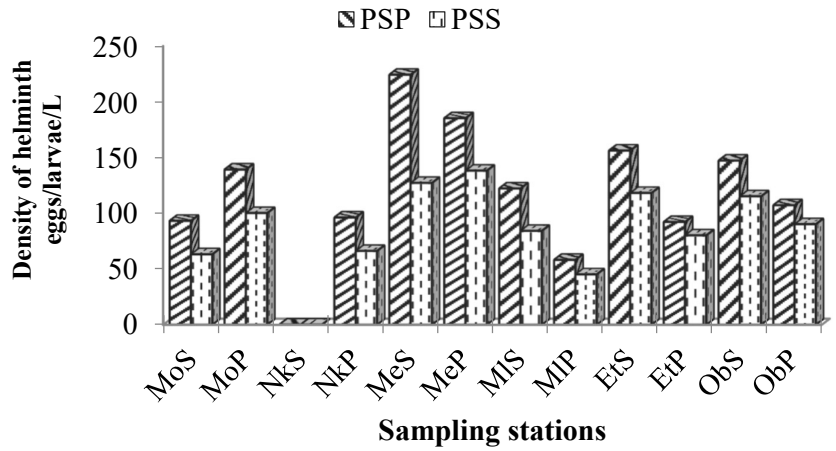


Figure 2: Spatio-temporal variation in the mean densities of helminth dissemination patterns during the study period

3.4. Spatial variation in the density of the different forms of helminth dissemination observed throughout the study period

Spatially, the densities of each helminth parasite ranged from 0 parasites/L for all nine genera to 42 ± 15 eggs/L for *Ascaris*. *Ascaris* eggs are the most abundant parasitic elements at all sampling stations. *Schistosoma* eggs, on the other hand, are the least abundant at the Melen 1 source (MeS) and Melen 1 (MeP) stations, whilst *Strongyloides* larvae are also the least abundant at the Nkomkana well site (Figure 3).

Throughout the study period, the Melen 1 spring (MeS) site had the highest pathogen load, with a total density of 176 pathogens per litre, followed by the Melen 1 well (MeP), Etoug-ébé spring (EtS), Obili spring (ObS), Mokolo well (MoP), Melen 7 (MlS), Obili well (ObP), Etoug-ébé well (EtP), Nkomkana well (NkP) and Melen 7 well (MlP), with respective total pathogen loads of 162, 137, 131, 120, 103, 99, 86, 81 and 52 pathogens per litre. However, no parasites were observed at the Nkomkana spring (NkS) station.

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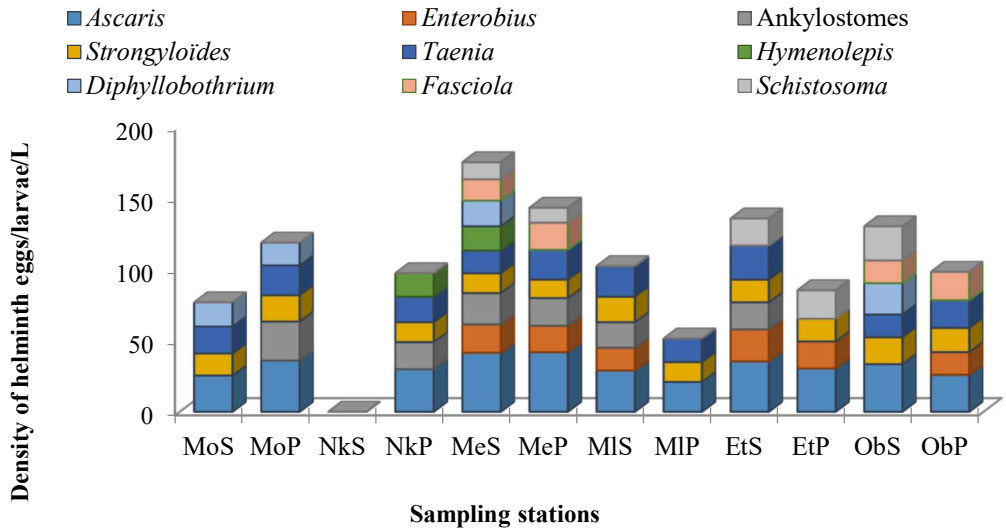


Figure 3: Spatial variation in the densities of the various intestinal helminth parasites.

3.5. Linear relationships

3.5.1. Between physico-chemical parameters

Significant positive correlations were observed during the study between the physico-chemical parameters. Thus, suspended solids (MES) are positively and significantly correlated with colour ($r = 0.886$; $p = 0.000$), turbidity ($r = 0.784$; $p = 0.000$), oxidisability ($r = 0.543$; $p = 0.006$) and dissolved oxygen ($r = 0.490$; $p = 0.015$). Colour, for its part, shows significant and positive correlations with pH ($r = 0.530$; $p = 0.008$). Electrical conductivity is positively and significantly correlated with TDS ($r = 0.999$; $p = 0.000$) and alkalinity ($r = 0.555$; $p = 0.012$). Oxidisability is positively correlated with dissolved oxygen ($r = 0.654$; $p = 0.001$) and alkalinity ($r = 0.440$; $p = 0.032$). As for dissolved CO_2, it is positively and significantly correlated with orthophosphates ($r = 0.418$; $p = 0.042$).

3.5.2. Between physico-chemical parameters and various parasitic agents

Correlations were also detected between the physico-chemical parameters and the parasitic agents of certain helminth species. Thus, a significant positive correlation was observed between TSS and Ascaris sp. eggs ($r = 0.585$; $p = 0.003$) as well as with Strongyloides sp. larvae ($r = 0.448$; $p = 0.028$). Colour is significantly and positively correlated with Ascaris sp. eggs ($r = 0.475$; $p = 0.019$). Electrical conductivity is positively and significantly correlated with hookworm eggs ($r = 0.530$; $p = 0.008$) and with *Hymenolepis nana* eggs. ($r = 0.405$; $p = 0.050$). Total dissolved solids (TDS) are positively and significantly correlated with hookworm eggs ($r = 0.529$; $p = 0.008$) and *Hymenolepis nana* eggs. ($r = 0.406$; $p = 0.049$). Oxidisability is positively and significantly correlated with *Ascaris* sp. eggs ($r = 0.898$; $p = 0.000$), *Enterobius vermicularis* eggs ($r = 0.461$; $p = 0.023$), hookworm eggs ($r = 0.651$; $p = 0.001$) and *Strongyloides* sp. larvae ($r = 0.438$; $p = 0.032$). Dissolved oxygen is significantly and positively correlated with *Ascaris* sp. eggs ($r = 0.631$; $p = 0.001$), as shown in the following table.

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Table II : presents the significant correlations between the physico-chemical parameters and the densities of the various helminthic parasites.

Parameters		MES	Colour	Conductivity	TDS	Oxydability	Dissolved O_2
species	*Ascaris* sp.	0,585**	0,475*	0,293	0,291	0,898**	0,631**
	Enterobius vermicularis	0,201	0,190	0,209	0,220	0,461*	0,131
	Ankylostomes	0,336	0,260	0,530**	0,529**	0,651**	0,370
	Strongyloïdes sp.	0,448*	0,359	0,066	0,074	0,438*	0,342
	Hymenolepis nana	0,176	0,013	0,405*	0,406*	0,188	0,151

*= significant correlation at the 5 per cent level **= significant correlation at the 1 per cent level

Legend: TDS= Total dissolved solids

3.6. Influence of abiotic factors on the abundance dynamics of helminth dissemination forms

Principal Component Analysis (PCA) (Figure 4) shows that some of the measured parameters and sampling stations cluster into three clusters. In Group I, physico-chemical parameters such as suspended solids (MES), colour, turbidity and pH show strong correlations with helminth parasite components and characterise the Etoug-ebe well (EtP), Nkomkana well (NkP) and Mokolo well (MoP) sampling stations. Group II shows strong correlations between physico-chemical parameters such as dissolved oxygen, alkalinity, dissolved CO_2, oxidisability, electrical conductivity, TDS and helminth parasite elements. These parameters characterise the Melen 1 well (MeP), Melen 1 spring (MeS) and Melen 7 spring (MlS) sampling points. Group III, meanwhile, shows positive correlations between physico-chemical parameters such as temperature, nitrates and orthophosphates; and characterises the Melen 7 well (MlP), Mokolo spring (MoS) and Obili spring (ObS) sampling stations.

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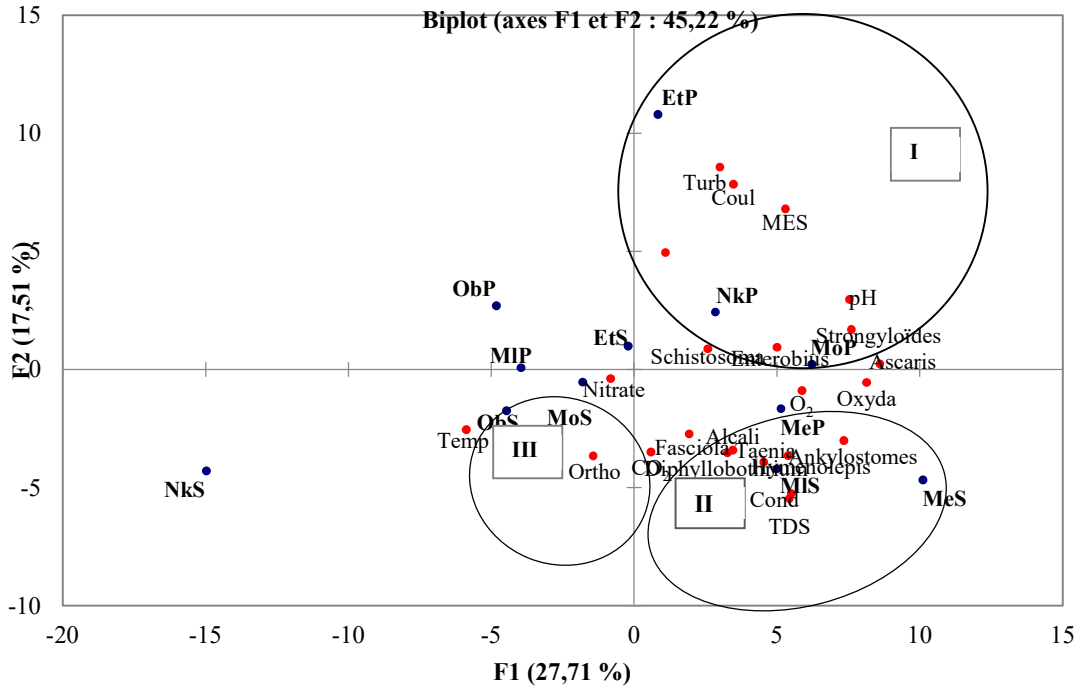


Figure 4: Characteristics of the sampling sites according to the variables measured.

4. Discussion

4.1. Physico-chemical characteristics of the water from the wells and springs studied

The temperature of the water studied shows little variation between the different sampling sites. Overall, it is lower during the short dry season (PSS) and higher during the short rainy season (PSP). At several water points, it exceeds the maximum permissible threshold of 25 °C recommended by the World Health Organisation (WHO, 2017). This warming is due to the direct exposure of shallow aquifers and well reservoirs to solar radiation, as the subsurface environment is highly responsive to ambient temperature (Degbey *et al.,* 2010; Kamdem *et al.,* 2023). These values are consistent with those obtained by Tuékam Kayo (2007) and, more recently, by Ticha *et al.* (2021) in the urban subsoil of Yaounde.

Furthermore, maximum values were recorded for suspended solids (SS: 44.75 mg/L and 42.75 mg/L), turbidity (17.61 FTU and 19.09 FTU) and colour (47.75 Pt-Co and 135.25 Pt-Co) were recorded at the Nkomkana (NkP) and Etoug-ebe (EtP). These high particulate loads can be attributed to the structural vulnerability and poor condition of the infrastructure. Indeed, the installation of raised well rims of at least 0.5 m, as recommended by the OMS (2017), effectively prevents the intrusion of surface runoff and exogenous contaminants (Boutin, 1993; Zébazé Togouet *et al.,* 2009; Mbawala *et al.,* 2018; Djeunang *et al.,* 2022).

Water from wells and springs in the study area is slightly acidic (pH < 7). This natural acidity is attributable to leaching and the passage through the acidic ferrallitic soils that characterise the Yaoundé catchment area (Nola *et al.,* 1999; Mbawala *et al.,* 2018). The pH of the groundwater reflects the geological nature of the weathered formations through which it flows, which is a consistent characteristic of shallow aquifers in humid tropical regions (Ajeagah *et al.,* 2018).

Furthermore, the oxidisability measured at the Nkomkana well (NkP), Melen 1 spring (MeS) and Melen 7 spring (MlS) monitoring points exceeds the guideline value recommended by the WHO (2017) of 5 mg O_2/ml. This exceedance reflects a

significant accumulation of reducing organic matter originating from the surface, indicating sustained anthropogenic pressure in the vicinity of the water points (Kamdem *et al.,* 2023).

High electrical conductivity values were measured depending on the season: During the short dry season (PSS), conductivity exceeded the 1,000 µS/cm threshold at the MoP and MlS stations; during the short rainy season (PSP), it exceeded 500 µS/cm at the MoS, MoP, MeS, MeP, MlS and MlP stations, as well as at the MoS, MeS and MeP stations during the PSS. These high conductivity levels are explained by the microbial mineralisation of organic matter (Baldy *et al.,* 1995; Nola *et al.,* 2006), which releases dissolved ions that can be mobilised by infiltration flows (Mbonde *et al.,* 2020).

4.2. Biological characteristics of the water from the springs and wells studied

Parasitological analysis of water from wells and springs in the study area reveals significant contamination by helminth propagules, with average densities ranging from 52 to 176 parasite units per litre (parasite units/L). The taxonomic survey identified nine genera of parasitic helminths of medical and veterinary interest: Ascaris sp., Enterobius sp., hookworms (*Necator* sp. and/or *Ancylostoma* sp.), *Strongyloides* sp., *Taenia* sp., *Hymenolepis nana*, *Diphyllobothrium latum*, *Fasciola hepatica* and *Schistosoma* sp.

This significant diversity reflects the health status and level of endemicity of faecal parasitic infections amongst human and animal populations in these urban sub-catchment areas (Bouhoum *et al.,* 1997; Djeunang *et al.,* 2022). Forms of infestation (eggs and larvae) excreted into the external environment via faeces reach surface and shallow water bodies due to the absence or poor condition of on-site sanitation systems (Kamdem *et al.,* 2023). Indeed, the shallow depth of the water table and the permeability of the weathered rock facilitate the vertical and lateral migration of pathogenic microorganisms to water sources (Degbey *et al.,* 2010; Ticha *et al.,* 2021).

Ascaris sp. eggs were found to be the most common and abundant parasite across all sampling sites. This prevalence is explained by the remarkable structural resistance of their chitinous shell to adverse environmental conditions, which allows this helminth to persist for extended periods in aquatic environments and soils. Consequently, Ascaris eggs are widely recognised as biochemical indicators and descriptors of water hygiene quality (WHO, 2017; Ajeagah *et al.,* 2018; Djeunang *et al.,* 2022).

Quantitative fluctuations in helminth eggs and larvae show a clear seasonal pattern, characterised by peaks in abundance during the short rainy season (PSP) and minimum densities during the short dry season (PSS). The increase in parasite load during the rainy season results from surface runoff, which carries open faecal deposits, water from drains and leachate from pit latrines into shallow groundwater and spring catchments (Ajeagah *et al.,* 2018; Mbawala *et al.,* 2018). This transport mechanism explains the positive and significant correlations observed between suspended solids (MES), turbidity, oxidisability and the density of infestation forms. As established by Bouhoum *et al.* (1997) and confirmed by Mbonde *et al.* (2020), suspended particles act as adsorption substrates for eggs and larvae, facilitating their transport, protecting them from photo-oxidation and aiding their dispersal within the aquatic ecosystem.

Conversely, the low parasite loads recorded during the low-water period result from the scarcity of runoff and the reduction in direct faecal infiltration (Djeunang *et al.,* 2022). Furthermore, during this low-flow period, the gradual mineralisation of stored organic matter leads to an increase in electrical conductivity and the concentration of dissolved mineral ions. These conditions of extensive mineralisation and rising water temperatures induce osmotic and thermal stress, accelerating the inactivation and loss of viability of eggs and larvae in the water column (Ajeagah *et al.,* 200; Mbonde *et al.,* 2020).

4.3. Spatial variations and the impact of environmental management measures

From a spatial perspective, the maximum parasite load observed at the Melen 1 source monitoring station (176 eggs/L) can be explained by a combination of adverse environmental and behavioural factors. The absence of a protection zone and the lack of sanitation in the immediate vicinity of the spring contribute to ongoing faecal contamination (Davis & Hirji, 2003; Torkil, 2004; Kamdem *et al.,* 2023). Furthermore, the regular use of this spring by domestic and stray animals (livestock, dogs, pigs)

coming to drink contributes to the direct deposition of faeces, introducing zoonotic pathogens such as *Fasciola hepatica* and *Taenia* sp. (Djeunang *et al.,* 2022).

In contrast, the lowest parasite loads recorded at the Melen 7 well (52 parasite elements/L) are directly linked to the presence of a concrete well curb 0.65 m high, in line with the criteria recommended by the WHO (2017) to limit the intrusion of surface runoff (Tuékam Kayo, 2013; Mbawala *et al.,* 2018). Finally, the complete absence of parasite forms observed at the Nkomkana spring (0 eggs/L) can be explained by the high standard of structural design of the facility (watertight catchment, drainage slab) combined with its topographical location away from areas prone to flooding and concentrated runoff (Kamdem *et al.,* 2023).

5. Conclusion

The water from the springs and wells studied is slightly acidic and characterised by a temperature that varies only slightly. In addition to the relatively high electrical conductivity values (1242.50 ± 262.34 µS/cm) – indicative of chemical pollution – these waters also show high oxidisability values (10.76 ± 2.77 mg/L of $KMnO_4$); they cannot therefore be recommended as drinking water without prior treatment. Due to inadequate protection of water sources, wastewater seeps into them via soil infiltration, causing organic pollution. This can become chemical in nature through the conversion of organic compounds into chemical compounds and dissolved salts during rainfall. Biological analysis indicates the presence of helminth-borne pathogens, revealing a high level of faecal contamination in the water, including springs and wells. The Melen 1 spring and well sampling points (MeS and MeP) are characterised by the highest parasite loads. The highest densities of eggs and larvae were recorded in PSP. Statistical analyses show positive and significant correlations ($p<0.05$ and $p<0.01$) between the density of these parasitic elements and physico-chemical parameters such as dissolved oxygen, oxidisability, colour, suspended solids, electrical conductivity and TDS. The very high prevalence of helminth transmission forms undoubtedly poses a threat to residents who use water from these water points for their daily needs. The water from the Nkomkana spring is of good hygienic quality.

Competing interests

All authors have declared that no competing interests exist.

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