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DEPARTMENT OF ANIMAL BIOLOGY AND PHYSIOLOGY
DEPARTEMENT DE BIOLOGIE ET PHYSIOLOGIE ANIMALES
LABORATORY OF HYDROBIOLOGY AND ENVIRONMENT
LABORATOIRE D` HYDROBIOLOGIE ET ENVIRONNEMENT

Biodiversity of environmental forms of intestinal protozoa and helminths in domestic water sources in the city of Bamenda and its environs (North West Region): Relationship to physico-chemical parameters

Thesis

presented and defended with a view to obtaining the award of Ph.D or Doctorate degree in Biology of Animal Organisms

Option: **Hydrobiology and Environment**

by:

ASAKIZI NJI AUGUSTINE

Msc, ANIMAL BIOLOGY, UNIVERSITY OF DSCHANG
Matriculation: 21V2600

Before the jury

Président : **NOLA Moïse, Professeur, Université de Yaoundé I ;**

Rapporteur : **AJEAGAH Gideon AGHAINDUM, Professeur, Université de Yaoundé I ;**

Membres : **AKONO NTONGA Patrick ; professeur, Université de Douala ;**
TOMBI Jeanette, Maître de Conférences, Université de Yaoundé I ;
FOTO MENBOHAN Samuel, Maître de Conférences, Université de Yaoundé I ;
MOUNGANG Luciane Marlyse, Maître de Conférences, Université de Yaoundé.

Year: 2025

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****
UNIVERSITE DE YAOUNDE I
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****
B.P. 812 Yaoundé
Tél: (237) 242 23 95 84
Fax: (237) 242 23 44 96

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UNIVERSITY OF YAOUNDE I
FACULTY OF SCIENCE
****
P.O. BOX 812 Yaounde
Phone: (237) 242 23 95 84
Fax: (237) 242 23 44 96

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DEPARTMENT OF ANIMAL BIOLOGY AND PHYSIOLOGY

ATTESTATION DE CORRECTION

****

Nous soussignés, membres du jury de soutenance de la **Thèse de Doctorat/Ph.D** en **Biologie des Organismes Animaux**, Option : **Hydrobiologie et Environnement**, de Monsieur **ASAKIZI NJI Augustine**, matricule **21V2600,** soutenance autorisée par la correspondance N° 25--2791/UYI/VR-EPDTIC/DAAC/DA-AAC/DRD/SR/SR-A/mna du Recteur de l'Université de Yaoundé I en date du 30 Juin 2025 sur le sujet intitulé : « **Biodiversity of environmental forms of intestinal protozoa and helminths in domestic water sources in the city of Bamenda and its environs (North West Region): Relationship to physico-chemical parameters**», attestons que les corrections exigées au candidat lors de cette évaluation, qui a eu lieu le **vendredi 04 juillet 2025** dans la **salle Multimédia** de la **Faculté des Sciences**, ont réellement été effectuées et que le présent document peut être déposé sous sa forme actuelle.

En foi de quoi, la présente attestation lui est délivrée pour servir et valoir ce que de droit.

Fait à Yaoundé, le..... 29 JUIL 2025 .....

Les Examinateurs

Pr L. Foto Menbohan

Mougang L. M.

Le Chef de Département

Pr. Sévilor KEKEUNOU
Faculté des Sciences
Université de Yaoundé I

Le Président du Jury

Nola Moïse
Professeur

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ANNÉE ACADEMIQUE 2024/2025

(Par Département et par Grade)

DATE D'ACTUALISATION 16 janvier 2025

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DÉPARTEMENT	**Professeurs**	**Maîtres de Conférences**	**Chargés de Cours**	**Assistants**	**Total**
BCH	08 (01)	25 (15)	11 (05)	00 (00)	**44 (21)**
BPA	12 (02)	18 (06)	16 (06)	01 (01)	**47 (15)**
BPV	08 (02)	10 (03)	14 (06)	06 (03)	**39 (14)**
CI	06 (01)	14 (02)	05 (01)	03 (01)	**28 (05)**
CO	06 (01)	14 (05)	12 (03)	02 (00)	**33 (09)**
ER	01 (00)	/	/	/	**01 (0)**
IN	03 (00)	03 (00)	13 (01)	06 (00)	**24 (01)**
MAT	01 (00)	08 (00)	20 (01)	07 (01)	**36 (02)**
MIB	05 (03)	05 (01)	13 (06)	01 (01)	**24 (11)**
PHY	17 (01)	11 (04)	15 (01)	04 (02)	**45 (08)**
ST	10 (00)	14 (05)	09 (02)	00 (00)	**33 (07)**
Total	**67 (11)**	**122 (41)**	**128 (32)**	**30 (09)**	**342 (88)**

Soit un total de **360 (94)** dont :

- Professeurs **67 (11)**
- Maîtres de Conférences **122 (41)**
- Chargés de Cours **128 (32)**
- Assistants **30 (09)**

( ) = Nombre de Femmes **94**

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6.	NGADJUI TCHALEU BONAVENTURE	546959-G	15/09/1953	FONTSIGA	M	12/08/1982	RETRAITE – CONTRAT DE COLLABORATION	PR
7.	NGO BILONG ANASTASIE épse TIH	546164-I	27/12/1955	MBANGA	F	28/07/2000	RETRAITE - CONTRAT DE COLLABORATION	MC
8.	NKENGFACK EPHRAIM AUGUSTIN	546948-F	17/06/1955	YAOUNDE	M	01/09/1983	RETRAITE - CONTRAT DE COLLABORATION	PR
9.	NDIKONTAR MAURICE KOR	169784G	09/05/1958	Mbaa	M	10/01/1991	RETRAITE - CONTRAT DE COLLABORATION-EN COURS DE SIGNATURE	PR
10.	NJIOKOU FLOBERT	547321H	11/06/1958	Nkongsamba	M	03/05/1993	RETRAITE - CONTRAT DE COLLABORATION-EN COURS DE SIGNATURE	PR
11.	BENG NEE NINTCHOM PENLAP VERONIQUE	546643B	07/01/1957	Melong I	F	02/10/1992	RETRAITE-CONTRAT DE COLLABORATION	PR
12.	FOKOU ELIE	546725J	08/06/1957	Fiéla-Bamendjinda	M	01/04/1988	RETRAITE-CONTRAT DE COLLABORATION EN COURS DE FINALISATION	PR
13.	TCHOUANKEU JEAN CLAUDE	547295-E	06/01/1959	Douala	M	01/12/1989	RETRAITE-CONTRAT DE COLLABORATION EN COURS DE FINALISATION	PR
12.	BOYOMO ONANA						CONTRATS TRAITES LORS DU CONSEIL D'UNIVERSITE DU 12 JUILLET 2024	MC
13.	WANDJI JEAN	162242M	09/06/1958	Bangou	M			UYI
14.	YOUMBI EMMANUEL	547332Z	12/02/1959	Bangou	M	Bangou		PR
15.	NGODO MELINGUI JEAN	500475X	05/09/1958	Endoum		20/10/2005		MC
16.	KOFANE TIMOLEON CREPIN							PR
17.	NGAMENI EMMANUEL	547277-C	24/04/1959	Mbanga	M			PR
18.	BITOM DIEUDONNE	547050X	23/11/1958	Ambam	M			PR

DEDICATION

I dedicate this work to my mother, my wife and children.

ACKNOWLEDGMENTS

All praises and thanks go to God Almighty for granting me the strength, courage, good health and wisdom to be able to realize this scientific study on intestinal gastroenteritis.

I have the distinct honor of presenting my warm and sincere thanks to Professor **AJEAGAH Gideon AGHAINDUM**, the director of my my thesis who agreed to supervise this work, His scientific rigor, his scientific advice, his dynamism, the identification techniques that he instilled in me and the confidence shown in me since my initiation into research, have been a source of motivation throughout these years of my Ph.D program.

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I thank the research team of the Laboratory of Hydrobiology and Environment and all the Department for the enthusiasm and moments of constructive and enriching discussions that we had during the scientific debates and during the seminars within the laboratory, These are include the head of Department Professor **KEKEUNOU Sévilor**, Professor **NOLA Moise**, Professor **ZEBAZE TOGOUET Serge Hubert**, Professor **FOTO Menbohan Samuel,** Professor **AKONO Ntonga Patrick**, Professor **TOMBI Jeannette**, **Professor MOUNGANG Lucine Marlyse,** Professor **DJIETO Lordon Champlain,** Professor **MEGNEKOU Rosette**, Professor **TAMSA ARFAO Antoine**, Dr, **TUEKAM KAYO Raoul Polycarpe**, Dr **ASI QUIGGLE Atud**, Dr, **TSOMENE NAMEKONG Pierre**, Dr **POUNTOUGNIGNI Oumarou Farikou,** Dr **KOUEDEUM Eric** Dr **NANFACK DONGMO Rodrigue**, Dr **OWONA EDOA Francois**, M. **NGANGOUE Arthur**, M. **NDOURWE Far Bolivar**, M. **ZAMBO Bertrand Gabriel** and **M. NSANGOU MOUNDIGNIGNI Hénock Yves**.

I would also like to express my gratitude to our various motorcycle drivers from Bamenda for their availability and their bravery in giving us access to all the sampling points during difficult times on the ground.

Thank you all for your support, I have taken another step forward in the vast world of research and the wish of our late father (Peace to his soul). It depends on the collaboration, encouragement, advice and sympathy that others give us. It is an opportunity for me to thank the people who helped me carry out this work, and also those who, without knowing it, constituted a source of inspiration, a stimulus, a model or a reference.

TABLE OF CONTENTS

LIST OF ABBREVIATIONS AND ACRONYMS

WHO : World Health Organization,

UNICEF : United Nations International Children's Emergency Fund

Temp : Temperature

TU : Turbidity unit

HEL : Hydrobiology and Environment Laboratory

WEHL : Water and Environmental Health Laboratory

SS : Suspended solids

TME : Metal Trace elements

OPI : Organic pollution Index

BOD_5 : Biochemical 0xygen Demand

SPSS : Statistical Package for Social Sciences

UPT1 : Up Station tap 1

UPT2 : Up Station tap 1

UPW1 : Up Station well 1

UPW2 : Up Station well 2

UPSP1 : Up Station spring 1

UPSP2 : Up Station spring 2

NKT1 : Nkwen tap 1

NKT2 : Nkwen tap 2

NKW1 : Nkwen well 1

NKW2 : Nkwen well 2

NKSP1 : Nkwen spring 1

NKSP2 : Nkwen spring 2

NST1 : Nsongwa tap 1

NST2 : Nsongwa tap 2

NSW1 : Nsongwa well 1

NSW2 : Nsongwa well 2

NSSP1 : Nsongwa spring 1

NSSP2 : Nsongwa spring 2

MAT1 : Mankon tap 1

MAT2 : Mankon tap 2

MAW1 : Mankon well 1

MAW2 **:** Mankon well 2

MASP1 **:** Mankon spring 1

MASP2 **:** Mankon spring 2

TDS **:** Total dissolve solids

DNA **:** De-oxyribonucleic acid

DOC **:** Dissolved Organic Carbon

FTU **:** Formazin Turbidity Units

pH **:** Hydrogen Potential

UC **:** Conventional Unit

MLST **:** Multi Locus Sequence Typing

Vx : volume of the entire pellet

Vy (in L) : volume of the pellet taken for observation (in L)

PCA : Principal Component Analysis (PCA)

NWTS : Normalized Weighted Total Scores

RCS : Risk level of Contamination of Structure

WTSS : Weighted total score for a Station

Is : Sanitation index

NoVs : Noroviruses

RVs : Rotaviruses

SaVs : Sapoviruses

AsVs : Astroviruses

AdVs : Adenoviruses

IR : Induced recharge from surface water

ST : Septic tanks

WT : Water treatment

ACH :Hierarchical Classification Analysis

LIST OF FIGURES

LIST OF TABLES

LIST OF ANNEXES

ABSTRACT

Parasitic water borne diseases are particularly severe in children, and also in all individuals, in whom they affect health and development, while they reduce productivity and ability to adult work. In Cameroon, waterborne diseases are among the most chronic parasitic diseases thus the municipality of Bamenda and its environs are not left out. The intestinal Protozoa and helminths show various forms of resistances in the domestic water system (cysts and oocysts for Protozoa; eggs and larvae for Helminths). Their presence in the domestic water sources constitutes a public health problem and must have special attention. The comprehension

of some physico- chemical parameters linked up abiotic factors can influence or favour of the distribution of these parasites in water together with the control of their maturation stages are necessary to understand the ecology of these parasites and their contribution to the activation, viability and transmission of diseases. This study aimed at evaluating the Biodiversity of environmental forms of intestinal protozoa and helminths in relationship to physico- chemical parameters in domestic water sources in Bamenda and its environs (North West Region). More specifically, to evaluate the main physicochemical parameters of these water, to characterize the different environmental forms of enteric Protozoa and Helminths in these waters and to evaluate the influence of physicochemical parameters on the distribution and the maturation of enteric pathogens in these aquatic environments. For this study, 24 sampling stations where selected divided into 6 sampling points for each quarter which comprised of tap, wells, and spring water sources, (Upstation, Nkwen, Nsongwa and Mankon). In each of these sampling points, 08 study campaigns were conducted from November 2022 to June 2023 following the monthly frequency. The hydrological and physicochemical parameters were analyzed in the field and in the laboratory according to the standard methods. The isolation, identification and enumeration of the parasites were carried out using microscope at 40x and 100x after concentration and coloration of parasites according to the techniques of sedimentation, Kato-Katz, Ritchie and Ziehl-Neelsen. The maturation rates were been done in species *Ascaris lumbricoides* (49%), *Hymenolepis nana* (26%), *Diphyllobothrium latum* (8%), *Schistosoma hematobium* (5%), *Tenia saginata* (5%), *Toxocara cati* (4%) and *Fasciola hepatica* (3%). Physico-chemical analysis show that domestic water sources at Mankon, Nsongwa and Nkwen which are located on the outskirts of the city with the abundant vegetation near the water sources, showed well oxygenated water (69.75 ± 2.56%), low values of temperature (21.66 ± 0.20° C), low mineralization (61.94 ± 41.20 µS / cm) and low organic pollution (2.41 ± 1.71 mg / L). The water of these domestic water sources are subject to domestic and agricultural pollution. On the other hand, the Upstation, and central city of Mankon water sources that cross the urban center, are more polluted ($2.0 \leq IPO \leq 3.6$), with high values of temperature (24.05 ± 2.14 °C) and high mineralization (185.37 ± 122.71 µS / cm), This urban water is subject to domestic, municipal and agricultural pollution, *Entamoeba histolytica* which had 32 Cysts/L in UPSP1, *Balantidum coli* also had high density values in MAW2 and MASP2 (32 Cysts/L), MaW1 and NSW1 sources recorded relatively high densities (21 and 19 Cysts/L respectively) for *Gardia Lambia* , Nkwen spring 2, Nsongwa spring 1, Mankon spring 2, and Mankon spring 1 (6, 4, 4, 3 Cysts/L respectively) generally recorded low densities for *Cryptosporidium parvum,* The spatiotemporal distribution of enteropathogenic Protozoan showed high densities in the month of April and May

during the rainy season at the Mankon wells, upstation springs and Nsongwa wells, While the other stations had low densities, Statistical analysis revealed positives correlations between the densities of enteropathogenic Protozoan, sporulated oocysts with color, Carbondioxide , turbidity and suspended solids and dissolved oxygen ($p \leq 0.05$). Concerning the enteropathogenic Helminths, biological analysis allowed the identification and the characterization of 7 species belonging to 3 classes, The density in class of Nematoda was *Ascaris lumbricoïdes* (28 Eggs/L) in NSSP1, Class of Cestoda with *Tenia saginata* abundance in NST2 (6 Eggs/L), *Diphyllobothrium latum in* MaW1 (10 Eggs/L) and *Hymenolepis nana* (34 Eggs/L) in NSSP1, *Toxocara cati* abundance was very low in MAW2 and MASP2 (3 and 4 Eggs/L). The least dominant class is the class of Trematoda represented by *Schistosoma haematobium* (2 Eggs / L) in NKSP1 and *Fasciola hepatica* (1 Egg/L). The stations of Nsongwa spring 1, Nsongwa well 2 and Nsongwa well 1 were the most contaminated with Helminthic eggs and larvae; while the other stations showed low densities of these parasites. The statistical analysis ($p \leq 0.05$) show that Helminths eggs and larvae show negatives correlations with temperature, pH, othorphosphates, nitrates, and dissolved oxygen have great affection with environments which have low or moderate organic pollution and rich in dissolved oxygen. These results show the bioaccumulation effect of minerals by intestinal parasites in the water. Respecting basic environmental hygiene as well as treating or purifying water before use would reduce the risk of contamination of the population.

Keywords: Biodiversity, Physicochemical parameters, enteropathogens, Protozoa, Helminths, Bamenda urban municipality.

RESUMÉ

Une étude visant à évaluer la biodiversité des formes environnementales des protozoaires intestinaux et des helminthes en relation avec les paramètres physico-chimiques dans les sources d'eau domestique a été menée à Bamenda et ses environs (Région du Nord-Ouest du Cameroun)**.** Pour cette étude**,** 24 stations de prélèvement ont été sélectionnées, réparties en six points d'échantillonnage pour chacun des quartiers suivants : Upstation, Nkwen, Nsongwa et Mankon, Ces points incluaient des sources d'eau de robinet, de puits et de sources naturelles, Huit campagnes d'échantillonnage ont été menées entre novembre 2022 et juin 2023, à une fréquence de 4 campagnes par saison. Les paramètres hydrologiques et physico-chimiques ont été analysés sur le terrain et en laboratoire selon les méthodes standards. L'isolement, l'identification et le dénombrement des parasites ont été réalisés par microscopie (grossissements ×40 et ×100), après concentration et coloration des parasites selon les techniques de sédimentation, Kato-Katz, Ritchie et Ziehl-Neelsen. Les taux de maturation ont été observés pour les espèces suivantes : *Ascaris lumbricoides* (49 %), *Hymenolepis nana* (26 %), *Diphyllobothrium latum* (8 %), *Schistosoma haematobium* (5 %), *Tenia saginata* (5 %), *Toxocara cati* (4 %) et *Fasciola hepatica* (3 %). L'analyse physico-chimique a montré que les sources d'eau domestique de Mankon, Nsongwa et Nkwen, situées en périphérie urbaine et entourées d'une végétation abondante, présentaient une eau bien oxygénée (69,75 ± 2,56 %), des températures basses (21,66 ± 0,20 °C), une faible minéralisation (61,94 ± 41,20 µS/cm) et une faible pollution organique (2,41 ± 1,71 mg/L), Toutefois, ces eaux sont soumises à une pollution domestique et agricole, En revanche, les sources d'eau d'Upstation et du centre urbain de Mankon, traversant la ville, sont plus polluées ($2,0 \leq IPO \leq 3,6$), avec des températures plus élevées (24,05 ± 2,14 °C) et une forte minéralisation (185,37 ± 122,71 µS/cm), Ces eaux urbaines sont soumises à une pollution domestique, municipale et agricole. Concernant les protozoaires entéropathogènes, *Entamoeba histolytica* a été détectée avec 32 kystes/L à UPSP1, *Balantidium coli* a également présenté des densités élevées à MAW2 et MASP2 (32 kystes/L). Les sources MaW1 et NSW1 ont enregistré des densités relativement élevées (21 et 19 kystes/L respectivement) pour *Giardia lamblia*. Les stations Nkwen spring 2, Nsongwa spring 1, Mankon spring 2 et Mankon spring 1 ont généralement enregistré de faibles densités de *Cryptosporidium parvum* (6, 4, 4 et 3 kystes/L respectivement). La distribution spatio-temporelle des protozoaires entéropathogènes a révélé des densités élevées en avril et mai, pendant la saison des pluies, notamment dans les puits de Mankon, les sources d'Upstation et

les puits de Nsongwa, tandis que les autres stations affichaient de faibles densités. L'analyse statistique a révélé des corrélations positives significatives ($p \leq 0,05$) entre les densités des protozoaires entéropathogènes, des oocystes sporulés et les paramètres tels que la couleur, le dioxyde de carbone, la turbidité, les matières en suspension et l'oxygène dissous. Concernant les helminthes entéropathogènes, l'analyse biologique a permis l'identification et la caractérisation de 7 espèces réparties en 3 classes : la Classe des Nématodes : *Ascaris lumbricoides* (28 œufs/L) observée à NSSP1. La Classe des Cestodes : *Tenia saginata* (6 œufs/L à NST2), *Diphyllobothrium latum* (10 œufs/L à MaW1) et *Hymenolepis nana* (34 œufs/L à NSSP1). La Classe des Trématodes : peu représentée, avec *Schistosoma haematobium* (2 œufs/L à NKSP1) et *Fasciola hepatica* (1 œuf/L). Les stations de Nsongwa spring 1, Nsongwa well 2 et Nsongwa well 1 se sont révélées être les plus contaminées par les œufs et larves d'helminthes, tandis que les autres stations présentaient de faibles densités. L'analyse statistique ($p \leq 0,05$) a mis en évidence des corrélations négatives entre les œufs et larves d'helminthes et des paramètres tels que la température, le pH, les orthophosphates, les nitrates, et l'oxygène dissous, ces parasites étant davantage associés à des environnements faiblement ou modérément pollués organiquement et riches en oxygène dissous. Ces résultats mettent en évidence l'accumulation des parasites intestinaux dans les milieux aquatiques. Le respect des règles d'hygiène environnementale de base ainsi que le traitement ou la purification de l'eau avant utilisation contribueraient significativement à la réduction des risques de contamination des populations.

Mots-clés : biodiversité, paramètres physico-chimiques, entéropathogènes, protozoaires, helminthes, municipalité urbaine de Bamenda

INTRODUCTION

Water is one of the most important of all natural resources known on earth. It is important to all living organisms, most ecological systems, human health, food production and economic development (Brigas *et al*,, 2020). Water is the most necessary component for the living beings. It is being used for many purposes such as industrial water supply, drinking, irrigation, propagation of fish and other aquatic systems and generation of hydro-power plants, Water is present in ponds, lakes, rivers, and dams, which is used by human beings for drinking, industrial domestic and agricultural purposes (Ahmed *et al.*, 2020).

The safety of drinking water is an ongoing concern within the global village. Based on its biological and physico-chemical characteristics at a particular time and place, water has become a formidable factor in diseases transmission. Polluted water contains vast amounts of organic and inorganic matter. Water pollutants can be classified as organic pollutants, inorganic pollutants, pathogens, suspended solids, nutrients and agriculture pollutants, thermal, radioactive, and other pollutants. Heavy metal and other inorganic pollutants such as trace elements, mineral acids, sulfates, inorganic salts, metals, complexes of metals with organic compounds, and cyanides of higher concentrations pollute water bodies (Lou *et al.*, 2007).

Waterborne pathogens spread to humans through ingestion of contaminated drinking water, exposure to contaminated water from recreational activities like swimming, or indirectly through contaminated food (Rose *et al.*, 2000). These pathogens are responsible for intestinal infections (gastroenteritis) such as bacillary dysentery, diarrhea, typhoid fever, cholera and paratyphoid fever, amoebiases, helminthiases, and many other water born diseases (Yeboah *et al*,, 2022). Outbreaks of waterborne illness are most prevalent in economically disadvantaged communities where water supplies and sanitation are often inadequate.

Surface water and groundwater are susceptible to fecal contamination (which may contain pathogenic organisms) from agricultural runoff, sewage, and domesticated animals. Fecal waste can be discharged directly into waterbodies as point sources or transported to waterbodies in runoff from Non Point Sources (NPSs) or subsurface water flow (Schijven *et al*., 2007). Infrastructural impediments in favour of fecal contamination include septic tank leachate, runoff from land, urban litter, contaminated refuse, domestic pet and wildlife excrement (USEPA 2001). Sunlight directly affects the survival of pathogens that are vulnerable to ultraviolet radiation and desiccation (Alegbeleye *et al*., 2020), Precipitation and runoff transport fecal waste from upland sources to waterbodies.

There exist many water sources which can be exposed to biological and physic-chemical agents there by making the water water not good for drinking. Over 1 billion people lack access to safe drinking water worldwide (World Health Organisation, 2006). Domestic water should

be free from color, turbidity, odor, and microbes. The need for safe drinking water and proper sanitation management is a concern for sustainable life globally. Despite significant progress that has been made in this regard, discrepancies still exist. Globally, there are approximately 2,1 billion people who lack access to quality drinking water sources, and 4,5 billion that lack proper sanitation (UNICEF, 2018). Water, sanitation and hygiene is responsible for 1,9 million annual deaths from diarrhoea and 4,2% of the global burden of diseases, 90% of which are children under 5 mostly in developing countries (WHO, 2006). Three thousand (3000) children die each day from water related diseases of which 88% are due to poor drinking water, lack of sanitation and poor hygiene (Hunter *et al*., 2001).

These biological and physic-chemical properties of water are much related to gastroenteritis in many ways. These pathogens are responsible for intestinal infections (gastroenteritis) such as bacillary dysentery, diarrhea, typhoid fever, cholera and paratyphoid fever, amoebiases, helminthiases, and viral water born diseases.

There exist many water sources which can be exposed to biological and physic-chemical agents there by making the water water not good for drinking. In Cameroon, waterborne diseases are among the most chronic parasitic diseases (Ajeagah *et al*., 2016). However, the water supply quality and an adequate sanitation system in Cameroonian cities are very insufficient to meet the needs of populations subject to a strong demographic explosion. The city of Bamenda and its environs (North West, Cameroon) is no exception. Moreover, for populations living near wetlands, watercourses are the means par excellence waste disposal, including the contents of septic tanks (Djuikom *et al*., 2009). Also, there is little data exist on the physico-chemical quality of these waters in relation to the biodynamics of forms of the Protozoa and Helminths present in these environments.

In Bamenda and its environs, Cam water supplies water to only half of the total population which can afford the piped water while the rest of the population rely on the unprotected drinking water sources (boreholes, springs, wells) and rainwater to access drinking water, However these natural domestic water sources are at a high risk of contamination from many sources of contaminants like pit latrines, agricultural pesticides and fertilizers, domestic and industrial wastes, leakages from landfills (Narendra *et al*., 1993). Due to uncontrolled increase in human population and development of township at large, these freshwater bodies are under enormous pressure owing to their overuse on one hand and enrichment due to nutrients and organic matter on the other, leading to the cultural eutrophication. Erosion of catchment and direct pouring of domestic effluents along with sewage are threatening these wetlands all over the town and its environs (Ahmed *et al*., 2020).

Unfortunately the public due to the less sensitization and limited knowledge about the quality of these water sources in Bamenda municipality and its environs, they have continued to use them for drinking and cooking purposes. It is of interest to evaluate the biological and physico-chemical contents of drinking water sources in Bamenda and its environs since it is important for those who manage and operate water system, public healthcare services and community health. It is not worth wise to evaluate biological contents of water sources alone without also evaluating the physic-chemical contents of water sources which are also directly related to pollution of drinking water sources. Therefore it is of interest to know the biodiversity of environmental forms of intestinal protozoa and helminths in domestic water sources in Bamenda and its environs and aslo to know if the population and the location of domestic sources increase the risk of contamination.

All these above mentioned facts are what moltivated us to carry out this study in order to assess some of the biological and physico-chemical quality of different drinking water sources in Bamenda and its environs in relation to gastroenteritis and to correlate their availability with organoleptic properties of the ecosystems (well, tap, spring water).

The general objective of this study was;

To evaluate the Biodiversity of environmental forms of intestinal protozoa and helminths in relationship to physico- chemical pararameters in domestic water sources in Bamenda and its environs (North West region).

The specific objectives were;

1- To assess the physico-chemical parameters of these domestic water sources in in Bamenda and its environs;
2- To determine enteropathogenic protozoa contents (Protozoa) of different domestic water souces in Bamenda and its environs;
3- To isolate the enteropathogenic intestinal helminthic organisms in different domestic water sources in Bamenda and its environs;
4- To analyse the relationship between the biological contents (Protozoa and Helminthes) and the physico- chemical parameters.

After this introduction, this study is structured into three chapters. The first chapter presents a review of the literature. The second chapter deals with the materials and methods used in this study. The third chapter presents the results obtained, their interpretation, and the discussions of the results. The final chapter contains conclusion, recommendations and future research perspectives.

CHAPTER I :

LITERATURE REVIEW

I,1- GENERAL SYNOPSIS ABOUT WATER

Water is a critical element and an important core for sustainable socio-economic development, along with the eradication of poverty and health discrepancies. The need for safe drinking water and proper sanitation management is a perennial concern for sustainable life globally (Mara *et al.*, 2003).

Water is a chemical compound made up of hydrogen and oxygen atoms in the ratio 2:1, connected by covalent bonds, It has as chemical formula H_2O. Water is a liquid at temperatures above 0 °C (273,15 K, 32 °F) at sea level, but it often co-exists on Earth with its solid state,(ice), and gaseous state (water vapor or steam). Water also exists in a liquid crystal state near hydrophilic surfaces. Water covers 71% of the Earth's surface, and is vital for all known forms of life. On Earth, 96,5% of the planet's water is found in oceans, 1,7% in groundwater, 1,7% in glaciers and the ice caps of Antarctica and Greenland, a small fraction in other large water bodies, and 0,001% in the air as vapor, clouds (formed of solid and liquid water particles suspended in air), and precipitation. Only 2,5% of the Earth's water is fresh water, and 98,8% of the 2,5% is in ice and groundwater. Less than 0,3% of all freshwater is in rivers, lakes, and the atmosphere, and an even smaller amount of the Earth's freshwater (0,003%) is contained within biological bodies and manufactured products. The Standardized properties of water quality are summarized in Table-I below.

Table I: General properties of water quality standard (World Health Organization, 2006)

Parameter	**Existing standard**	**Importance to water quality**
pH at 25°C	8.2 – 8.8	pH can also affect the solubility and toxicity of chemicals and heavy metals in the water
Colour	Not exceeding 5 Hazen units	Colored water imparts adverse effect on human health and aquatic environment
Turbidity	Not exceeding 1.5 NTU	Turbidity is measured at nearly all drinking water treatment facilities, it provide a general indication of water quality, High levels are associated with disease-causing microorganisms

Iron as Fe	Not exceeding 0.1 mg/L	Essential for good health, iron helps transport oxygen in the blood. Most tap water contain the dietary requirement for iron
Manganese as Mn	Not exceeding 0.05 mg/L	It aids digestion, increases bone strength and strengthens immune system function
Aluminium as Al	Not exceeding 0.10 mg/L	It aids conservation efforts by providing tools to monitor and protect water-dependent ecosystems
Free residual chlorine	0.5 - 1.5 mg/L	chlorine is the most important because the chlorine keeps actively sanitizing your pool
Fluoride as F	± 10% of norminal level (current 0.5 mg/L)	Fluoride for drinking water to prevent dental mottling and skeletal fluorosis
Taste and odour	Unobjectionable	Taste and odour in drinking-water may be indicative of some form of pollution or of a malfunction during water treatment or distribution. It may therefore be an indication of the presence of potentially harmful substances
Total Coliforms & E.coli (no./100mL)	Absent	E, coli is considered an indicator organism, used to identify fecal contamination in freshwater and indicate the possible presence of disease-causing bacteria and viruses (pathogens)
Helminths	4-log (99.99%) reduction or inactivation	These parasites may be found in water, food, soil or surfaces that have been contaminated with the poop of infected humans or animals
Protozoa	4-log (99.99%) reduction or inactivation	protozoa have proven to be excellent tools for assessing the occurrence of pollution during wastewater biological treatment, along with its role in the control of pollution itself through the grazing of dispersed bacteria and maintenance of a healthy trophic web in those artificial ecosystems
Viruses	4-log (99.99%) reduction or inactivation	Viral waterborne illnesses have been associated with diarrhea, dizziness, nausea, dehydration, fever, abdominal cramps, headaches, and death

Water on Earth moves continually through the hydrological cycle of evaporation and transpiration, condensation, precipitation, and runoff, usually reaching the sea. Evaporation and transpiration contribute to the precipitation over land (Shrivastava and Kanungo, 2013).

I.2 Importance of Water

I.2.1 Chemical uses

Water is widely used in chemical reactions as a solvent or reactant and less commonly as a solute or catalyst. Nevertheless, these properties are sometimes desirable.

1) Heat exchange

Water and steam are used as heat transfer fluids in diverse heat exchange systems, due to its availability and high heat capacity, both as a coolant and for heating, In the nuclear power industry, water can also be used as a neutron moderator. In most nuclear reactors, water is both a coolant and a moderator. This provides something of a passive safety measure, as removing the water from the reactor also slows the nuclear reaction down.

2) Fire extinction

Water has a high heat of vaporization and is relatively inert, which makes it a good fire extinguishing fluid. Its evaporation carries heat away from the combustible materials.

3) Industrial applications

Water is used in power generation. Hydroelectricity is electricity obtained from hydropower, Hydroelectric power comes from water driving a water turbine connected to a generator. Pressurized water is used in water blasting and water jet cutters. It is also used in the cooling of machinery to prevent overheating, or prevent saw blades from overheating.

I,2,2 Multi-porpose uses

Water has many distinct properties that are critical for the proliferation of life that set it apart from other substances. Water is vital both as a solvent in which many of the body's solutes dissolve and as an essential part of many metabolic processes within the body. Without water, these particular metabolic processes could not exist. Water is considered to be neutral, with a pH (the negative log of the hydrogen ion concentration) of 7, Acids have pH values less than 7 while bases have values greater than 7.

1) Agriculture

The most important use of water in agriculture is for irrigation, which takes up to 90% of water withdrawn in some developing countries. It takes around 3,000 liters of water, converted from liquid to vapor, to produce enough food to satisfy one person's daily dietary need. This is a considerable amount, when compared to that required for drinking, which is

between two and five liters. Fifty years ago, the common perception was that water was an infinite resource. At this time, there were fewer than half the current numbers of people on the planet. People were not as wealthy as today, consumed fewer calories and ate less meat, so less water was needed to produce their food. Increase population, their consumption of water-thirsty meat and vegetables is rising, and increasing competition for water from industry, urbanization and biofuel crops is giving rise to the concept of peak water.

2) Recreation

Humans use water for many recreational purposes, as well as for exercising, sports, and relaxation, for decoration like fountains, aquariums or ponds for fun or companionship.

3) Washing

The propensity of water to form solutions and emulsions is useful in various washing processes. Many industrial processes rely on reactions using chemicals dissolved in water, Washing is also an important component of several aspects of personal body hygiene.

4) Transportation

The use of water for transportation of materials through rivers and canals as well as the international shipping lanes are an important part of the world economy.

5) Food processing

Water plays many critical roles within the field of food science. It is important for a food scientist to understand the roles that water plays within food processing to ensure the success of their products. The boiling and freezing points of water are affected by solutes, as well as air pressure, which is in turn affected by altitude. Water boils at lower temperatures with the lower air pressure which occurs at higher elevations, Solutes in water also affect water activity which affects many chemical reactions and the growth of microbes in food, Solutes in water lower water activity, Water hardness is also a critical factor in food processing. Its hardness is classified based on the amounts of removable calcium carbonate salt it contains per gallon, Water hardness is measured in grains; 0.064 g calcium carbonate is equivalent to one grain of hardness (Elizabeth, 2007). Water is classified as soft if it contains 1 to 4 grams, medium if it contains 5 to 10 grams and hard if it contains 11 to 20 grams. Water hardness also affects sanitation; with increasing hardness, there is a loss of effectiveness for its use as a sanitizer, Boiling, steaming, and simmering are popular cooking methods that often require immersing food in water or its gaseous state, steam, Water is also used for dishwashing.

6) For Drinking

Safe drinking water is essential to humans and other life forms. To function properly, the body requires between one and seven liters of water per day to avoid dehydration; the

precise amount depends on the level of activity, temperature, humidity, and other factors. Most of this is ingested through foods or beverages other than drinking straight water. It is not clear how much water intake is needed by healthy people, though most advocates agree that approximately 2 liters (6 to 7 glasses) of water daily is the minimum to maintain proper hydration. Medical literature favors a lower consumption, typically 1 liter of water for an average male, excluding extra requirements due to fluid loss from exercise or warm weather (Rhoades *et al.*, 2003). For those who have healthy kidneys, it is rather difficult to drink too much water, but (especially in warm humid weather and while exercising) it is dangerous to drink too little. People can drink far more water than necessary while exercising, however, putting them at risk of water intoxication (hyper hydration), which can be fatal (Noakes *et al*,, 2005). The latest dietary reference intake report by the United States National Research Council in general recommended (including food sources): 3.7 liters for men and 2.7 liters of water total for women.

Specifically, pregnant and breastfeeding women need additional fluids to stay hydrated. The Institute of Medicine (U.S) recommends that, on average, men consume 3.0 liters and women 2.2 liters; pregnant women should increase intake to 2.4 liters (10 cups) and breastfeeding women should get 3 liters (12 cups), since an especially large amount of fluid is lost during nursing, Also noted is that normally, about 20% of water intake comes from food, while the rest comes from drinking water and beverages (caffeinated included), Water is excreted from the body in multiple forms; through urine and feces, through sweating, and by exhalation of water vapor in the breath. With physical exertion and heat exposure, water loss will increase and daily fluid needs may increase as well. Currently, about 20% of the world's population lacks access to safe drinking water, and more than 5 million people die annually from illness associated with safe drinking water or inadequate sanitation, Humans require water with few impurities. Some solutes are acceptable and even desirable for taste enhancement and to provide needed electrolytes. Access to safe drinking water has improved over the last decades in almost every part of the world, but approximately one billion people still lack access to safe water and over 2.5 billion lack accesses to adequate sanitation (WHO, 2006). There is a clear correlation between access to safe water and gross domestic products.

I.3 –Domestic water sources

Three main sources of water include: Rain, surface water (rivers, streams, tanks, lakes, ponds, ocean), and ground water (springs, wells and bore holes).

I.3.1- Rain water

It is the primary source of all water. Part of rain sinks into the ground to form ground water; some evaporate back to the atmosphere, and some runs off to form streams and rivers which eventually flow into the sea. Some of the water in the soil is taken up by the plants and is evaporated by the leaves. This is known as water cycle (Shrivastava and Kanungo, 2013), Rain water is the purest water in nature, Physically, it is clear, bright and sparkling, Chemically, it is very soft water containing only traces of dissolved solids (0.0005 percent). Being soft; it has a corrosive action on lead pipes, Bacteriologically, rain water from clean districts is free from pathogenic agents, Impurities are acquired as it passes through the atmosphere. It picks up suspended impurities such as dust, soot, microorganisms as well as gases such as carbon dioxide, nitrogen, oxygen and ammonia, Rain catchments can be developed for portable water supply in high rain areas though its quality varies depending on location, topography, weather (Evans *et al*., 2007) and characteristics of the rain catchment.

I.3.2- Water bodies on surface

It originates from rain water, It is the main source of water supply in many areas, Examples of surface water include rivers, tanks, lakes, man-made reservoirs and seawater, Surface water is prone to contamination from human and animal sources. As such it is never safe for human consumption unless subjected to sanitary protection and purification, Surface water picks up the characteristics of the surface over which it passes.

1) Rivers; many rivers furnish a dependable supply of water, The chief drawback of river water is that it is always grossly polluted and is quite unfit for drinking without treatment, River water is turbid during rainy season; it may be clear in other seasons. Clarity of water is no guarantee that the river water is safe for drinking, Certain amount of self-purification occur in river water by natural forces of purification such as dilution, sedimentation, aeration, oxidation, sunlight, plant and animal life but these agencies are not sufficient to render the water potable, River water needs purification before it can be used for drinking purposes.

(2) Seawater: Though this source is plentiful, it has great many limitations. It contains 3.5 percent of salts in solution, Desalting and demineralization process involves heavy expenditure. It is adopted in places where sea water is the only source available.

I.3.3-Under-ground water

Rain water percolating into ground constitutes ground water. Water used by humans comes mainly from land. It is now realized that there is a limit to ground water in the world,

Ground water is the cheapest and most practical means of providing water to small communities. Ground water is superior to surface water, because the ground itself provides an effective filtering medium. It is likely to be free from pathogenic agents, usually requires no treatment; supply is likely to be certain even during dry season. It is less subject to contamination than surface water. The disadvantages of ground water are high mineral content, and the fact that it requires pumping or some arrangement to lift the water. Example is the hand pump.

1-Well or bore hole:

Traditionally wells are an important source of water supply, Even today, they are an important source of water supply in many communities, Technically, wells are of two kinds-shallow and deep, Shalow wells are the water from above the first impervious layer in the ground, (see figure 3a and 3b below). They provide limited quantities of water, and the water is easy to be polluted unless care is taken in well construction (Okon *et al*., 2021).

Deep wells: a deep well is one which taps water from the water-bearing stratum below the first impervious layer in the ground (see figure 1a below). Deep wells are usually machine-dug and may be several hundred meters deep. Deep wells furnish the safest water, and are often the most satisfactory sources of water supply, (Okon *et al*., 2021).

Figure 1 a: Shalow well water (Researcher 2023)

Figure 1b: Deep well water (Researcher 2023)

2-Springs;

When ground water comes to the surface and flows freely under natural pressure, it is called a "**spring**", Springs may be of two types; shallow springs and deep springs, Shallow springs dry up quickly during summer months, whereas deep springs do not show seasonal fluctuations in the flow of water, In some geographic areas, springs constitute an important source of water, Springs are simpler to exploit, as no pumping is needed to bring the water to the surface, Springs can either be;

Protected spring –

A spring that is properly covered by stone masonry with one or two boxes, and a distribution site near the protection or collection boxes, Unprotected or open springs which are those not covered by stone masonry and are thus exposed to contamination (see figure 2 below).

Figure 2: Spring water source (Researcher, 2023)

Water can be collected into catchments and distributed in pipes providing drinking sources as stand posts or taps. It is inevitable that water quality deteriorates in distribution a result of corrosion in pipes allowing soil contamination and thus the larger the population served, the longer the distribution system and therefore the greater the risk of contamination, Water collected in catchments or tanks and distributed in pipes, providing sources as taps, is easily treated and is considered safe. Liguori *et al*, (2010) showed this in their comparative study of tap and water plumbed in coolers in commercial stores in Italy, and contamination can also occur between the source and the hygienic condition around point of usage.

I.4- Water quality and pollution

There are many ways in which human activities affect water systems, Polluting substances cause disruption or change in the chemical makeup of the aquatic environment (Oniye *et al.,* 2002). Improper management of toxic waste is allegedly causing some serious environmental problems, The improper practices such as dumping of refuse, toxic waste in municipal dustbins, open spaces, and water bodies when dump or wash into drinking water source, it leads to the contamination of the water and spread of diseases, (Nwilo and Badejo, 2001).

In a slow moving river, sewage effluent can give rise to the deposition of blanket of sludge on river bed, which adversely affects macro fauna and plants. Sewage effluent contains large numbers of bacteria and its presence causes a significant rise in the bacterial content of the river (Meays and Nordin, 2013). Depending on the nature of discharge and its quantity, it may quickly dissipated by dilution or self- purify by aquatic organisms (algae), but if the effluents are non-biodegradable the effect may persist downstream, Phytoplankton being the autotroph in the food chain of freshwater ecosystem, play a key role in bio- monitoring the ecological disturbance cause by pollutants.

Water-borne diseases are infectious diseases spread primarily through contaminated water, Though these diseases are spread either directly or through flies or filth, water is the chief medium for spread of these diseases and hence they are termed as water-borne diseases, Most intestinal (enteric) diseases are infectious and are transmitted through faecal waste, Pathogens – which include virus, bacteria, protozoa, and parasitic worms – are disease-producing agents found in the faeces of infected persons. These diseases are more prevalent in areas with poor sanitary conditions. These pathogens travel through water sources and interfuses directly through persons handling food and water. Since these diseases are highly infectious, extreme care and hygiene should be maintained by people looking after an infected patient, Hepatitis,

cholera, dysentery, and typhoid are the more common water-borne diseases that affect large populations in the tropical regions (WHO, 2006).

Water fit for human consumption is called drinking water or potable water, Water that is not potable may be made potable by filtration or distillation, or by a range of other methods, Its use is highly technical and is usually monitored by government regulations (typically 1 part per million (ppm) for drinking water, and 1–2 ppm of chlorine not yet reacted with impurities for (bathing water), Chlorine is a skin and mucous membrane irritant that is used to make water safe for bathing or drinking, Water for bathing may be maintained in satisfactory microbiological condition using chemical disinfectants such as chlorine or ozone or by the use of ultraviolet light, In the USA, non-potable forms of wastewater generated by humans may be referred to as grey water, which is treatable and thus easily able to be made potable again, and black water, which generally contains sewage and other forms of waste which require further treatment in order to be made reusable, Grey water composes 50–80% of residential wastewater generated by a household's sanitation equipment (sinks, showers and kitchen runoff, but not toilets, which generate black water).

This natural resource is becoming scarcer in certain places, and its availability is a major social and economic concern, Currently, about a billion people around the world routinely drink unhealthy water, Poor water quality and bad sanitation are deadly; some five million deaths a year are caused by polluted drinking water (WHO, 2006). The World Health Organization estimates that safe water could prevent 1.4 million child deaths from diarrhea each year (WHO, 2006). Water, however, is not a finite resource, but rather re-circulated as potable water in precipitation in quantities many degrees of magnitude higher than human consumption, Therefore, it is the relatively small quantity of water in reserve in the earth (about 1% of our drinking water supply, which is replenished in aquifers around every 1 to 10 years), that is a non-renewable resource, and it is, rather, the distribution of potable and irrigation water which is scarce, rather than the actual amount of it that exists on the earth. In the developing world, 90% of all wastewater still goes untreated into local rivers and streams.

The distribution of drinking water is done through municipal water systems, tanker delivery or as bottled water, Governments in many countries have programs to distribute water to the needy at no charge, Reducing usage by using drinking (portable) water only for human consumption is another option, Polluting water may be the biggest single misuse of water; to the extent that a pollutant limits other uses of the water, it becomes a waste of the resource, regardless of benefits to the polluter, Like other types of pollution, this does not enter standard accounting of market costs, being conceived as externalities for which the market cannot

account, Thus other people pay the price of water pollution, while the private firms' profits are not redistributed to the local population victim of this pollution, Pharmaceuticals consumed by humans often end up in the waterways.

I.4.1 Groundwater pollution

Groundwater pollution is the contamination of groundwater by undesirable substances that cause nuisance and render the water unsuitable for certain uses. It has various origins including domestic, agricultural, industrial, urban and road (Kevin, 2012). There are 3 types of groundwater pollution: chemical pollution, physical pollution and biological pollution.

I.4.2 Physical pollution

Physical pollution is materialized in the underground aquatic environment by changes in the physical properties of water such as the load of suspended solids, temperature, color or transparency (Rodier *et al.,* 2009). Wastewater from various sources is loaded with suspended solids that can contaminate well water. These materials, responsible for organic pollution, increase the turbidity of the water, reduce its transparency and reduce the power of light penetration. A large amount of these suspended solids represent an important substrate for bacteria that can adhere to them and form biofilms (Rodier *et al.,* 2009).

I.4.3. Chemical pollution

Chemical pollution in an aquatic environment is confirmed by measuring its pH and its electrical conductivity. The pH of groundwater varies with the nature of the soil crossed and the activity of the microorganisms present (Rodier *et al.,* 2009). Other parameters such as dissolved organic carbon (DOC), nitrites (NO_2^-) and ammoniacal nitrogen ($N\text{-}NH_3$) are often measured.

I.44. Biological pollution

Many pathogenic microorganisms isolated in groundwater come from septic tanks and sewage spreading. The risk of microbiological pollution of a water table is strongly linked to the characteristics of the soil and the nature of the layers crossed (Beauchamp, 2006). The dissolved organic matter present in water is decomposed by microorganisms and promotes their proliferation.

I.5. Chemical and physical properties of water

The major chemical and physical properties of water are as follows: Water is a liquid at standard temperature and pressure. It is tasteless, odorless with a very slight blue color although it is usually colorless, water is transparent in the visible electromagnetic spectrum. Water is a good polar solvent and is often referred to as the universal solvent. Substances that dissolve in water are known as hydrophilic (water-loving) substances, while those that are immiscible with water are known as hydrophobic (water-fearing) substances. Most of the major components in cells (proteins, DNA and polysaccharides) are also dissolved in water, Pure water has a low electrical conductivity, but this increases with the dissolution of a small amount of ionic material such as sodium chloride. The boiling point of water is 100 °C (212 °F) at sea level, Water has a high specific heat capacity as a result of the extensive hydrogen bonding between its molecules, Water has its maximum density at 3,98 °C (39,16 °F), becoming less dense when it is cooled to its solid form, ice, That is 1,000 kg/m3 (62,428 lb/cu ft or 8,3454 lb/US gal) liquid (at 4 °C; ice has a density of 917 kg/m^3), Water is miscible with many liquids, such as ethanol, in all proportions, forming a single homogeneous liquid.

On the other hand, water and most oils are immiscible, usually forming layers according to increasing density from the top, As a gas, water vapor is completely miscible with air, Water can be split by electrolysis into hydrogen and oxygen, Water is not a fuel; it is an end-product of the combustion of hydrogen with greater energy than that collected when the hydrogen and oxygen recombine, The reaction of water with elements which are more electropositive than hydrogen may be violently explosive, Water can dissolve many different substances, giving it varying tastes and odors, Humans and other animals have developed senses that enable them to evaluate the portability of water by avoiding water that is too salty or putrid, The purity of spring and mineral water refers to absence of toxins, pollutants and microbes, not the absence of naturally occurring minerals.

I.6 – Inorganic contaminants found in groundwater

There exist many inorganic contaminants that can be found in ground water, And these contaminants consist trace elements, inorganic compounds and dissolved solids as seen in table II below.

Table II: Inorganic contaminants found in groundwater (World Health Organization, 2006)

Contaminant	**Sources to groundwater**	**Potential health and other effects**
Aluminum	Occurs naturally in some rocks and drainage from mines	Can precipitate out of water after treatment, causing increased turbidity or discolored water, Causes Alzheimer's disease
Antimony	Enters environment from natural weathering, industrial production, municipal waste disposal, and manufacturing of flame retardants, ceramics, glass, batteries, fireworks, and explosives	Decreases longevity, alters blood levels of glucose and cholesterol in laboratory animals exposed at high levels over their lifetime causes chronic emphysema
Arsenic	Enters environment from natural processes, industrial activities, pesticides, and industrial waste, smelting of copper, lead, and zinc ore	Causes acute and chronic toxicity, liver and kidney damage; decreases blood hemoglobin. A carcinogen, Causes cancer and skin lesions
Barium	Occurs naturally in some limestones, sandstones, and soils in the eastern United States	Can cause a variety of cardiac, gastrointestinal, and neuromuscular effects causing Associated with hypertension and cardiotoxicity in animals, This causes heart rhythm or paralysis
Beryllium	Occurs naturally in soils, groundwater, and surface water, Often used in electrical industry equipment and components, nuclear power and space industry, Enters the environment from mining operations, processing plants, and improper waste disposal	Causes acute and chronic toxicity; can cause damage to lungs and bones, Possible carcinogen. Causes berylliosis, is a chronic granulomatous lung disease
Cadmium	Found in low concentrations in rocks, coal, and petroleum and enters the groundwater and surface water when dissolved by acidic waters, May enter the environment from industrial discharge, mining waste, metal plating, water pipes, batteries, paints and pigments, plastic stabilizers, and landfill leachate	Replaces zinc biochemically in the body and causes high blood pressure, liver and kidney damage, and anemia. Destroys testicular tissue and red blood cells, Toxic to aquatic biota. It causes Itai-itai disease

Chloride	May be associated with the presence of sodium in drinking water when present in high concentrations. Often from saltwater intrusion, mineral dissolution, industrial and domestic waste	Deteriorates plumbing, water heaters, and municipal water-works equipment at high levels, Causes Hyperchloremia
Chromium	Enters environment from old mining operations runoff and leaching into groundwater, fossil-fuel combustion, cement-plant emissions, mineral leaching, and waste incineration, Used in metal plating and as a cooling-tower water additive	Chromium III is a nutritionally essential element, Chromium VI is much more toxic than chromium III and causes liver and kidney damage, internal hemorrhaging, respiratory damage, dermatitis, and ulcers on the skin at high concentrations, Causes Sinus cancers, kidney and liver damage
Copper	Enters environment from metal plating, industrial and domestic waste, mining, and mineral leaching	Can cause stomach and intestinal distress, liver and kidney damage, anemia in high doses, Imparts an adverse taste and significant staining to clothes and fixtures, Essential trace element but toxic to plants and algae at moderate levels, Causes Wilson disease
Cyanide	Often used in electroplating, steel processing, plastics, synthetic fabrics, and fertilizer production; also from improper waste disposal	Poisoning is the result of damage to spleen, brain, and liver, May cause other health effects well: Coma, Death, High or low blood pressure
Dissolved solids	Occur naturally but also enters environment from man-made sources such as landfill leachate, feedlots, or sewage, A measure of the dissolved “salts” or minerals in the water, May also include some dissolved organic compounds	May have an influence on the acceptability of water in general. May be indicative of the presence of excess concentrations of specific substances not included in the safe water drinking Act, which would make water objectionable, High concentrations of dissolved solids shorten the life of hot water heaters and can cause Kidney stones

Fluoride	Occurs naturally or as an additive to municipal water supplies; widely used in industry which leads to fluorosis	Decreases incidence of tooth decay but high levels can stain or mottle teeth, Causes crippling bone disorder (calcification of the bones and joints) at very high levels, skeletal fluorosis
Hardness	Result of metallic ions dissolved in the water; reported as concentration of calcium carbonate, Calcium carbonate is derived from dissolved limestone or discharges from operating or abandoned mines	Decreases the lather formation of soap and increases scale formation in hot-water heaters and low-pressure boilers at high levels
Iron	Occurs naturally as a mineral from sediment and rocks or from mining, industrial waste, and corroding metal	Imparts a bitter astringent taste to water and a brownish color to laundered clothing and plumbing fixtures
Lead	Enters environment from industry, mining, plumbing, gasoline, coal, and as a water additive	Affects red blood cell chemistry; delays normal physical and mental development in babies and young children, Causes slight deficits in attention span, hearing, and learning in children, Can cause slight increase in blood pressure in some adults, The condition it cause is plumbism and saturnism
Manganese	Occurs naturally as a mineral from sediment and rocks or from mining and industrial waste,	Causes aesthetic and economic damage, and imparts brownish stains to laundry. Affects taste of water, and causes dark brown or black stains on plumbing fixtures. It causes the condition called manganism, a neurodegenerative disorder that causes dopaminergic neuronal death and parkinsonian-like symptoms
Mercury	Occurs as an inorganic salt and as organic mercury compounds, Enters the environment from industrial waste, mining, pesticides, coal, electrical	Causes Minamata disease, acute and chronic toxicity, Targets the kidneys and

	equipment (batteries, lamps, switches), smelting, and fossil-fuel combustion, (Hydragyrism)	can cause nervous system disorders
Nickel	Occurs naturally in soils, groundwater, and surface water. Often used in electroplating, stainless steel and alloy products, mining, and refining	Nickel allergy is a common cause of allergic contact dermatitis
Nitrate (as nitrogen)	Occurs naturally in mineral deposits, soils, seawater, freshwater systems, the atmosphere, and biota. More stable form of combined nitrogen in oxygenated water. Found in the highest levels in groundwater under extensively developed areas, Enters the environment from fertilizer, feedlots, and sewage	Toxicity results from the body's natural breakdown of nitrate to nitrite, Causes "bluebaby disease," or methemoglobinemia, which threatens oxygen-carrying capacity of the blood, A condition called Methemoglobinemia
Nitrite (combined nitrate/nitrite)	Enters environment from fertilizer, sewage, and human or farm-animal waste	Causes "bluebaby disease," or methemoglobinemia, which threatens oxygen-carrying capacity of the blood
Selenium	Enters environment from naturally occurring geologic sources, sulfur, and coal,	Nutritionally essential element at low doses but toxic at high doses, Keshan disease, a type of cardiomyopathy, or disease of heart muscle, and Kashin-Beck disease, a form of osteoarthritis.
Silver	Enters environment from ore mining and processing, product fabrication, and disposal. Often used in photography, electric and electronic equipment, sterling and electroplating, alloy, and solder, Because of great economic value of silver, recovery practices are typically used to minimize loss	Can cause argyria, a blue-gray coloration of the skin, mucous membranes, eyes, and organs in humans and animals with chronic exposure
Sodium	Derived geologically from leaching of surface and underground deposits of salt and decomposition of various minerals, Human activities contribute through de-icing and washing products	Can be a health risk factor for those individuals on a low-sodium diet
Sulfate	Elevated concentrations may result from saltwater intrusion, mineral dissolution, and domestic or industrial waste	Forms hard scales on boilers and heat exchangers; can change the taste of water, and has a laxative effect in high doses

Thallium	Enters environment from soils; used in electronics, pharmaceuticals manufacturing, glass, and alloys	Damages kidneys, liver, brain, and intestines in laboratory animals when given in high doses over their lifetime
Zinc	Found naturally in water, most frequently in areas where it is mined, Enters environment from industrial waste, metal plating, and plumbing, and is a major component of sludge	Aids in the healing of wounds, Causes no ill health effects except in very high doses, Imparts an undesirable taste to water, Toxic to plants at high levels
Volatile organic compounds	Enter environment when used to make plastics, dyes, rubbers, polishes, solvents, crude oil, insecticides, inks, varnishes, paints, disinfectants, gasoline products, pharmaceuticals, preservatives, spot removers, paint removers, degreasers, and many more	Can cause cancer and liver damage, anemia, gastrointestinal disorder, skin irritation, blurred vision, exhaustion, weight loss, damage to the nervous system, and respiratory tract irritation
Pesticides	Enter environment as herbicides, insecticides, fungicides, rodenticides, and algicides	Cause poisoning, headaches, dizziness, gastrointestinal disturbance, numbness, weakness, and cancer, Destroys nervous system, thyroid, reproductive system, liver, and kidneys
Plasticizers, chlorinated solvents, benzo[a]pyrene, and dioxin	Used as sealants, linings, solvents, pesticides, plasticizers, components of gasoline, disinfectant, and wood preservative, Enters the environment from improper waste disposal, leaching runoff, leaking storage tank, and industrial runoff	Plasticizers, chlorinated solvents, benzo[a]pyrene, and dioxin

Chemical materials present in water are arsenic, antimony, boron, beryllium, barium, chloride, calcium, copper, cadmium, chromium, cobalt, lead, iron, fluoride, manganese, molybdenum, magnesium, mercury, nitrate, nickel, nitrite, phosphates, potassium, phosphorus, salmonella, selenium, silica, sodium, silver, sulfate, sulfide, tin, tellurium, thallium, titanium, uranium, tritium, vanadium, zinc, and many others. These materials, in the form of elements or in combination with other compounds, may be considered as inorganic pollutants if their limit exceeds permissible values, which in turn harms the environment. Heavy metal and other inorganic pollutants such as trace elements, mineral acids, sulfates, inorganic salts, metals, complexes of metals with organic compounds, and cyanides of higher concentrations pollute water bodies.

Chemical contaminants are therefore elements or compounds. These contaminants may be naturally occurring or man-made, Examples of chemical contaminants include nitrogen, bleach, salts, pesticides, metals, toxins produced by bacteria, and human or animal drugs.

I.7- Organic contaminants found in groundwater

Organic contaminants in groundwater are chemical compounds that originate from human activity and can pollute water supplies. These contaminants can pose significant risks to both environmental and public health. Organic contaminants in ground water include a variety of compounds that can eneter the enevironmenet through a number of sourcessuch as improper waste disposal, industrial runoffs and leaking storage of tanks. These organic contaminats can cuase health issues such as cancer, liver damage, anaemia, gastrointestinal disirders, skin irritations, and blurred vision, Common organic contaminants include carbon tetrachloride , dichloromethane, 1,2-dichloroethane, 1,1,1-trichloroethane, vinyl chloride , 1,1-dichloroethene, 1,2-dichloroethene, trichloroethene, tetrachloroethene, benzene, toluene, xylenes, ethylbenzene, styrene, benzo(a)pyrene, monochlorobenzene, 1,2-dichlorobenzene, 1,4-dichlorobenzene, trichlorobenzenes(total), epichlorohydrin, Sources of organic contamination include agricultural runoff (pesticides, herbicides, and fertilizers can leach into groundwater from farms), industrial discharges (manufacturing plants may release organic chemicals that can infiltrate groundwater), improper waste disposal (chemicals, including household products and pharmaceuticals, improperly disposed of can migrate to groundwater) and leaks from underground storage tanks (usts): (leaking tanks storing chemicals such as fuel or solvents can contaminate the soil and groundwater). They have no direct toxic effects on loiving beings but can reduce the dissolved oxygen levels in ground water. These compounds have guideline values for drinking water recommended by WHO, in view of their health effects on humans as seen in table III.

Table III: WHO Guidelines for with respect to organic contaminants of drinking water quality (World Health Organization, 2006)

Compounds	**Guideline value ($\mu g.L^{-1}$)**
Carbon tetrachloride	2
Dichloromethane	20
1,2-dichloroethane	30
1,1,1-trichloroethane	2000(p)
Vinyl chloride	5
1,1-dichloroethene	30
1,2-dichloroethene	50
Trichloroethene	70(p)
Tetrachloroethene	40
Benzene	10
Toluene	700
Xylenes	500
Ethylbenzene	300
Styrene	20
Benzo(a)pyrene	0,7
Monochlorobenzene	300
1,2-dichlorobenzene	1000
1,4-dichlorobenzene	300
Trichlorobenzenes(total)	20
Epichlorohydrin	0,4(p)

(p): Provisional guideline value

I.8: Physical Characteristics of Groundwater

The physical characteristics of ground water bodies are well sumarised in the table IV below.

Table IV: Physical characteristics of groundwater (World Health Organization, 2006)

Contaminant	**Sources to groundwater**	**Potential health and other effects**
Turbidity (NTU)	Caused by the presence of suspended matter such as clay, silt, and fine particles of organic and inorganic matter, plankton, and other microscopic organisms. A measure how much light can filter through the water sample	Objectionable for aesthetic reasons. Indicative of clay or other inert suspended particles in drinking water, May not adversely affect health but may cause need for additional treatment, Following rainfall, variations in groundwater turbidity may be an indicator of surface contamination.
Color (Pt/Co)	Can be caused by decaying leaves, plants, organic matter, copper, iron, and manganese, which may be objectionable, Indicative of large amounts of organic chemicals, inadequate treatment, and high disinfection demand, Potential for production of excess amounts of disinfection byproducts	Suggests that treatment is needed, No health concerns. Aesthetically unpleasing
pH (CU)	Indicates, by numerical expression, the degree to which water is alkaline or acidic. Represented on a scale of 0–14 where 0 is the most acidic, 14 is the most alkaline, and 7 is neutral	High pH causes a bitter taste; water pipes and water-using appliances become encrusted; depresses the effectiveness of the disinfection of chlorine, thereby causing the need for additional chlorine when pH is high. Low-pH water will corrode or dissolve metals and other substances
Odor	Certain odors may be indicative of organic or non-organic contaminants that originate from municipal or industrial waste discharges or from natural sources	
Taste	Some substances such as certain organic salts produce a taste without an odor and can be evaluated by a taste test	Taste

Physical properties of water are related to the appearance of water, namely, the color, temperature, turbidity, taste, and odor. To be suitable for use, water must be free from all impurities that are offensive to the sense of sight, taste, or smell and one very important physical characteristic that should be encountered when discussing water quality is turbidity. The presence of suspended materials such as clay, slit, finely divided organic material, plankton, and other inorganic materials in water is called turbidity. Turbidity is a measure of the clarity of water, Low-turbidity water is clear, while high turbidity water is cloudy or murky. The unit of measuring turbidity is turbidity unit (TU), Turbidity larger than 5 TU is easily detected in a glass of water and is objectionable for aesthetic reasons.

I.9- Physico-chemical parameters of water

I.9.1. Temperature and Suspended Solids

Water temperature (in °C) is one of the main physical factors that affect chemical and biological reactions. It plays an important role in the solubility of salts and gases necessary for the balance of aquatic life. It depends on the Latitude, the Altitude, the season, the time of sampling and the flow rate of the water (Rodier *et al*,, 2009). In lotic systems, temperature determines the speed of chemical and biochemical reactions. Thus, for a temperature increase of 10°C, the speeds of chemical and biochemical reactions increase by a factor of 2 to 3 (IBGE, 2005). The metabolic activity of aquatic organisms and the maturation of certain Protozoan cysts and oocysts as well as Helminth eggs and larvae is also accelerated when water temperature increases, According to Rodier *et al*, (2009), high temperature (above 20°C) promotes the maturation of enteric parasites in aquatic environments.

Suspended solids (MES) (in mg/L) include mineral or organic materials that do not solubilize in water (clay, sand, silt, plankton, among others).

Most enteric pathogens live attached to suspended matter in water (Medema *et al.*, 1998). SS vary with the type of watershed, the nature of the land crossed, the season and possible effluent inputs (Rodier *et al.*, 2009). Furthermore, suspended matter can accumulate high quantities of toxic materials (metals, pesticides, mineral oils, polycyclic aromatic hydrocarbons, etc,) (IBGE, 2005), SS increases the turbidity and color of the water. The abundance of these particles in water measures its degree of turbidity; while the color of the water is due to mineralization and the presence of humic substances (Zébazé Togouet, 2008).

I.9.2. Alkalinity, Hydrogen Potential and Electrical Conductivity

The alkalinity of water (in mg/L) reflects its ability to absorb protons Also called complete alkalimetric titer (TAC), it corresponds to the sum of bicarbonate ions (HCO_3^-), carbonate ions (CO_3^{2-}) and hydroxide ions (OH^-). In natural waters, alkalinity varies from 10 to 350 mg/L, with values between 25 and 50 mg/L for watercourses located in regions with an acidic substrate (Rodier *et al*., 2009*).* Variations in alkalinity should be compared with those in the degrees of mineralization of water and oxidation of organic compounds, but also with the carbon dioxide content (Lévêque and Balian, 2005).

The Hydrogen potential (pH) is a measure of the acidity of the water, that is to say the concentration of Hydrogen ions (H^+). The pH of natural waters is determined in part by the geological nature of the watershed, by acid precipitation and by the biological activity of microorganisms (Painchaud, 1997). According to WHO standards, it is generally accepted that a natural pH between 6.5 and 8.5 characterizes waters where life develops optimally (IBGE, 2005). The action of pH on enteric pathogens in water can be indirect and is achieved in particular by the modification of the assimilation coefficient of the different mineral or organic nutrient compounds, the importance of which will depend on the tolerance of the organisms towards -vis the acidity of the environment.

Electrical conductivity (in µS/cm) is a numerical expression of the ability of water to conduct electric current. It is proportional to the quantity of ionizable salts and its measurement constitutes a good indication of the degree of mineralization of water. The evaluation of this parameter integrates the entire ionic composition of water (anions and cations), therefore all the salts dissolved in water. Knowledge of the dissolved salt content is important as the survival of intestinal parasites depends on their tolerance. Water pollution results in an increase in conductivity and Total Dissolved Solids (TSD) and therefore, an increase in the dissolved salt content (Zébazé Togouet, 2004).

I.9.3. Dissolved Oxygen and Oxidability

Dissolved oxygen (in % saturation and can also be mg/l) is a chemical variable whose content has a specific meaning relating to the quality of organisms present in water (Rodier et *al,*, 2009). Normal ecological balance conditions require an oxygen saturation rate of 75%, the situation becoming critical below 50% (Foto Menbohan and Njiné, 1991). The dissolved oxygen concentration varies daily and seasonally and depends on many factors such as atmospheric oxygen partial pressure, water temperature, salinity, light penetration, water

agitation and nutrient availability (IBGE, 2005). It also depends on the activity of aquatic microorganisms during the processes of oxidation and decomposition of organic matter present in the water, A well-oxygenated environment would favor the maturation of Helminth eggs and the cysts of intestinal protozoa. Sporulation of Protozoan oocysts takes place in an oxygenated environment.

Oxidizability (in mg/L of $KMnO_4$) is a parameter generally used to assess the quality of water with a low organic matter content (AFNOR, 1999). It determines the quantity of oxygen released by the permanganate ion to oxidizable materials in the water, especially organic matter. In fact, it takes into account all organic and mineral materials which come from domestic, agricultural and industrial waste (iron, nitrite) which are easily oxidizable (Rodier, 1996; AFNOR, 1999). The decomposition of organic matter in water can cause asphyxiation of aquatic wildlife, Surface water with an oxidizability above 2 mg/L shows traces of pollution.

I.9.4. Orthophosphates and forms of Nitrogen

Orthophosphates (in mg/L of PO_4^{3-}) correspond to the form of phosphorus directly assimilated by plants (Rodier *et al.*, 2009). They are used in the composition of many detergents and provide information on water pollution by human activities. Indeed, when the concentration of phosphorus in the water is low, plant production is low. On the other hand, when the concentration of phosphorus in the water increases, plant production increases, with the corollary of a reduction in illumination at depth, an increase in pH likely to generate concentrations of ammonia toxic to the kingdom, animal.

In hydrosystems, nitrogen is found in the form of organic nitrogen, ammoniacal nitrogen (NH_4^+), nitrites (NO_2^-), nitrates (NO_3^-), or associated with other compounds (CEAEQ, 2007). These forms of nitrogen, expressed in mg/L, are important for monitoring the quality of surface water and their contents in the water are dependent on exogenous inputs, the degree of oxygenation of the water and the biological activity. During nitrogen releases (proteins, amino acids, urea), the molecules are first transformed into ammonium (NH_4^+) which is then oxidized into nitrites then into nitrates under the action of nitrifying bacteria (IBGE, 2005).

Nitrogen usually reflects a process of incomplete degradation of organic matter. The concentration of ammoniacal nitrogen in a body of water provides information both on the dissolved oxygen content of this ecosystem and on its pollution (Liechti *et al.*, 2004). The content of $NH_4^{+\ ions}$ is very high in waters rich in organic matter when the percentage of oxygen saturation is insufficient to ensure its oxidation into nitrates (CEAEQ, 2007). In addition, an

excessive increase in temperature transforms the NH_4^{+} ion into NH_3 which is toxic for many aquatic organisms (IBGE, 2005). However, human activity accelerates the process of enriching water with this element through the supply of urban and industrial effluents, the discharge of domestic wastewater, and the leaching of agricultural soils highly enriched with fertilizers and pesticides (Bhat *et al.*, 2013).

Nitrates present in water can come from land leaching after fertilizer application, domestic wastewater and certain basic wastewater, Unpolluted natural waters generally contain little nitrates. They represent the most common nitrogenous mineral compound in well-oxygenated waters.

Nitrites appear as intermediate products in the phenomenon of nitrification, that is to say in the biological transformation of ammonium into nitrates. They only persist in running water when the environment is not sufficiently oxidized and their long-term presence indicates a state of organic pollution (Foto Menbohan and Njiné, 1991).

I.9.5- Trace elements and metal ions

Trace metal elements (TMEs) or heavy metals characterize certain types of pollution. These include essential metals, heavy metals, oligo metals and toxic metals as seen in table 1 of inorganic substances in water bodies. They have a capacity for bioaccumulation along food chains and, unlike organic pollutants, cannot be degraded biologically or chemically. They dissolve well in acidic water; on the other hand, in neutral or basic waters, they precipitate and accumulate in the sediments. The analysis of sediments thus makes it possible to obtain an overview of all the heavy metal spills that have taken place, both in nature and in quantity (IBGE, 2005). They are persistent in the environment and can also accumulate in living organisms and be toxic even at very low concentrations. The phenomena of absorption, adsorption and desorption or precipitation of metallic trace elements depend on the physicochemical quality of the water (Jouanneau, 1983).

A certain number of metals are generally taken into account in physicochemical water quality monitoring programs. These are Lead (Pb), Iron (Fe), Zinc (Zn), Copper (Cu), Nickel (Ni), Chromium (Cr), Cadmium (Cd), Mercury (Hg), Manganese (Mn) and Aluminum (Al), These metals can be found in solution, in the state of mineral or organic complexes, in colloidal form, particulate hydroxides and insoluble oxides. If some of these metallic trace elements (Fe, Ni and Cr) are essential and even essential to biological processes, others (most) are toxic to most intestinal parasites (Desaunay, 2011). Iron is the most abundant metal in the earth's crust,

As a result, it can be naturally released, mainly from igneous rocks, sulphide ores and sedimentary rocks (Rodier *et al.*, 2009). These metallic elements originate from mining activities, industries as well as fertilizers and pesticides used in agriculture (Miguel., 2008).

The response of enteric parasites to metal pollution varies greatly with the type, concentration and frequency of emission of the pollutant, but also with the nature of the microorganism, Interactions between microorganisms and metals are governed by passive or active mechanisms (Haferburg and Kothe, 2007). The first are independent of metabolism and therefore of the physiological state of cells (living or dead), they are rapid and reversible. They take place at the cell/solution interface and involve mechanisms such as ion exchange, surface complexation or precipitation. The second depend on cell metabolism and are therefore specific to each parasitic organism, they are slower and generally inducible. These passive and active interactions will depend on the cellular structure and can occur simultaneously. Generally speaking, heavy metals can be fixed on the cellular structure and consequently biosorbed on binding sites, This is independent of metabolism and is known as biosorption (Malik, 2004), Heavy metals can also enter cells by passing the membrane via metabolism. This mode of transport is known as assimilation (Malik, 2004). These two modes of interaction are more generally grouped under the term bioaccumulation (Desaunay, 2011).

Other metal ions such as Calcium ions (Ca^{2+}), Magnesium (Mg^{2+}), Potassium (K^{+}), Fluorides (F^{-}), Chlorides (Cl^{-}) and Sulfates (SO_4^{2-}) are elements in solution which can intervene in the composition of the cellular membranes of certain organisms and during membrane exchanges, K^{+}, Na^{+}, Mg^{2+} and Ca^{2+} ions are essential for microorganisms and participate in the functioning of cells, A high content of Cl^{-} and SO_4^{2-} ions may indicate pollution by domestic wastewater or certain industrial wastewater. It is especially the sudden and significant changes in the levels of these ions which prove harmful for most microorganisms, including the eggs and cysts of intestinal parasites, High concentrations of some of these mineral elements in solution can slow down the maturation of parasite cysts through their great capacity to penetrate cell walls (Jenkins *et al*., 1998); thus contributing to their destruction.

I.10- Biological Organisms affecting drinking water quality

Biological organisms are among the oldest health threats to drinking water quality and the agents currently responsible for most waterborne diseases. They are the most common contamination incident water operators will encounter, Organisms known to cause disease include bacteria, protozoa, and viruses; some algae and helminths (worms) may also be capable

of producing disease. These disease-causing organisms thrive in the intestines of warm-blooded animals. They are easily transmitted to drinking water if the feces of an animal contaminates a water supply for which there is not suitable disinfection, Potential sources of contamination include sewers, septic systems, feedlots, and animal yards, Role of coliforms in detecting contamination, Unfortunately, specific disease-producing (pathogenic) organisms present in water are not easily identified. It would be very difficult, expensive, and time consuming to monitor for them. For this reason, it is necessary to select an easily measured "indicator organism," whose presence indicates that pathogenic organisms may be present, A group of closely related bacteria, the total coliform, has been selected as an indicator of harmful organisms in drinking water.

I.10.1- Enteropathogenic Protozoa

In biology, the term Protozoa (from the ancient Greek proto = first and zoo zoa = animal) designates animal Protists, Protozoa are eukaryotic, unicellular and heterotrophic animals belonging to the Protista group (Parry, 2004). Most Protozoa are mobile and can be isolated from a wide variety of ecological niches, including water, moist soils as well as within other organisms (Parry, 2004), Some of them can be pathogenic and cause disease.

Most Protozoa reproduce by asexual multiplication and their forms of resistance are represented by cysts and oocysts, Protozoa play an important role in nature (Parry, 2004) where they have conquered and adapted to all environments and habitats (fresh water, sea water, as symbionts or as parasites) and even environments extremes (hot water springs, super saline lakes), Biologically and evolutionarily, Protozoa are considered the first eukaryotic cells and are divided into 4 subgroups according to their mode of locomotion: Rhizopods (pseudopods), Flagellates (flagellae), Ciliates (cilia) and Sporozoa (intracellular) (Parry, 2004).

I.10.2. Enteropathogenic rhizopods

Systematic

The justified systematics of enteropathogenic Rhizopods is summarized in the table V below, Rhizopods constitute the super class of Protozoa presenting neither flagella nor characteristic cilia. To move, they use cellular protuberances called pseudopodia which provide a second essential function, nutrition (Lacoste, 2009). They belong to the order Amœbida which are Protozoa commonly known as amoebae. Depending on the lifestyle, amoebae are distinguished into free-living amoebae and enteroparasitic amoebae, The latter are grouped in the family Entamoebidae (or intestinal amoebae), Based on the appearance of the nucleus, intestinal

amoebae are classified into two groups (see table V below). The Entamiba group with their nucleus consisting of a peripheral membrane lined with a layer of chromatin, a small, central or eccentric karyosome (genus *Entamoeba*) and the Limax group whose nucleus has a very thin nuclear membrane and a large, central karyosome, surrounded by achromatic granules, also called perikaryosomal granules, corresponding to the chromosomes (genus *Limax*).

Table V: Justified systematics of enteropathogenic Rhizopods (Lacoste, 2009)

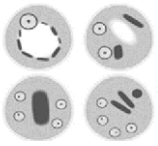
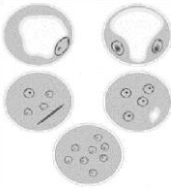
Systematic	**Rationale**
Branch: Sarcomastigophora	Protozoa that move using flagella, pseudopodia, or both
Under branch: Sarcodina	Protozoans which have a locomotor apparatus consisting of either flagella, cilia or pseudopods
Superclass: Rhizopoda	Protozoans that move using pseudopodia
Class: Lobosea	Pseudopods lobed and more or less filiform
Order: Amoebida	Amoebae that have cells that are usually naked
Family: Entamoebidae	Intestinal amoebas
Genus: *Entamoeba* *Endolimax* *Pseudolimax* *Dientamoeba*	Nucleus consisting of a peripheral membrane lined by a layer of chromatin and provided with a small, central or eccentric karyosome Nucleus with a thin nuclear membrane and a large, eccentric karyosome Nucleus with a very thin nuclear membrane and a large central karyosome surrounded by achromatic granules Nucleus with a very thin membrane and a karyosome formed of numerous fine granulations
Species : *Entamoeba histolytica, Entamoeba coli, Entamoeba polecki* and *Entamoeba hartmanni Endolimax babe, Pseudolimax butschilii , Dientamoeba fragilis*, *Entamoeba dispar,* and *Entamoeba bangladeshi,*	

I.10.3. Morphological characteristics of enteropathogenic rhizopod cysts

Table VI presents the morphological characteristics which make it possible to identify entero-pathogenic rhizopod cysts. The cysts vary in size between 5 and 25µm and generally have a rounded shape. Their cytoplasm sometimes contains chromid inclusions, glycogen vacuoles and even granules. The structure of the nuclei varies depending on the gender and their number depends on the degree of maturity of the cell, Immature forms of *Entamoeba histolytica* and *Endolimax nana* have between 1 and 2 nuclei, while mature forms have 4, In

Entamoeba coli, mature forms have 8 nuclei. The species *Entamoeba polecki* and *Pseudolimax butschilii* are characterized by the presence of a single nucleus. Most of these cysts are released into the external environment in immature form and acquire maturity in the environment under certain conditions (Lacoste, 2009).

Table VI: Morphological characteristics of enteropathogenic rhizopod cysts (Lacoste, 2009)

Parasite	**Size (µm)**	**Shape**	**Core (number)**	**artwork**
Entamoeba histolytica	10-20 µm (population 12-15 µm)	Rounded	Immature form (1 or 2) Mature form (4)	
Entamoeba hartmanni	5-10 µm (hab, 6-8 µm)	Rounded	Immature form (1 or 2) Mature form (4)	
Entamoeba coli	10-35 µm (population 15-25 µm)	Rounded or elongated	Immature form (1 or 2) Mature form (8)	
Entamoeba polecki	9-24 µm (hab, 9-15 µm)	Rounded	1 only rarely 2	
Endolimax babe	5-10 µm (hab, 6-8 µm)	Rounded or ovoid	Immature form (1 or 2) Mature form (4)	
Pseudolimax butschilii	5-20 µm (population 10-12 µm)	Rounded or ovoid	1 only	

hab = usually,

I.10.4. Morphology and development cycle of *Entamoeba histolytica*

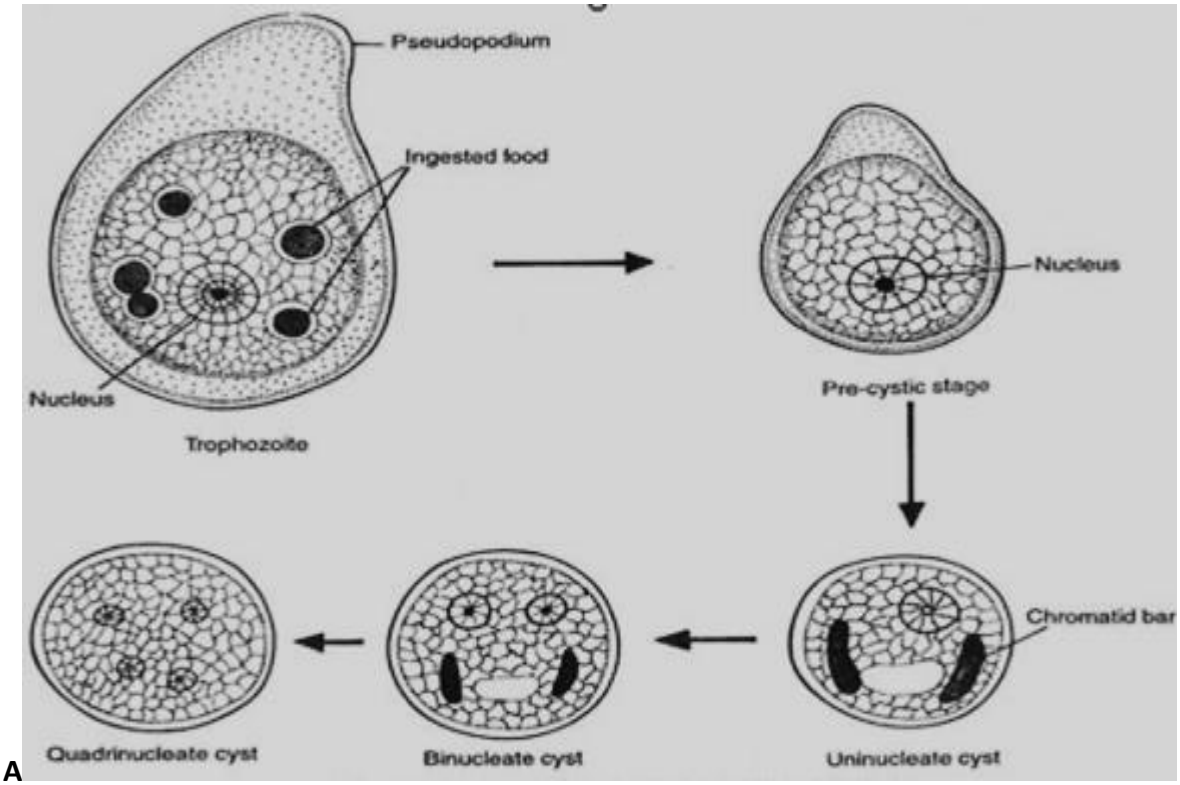
Entamoeba histolytica occurs in three morphologically and biologically different forms, Two vegetative and mobile forms: the shape minuta (small size, non-hematophagous and which can encyst alone) and the form histolytica (large, hematophagous and able to necrotize tissues thanks to significant enzymatic equipment), *Entamoeba histolytica* exists in two main morphological forms, The trophozoite is the active, motile form that is responsible for causing tissue damage in the host's intestine, Nucleus: It has a single, centrally located nucleus, The nucleus contains a finely granular chromatin and a prominent karyosome (a compact mass of chromatin in the center of the nucleus), Cytoplasm: The cytoplasm is divided into an outer (ectoplasm) and inner (endoplasm) layer, The ectoplasm is clear, and the endoplasm is granular, It may also contain red blood cells, which are ingested by the parasite during infection, Motility: The trophozoite moves by pseudopodia (false feet), extending and retracting its cytoplasm for locomotion and feeding, Cyst (Infective form) is the dormant, environmentally resistant form of *E, histolytica*, which allows the parasite to survive outside the host, The cyst contains 1 to 4 nuclei, depending on its stage of maturity, Inside the cyst, there may be remnants of ingested material and the chromatin of the nucleus.

A cystic, immobile form which is the form of resistance and dissemination with nuclei which vary from 1 to 4 (Figure 3).

The histolytica form measures 12 to 40 µm in diameter, It has a clearly visible hyaline ectoplasm at the level of the pseudopodia when this one is constituted and a granular endoplasm containing small digestive vacuoles, some of which contain more or less lysed red blood cells and retracted, These red blood cells can be very numerous and are stained red, Others vacuoles contain food debris and bacteria, Its nucleus, invisible when fresh, appears after staining, The chromatin is fine, regular and its shape is reminiscent of a "string of pearls", the karyosome is punctiform and central. The ectoplasm is quite distinct from the endoplasm which presents granulations made up of bacteria, yeast and red blood cells, hence its name hematophagous amoeba.

The minuta form is smaller than the previous form and measures 10 to 15 µm in diameter. The hyaline and transparent ectoplasm is clearly visible (Tchouyabe, 2012). The endoplasm contains numerous small vacuoles and its nucleus is peripheral, 3 to 4 µm, with a small central karyosome, punctiform, with a thin nuclear membrane and peripheral chromatin, The endoplasm is granular, contains numerous vacuoles and phagocytosed bacteria but never red blood cells, The cysts are round or spherical in shape and measure 10 to 15 µm in diameter

(cysts with 1 nucleus are larger than those with 4 nuclei). They are surrounded by a double membrane, 1 nucleus are larger than those with 4 nuclei). They are surrounded by a double membrane.



A

B

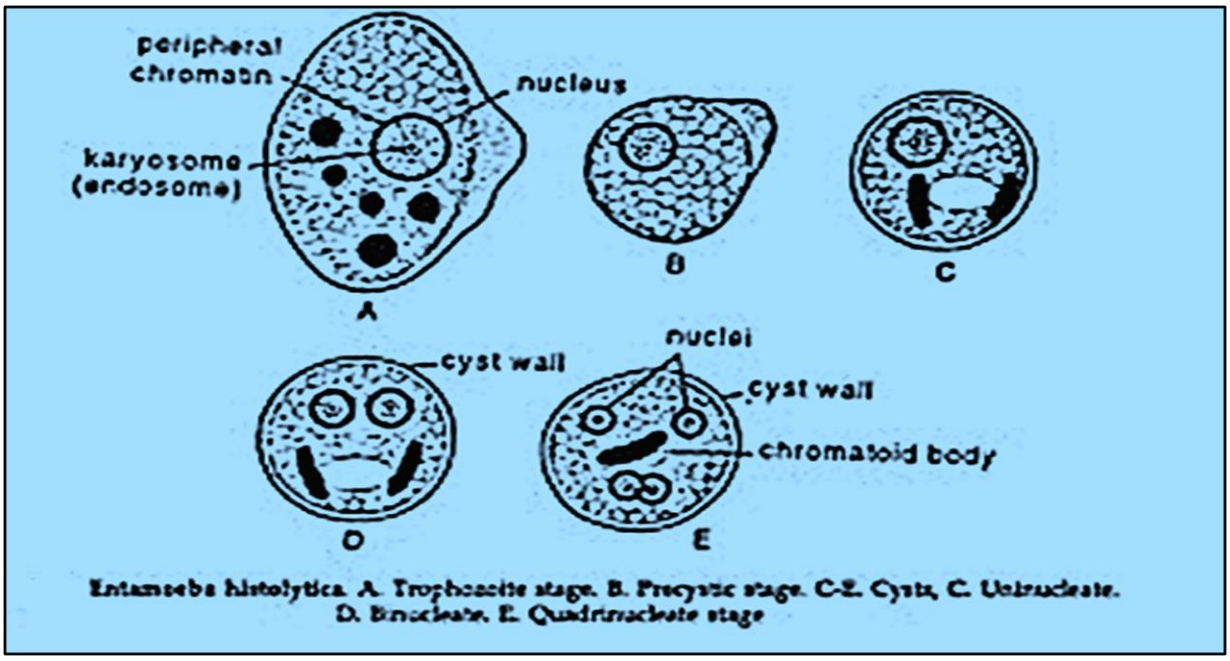


Figure 5: Structural organization of trophozoites (A) and cysts (B) of *Entamoeba histolytica* (Lacoste, 2009)

The cysts are refractile in the fresh state and their cytoplasm may contain chromidial or crystalloid inclusions which are elongated elements and a glycogen vacuole (Tchouyabe, 2012).

The development cycle of *Entamoeba histolytica* is monoxenous. It begins with the ingestion of a mature cyst through contaminated water or food, However, cases of transmission via oral-anal sexual practices or via inoculation by introduction of endoscopic material into the colonic passages are reported, Once the host has ingested the cyst, decystation or hatching occurs in the small intestine under the action of temperature, pH and trypsin. At this level, we can have two scenarios: the non-pathogenic cycle and the pathogenic cycle. The pathogenic cycle is the cause of the disease amoebiasis, Under the influence of factors depending on both the host and the strain of *Entamoeba histolytica* (virulence of the strain, immunity deficiency, modification of the bacterial flora of the colon), the minuta form transforms into the aggressive histolytica. This form is very mobile and has numerous proteolytic enzymes which give it significant necrotizing power. The parasite breaks through the colonic mucosa, engulfs red blood cells, thus producing ulcerations. It reaches the submucosa where it actively multiplies by fissiparity and forms abscesses that are more extensive in depth and laterally than on the surface (shirt button abscess). The trophozoites reach the lumen of the vessels of the portal system and are passively carried into the liver where they form hepatic abscesses or, passing through the suprahepatic veinlets, reach the right heart.

The non-pathogenic or amoebiasis-infection cycle begins before excystation. The amoeba becomes mobile and then pushes through a pore in the cyst wall, a pseudopod that pulls the entire parasite out of the shell, The latter transforms into a plasmodial mass with 4 nuclei, which undergoes karyokinesis and cytodieresis evolving into 8 amoebules which become amoebae (non-hematophagous *Entamoeba histolytica* or *minuta form)* and live as a *saprophyte* in the colon, These minuta forms will divide by fissiparity, then round to give precystic forms, The latter surround themselves with a shell and divide to form cysts (Aminata, 2006). They then pass to the lung where they can stop or are brought to the left heart from where they can reach the brain, kidney and spleen, Immature cysts as well as trophozoites are eliminated with the feces, The cysts mature in the environment and ensure dissemination while the trophozoites passed in the stools are quickly destroyed once outside. All these are summarised in figure 4 below.

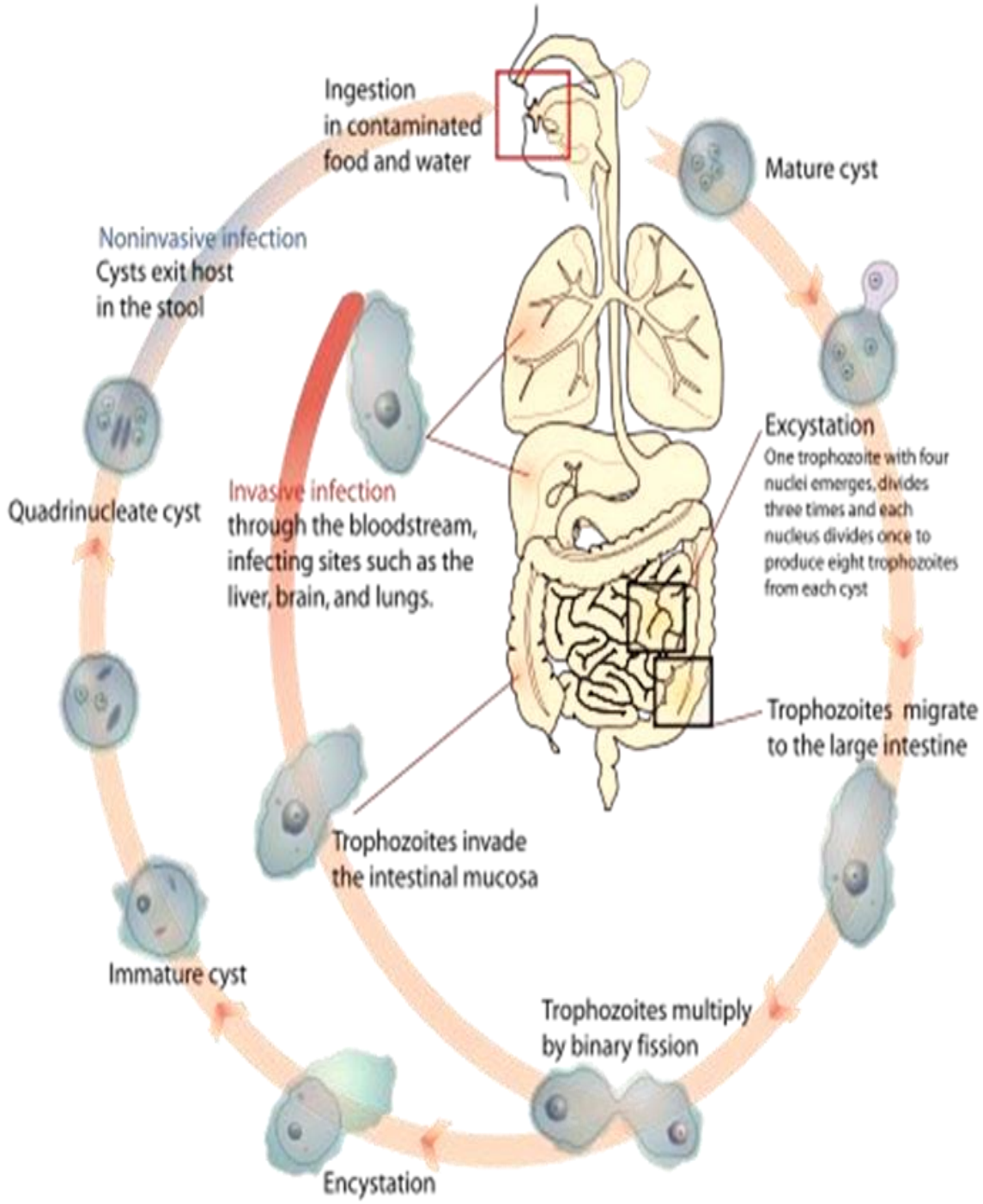


Figure 4: Development cycle of *Entamoeba histolytica* (ANOFEL, 2016)

I.10.5. Enteropathogenic flagellates

Systematic

Flagellated protozoa are grouped in Flagellata (Mastigophora), They are sometimes divided into Phytoflagellata (Phytomastigina, mostly autotrophic) and Zooflagellata (Zoomastigina, heterotrophic), Taxonomic systematics of protozoa flagellates are grouped into Sarcomastigophora as seen in table VII below.

Table VII: Justified systematics of enteropathogenic flagellates (Lacoste, 2009)

Systematic	**Rationale**
Phylum: Sarcomastigophora	Protozoa that move using flagella, pseudopodia, or both
Sub-division: Mastigophora	Protozoans that move using flagella
Class: Zoomastigophora	Protozoa with animal affinity
Orders: Diplomonadida Retortamonida Trichomonadida	Presence of a nucleus and split cellular organelles as well as a symmetrical body Presence of 2 to 4 flagella including one undulating in a cytostome Presence of 4 to 6 flagella including one recurrent bordering an undulating membrane
Families: Hexamitidae Chilomastigidae Enteromonadidae Trichomonadidae	Presence of six flagella Presence of a torsion groove Absence of a visible cytostome Presence of an axostyle which clearly extends beyond the posterior end of the cell
Genera: *Giardia* *Chilomastix* *Retortamonas* *Enteromonas* *Trichomonas*	**Species:** *Giardia intestinalis*, *Giardia muris* and *Giardia agilis* *Chilomastix mesnili* *Retortamonas intestinalis* *Enteromonas hominis* *Trichomonas intestinalis*

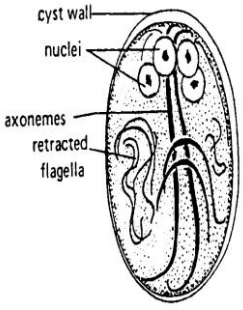
Flagellates are protozoa characterized by the presence of one or more flagellum-type locomotor organelles (Lacoste, 2009), Sometimes, this flagellum is attached over part of its length to the surface of the cell, to form an undulating membrane. They are generally small (2 to 30 µm), They are distinguished by the number and direction of flagella, the number and position of the nucleus, and the presence or absence of the axostyle.

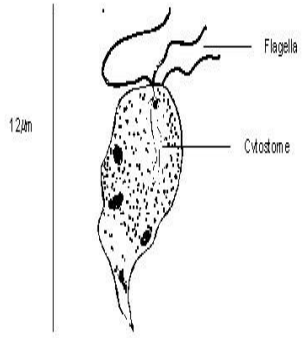
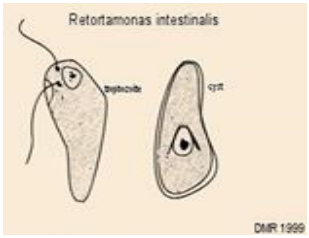
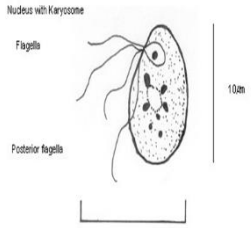
Enteropathogenic Flagellates are represented by three orders (Diplomonadida, Trichomonadida and Retortamonida), four families (Hexamitidae, Chilomastigidae, Enteromonadidae and Trichomonadidae) and five genera, The genus *Giardia* was initially separated into 3 main species: *Giardia intestinalis* (parasite of humans and other mammals), *Giardia agilis* (amphibian parasites) and *Giardia muris* (rodent parasites) (Byrne, 2001).

I.10.6. Morphological characteristics of enteropathogenic flagellate cysts

The elements which enter into the morphological identification of the different species of enteropathogenic flagellates are, among others, the shape, size and content of the cells. Enteric flagellate cysts are oval or pear-shaped, and their size varies between 4 and 19 µm, Cysts of the *Giardia* and *Enteromonas genera* have smooth contours, while those of the *Chilomastix* and *Retortamonas genera* have thick, refractive shells, Their cytoplasm sometimes contains remains of the flagella, the parabasal bodies, the axostyle and also the cytostome, The number and position of the nucleus vary depending on the type and degree of maturity of the cell, In the genera *Chilomastix* and *Retortamona*, the nucleus is central or eccentric, while in those of *Giardia* and *Enteromonas*, they are grouped or arranged at the ends of the cell (see table VIII below. Infection by *Giardia intestinalis* is the leading cause of parasitic gastroenteritis worldwide and the number of new cases is estimated at 200 million per year (Karanis *et al.*, 2007). According to Lacoste (2009), giardiasis is one of the human parasitic conditions widespread throughout the world and the number of healthy carriers is infinitely greater than that of sick (See Table VIII).

Table VIII: Morphological characteristics of enteropathogenic flagellate cysts (Lacoste, 2009).

Parasite	**Size**	**Shape**	**Outline**	**Content**	**artwork**
Giardia lambia	8-19 µm (hab, 11-14 µm)	Oval mature cysts and cysts ovoid immatures	Smooth contour, quite thin and quite refractive, Existence of a vacuum giving the impression of a double membrane	2 or 4 nuclei and the flagella grouped in bundles in the axis of the cyst, body parabasals and an axostyle	

Chilomastix mesnili	6-10 µm (hab, 7-9 µm)	Slightly pear-shaped, almost rounded	Smooth, thick, very clean and very refractive	1-large eccentric core, presence of cytostome and flagella	
Retortamonas intestinalis	4-8 µm (hab, 4-6 µm)	Pear shaped, slightly longer than wide, with a flattened pole	Relatively thick and refractive shell	1 elongated nucleus surrounded by a U-shaped flagellum	
Enteromonas hominis	6-8 µm (hab, 4-6 µm)	Oval or ellipsoidal	Very thin, indistinct and barely refractive outline	4 cores arranged 2 by 2 at the ends of the cyst	

hab = usually

I.10.7. Morphology of *Giardia intestinalis*

The vegetative form of *Giardia intestinalis* measures between 10 and 20 µm long by 6 to 10 µm wide. Figure 5 below shows the organism from the front, to have a shape of a “kite” with an anterior part hollowed out by a large kidney-shaped depression with posterior concavity in which there are two nuclei, Seen in profile, it has more of a crescent shape with a rounded front end, It is the only flagellate to have bilateral symmetry. There are four pairs of flagella, all directed posteriorly: two anterolateral pairs, one ventral pair and one posterior pair, The axostyle is quite clear and divides the body into two symmetrical halves (Nozais *et al*,, 1996), The newly formed cyst is ovoid with a wider end, while the mature cyst is oval, It measures between 8 and 19 µm in length. The cytoplasm of the cyst contains 2 or 4 nuclei, the parabasal bodies in the shape of large refracting commas, an axostyle and the flagella grouped in bundles (Nozais *et al*, 1996).

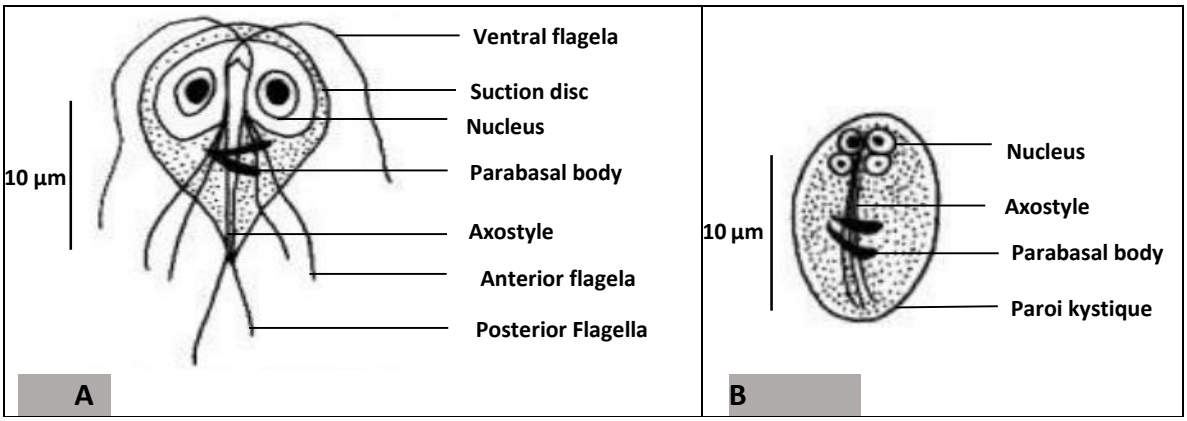


Figure 5: Structural organization of trophozoite (A) and cyst (B) of *Giardia intestinalis* (Lacoste, 2009)

I.10.8- Life cycle of *Giardia intestinalis*

Giardia development cycle *intestinalis* is direct, Humans are mainly contaminated by ingesting cysts from drinking water, contaminated food or by direct faecal-oral contact (Berrouch *et al*., 2020), Contamination can also occur through contact with an infected animal through its coat, Ingested cysts transform into trophozoites in the duodenum under the action of digestive juices and pH and each cyst gives rise to two vegetative form, Figure 8 below, shows how the cysts and trophozoites are eliminated in the feces, but only the cysts resist and ensure dissemination while the trophozoites are rapidly destroyed as seen in figure 6 below.

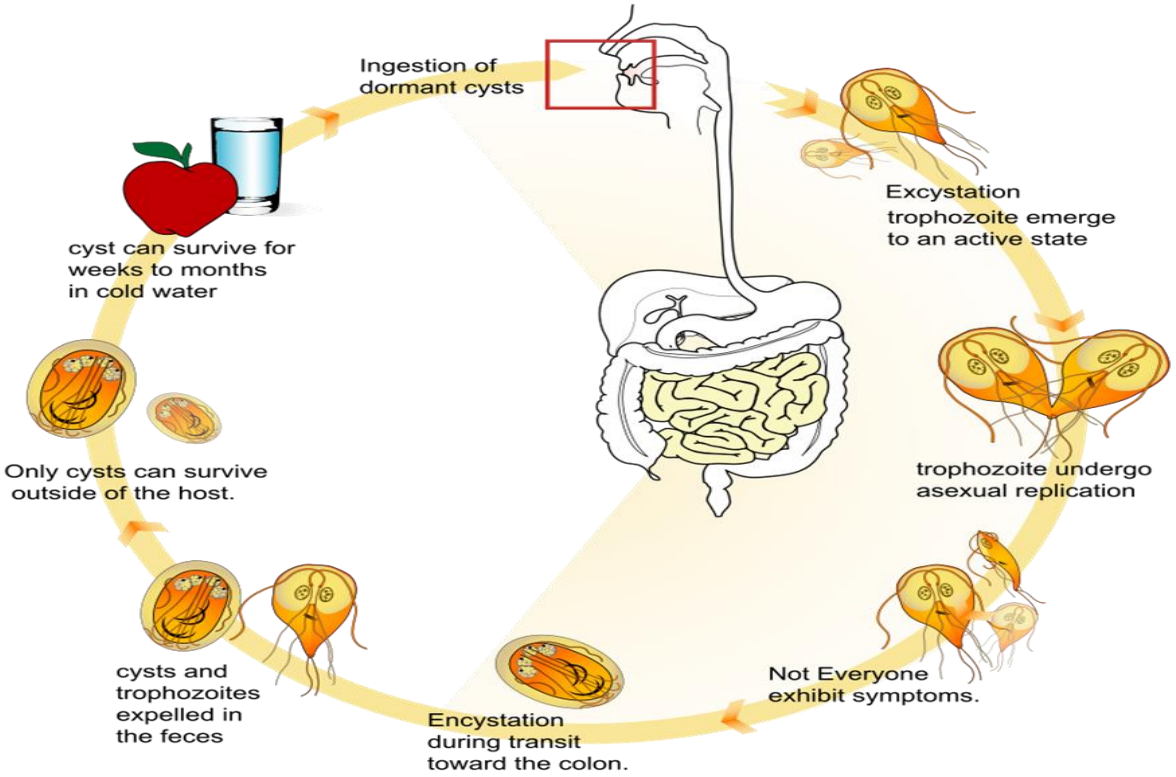


Figure 6: Development cycle of *Giardia intestinalis* (ANOFEL, 2016)

I.10.9. Enteropathogenic ciliates

Ciliates are unicellular dikaryotic organisms constituting the phylum Ciliophora. These are aquatic microorganisms that indicate water quality. They are the basis for the classification of aquatic environments according to the level of saprobia (Foto Menbohan and Njiné, 1991). Most Ciliates live a free life in the wild, most often in fresh water. Only the species *Balantidium coli* can parasitize the digestive tract of humans and other animals (Safaa, 2017). It is responsible for balantidiosis and is capable of encysting when environmental conditions become unfavorable (Lacoste, 2009). Their nuclear apparatus and the presence of numerous cilia (Ciliophora) make them a very homogeneous group, clearly distinct from other groups of Protozoa. The justified systematics of enteric Ciliates is presented in the table IX below.

Table IX: Justified systematics of enteropathogenic Ciliates (Lacoste, 2009)

Systematic	**Justifications**
Branch: Ciliophora	Musculoskeletal system made up of numerous vibrating cilia
Class: Kinetofragminophora	Cilia generally arranged in rows and each provided with a corpuscle
Order: Trichostomatida	Eyelashes gathered in membranes or waxes
Family: Balantidiidae	Presence of a cuticle generally interrupted at the level of the cytostome
Genus: *Balantidiidium*	Colon parasite with longitudinal streaks
Species: *Balantidium coli*	

I.10.10. Morphology of *Balantidium coli*

Balantidium coli trophozoite measures 50 to 200 µm long and 20 to 70 µm wide, Ovoid in shape, its anterior end carrying the cytostome is more tapered than the posterior part where the anus opens. Its orifice is lined with large, long eyelashes. In its cytoplasm, we note the presence of vacuoles and 2 nuclei: The macronucleus and the micronucleus. The macronucleus or vegetative nucleus is large, ovoid in appearance, kidney-shaped, bissac-shaped and contains

dense chromatin. It is polyploid and regulates the metabolism of the cell. It is the nucleus which is involved in vegetative life. It contains the genes that code for all the proteins necessary for vital functions. It is a nucleus with very high transcription activity. The micronucleus or reproductive nucleus is small, rounded and located in the concavity of the macronucleus (Lacoste, 2009), It is diploid and only involved in sexual reproduction. It is a nucleus with low transcription activity, but carries all the genetic information of the species (Jodra and Perrier, 2007), The cyst (Figure 7) is rounded, spherical and measures 50 to 60 µm in diameter. It is the largest cyst of intestinal protozoa. Its wall is thick and transparent. Their content is made up of two nuclei (a micronucleus and a macronucleus) (Lacoste, 2009).

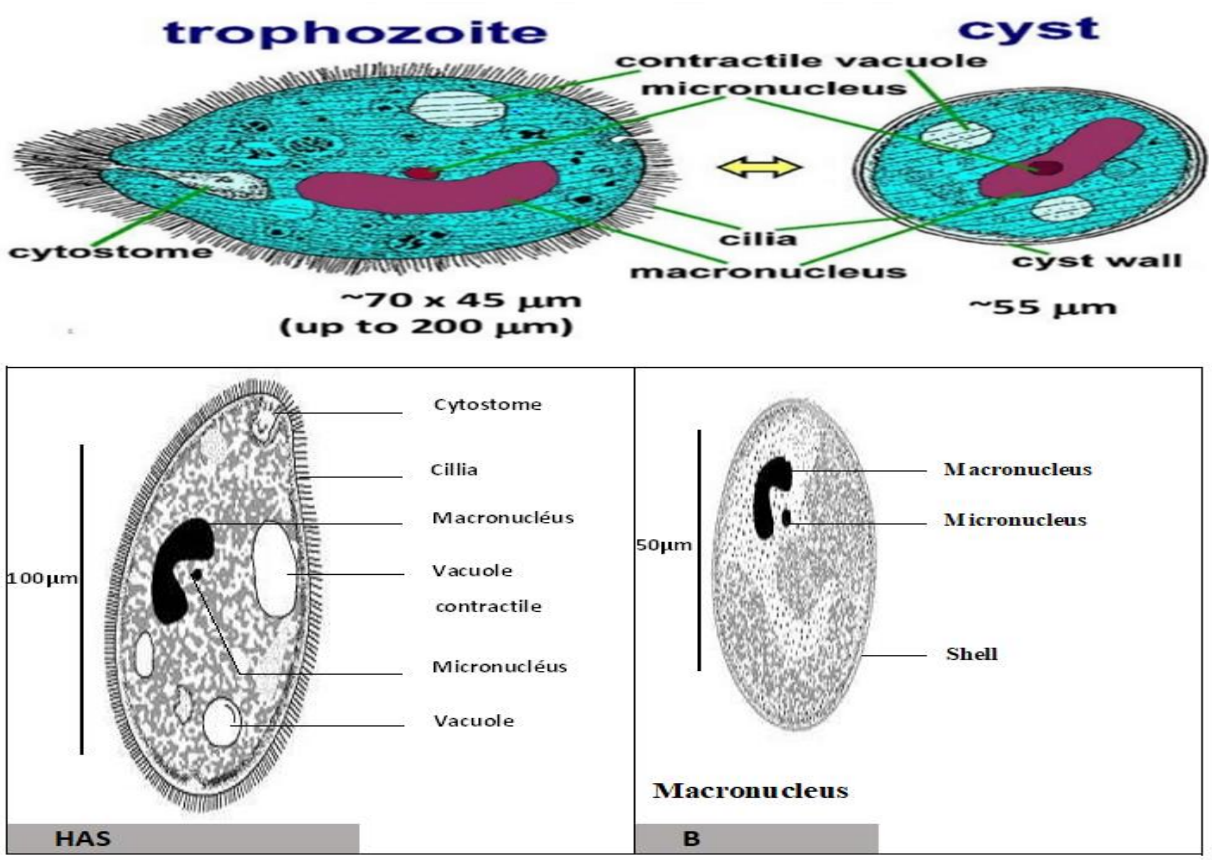


Figure 7: Structural organization of the trophozoite (A) and cyst (B) of *Balantidium coli* (Lacoste, 2009)

I.10.11- Life cycle of *Balantidium coli*

Balantidium development cycle *coli* is monoxene, Humans or animals become contaminated by ingestion of cysts, sometimes vegetative forms coming from contaminated water or food. These cysts pass through the digestive tract to the colon where they settle, Sexual reproduction takes place by conjugation of two vegetative forms and asexual multiplication is

possible by binary fission, Following an attack responsible for a drop in the resistance of the healthy carrier, the *Balantidium coli* cyst can cross the colonic mucosa, reach the submucosa where it multiplies and exerts a lytic action on the tissues (see figure 8 below). Two forms (the vegetative form and the cystic form) are eliminated with feces in the external environment (Lacoste, 2009).

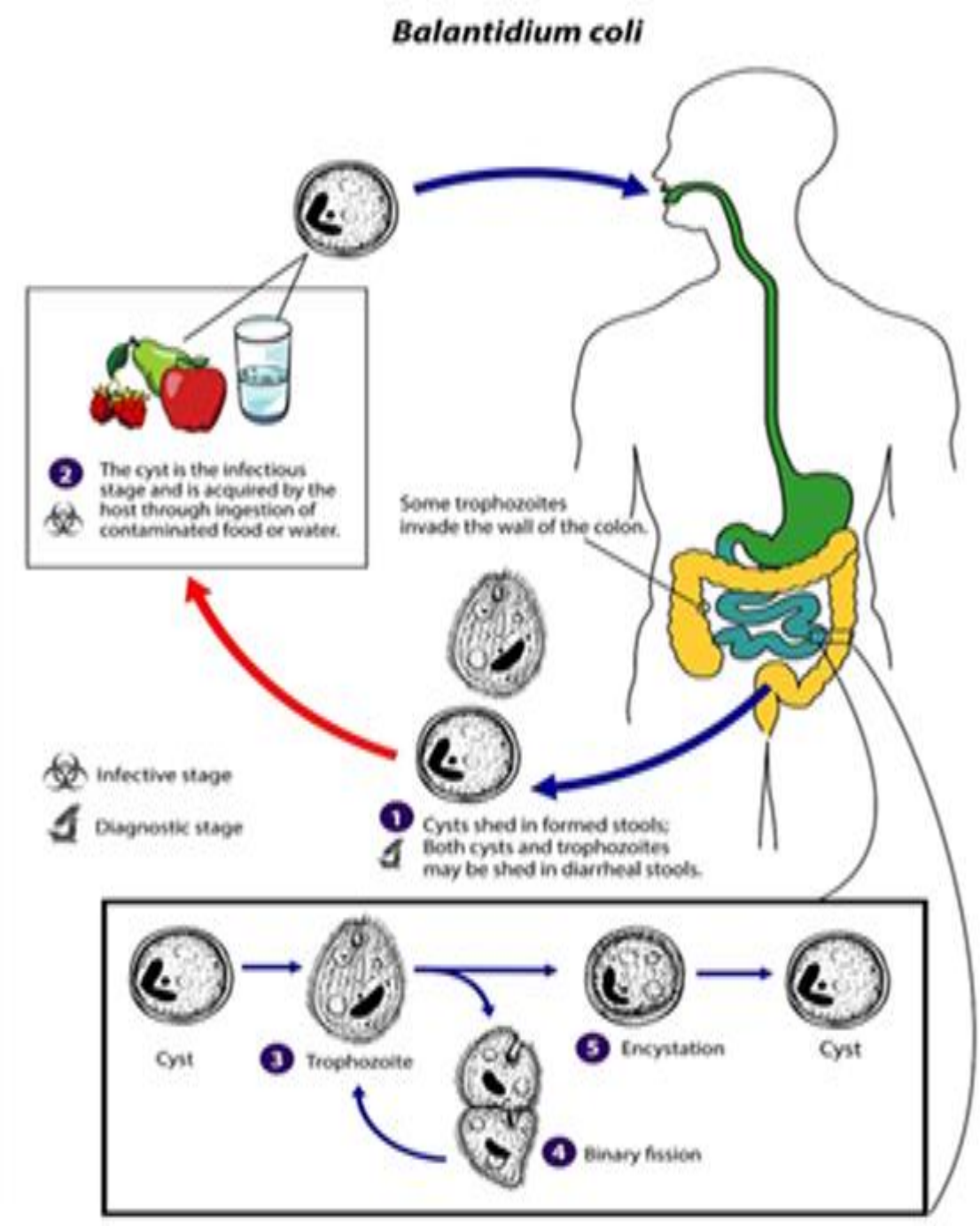


Figure 8: Development cycle of *Balantidium coli* (Huda., 2022)

I.10.12. Enteropathogenic sporozoans

Sporozoa are intracellular parasites capable of forming spores. They have a particular structure at the apical level and are formed of accumulation vesicles and vacuoles. They are monoxenes (a single host) or polyxenes (require several intermediate hosts), Four genera can parasitize the digestive tract of humans and animals (*Cryptosporidium*, *Cyclospora*, *Isospora* and *Sarcocystis*) as seen in table X.

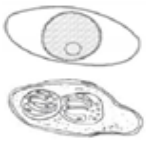
Table X: Justified systematics of enteropathogenic Sporozoa (Lacoste, 2009)

Systematic	**Justifications**
Phylum: Apicomplexa	Parasites lacking locomotor organelles and mitochondria
Class: Sporozoa	Parasites lacking a differentiated musculoskeletal system
Subclass: Coccidia	Presence of an apical complex
Order: Eucoccidida	Obligate intracellular parasites
Family: Eimeriidae	Intestinal or tissue coccidia
Genera: *Cryptosporidium* *Cyclospora* *Isospora* *Sarcocystis*	**Species:** *Cryptosporidium* spp, *Cyclospora cayetanensis* *Isospora belli* *Sarcocystis hominis*

I.10.13. Morphological characteristics of oocysts of enteropathogenic Sporozoa

The morphological characteristics which allow the identification of enteropathogenic Sporozoan oocysts are presented in the table below, Oocysts are spherical or ovoid and have sizes that vary between 4 and 33 µm, With the exception of species of the genus *Cryptosporidium*, oocysts are shed in the stools in non-sporulated form and acquire their sporulation in the environment depending on the physico-chemical conditions of the environment (Lacoste, 2009). Oocysts of the genera *Isospora* and *Sarcocystis* have thinner margins and contain sporocysts with sporozoites (see illustrations in table XII), while those of *Cryptosporidium* and *Cyclospora* have rigid double shells and contain naked sporozoites or granule cells.

Table XI: Morphological characteristics of enteropathogenic Sporozoan oocysts (Safaa, 2017)

Parasite	Size (um)	Shape	Outline and content	Illustrations
Cryptosporidium minor	4-6 µm	Ovoid or spherical	Sporulated oocyst surrounded by a double membrane Contains 4 naked sporozoites and a residual body	
Cyclospora cayetanensis	8-10 µm	Spherical	Non-sporulated oocyst when passed into the stool and surrounded by a rigid double wall Contains globular inclusions and 2 granular cells (sporocysts) when mature	
Isospora belli	20-33 µm x 10-19 µm	Oval or elongated	Oocyst surrounded by a smooth membrane and a more tapered end Immature form contains 1 median sporoblast Mature form contains 2 sporocysts each containing 4 sporozoites	
Human sarcocystis	15-20 µm x 8-10 µm	Ovoid	Oocyst surrounded by a smooth wall Contains 2 elongated banana-shaped sporocysts and a mass of granular cells	

I.10.14. Development cycle of *Cryptosporidium parvum*

The morphologies of the parasite are different depending on the stages of the cycle. At the sporozoite stage, it is a mobile, virguliform cell measuring 5 µm. At the trophozoite stage, the parasite becomes rounded, In the schizont stage, it is oval in shape with a large nucleolated nucleus, At the merozoite stage, it is banana-shaped, 5 µm long and mobile, At the microgametocyte stage, it is round and contains 12 to 16 non-flagellated microgametes 1 µm long which are placed on the periphery of a residual body, At the macrogametocyte stage, it contains large cytoplasmic granules rich in polysaccharides and phospholipids, At the oocyst stage, it measures 4 to 6 µm depending on the species and is surrounded by a double protein membrane, After sporulation, it contains 4 naked sporozoites around a residual body and a thick wall (Lacoste, 2009).

Cryptosporidium development cycle *parvum* is also direct, that is to say it takes place without an intermediate host. It begins with the host ingestion of mature oocysts which undergo decysting, releasing sporozoites which parasitize epithelial cells, It takes place in three phases: schizogony or asexual reproduction phase, gametogony or sexual reproduction phase and

sporogony or phase of formation of a sporulated oocyst containing 4 naked sporozoites without sporocyst as seen in figure 9. The oocysts are evacuated with the stools, thus contaminating the environment and ensuring the dissemination of the parasite (Percival *et al.*, 2000).

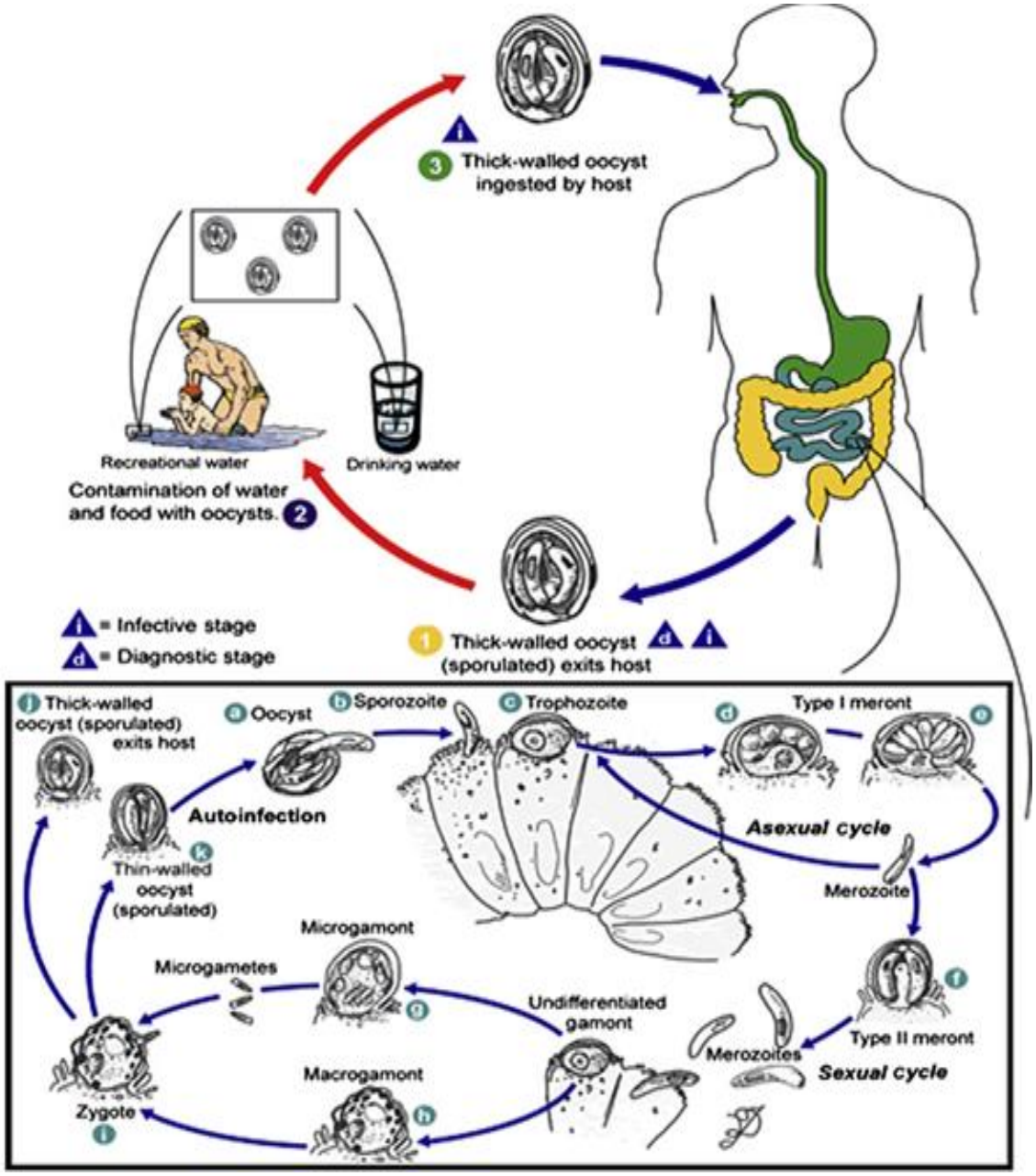


Figure 9: Development cycle of *Cryptosporidium parvum* (Percival *et al*,, 2000),

I.11-Enteropathogenic helminths

Helminths are triploblastic metazoans lacking a true coelom. They have a generally elongated body with a section that can be round (Nemathelminthes) or flattened (Plathelminths), Nemathelminthes that colonize the intestine of humans and other animals are represented by the class Nematodes, while the classes Cestodes and Trematodes represent

Platyhelminths (Aminata, 2006; Safaa, 2017), Most Helminths are pathogens and can cause diseases (helminthiasis) in humans.

Helminthic infections are common worldwide, as more than 1,5 billion people or 24% of the world's population are infected, especially in areas with poor sanitation (WHO, 2017), The species most encountered in Cameroon are: *Ascaris lumbricoides*, *Trichuris trichiura* and *Necator americanus* (Tchuem Tchuenté *and al*,, 2001), Transmission occurs via two main routes: Orally via water, food or soiled hands (eggs of *Schistosoma mansoni*, *Ascaris lumbricoides*, etc,) and transcutaneously by direct penetration of the infesting larvae through the skin (*Ancylostoma* larvae *duodenale*) (Davies-Colley *et al*., 2004).

I.11.1. Enteropathogenic nematodes

Nematodes are pseudocoelomate protostomian triploblastic metazoans, with a cylindrical body, tapering at both ends, non-segmented and covered with a thick chitinoid cuticle (Maggenti, 1981;), Particularly well adapted to their environment, enteropathogenic nematodes have developed two parallel lifestyles, On the one hand, we have the free species which are widespread in all terrestrial and aquatic environments and on the other hand the parasitic species which have as hosts both humans and other animals, Nematodes produce eggs which embryonic *in utero* or outside the host, Emerging larvae undergo 4 metamorphoses (molts) before maturing as adult male or female worms, It is estimated that there are between 40,000 and 100 million species of nematodes, of which approximately 26,000 have been described (Davies-Colley *et al*., 2004).

Most nematodes are gonochoric, we also observe some cases of proteandric hermaphroditism and parthenogenesis, Sexual dimorphism is generally clear with males smaller than females, The development cycle of Nematodes is punctuated by 4 molts which mark the passage from one larval stage to another (L1, L2, L3, L4 and adult) The resistance form of the infesting larva in parasitic forms is represented by the L3 stage (Maggenti, 1981).

According to Aminata (2006), enteropathogenic nematodes are represented by two subclasses: the Adenophorea subclass with an order, a family, a genus; and the subclass of Secernentea which presents the majority of parasitic nematodes of the digestive tract with 4 orders, 4 families and 4 genera as seen in table VIII, The two sub classes are distinguished by the shape of the body.

Table XII: Justified systematics of enteropathogenic nematodes (Lacoste, 2009)

Systematic	**Rationale**
Phylum: Nemathelminthes	Roundworms with elongated, non-segmented bodies
Class: Nematoda	Roundworms with elongated, non-segmented bodies
Subclasses: Adenophorea	Bodies usually showing annuli, complex and spiral amphids
Secernentea	Cylindrical, bottle-shaped or often vestigial esophagus
Order: Enoplida	Non-spiral sac-shaped amphids and smooth or finely ridged cuticle
Ascarida	End of males curved into a crook
Oxyurida	Esophagus often divided into three parts and presence of three or six lips
Rhabditida	
Strongylida	Parthenogenetic females in the intestine and cylindrical esophagus Copulatory bursa in males
Families: Trichuridae	Front part (2/3 of the body) tapered and the rest of the body (1/3) wider
Ascarididae	Vertebrate parasites with monoxenous and indirect life cycles
Oxyuridae	Strictly human parasites
Strongyloididae	Free male and female stercorals in the environment with constricted esophagus
Ancylostomatidae	Free-living adults in the environment and exhibit a pointed posterior end
Genus: *Trichuris*	**Species:** *Trichuris trichiura*
Ascaris	*Ascaris lumbricoides*, *Enterobius vermicularis*, *Strongyloides* sp,
Enterobius	*Ancylostoma* sp.
Strongyloides	
Ancylostoma	

I.11.2- Morphological characteristics of eggs and larvae of enteropathogenic nematodes

Table XIV below presents the size, shape, appearance of the wall, stage of development and particularities of the different species of enteropathogenic nematodes, The eggs vary in size between 50 and 95 µm and generally have an oval shape, In larvae, the size varies between 180 µm and 700 µm, The structures of the oral cavity and the posterior end help differentiate larvae of *Strongyloides* sp, those of *Ancylostoma* sp, Hookworm species can be found in the environment in the form of eggs or larvae, The presence of mucous plugs (genus *Trichuris*), a triple membrane (genus *Ascaris*) or blastomeres (genus *Ancylostoma*) are the characteristics that make it possible to differentiate the eggs of enteropathogenic nematodes, With the exception of the genus *Enterobius* which is embryonated upon laying eggs, the other species of enteric nematodes become mature in the environment. This maturation is facilitated by

oxygenation, humidity, shade, optimal temperature (28°C to 30°C) and a favorable pH (5.5 to 9).

Table XIII: Morphological characteristics of nematode eggs and larvae (Thivierge, 2024; Safaa, 2017).

Eggs

Parasite	Size (µm)	Form	Wall	Stage of development	Features	Illustrations
Ascaris lumbricoïdes	55-75 µm x 35-50 µm (fertile egg)	Round or ovale	Wall thick	Undeveloped embryo Does not fill the entire cavity egg	Thick shell made up of 3 membranes: outer, middle and inner	
	85-95 µm x 43-47 µm (Infertile egg)	elongated	Wall mince	Masses undifferentiated granular	Smooth shell made up of 3 membranes with the outer membrane sometimes absent	
Ancylostoma sp.	55-75 µm x 36-40 µm	Oval with more flattened ends	thin wall	Undeveloped embryo when passed in the stool	Clear space between the wall and the embryo Presence of 6 to 8 blastomeres	
Trichuris trichiura	50-55 µm x 22-24 µm	Oval (barrel-shaped)	thick wall	Embryo no developed	Mucous plugs at each end	
Enterobius vermicularis	50-60 µm x 20-30 µm	Oval and asymmetrical (one side more flattened)	thick wall	Larva folded to the inside of the egg	found mainly on the anal margin	

larvae

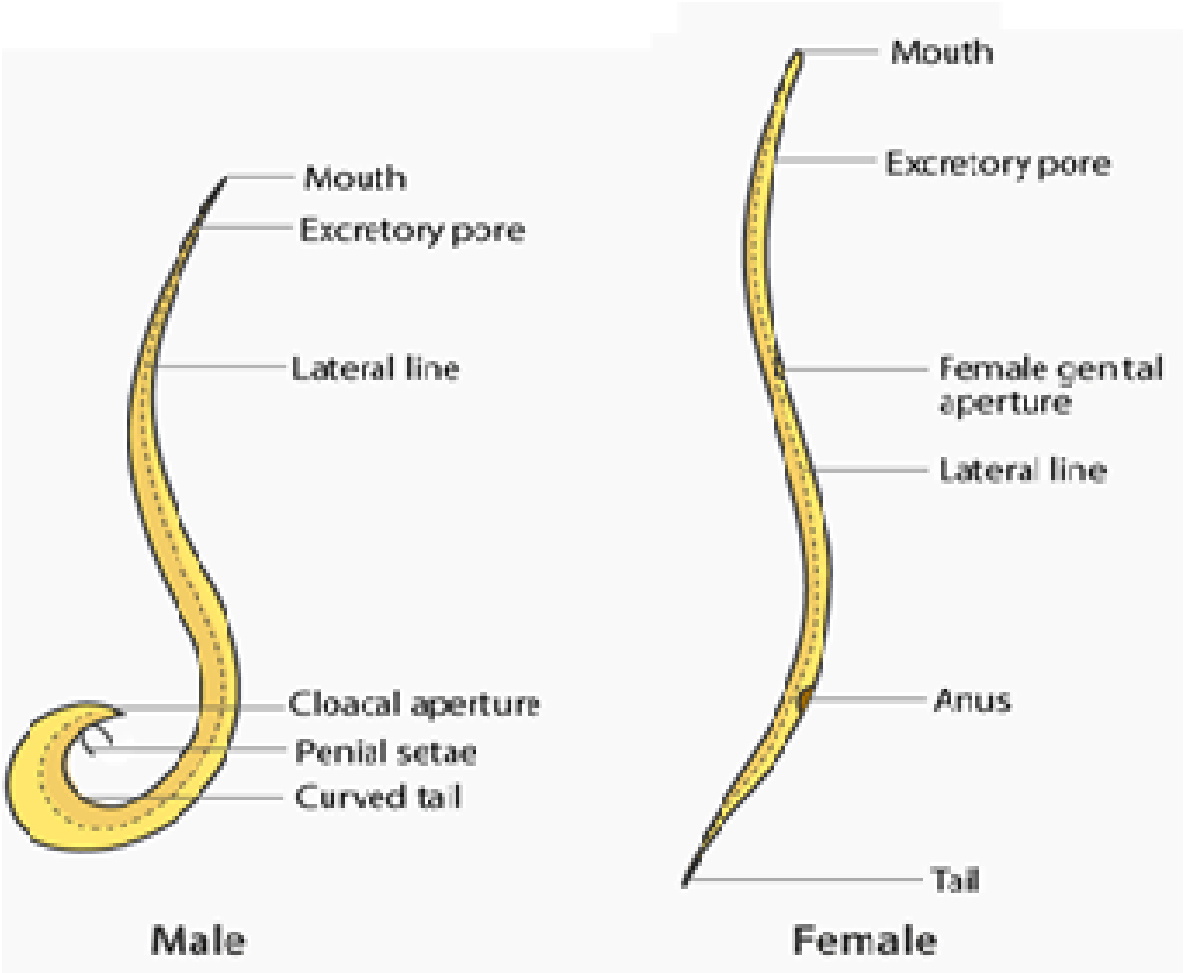
Parasite	type of larva	Size	Cavity buccal	Esophagus	Genital anlage	End posterior	Illustrations
Strongyloïdes sp.	larvae Rhabditoids	180-380 µm x 14-20 µm	Short	Double esophageal bulge Occupies approximately third of the larva	Visible (attached to intestine)	slightly tapered	
	larvae Strongyloïdes	500-630µm x 14-17 µm	Short	A single esophageal bulge Takes up about a third of the larva	Little or not visible	Truncated or bifide	

I.11.3. Morphology and development cycle of *Ascaris lumbricoides*

Ascaris lumbricoides worms measure 2 to 4 mm in diameter and 15 to 31 cm long. Their posterior end is curved like a crook and the genital tract, as well as the intestine, open into the

cloaca, Adult female worms measure 3 to 6 mm wide and 20 to 49 cm long and have their genital opening in the upper third of the body (Figure 12A). They live in the small intestine of their host and have a lifespan of 12 to 18 months, An adult female lays on average 200,000 eggs per day (WHO, 2004). The eggs of *Ascaris lumbricoides* are symmetrical and recognizable by the nippled and thick shell made up of 3 membranes: external, middle and internal (fertile eggs) or deformed, bloated with an external membrane sometimes absent (infertile eggs) (Guillaume, 2007), Fertile eggs measure 55 to 75 µm by 35 to 50 µm; they are golden yellow to brown and contain a single cell when passed in the stool, They have a clearly hilly surface, Unfertilized eggs measure 85 to 95 µm by 43 to 47 µm; have an elongated shape and are larger than fertilized eggs (Figure 8B), The contents of the egg are usually granular and show no organization (WHO, 1994). Its maturation in the external environment is facilitated by oxygenation, humidity, shade and the optimum temperature (28°C to 30°C). The infesting embryo only appears after a stay of 2 to 4 weeks and its metabolic life is very slowed down. It resists three months in a dry environment, between 5 and 24°C and more than two years on wet soil (Lacoste, 2009).

A



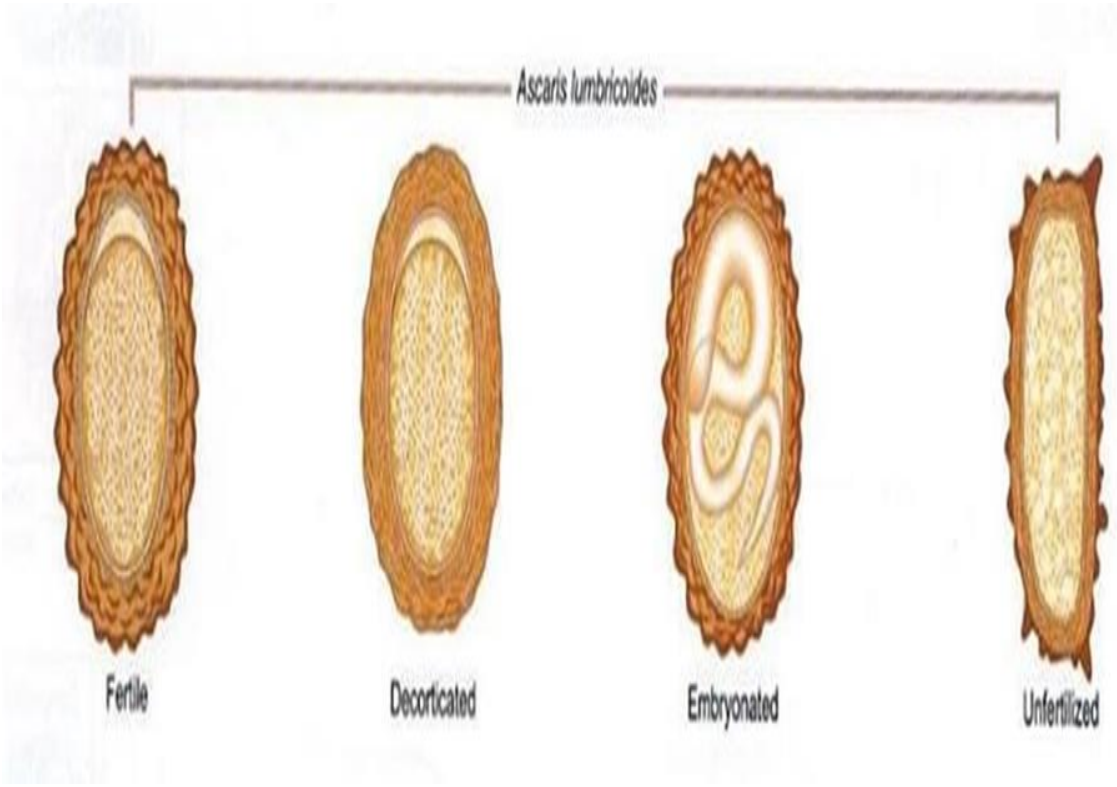


Figure 10: Structural organization of adult worms (A) and eggs (B) developmental stages of *Ascaris lumbricoides* (Fatima, 2019)

The development cycle of *Ascaris lumbricoides* is monoxenous (Figure 13). Humans become infected after ingesting an embryonated egg present in raw vegetables, fruits, contaminated water or through dirty hands, Once in the digestive tract, the larva is released, It crosses the intestinal wall and reaches the liver where it stays 3 to 4 days, undergoes a moult there and reaches the lung by blood (supra-hepathic vein then right heart), The larva then crosses the wall of the pulmonary alveolus and ascends the bronchial tree to the pharynx, Through swallowing, it reaches the jejunum and becomes an adult, After mating and fertilization, the fertilized females lay non-embryonated eggs which will be evacuated with the feces, The eggs mature in the external environment and the cycle begins again if the human ingests the embryonated eggs again (Fatima H, 2019), Illutration of this life cycles is seen in figure 11 below.

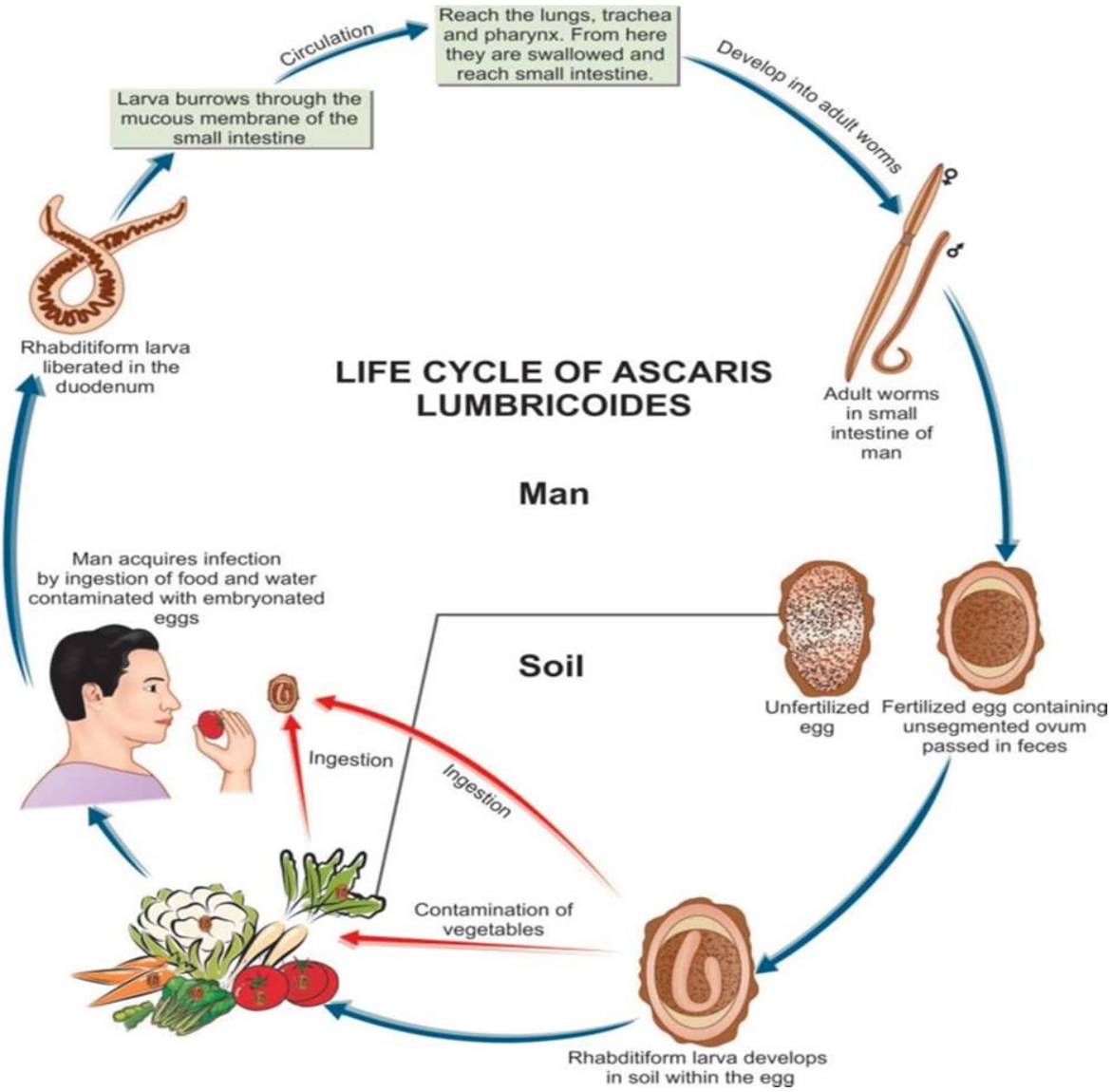


Figure 11: Development cycle of *Ascaris lumbricoides* (Fatima, 2019).

I.11.4 Enteropathogenic platyhelminths

Platyhelminths are flatworms with a fragile cuticle and no chitin. They are represented by two classes: the Cestodes class which are segmented flatworms, mainly hermaphroditic and having a scolex with four suckers and two longitudinal slits; and the class Trematodes which are non-segmented flatworms, with a leafy body and two suckers (Maggenti, 1981). They are generally hermaphrodite parasites with the exception of Schistosomes.

In table XIV, platyhelminths are subdivided into two main classes: the Cestodes class and the Trematodes class, The Cestodes class is represented by two orders (Cyclophyllida and Pseudophyllida), while that of Trematodes is represented by the order of Echinostomatida,

Table XIV: Justified systematics of enteropathogenic platyhelminths (Lacoste, 2009)

Systematics	Justifications
Phylum: Platyhelminthes	Flatworms with segmented or non-segmented bodies
Classes: Cestoda Trematoda	Banded, hermaphroditic and segmented-bodied worms, Leaf worms with non-segmented bodies
Order: Cyclophyllida Pseudophyllida Echinostomida	Esophagus often divided into three parts and scolex with 4 suckers Scolex bearing four ovoid, muscular, provided or without hooks Ventral or oral suckers
Families: Hymenolepidae Tæniidae Diphyllobothriidae Fasciolidae Schistosomidae	Presence of a caudal apparatus called cysticercoid Simple genitalia, irregularly alternating sexual pores Scolex with 2 slits, one of which is ventral and the other dorsal Large and hermaphrodite parasites Flattened and curved male with gynecophorous canal and cylindrical Female.
Genera: *Hymenolepis*	**Species:** *Hymenolepis* sp.
Tænia	*Tænia* sp.
Diphyllobothrium	*Diphyllobothrium latum*
Fasciola	*Fasciola hepatica*
Schistosoma	*Schistosoma* spp.

I.11.5. Morphological characteristics of enteropathogenic Cestodes and Trematodes,

Table XV below presents the morphological characteristics of the eggs of enteropathogenic Cestodes and Trematodes. In Cestodes, the eggs vary in size from 30 to 75 µm and the presence of striated walls, hooks and polar filaments makes it possible to differentiate the eggs of *Tænia* sp, those of *Hymenolepis* sp, Trematode eggs have thin walls, elongated shapes and are large, The presence or absence of a visible operculum makes it possible to differentiate between the eggs of *Fasciola hepatica* and those of *Paragonimus* sp,

In the genus *Schistosoma*, the position of the spur allows species to be differentiated, It can *be* lateral (*S, mansoni* and *S, japonicum*) or terminal (S, *haematobium).*

Table XV: Morphological characteristics of the eggs of enteropathogenic Cestodes and Trematodes (Safaa, 2017).

Parasite	**Size (µm)**	**Shape**	**Wall**	**Development stage**	**Special features**	**Artwork**
Diphyllobothrium latum	58-75 µm x 40-50 µm	Oval	Not very thick	Undeveloped embryo	Terminal cover and button	
***Taenia* sp,**	31-43µm	Round or slightly oval	Thick and ridged	6 hook embryo	Presence of a vitelline membrane	
***Hymenolepis* sp,**	30-60 µm	Round or slightly oval	Thin	6-hooked embryo	Polar filaments	
Fasciola hepatica	130-150 µm x 63-90 µm	Oval	Thin wall	Undeveloped embryo	Little visible operculum	
***Paragonimus* sp,**	80-120 µm x 45-70 µm	Oval	Thick wall	Undeveloped embryo	Obvious operculum Wall a little thicker at the posterior end	
Schistosoma mansoni	114-175µm x 45-70µm	elongated	Thin wall	Larva already developed (miracidium)	Side spur	
Schistosoma japonicum	70-100 µm x 55-65 µm	Round or slightly oval	Thin wall	Larva already developed (miracidium)	Side spur barely visible or absent	
Schistosoma haematobium	112-170 µm x 40-70 µm	Lying down	Thin wall	Larva already developed (miracidium)	Terminal spur	

I.11.6 Morphology and development cycle of an enteropathogenic Cestode: *Tænia* sp,

Two species of *Tænia* parasitize the human intestine: *Tænia saginata* and *Tænia solium*, *Tænia saginata* is a grayish-white banded worm that measures 8 to 12 m long. Its scolex is

pear-shaped and measures 1 to 2 mm in diameter. It is equipped with 4 suction cups and does not have a rostrum or hooks: it is said to be unarmed. Its strobilus is made up of thousands of rings that are longer than they are wide when mature. The uterus contains fine and numerous branches, *Tænia solium* measures 6 to 8 m long. Its scolex is slightly quadrangular and has a short rostrum decorated with a double crown of hooks and carries 4 suction cups, The rings carry a uterus with few, thick, dendritic branches. The egg of *Tænia* sp, has a spherical shape and measures 40 µm in diameter. It has a thick, radially ribbed shell like wheel spokes, It contains a hexacanth larva as seen in figure 12 below (Safaa, 2017).

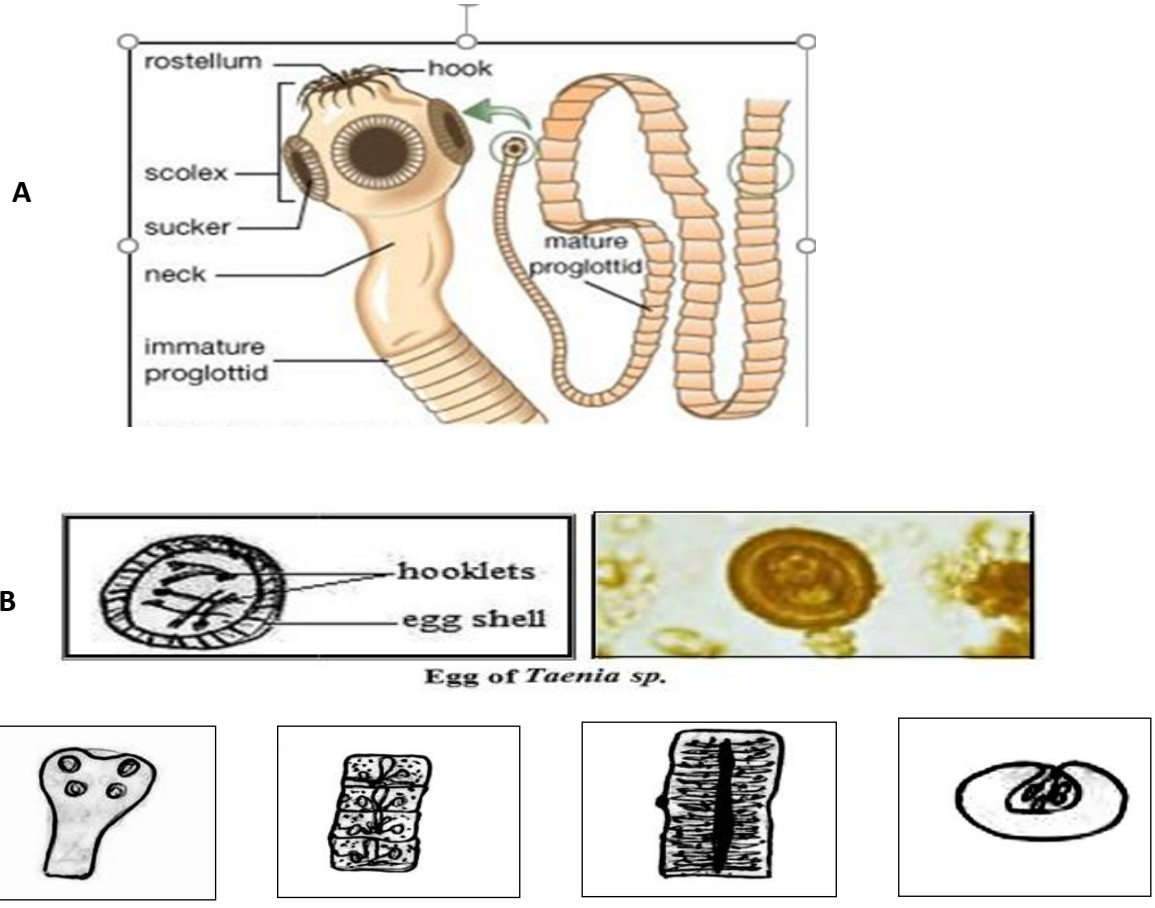


Figure 12: Structural organization of adult worms (A); egg (B) and Developmental stage to infective form (C) of *Tænia* sp. (Safaa, 2017),

Legend: 1 = Scolex of *Tænia saginata*, 2 = Scolex of *Tænia solium*

Figure 13 illustrates the heteroxene developmental cycle of *Tænia saginata* with two hosts: an intermediate host (ox) and a definitive host (human), Hermaphrodite adult worms live attached to the human intestinal mucosa thanks to their scolex, Eggs are removed with whole

portions of rings or mixed with feces. The eggs or embryophores are scattered on the ground and transported by rain, wind or the movement of animals. The intermediate host (pork for *Taenia solium* and beef for *Taenia saginata*) becomes contaminated by ingesting the contaminated plants, After hatching in the digestive tract of the animal, the released hexacanth larvae cross the mucosa, pass into the general circulation and reach the muscles where they encyst (form cysticerci), For *Taenia solium*, the larvae can also encyst in the eyes, tongue and nervous system (man becomes the intermediate host), Humans become infected by eating raw or undercooked beef or pork containing cysticerci, Arriving in the intestine, the larvae devaginate (form the protoscolex), attach to the mucosa and become adults after 3 to 4 months (Safaa, 2017).

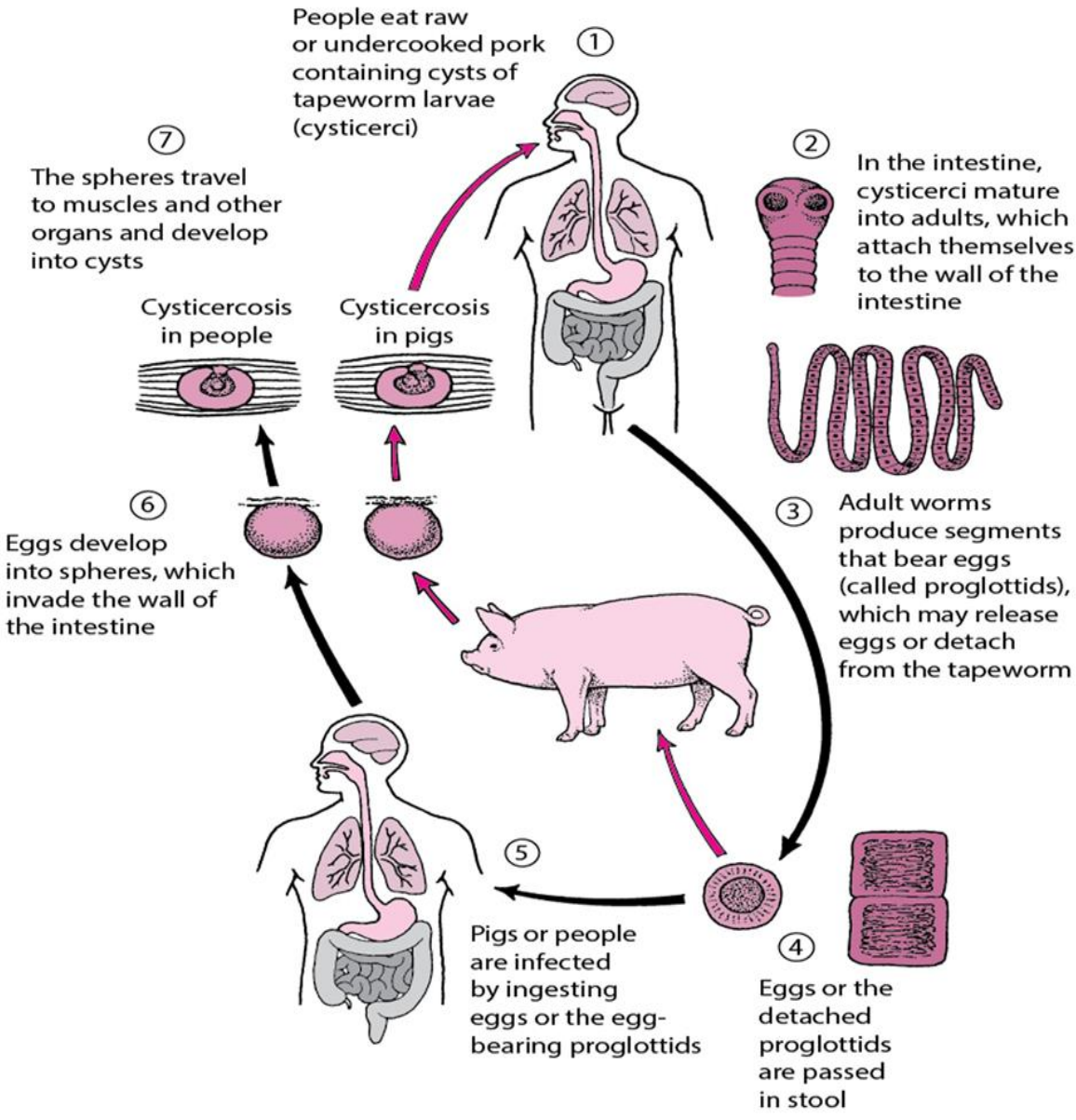


Figure 13: Development cycle of *Taenia spp* (Safaa, 2017).

I.117. Morphology and development cycle of an enteropathogenic trematode:

***Schistosoma* spp.**

Trematodes or flukes are leafy flatworms with non-segmented bodies, an incomplete digestive tract and no anus, Adult worms (male and female) live in the abdominal arteriovenous plexus, The male worm is flat, leafy, whitish, averaging 1,5 cm in size, equipped with 2 suction cups and folded lateral edges forming a gynecophorous canal where the female is housed (Figure 14), The female worm measures approximately 2 cm, grayish with a cylindrical and filiform appearance, It is equipped with 2 suction cups.

The eggs of *Schistosoma* spp, are round, ovoid or elongated, of variable size depending on the species and equipped with a more or less visible spur, The spur can be lateral (*Schistosoma mansoni* and *Schistosoma japonicum*) or terminal (*Schistosoma haematobium* and *Schistosoma intercalatum*). The shell of the egg is smooth and transparent.

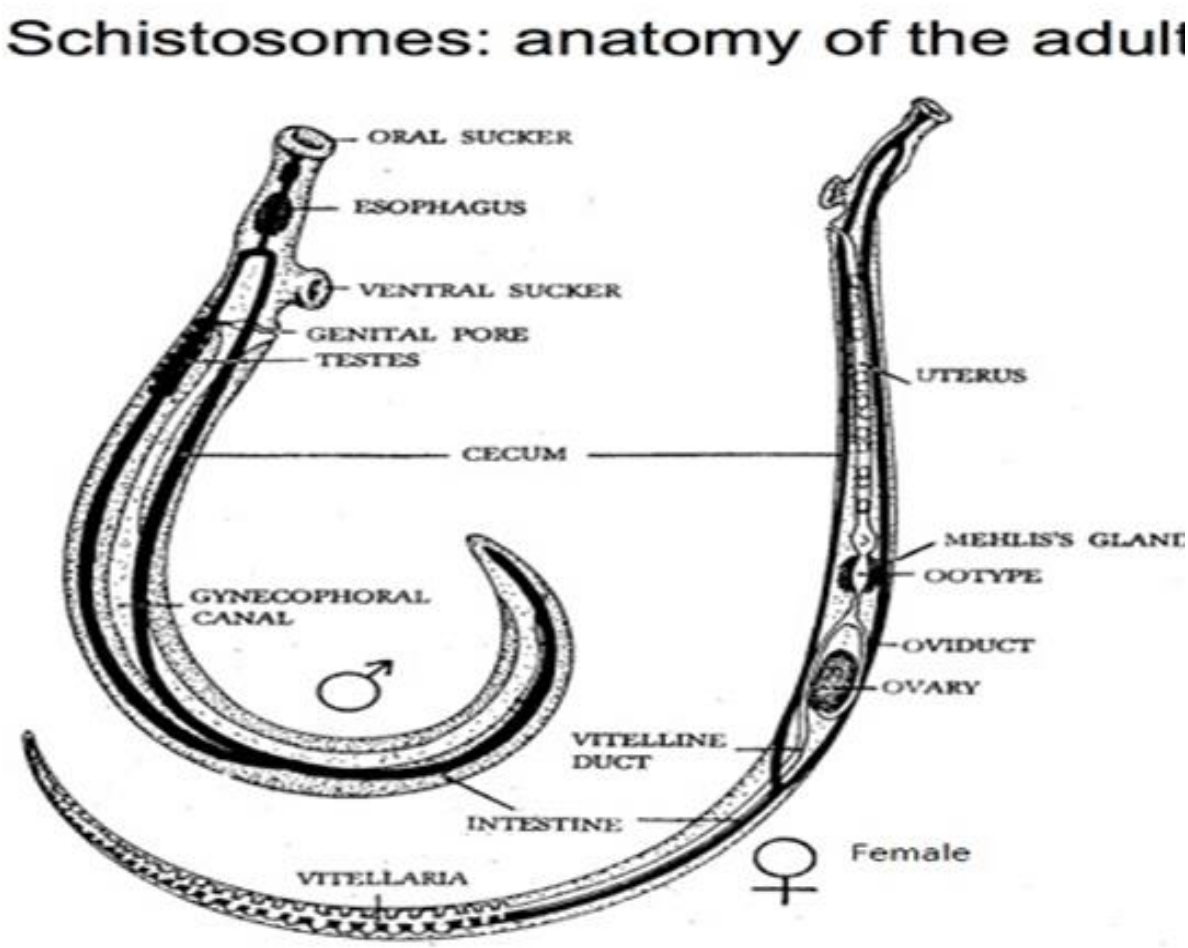


Figure 14: Structural organization of adult worms of Schistosoma spp, (Safaa, 2017)
Legend: 1 = *Schistosoma mansoni*, 2 = *Schistosoma japonicum*, 3 = *Schistosoma haematobium*, 4 = *Schistosoma intercalatum*

The life cycle of *Schistosoma* spp, (the causative agents of schistosomiasis) is complex and involves both human hosts and intermediate snail hosts. The cycle consists of several stages, transitioning between aquatic and human environments, Schistosomiasis is a parasitic disease caused by *Schistosoma* species, with different species (such as *Schistosoma mansoni*, *Schistosoma haematobium*, and *Schistosoma japonicum*) causing varied forms of the disease in humans, The life cycle of *Schistosoma* consists of both a human (definitive host) stage and a snail (intermediate host) stage, with key stages including the egg, miracidia, cercariae, and schistosomula.

The development cycle of the four species of Schistosome is essentially identical and requires the obligatory intervention of an intermediate host (freshwater mollusc), It begins with the penetration of a cercaria through the skin during contact with contaminated water, The released schistosomules will then migrate to the portal system where they become adults before reaching the abdominal arteriovenous plexuses. The females, located depending on the species in the fine venous branches of the intestine or the bladder, lay their eggs which, upon breaking, fall into the cavity of the organ and are eliminated by the stools (Schistosoma mansoni, Schistosoma *japonicum*, *Schistosoma interculatum*) or through urine (*Schistosoma haematobium*). In the external environment, if conditions are favorable (pH close to neutral and temperature between 18°C and 33°C), on contact with fresh water, the egg releases a ciliated larval form: the miracidium which swims in search of the specific mollusc of the species schistosome (intermediate host), Humans become infected by coming into contact with water contaminated with *Schistosoma* cercariae, The adult worms reside in the blood vessels and cause various symptoms, including abdominal pain, diarrhea, hematuria (blood in urine), liver damage, and in severe cases, organ fibrosis, Schistosomiasis is prevalent in tropical and subtropical regions, especially in sub-Saharan Africa, Asia, and parts of South America, These are Bulin (*Schistosoma haematobium*, *Schistosoma intercalatum*); of the Planorba (*Schistosoma mansoni*) or the Oncomélania (*Schistosoma japonicum*), The miracidiums transform into sporocysts which multiply to produce infesting cercariae, If these furcocercariae (cercariae with a bifid tail) come into contact with human skin again, the cycle begins again (WHO, 2016) as seen in figure 15 below.

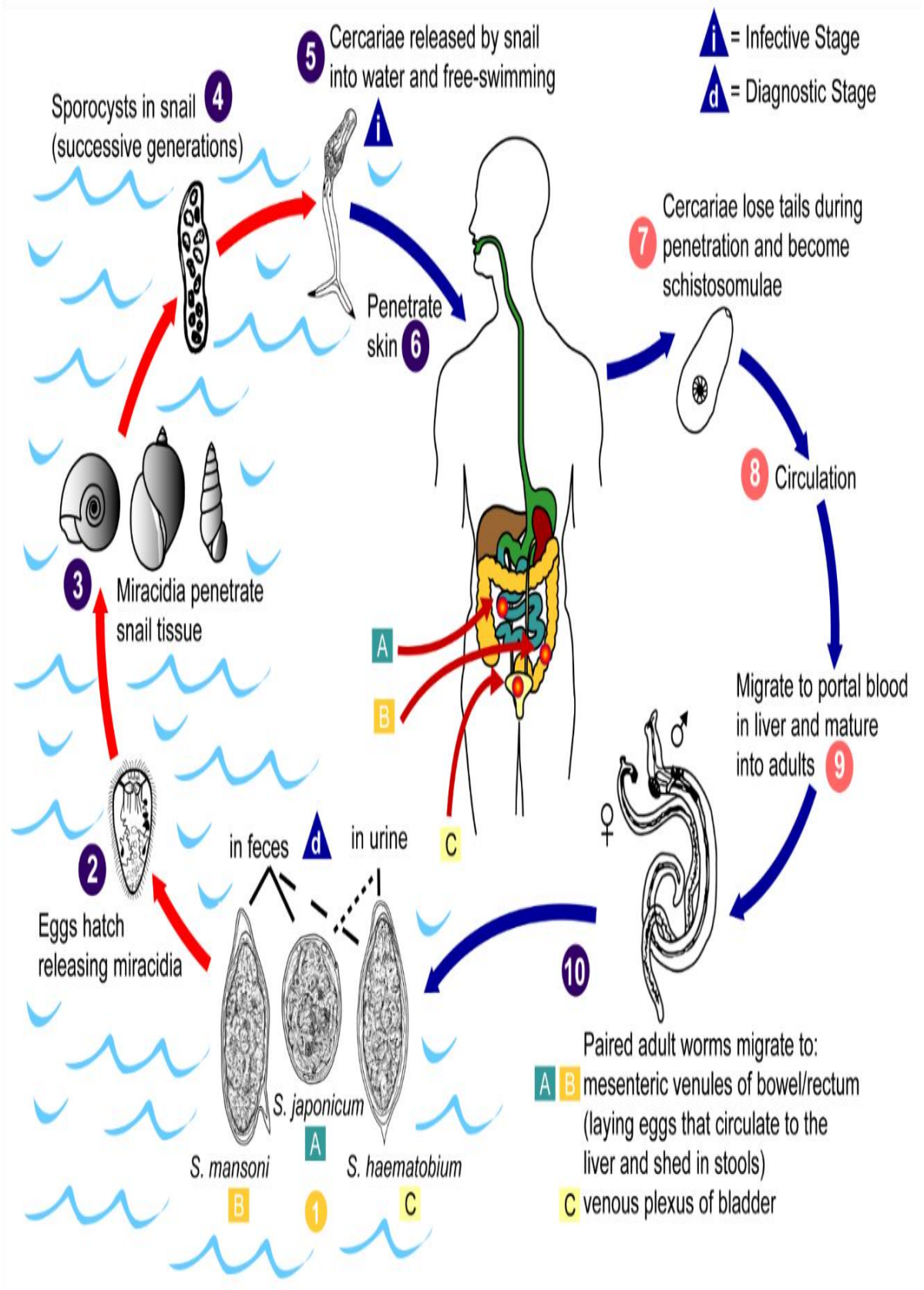


Figure 15: The life cycle of the Schistosoma parasites, Center for Disease Control and Prevention (CDC), **(**Agrawal *et al.*, 2022)

I.12. Description of mature forms of dissemination of Protozoa and Helminths

Protozoan cysts and oocysts, as well as Helminth eggs and larvae, are released into the environment in immature forms, The acquisition of their infective power or their maturation takes place in the external environment depending on the abiotic factors of the environment (humidity, oxygenation conditions, temperature, pH, etc,).

I.12.1. Mature forms of dissemination of enteropathogenic protozoa

The forms of transmission in enteropathogenic protozoa are represented by mature cysts and sporulated oocysts, In Rhizopods, mature cysts have a round shape and their cytoplasm may contain chromid inclusions, a glycogen vacuole often visible in *Entamoeba coli* and nuclei whose number varies from 4 (*Entamoeba histolytica*, *Entamoeba hartmani* and *Endolimax nana*) to 8 (*Entamoeba coli*), In flagellates, mature cysts of *Giardia* sp, have an oval shape and their cytoplasm contains 4 nuclei grouped on one side, bundles of flagella, parabasal bodies and an axostyle which passes in the axis of the cyst, The cysts of *Chilomastix mesnili* and *Retortamonas intestinalis* are slightly pear-shaped and present in their cytoplasm a large nucleus sometimes surrounded by a flagellum and a cytostome, Mature cysts in Ciliates are characterized by their oval or round shape, the persistence of cilia inside the cytoplasm and the presence of two types of nuclei (the micronucleus and the macronucleus), The forms of transmission in Sporozoa are spherical sporulated oocysts (*Cryptosporidium* spp, and *Cyclospora cayetanensis*) or elongated (*Sarcocystis hominis* and *Isospora belli*), Oocysts of *Cryptosporidium* spp, are surrounded by a double membrane and contain 4 naked sporozoites and a residual body, The sporulated oocysts of *Cyclospora cayetanensis* contain globose inclusions and 2 sporocysts containing 2 sporozoites. The sporulated oocysts of *Isospora belli* are characterized by their smooth membrane and a more tapered end and have 2 sporocysts each containing 4 sporozoites.

I.12.2. Mature forms of dissemination of enteropathogenic helminths

Among enteropathogenic helminths, the forms of transmission are represented by mature eggs and infective larvae, Mature Cestodes eggs are characterized by their round or slightly oval shape, thick walls with an operculum (*Dhyphyllobothrium latum*), streaked (*Taenia* sp,) or thin (*Hymenolepis* sp,) and the presence of hooks on the embryo. In Trematode species, the eggs are elongated or oval in shape and are generally large. Some species have an operculum (*Fasciola hepatica* and *Paragonimus* sp,) while others have a spur whose position

depends on the type of species. The spur is in a lateral position in *Schistosoma mansoni* and *Schistosoma japonicum* and terminal in *Schistosoma haematobium*. The infesting nematode larvae are large and characterized by their short oral cavity, a single bulge at the esophagus and the truncated or bifid posterior end. The mature eggs of *Ascaris lumbricoides* are round or oval and characterized by the presence of a thick, nippled shell made up of 3 membranes: external of protein nature, intermediate of chitinous nature and internal of lipid nature (Guillaume, 2007). The mature eggs of *Ancylostoma* sp, are characterized by the presence of a clear space between the wall and the embryo and 6 to 8 blastomeres, *Trichuris trichiura* eggs are oval barrel-shaped and have mucous plugs at each end, *Enterobius vermicularis* eggs are oval, banana-shaped with a clear wall and the presence of an embryo folded inside.

I.12.3 Diagnosis, health benefits and fight against the spread of intestinal parasites

I.12.4 Diagnosis of intestinal parasites

The biological diagnosis of intestinal protozoa and helminths can be direct (identification of the pathogen) or indirect (based on data resulting from host reactions to infection) (ANOFEL, 2014). Direct diagnosis tends to highlight the parasite in one or other of its different forms (adults, larvae, eggs, cysts or oocysts) and search in the main accessible areas (stools, blood, urine, among others), or in the natural environment (soil or water) in the case of environmental epidemiological research, In the aquatic environment, the diagnosis of environmental forms of enteric pathogens requires concentration techniques. These methods also make it easier to enumerate parasites in a more diverse sample. The most used concentration methods are the technique of Kato-Katz (Katz *and al.*, 1979). Ritchie's biphasic technique modified with formalin-ether (Ajeagah *et al*., 2014). Faust's modified or flotation technique, Ziehl- modified Neelsen and the direct sedimentation technique.

I.12.5. Health implications of intestinal parasites

Intestinal protozoa and helminths are of medical importance because many are pathogenic and cause disease. Some of them are human pathogens and can cause serious illness. Indeed, certain species have pathogenic power for various species, including humans. Among Protozoa, species such as *Entamoeba histolytica*, *Giardia intestinalis*, *Balantidium coli* and coccidia are respectively responsible for amoebic dysentery or amoebiasis, giardiasis, balantidiasis and coccidiosis, Among Helminths, species such as *Ascaris lumbricoides*, *Strongyloides stercoralis*, *Ancylostoma duodenale*, *Taenia* sp, and *Schistosoma* spp, are respectively at the origin of ascariasis, strogyloidosis or anguillulosis, ankylostomiasis, teniasis

and schistosomiasis. The prevalence of these parasites varies considerably in different population groups and is generally closely linked to socio-economic conditions. The highest rates are found in places without sanitation facilities such as toilets, sewers or without access to drinking water (WHO, 2011).

I.12.6- Fight against the spread of intestinal parasites

As intestinal parasitic diseases are associated with unsafe water and poor sanitation, their prevention, control and elimination will depend on the general improvement of health-related projects (WHO, 2017). Thus, their prophylaxis will be based on the implementation of a set of means tending to the eradication of faecal peril, among others: collective measures, including the installation of latrines and sewers, the abandonment of the use of human fertilizers, the treatment of drinking water (access to running and drinking water); chemotherapy, which consists of using drugs, namely nitroimidazoles (Metronidazole, Albendazole and Mebendazole) against Protozoa and anthelmintics (Niclosamide, Praziquantel, Triclabendazol and Flubendazole) against Helminths (Gambari, 2013).

I.13- Characteristics and generalities on Gastroenteritis

I.13.1-Background and concepts

The word "gastroenteritis" originates from the Greek word *gastron*, meaning "stomach," and enteron, meaning "small intestine," So the word "gastroenteritis" means "inflammation of the stomach and small intestine," Medically, gastroenteritis is defined as a diarrheal disease, in other words, an increase in bowel movement frequency with or without vomiting, fever, and abdominal pain, An increase in bowel movement frequency is defined by three or more watery or loose bowel movements in 24 hours or at least 200 grams of stool per day, It is classified in many ways, but according to the duration of symptoms, it is described as acute, persistent, chronic, or recurrent.

I.13.2- Etiology

Gastroenteritis is caused by a number of different agents, including bacteria, viruses, and parasites, Noroviruses (NoVs) and rotaviruses (RVs) of group A are the leading causes of viral gastroenteritis, Sapoviruses (SaVs), astroviruses (AsVs), and enteric adenoviruses (AdVs) are other important causes, Infectious gastroenteritis is caused by viruses, bacteria or parasites. In each case, infection occurs when the agent is ingested, usually by eating or drinking. Some of the common types of infectious gastroenteritis include:

Escherichia coli infection – this is a common problem for travellers to countries with poor sanitation, Infection is caused by drinking contaminated water or eating contaminated raw fruits and vegetables, Campylobacter infection – the bacteria are found in animal faeces (poo) and uncooked meat, particularly poultry, Infection is caused by, for example, consuming contaminated food or water, eating undercooked meat (especially chicken), and not washing your hands after handling infected animals, Cryptosporidium infection parasites are found in the bowels of humans and animals, Infection is caused by, for example, swimming in a contaminated pool and accidentally swallowing water, or through contact with infected animals, An infected person may spread the parasites to food or surfaces if they don't wash their hands after going to the toilet, Giardiasis – parasite infection of the bowel, Infection is caused by, for example, drinking contaminated water, handling infected animals or changing the nappy of an infected baby and not washing your hands afterwards, Salmonellosis are bacteria that are found in animal faeces, Infection is caused by eating contaminated food or handling infected animals, An infected person may also spread the bacteria to other people or surfaces by not washing their hands properly, Shigellosis are bacteria infections found in human faeces. An infected person may spread the bacteria to food or surfaces if they don't wash their hands after going to the toilet, And viral gastroenteritis infection is caused by person-to-person contact such as touching contaminated hands, faeces or vomit, or by drinking contaminated water or food.

I.13.3- Clinical manifestations

Gastroenteritis is a diarrheal disease characterized by an increase in bowel movement frequency with or without fever, vomiting, and abdominal pain, Gastroenteritis is a diarrheal disease of rapid onset, withor without nausea, vomiting, thirst, fever, or abdominal pain typically lasting less than two weeks, As a result of diarrhea and vomiting, the condition may deteriorate so quickly and patients become severely dehydrated, Some signs of dehydration that should be noted carefully include dry skin, a dry mouth, feeling lightheaded and drowsiness, and thirst urgency.

The signs and symptoms include Nausea, Diarrhea (watery or bloody in dysentery), Vomiting, Abdominal pain and Fever (suggests an invasive organism as the cause), On physical examination, the abdomen would be soft, but there may be voluntary guarding, Palpation may elicit mild to moderate tenderness, Fever suggests the cause is invasive pathogens, Signs of dehydration are the most important thing to look for while performing the physical examination; some cases may be alarming and help to identify that which patient needs hospitalization. Other associated health impacts include Dry mucous membranes (dry mouth), Decreased skin turgor,

Altered mental status, Tachycardia, Hypotension, orthostasis, Bloody stools and Recent hospitalization or antibiotics.

I.13.4- Pathogenesis

The gut bacteria cause diarrhea by different mechanisms including adherence, mucosal invasion, and toxin production. Knowledge of pathophysiology and the mechanism of these pathogenic strategies also help in the evaluation and management of the disease. One of the main functions of the small intestine is to absorb fluids. With the disorder of the small intestine, the fluid does not get absorbed properly, and the action of different toxins causes the intestinal lining to start excreting fluid which results in relatively loose or watery stools, Inoculum size is one of the important virulence factors that cause pathology, For *Shigella* and enterohemorrhagic *Escherichia coli* (EHEC), at a minimum of 10–100 bacteria can cause infection, while one hundred thousand or one million of *Vibrio cholerae* bacteria are required to cause infection. For this reason, infective doses of different pathogens differ in a great range and depend on the host as well as bacteria.

Adherence is another virulence factor for enteric pathogens, Some bacteria need to adhere themselves to the mucosal lining of the gastrointestinal tract initially, They produce various adhesins and other cell-surface proteins which help them to attach to intestinal cells, *V, cholerae*, for example, adheres to the brush border of small-intestinal enterocytes via specific surface adhesins, including the toxin-coregulated pilus and other accessory colonization factors, Enterotoxigenic *E, coli*, which causes watery diarrhea, produces an adherence protein called colonization factor antigen. This is necessary for colonization of the upper small intestine by the organism before the production of enterotoxin, causing disease, Both cytotoxin production and bacterial invasion and destruction of intestinal mucosal cells can cause dysentery, *Shigella* and enteroinvasive *E, coli* infections are characterized by the organisms' invasion of mucosal epithelial cells, intraepithelial multiplication, and subsequent spread to adjacent cells, Toxin production is another important virulence factor. These toxins include enterotoxins, which cause watery diarrhea by acting directly on secretory mechanisms in the intestinal mucosa, and cytotoxins, which destroy mucosal cells and associated inflammatory diarrhea (Huyen, 2012).

I.13.5- Epidemiology

Acute infectious diarrhea is a very common disease worldwide, even in a developed country like the United States. It is among the leading causes of illness globally and associated with 1,5 to 2,5 million deaths per year. In children younger than 5 years, diarrheal disease is the second most common cause of death by infectious diseases. Worldwide, it affects more than 3 to 5 billion children each year, In the United States, there are more than 350 million cases of acute gastroenteritis annually, and among these, food-borne bacteria are the cause of 48 million cases. It accounts for 1,5 million visits to primary care doctors each year and approximately 200,000 hospital admissions of children under 5 years of age, In the United States, it rarely causes death, but it is still responsible for 300 deaths per year, In general, developed countries like the United States, the United Kingdom, and Canada have lower hospital admissions rates in comparison to developing countries, Traveler's diarrhea affects more than 50% of people traveling from developed to developing countries. In the United States, children under 5 years of age are admitted to the hospital in 9 out of 1000 cases per year. In the United Kingdom and Australia, the admission rate is around 12 per 1000 annually (Dos Santos *et al*, 2019).

I.13.6- Diagnosis of gastroenteritis

Diagnostic testing for patients with apparent gastroenteritis is guided by the clinical assessment, Routine laboratory tests, including a complete blood count and serum metabolic profile, are not needed in every case, Further evaluation may be required for patients presenting with severe illness or severe dehydration.

Laboratory tests should be done for patients with high fevers, severe abdominal pain, bloody stools or persistent diarrhea, Special attention should be given to older adults with abdominal pain and immunocompromised patients. For most cases of gastroenteritis, if the patient appears well and is likely to have a self-limited illness, stool cultures are not required, Stool cultures should be sent for patients with severe illness, fever of 38,5° C (101°F) or higher, dysentery, persistent diarrhea for 14 days or longer and for patients who are immunocompromised or who have been recently hospitalized or placed on antibiotics. If diarrhea is persistent, stools for ova and parasite should be sent, Stools sent for fecal leukocytes, lactoferrin, or hemoccult testing may help identify colonic inflammation with an invasive organism, Stool studies and culture should be performed when certain bacterial and parasitic infections are suspected, such as *C, difficile*, *Campylobacter*, Shiga toxin–producing *Escherichia coli* (STEC), or giardiasis because targeted antibacterial treatment may

be initiated to prevent the spread (eg, in an outbreak of daycare workers) and decrease the duration of symptoms.

I.13.7- Treatment for gastroenteritis

Treatment depends on the cause, but may include Plenty of fluids, Oral rehydration drinks, available from your pharmacist, Admission to hospital and intravenous fluid replacement, in severe cases, Antibiotics, if bacteria are the cause, Drugs to kill the parasites, if parasites are the cause and Avoiding anti-vomiting or anti-diarrhoea drugs unless prescribed or recommended by your doctor, because these medications will keep the infection inside your body.

I.13.8- Prevention and Control

Gastroenteritis is highly contagious, general suggestions on how to reduce the risk of infection, Stay home while sick, until 48 hours after symptoms have stopped. If symptoms persist, visit your GP. Wash hands thoroughly with soap and water after going to the toilet or changing nappies, after smoking, after using a handkerchief or tissue, or after handling animals, Wash your hands thoroughly with soap and water before preparing food or eating. Use disposable paper towels to dry your hands rather than cloth towels, since the bacteria can survive for some time on objects, Do not handle raw and cooked foods with the same implements (tongs, knives, cutting boards), unless they have been thoroughly washed between uses, Keep all kitchen surfaces and equipment clean, Keep cold food cold (below 5 °C) and hot food hot (above 60 °C) to discourage the growth of bacteria, Make sure foods are thoroughly cooked, Clean kitchen tops, toys, toilet seats, nappy change tables and taps to ensure you don't spread the infection to others at home, Clean the toilet and bathroom regularly (especially the toilet seat, door handles and taps), Clean baby change tables regularly And when travelling overseas to countries where sanitation is suspect, only drink bottled water, Don't forget to brush your teeth in bottled water too. Avoid food buffets, uncooked foods or peeled fruits and vegetables, and ice in drink.

I.14 -Environment and transmission impacts related to gastroenteritis

The environmental Impacts such as unsafe water supply, affects human well-being, as infections and intoxications in people will create a disease burden, influence well-being and eventually reduce life span. Whether or not an environmental State affects the human health State is determined by the impact pathways, their virulence (for pathogens) or their toxicity (for chemical compounds and plastic waste), exposure levels, and people's susceptibility or

compound thresholds (Fewtrell and Kay, 2008), Human behaviour, influenced by socio-economic circumstances and individual choices, co-determine the extent of exposure, i,e, the Pressures, and whether or not the total of pressures over time, the exposome, ultimately results in ill health.

Planning and management of the environment are typical responses in the realm of other sectors, such as agriculture, urban planning and water management, which have the potential to influence transmission of diseases pressures, states and impacts of various water-related health issues.

I.14.1 -Chemical pollution

Population growth, rapid urbanization, economic growth and efforts to reduce poverty lead to intensified food production, mining of resources and industrial development. The rising population density in urbanised areas intensifies environmental Pressures from the domestic, agricultural and industrial emissions that are influenced by agricultural and industrial practices as well as waste disposal habits, Industrial activities that pollute the water system are manifold, including (small-scale) mining and raw resource manufacturing, the leather and textile industry, electronics industry, chemical industry, pharmaceutical industry, energy production, and transport, Water is used in these industries in processes, as a cooling agent, or to remove waste loads, sometimes directly emitted to surface waters. Mining can be highly polluting; for instance, small-scale gold mining in low-income countries exposes 15 million people to mercury that ends up in the aquatic environment and the local food chain (Gibb and O'Leary, 2014).

I.14.2- Domestic, industrial, and agricultural factors

Domestic, industrial, and agricultural emissions in water lead to a polluted State with thousands of substances and their residues including nutrients, heavy metals, pesticides (insecticides, herbicides, fungicides), and pharmaceuticals (Evans *et al.,* 2018). Substances from urban areas and industry usually pollute the environment as point sources, while agricultural chemicals may create diffuse pollution-these require very different risk management approaches. In many countries effluent treatment is insufficient. The resulting environmental State of chemical water pollution then depends on the development stage of the country or region, where rapidly urbanising and industrialising lower- and middle-income countries generally have poor water quality, reflected in high organic loads leading to high nutrient levels and low dissolved oxygen levels that can upset ecological systems. This

generates a reduction in ecosystem services, such as safe water supply and recreational opportunities.

I.14.3 Health impacts related to environmental pollution

The health Impacts are both direct, by exposure to polluted water via drinking, bathing, swimming or inhaling, and indirect, via the ecosystem. Sometimes exposure is trigered by flood events. Occasionally, acute intoxication occurs, but more often the effects take years to manifest, affecting life span, causing birth defects and incurring other long term health effects, The accumulation of confounding factors over time hampers specific attribution, Persistent and bioaccumulative chemicals will build up in the food chain (especially in water-related food such as fish and shellfish) and might pose health effects through food consumption, In addition, there is evidence that polluted water fosters more pathogens (van der Zaan *et al.,* 2010). The health Impact of chemical water pollution remains largely unknown but 0.7 million deaths worldwide are estimated to be related to the combination of 'soil pollution, heavy metals and chemicals' In a deteriorating environment the health burden is not equally distributed, but the heaviest burden lies with the lower incomes (Myers *et al*., 2013).

Environmental Responses include restoration of ecosystems, whereby water sources are harmonized with their functions. Where feasible, intensive water quality monitoring can support the identification of areas for wastewater treatment.

CHAPTER II:

GEOGRAPHICAL CONTEXT, MATERIAL AND METHODS

II.1 -Study design and period

A cross sectional analysis was conducted on domestic water sources in Bamenda and its neighboring localities to assess the biological (Protozoa and Helminths) and physico-chemical contents of drinking water sources. Also the relationship of these biological contents to gastroenteritis was assessed in the population using these water sources. The sampling strategy was based on capturing all types of water sources used by the Community. The period for this study was eight months ranging from November 2022 to June 2023. Also samples were analysed based on the two climatic seasons of dry and rainy seasons.

II.2 -Study area

The North-West region (Cameroon), located at an average altitude of 1,550 m, is a region of high plateaus dominated by a chain of mountains culminating in Mount Oku, at an altitude of more than 3,000 m (National Institute of Cartography, 2016). Its relief, covered with grassy vegetation and small trees, is characterized by plains surrounded by mountain ranges, deep valleys which sometimes shelter streams with waterfalls and numerous crater lakes. According to the General Population and Housing Census (2010), the North West region has an estimated population of 1,8 Million and in 2021 it was estimated 2,213,984 inhabitants and an area of 17,300 km^2. It is bordered to the North by the Federal Republic of Nigeria, to the West by the South West region, to the East by the Adamaoua region and to the South by the West region (National Institute of Cartography, 2016). It has 7 departments (Boyo, Bui, Donga-Mantung, Menchum, Mezam, Momo and Ngo-ketunjia). The Mezam department is the most populated in the region (700,000 inhabitants) (Results of General Population and Housing Census, 2010). Agriculture is the main activity carried out in the region based on food crops, market gardening, livestock breeding and cottage industries.

The town of Bamenda, which is the main town and capital of the region and the department of Mezam is sub-divided into 3 districts which are Bamenda I, Bamenda II and Bamenda III council municipalities. It is a town located at the bottom of a steep cliff whose entrance, going downhill, overlooks the Rock as its highest point. The topography of Bamenda is characteristic of a high plateau region marked by very rugged relief with sometimes very high slopes which alternate with deep valleys. This relief is divided into two large groups by an escarpment oriented North East – South West, Above the escarpment, rises the upper plateau representing 10% of the total area of the city and made up of Bamenda I (administrative center) with altitudes varying between 1472m and 1573m. We then have the lower plateau whose minimum altitude is 1201m. This part of the city is home to almost 90% of urban facilities and

is made up of Bamenda II and III. In terms of soil, the city of Bamenda mainly has ferralitic soils, andosols and vertisols, which gives it a slightly acidic to neutral pH (Azinwi *et al.*, 2017). These soils result from the degradation of magmatic rocks from ancient volcanism in the area (see figure 17 below).

II.3. Specimen collection sites

The Region in general has two major climatic seasons which are the rainy and dry seasons. The rainy seasons normally starts from the 15th of March to the 15th of October meanwhile the dry season starts from 15th of October to 15th of March, Due to global warming world wide and climate change, at times rain fall is observed for some weeks in the months of December interrupting the dry seasons.

The sites chosen for our study were Nkwen, Mankon, Nsongwa and Upstation (mile 1 council muicipality including Bamendankwe), The climate is humid equatorial and is subdivided into two seasons: a long rainy season which extends from March to October and a short dry season which goes from November to February (Tita *et al*., 2012*).* The average temperature is 21,5°C and abundant precipitation averages 2311 mm per year (Saha and Tchindjang, 2017). This area experiences intense rainfall activity which feeds a very dense hydrographic network, made up of the streams, river (main watercourse) and its tributaries (Mugheb, Sisia, Ayaba, Mufueh, Mankon, Formuki, among others) most of which take their sources on the slopes of the mountains of "Up station" (see sample point in figure 19 below). These waters are used by populations for agricultural, household (dishes, laundry), recreational activities and even for consumption.

In Bamenda and its environs, CamWater supplies water to only half of the total population which can afford the piped water while the rest of the population rely on the unprotected drinking water sources (boreholes, springs, wells) and rainwater to access drinking water, However these natural domestic water sources are at a high risk of contamination from many sources of contaminants like pit latrines, agricultural pesticides and fertilizers, domestic and industrial wastes, leakages from landfills. Due to uncontrolled increase in human population and development of township at large, these freshwater bodies are under enormous pressure owing to their overuse, Bamenda is a grassfield area with many hilly topography. The map showing the council municipalities and their locations in Bamenda (see figure 16) and that showing domestic water sampling points (Figure 19) are represented below.

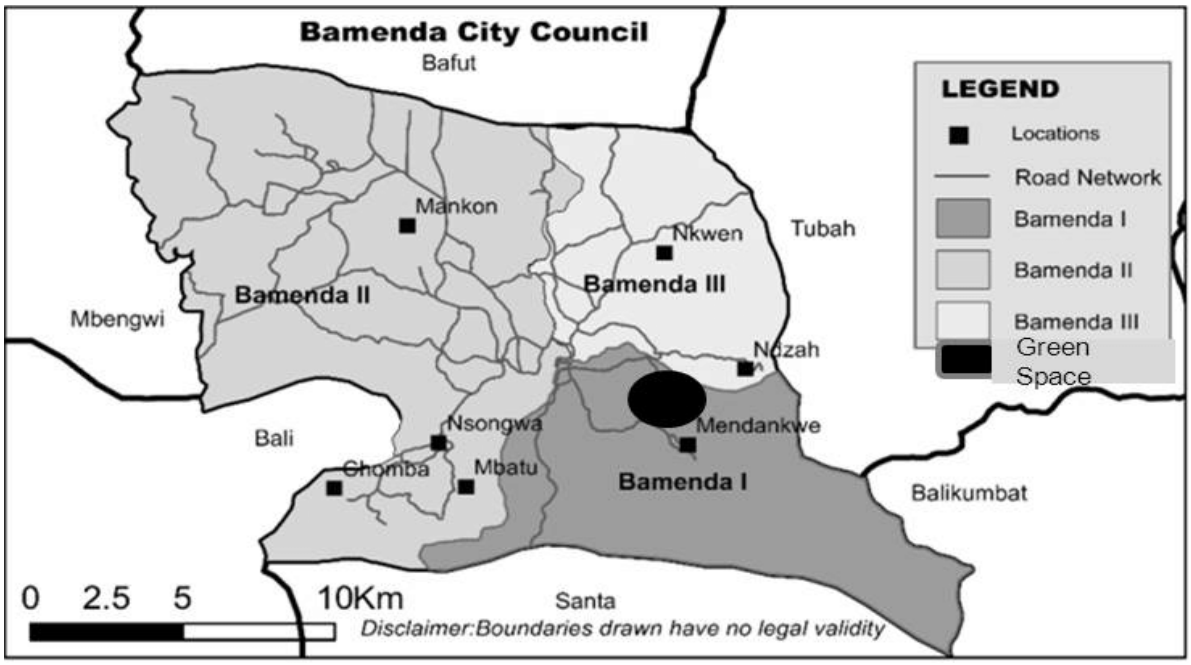


Figure 16: Map showing the main council municipalities locations of Bamenda city and its environs (National Institute of Cartography, 2016 modified)

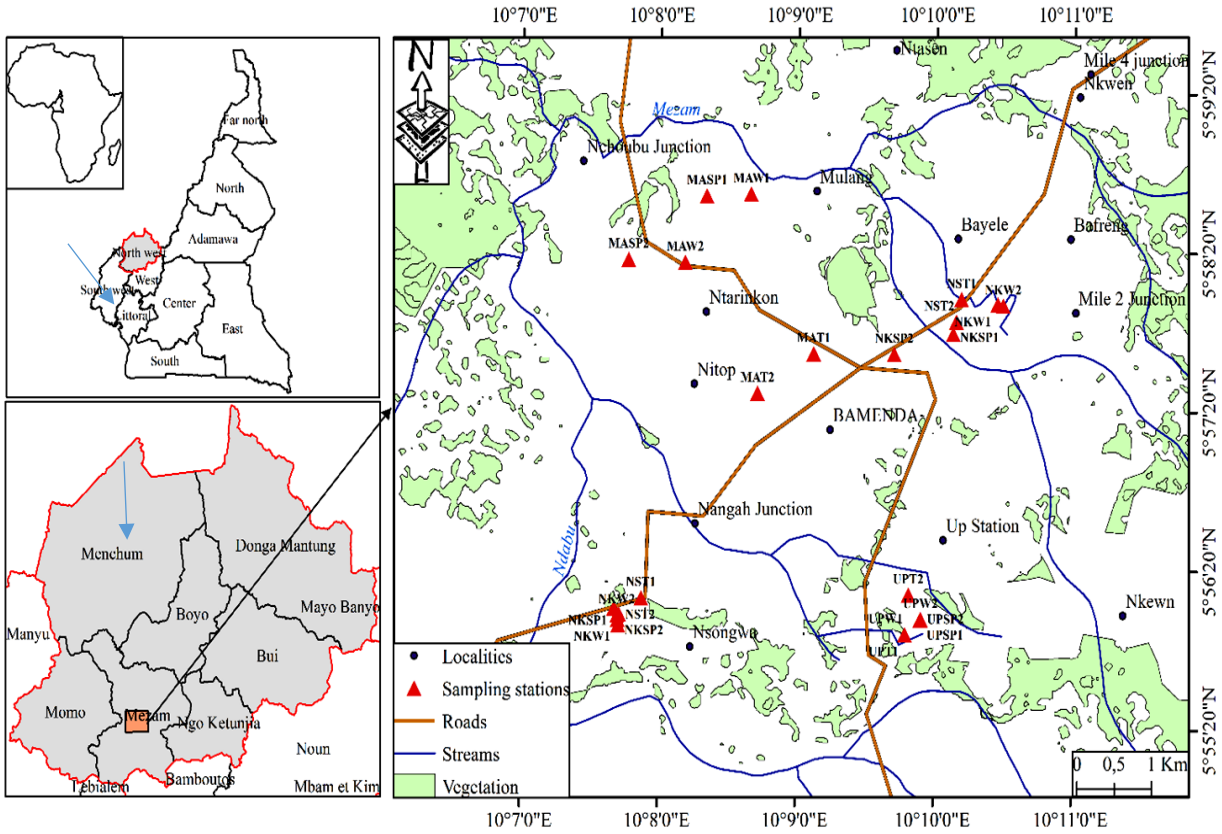


Figure 17: Map of Bamenda and its environs showing the domestic water sampling points (National Institute of Cartography, 2016 modified)

II.4- Choice and description of sampling stations

Common sources of drinking water here include; protected and unprotected springs, tube well, stand posts in quarters with community water and those with Cameroon Water Utilities Corporation (CAMWATER) as presented in figures 18 to 29.

a) Upstation (mile 1 council area)

The tap UPT1 is situated just above the mile 1 police station before the junction of mile 1 while the (UPT2) is located araound the petrol station Tradex before former mile 1 council premises, The soils are loamy sand to sandy clay loam texture, fine to coarse sub-angular blocky structure and loose to hard consistency. These two stations are characterized agricultural product transformation (coffee, basic foods), handicrafts, education, tourism, transport activities, construction works and many new infrastructure investments (Figure 18).

Upstation Tap 1 (UPT1)

Upstation Tap 2 (UPT2)

Figure 18: Upstation tap1 and tap2 domestic water sampling points

The tap UPW1 is situated blue moon after former Guarantee agency upstation before while the (UPW2) is located around the MTN antenna at blue moon quarter. These two stations are characterized by low vegetation, hilly topography, few forestations, few agricultural activities and many new settlement housing facilities. The soils are loamy sand to sandy clay

loam texture, fine to coarse sub-angular blocky structure and loose to hard consistency. The equipment used to draw water in most wells is small 10 litres buckets whose handles are been tied with a strong rope (Figure 19).

Upstation well 1 (UPW1) **Upstation well 2** (UPW2)

Figure 19: Upstation well 1 and well 2 -domestic water sampling points

The Upstation spring UPS1 is situated around the pastoral center after world hospital, and about 1 km from the mile 1 juntion while the (UPS2) is located around Mendankwe park, These two stations are characterized by low vegetation, hilly topography, no forestation, few agricultural activities and many new settlement housing facilities and few infrastructure investments (Figure 20).

Upstation Spring 1 (UPS1) **Upstation Spring 2 (UPS2)**

Figure 20: Upstation Spring 1 and Spring 2 domestic water sampling points

b) Mankon

The MAT1 is situated around Paul computer institute in mile 7 Mankon, while the MAT2 is located araound Catholic church mile 7 mankon. These two stations are characterized by volcanic soils and rather fertile although soil pH is on the low slide. Most of its population being rural dwellers who are fully involve in agricultural activities. The area is a low land surface of low landscape, few trees, few agricultural activities, few settlement housing facilities and few infrastructure investments (Figure 21)**.**

Mankon Tap 1 (MAT1)

Mankon Tap 2 (MAT2)

Figure 21: Mankon tap 1 and tap 2, domestic water sampling points

The MAW1 is situated around Mukweboh quarter vicinity in Mankon, while the MAW2 is located around Binfibi mankon. These two stations are characterized by many vegetations, low landscape, many trees, much agricultural activities and few settlement housingfacilities Most of its population being rural dwellers who are fully involve in agricultural activities (Figure 22).

Mankon well 1 (MAW1)

Mankon well 2 (MAW2)

Figure 22: Mankon well 1 and well2 , domestic water sampling points

The MAS1 is situated around resort hotel in a hilly slope in mile 6 quarter vicinity in mankon, while the MAS2 is located around below Sacred heart college mankon, MAS1 collection source has no vegetation around the source, no agriclural activities but more of human urbanization activities, while MAS2 has low landscape, many trees and vegetation, much agricultural activities and few settlement housing facilities (Figure 23).

Mankon Spring 1 (MASP1)

Mankon Spring 2 (MASP2)

Figure 23: Mankon Spring 1 and Spring 2 domestic water sampling points

c) Nkwen area

The NKT1 is situated around Ndamukong first tap vicinity in Nkwen, while the NKT2 is located around Cow streets nkwen getting toward mile 2. These two stations are characterized by clay loam soils, few or no vegetations, low landscape, little or no agricultural activities and many settlement housing facilities and urbanisation (figure 24).

Nkwen Tap 1 (NKT1)

Nkwen Tap 2 (NKT2)

Figure 24: Nkwen tap 1 and tap 2 domestic water sampling points

The NKW1 is situated around Bayele catholic church area, while the NKW2 is located around mile 3 apposite guiness depot Nkwen. These two stations are characterized by low vegetations, low landscape, few trees, less agricultural activities and compact settlement housing facilities (figure 25).

Nkwen Well 1 (NKW1)

Nkwen well 2 (NKW2)

Figure 25: Nkwen well 1 and well 2 domestic water sampling points

The NKS1 is situated around mile 4 council Nkwen vicinity, while the NKS2 is located around Atailah qauter after mile 4 park Nkwen. These two stations are characterized by many vegetations, low landscape, many trees, much agricultural activities and few settlement housing facilities (Figure 26).

Nkwen Spring 1 (NKS1)

Nkwen Spring 2 (NKS2)

Figure 26: Nkwen Spring 1 and spring 2 domestic water sampling points

d) Nsongwa

The tap NST1 is situated just at Cenajes campus are about 1km form the mile 90 junction while the NST2 is located around the Police check point just 100 metters from mile 90 junction. These two stationsare characterized by low vegetation, many agricultural activities and slow urbanization and dispersed housing facilities (Figure 27).

Nsongwa Tap 1 (NST1)

Nsongwa Tap 2 (NST2)

Figure 27: Nsongwa Tap 1 and Tap 2 domestic water sampling points

The NSW1 is situated around Mukweboh quarter vicinity in mankon, while the NSW2 is located around Binfibi mankon. These two stations are characterized by many vegetations, low landscape, many rees, much agricultural activities and few settlement housing facilities (Figure 28).

Nsongwa well 1 (NSW1)

Nsongwa well 2 (NSW2)

Figure 28: Nsongwa Well 1 and Well 2 domestic water sampling points

The NSS1 is situated around the hill going to to Nsongwa Fons palace, while the NSS2 is located around after former Moghamo garage towards the mile 90 junction. These two stations are characterized by many vegetations, hilly landscape, many trees, much agricultural activities and few settlement housing facilities (Figure 29).

Nsongwa Spring 1 NSSP1 **Nsongwa Spring 2 NSSP2**

Figure 29 : Nsongwa Spring 1 and Spring 2 domestic water sampling points

II.4.1- Sampling

In this study we targeted about water sources in about 12 villages 30 quarters within Bamenda and its environs. The samples included spring water samples, well water and tap water samples; which were collected in 15 of the quarters with community water and 4 organizational water projects (3 samples each, one from the catchment, and one from the middle of distribution and one at the terminal), samples from tube well in the area and samples from Cam Water. Water samples will be collected in bottles sterilized by dry air at 160^{o}C for 1 hour, Tap water, Spring water and tube well samples were collected.

II.4.2- Collection of water samples

▪***Tap water collection***.

The outside nozzle of the tap was carefully cleaned and the tap turned on fully to run for 2 minutes, The taps were sterilized using an ignited piece of cotton wool soaked in methylated spirit until the whole tap will be unbearably hot to the touch. And then it was cooled by running the water to waste for 1 minute. The sample bottle was then filled from a gentle flow of water aseptically, labeled and place in an insulated cold box.

▪Spring water collection; (protected and unprotected);

The cap of the sterile sample bottle is aseptically removed and the neck plunge downward to about 30cm below the water surface. The neck is tilted slightly upward to let it fill completely before replacing the cap aseptically. Where there is no current, the bottle is horizontally pushed until it is made full. It is then labeled and placed in an insulated cold box.

Collection from well*;*

The hand pump is continuously operated for 5 minutes, and then the nozzle of the pomp heat sterilized. Several gallons of water are pumped to waste before aseptically collecting the sample by allowing water from pump to flow directly into the sterile sample bottle, The cap is carefully replaced; the bottle labeled and placed in a cold box. The samples were then be transported to the laboratory of Hydrobiology and Environment of university of Yaounde 1 and also in Standard Medical Diagnostic Center at Mile 3 Nkwen Bamenda for analysis.

II.5. Measurement of physicochemical parameters

Measurements of physicochemical parameters took place both in the field and in the laboratory following the recommendations of Rodier *et al.,* (2009).

II.5.1- *In situ* measurements

The water temperature (°C) was measured *in situ*, using a mercury thermometer graduated to 1/10°C by directly immersing the thermometer 2/3 into the water, Similarly, salinity (PSU), pH (UC), resistivity (Ω/cm), electrical conductivity (µS/cm) and Total Dissolved Solids (TSD) (mg/L) were measured in *situ* at using a portable multi-parameter brand HANNA model 9839. To do this, the previously calibrated measuring device was powered on, its probes were then immersed in water and the selection of the function of the desired parameter made it possible to obtain its value on the display screen.

II.5.2- Laboratory measurements

For the physicochemical parameters measured in the laboratory **(suspended solids, turbidity, color, alkalinity, oxidizability, ammonia**, **nitrates and orthophosphates and many others),** the water samples were taken against the flow without making bubbles at each station and at each sampling campaign using 1000 mL double-capped polyethylene bottles and transported in a refrigerated enclosure (around 4°C) to the laboratory, Suspended Solids, turbidity and water color were measured colorimetrically with the HACH DR 2010 spectrophotometer, at the respective wavelengths λ= 810 nm, λ= 450 nm and λ= 455 nm, The results were expressed in mg/L, NTU and Pt, Co respectively.

Color: The color was measured using a HACH DR/2000 spectrophotometer, The reading was made at the 455 nm wavelength and the values obtained were expressed in Platinum Cobalt (Pt.Co).

The water contents of **orthophosphates and different forms of nitrogen (NH_4^+ and NO_3^-)** were measured spectrophotometrically using the HACH DR 2010 spectrophotometer. The concentration of ammoniacal nitrogen (mg/L of NH_4^+) was measured by the Nessler method on 25 mL of raw water sample and the reading was taken at the wavelength γ = 425 nm. As for the nitrate (NO_3^-) and orthophosphate (PO_4^{3-}) contents, they were measured on 10 mL of sample with Nitraver V and Phosver III as reagents respectively. The readings were taken respectively at wavelengths γ = 507 nm and γ = 530 nm and the results were expressed in mg/L of NO_3^- and PO_4^{3-}.

Oxidability: Oxidability as measured volumetrically. Thus, in a 500 mL Erlenmeyer flask, 200 mL of raw water sample were introduced, then 2 mL of monosodium carbonate and the whole was brought to the boil on a hot plate. From the start of boiling, 20 mL of $KMnO_4$ N/80 were added, Ten (10) minutes after the start of boiling, the Erlenmeyer flask was cooled under running water, then 5 mL of 25% H_2SO_4 and 20 mL of Mohr's salt were added successively.

The decolorized sample was then titrated with $KMnO_4$ N/80 until a persistent pink color was obtained. The control sample was prepared under the same conditions, but with distilled water instead of the raw water sample, The results expressed in mg/L of $KMnO_4$ were obtained by the formula below:

$$\textbf{Oxidability (mg/L of KMnO 4)} = \frac{(q-qo)}{2} \times 3{,}95$$

With q = burette descent of the sample and q_0 = burette descent of the control.

Alkalinity was determined volumetrically by titrating 50 mL of water sample with N/50 sulfuric acid, in the presence of methyl bromocresol red green as a color indicator. The results expressed in mg/L of HCO_3^- are obtained by the formula below:

Alkalinity (mg/L of HCO_3^-) = (buret descent of sample) × 20

The dissolved oxygen content was measured by the Winkler volumetric method, In the field, in a 125 mL Winkler bottle, 123 mL of sample was mixed with 1 mL of Winkler reagent (KOH+IK) and 1 mL of manganese chloride ($MnCl_2$). This resulted in the formation of a white precipitate, In the laboratory, the white precipitate was dissolved by adding 1 mL of concentrated sulfuric acid to the solution. Then 50 mL of this solution are taken and titrated with sodium thiosulfate N/80 in the presence of 2 or 3 drops of starch as a colored indicator. Finally, the results obtained in mg/L of sample, which correspond to the burette descent, were converted into percentage of oxygen saturation using the Mortimer chart (1956).

Dissolved oxygen:

The dissolved oxygen was determined in the laboratory using a WTW Oxy 340 brand oximeter, The values were given in percentage of saturation, The water sample content of **dissolved CO_2** was measured in two stages: in the field, the CO_2 was fixed by introducing into a 200 mL volumetric flask, 20 mL of NaOH N/20, 2 or 3 drops of phenolphthalein, and the water sample up to the mark. The mixture obtained, pink in color, was transferred into a 250 mL polyethylene bottle and transported to the laboratory, In the laboratory, 50 mL of this sample was titrated with N/10 HCl until complete decolorization. The CO_2 content of the water expressed in mg/L was determined by the formula below:

CO_2 (mg/L) = (control burette descent - sample burette descent) × 17.6

II.5.3. Calculation of the Organic Pollution Index (OPI)

The Organic Pollution Index (Leclercq, 2001) was calculated to account for the degree of organic pollution of the waters in the different sampling stations during the study period. The calculation of this index is based on three parameters (NH_4^+, NO_2^- and PO_4^{3-}) indirect indicators of organic pollution and one direct parameter, BOD_5. For our study, BOD_5 was replaced by

oxidizability. For each of the parameters, 5 content classes with ecological significance have been defined (Table XVI).

Table XVI: Classes of the Organic Pollution Index (OPI) according to the limit values of each parameter **(**Leclercq, 2001)

Classes	Settings		
	Ammonia $NH4^{+}$ (µg/L)	Nitrites NO_2^{-} (µg/L)	Orthophosphates PO_4^{3-} (µg/L)
5	<0.1	≤ 5	≤ 15
4	0.1 – 0.9	6-10	16 – 75
3	1 – 2.4	11-50	76 – 250
2	2.5 – 6	51 – 150	251 – 900
1	> 6	> 150	> 900

The OPI corresponds to the average of the class numbers of each parameter and the values obtained are distributed into 5 pollution levels (Table XVII).

Table XVII: Classification of the level of pollution according to the value classes of the Organic Pollution Index (OPI)

Class averages	5.0 – 4.6	4.5 – 4.0	3.9 – 3.0	2.9 – 2.0	1.9 – 1.0
Level of organic pollution	Nothing	Weak	Moderate	Strong	Very strong
Colors					

II.5.4. Measurement of trace metal elements in water and sediments

The water samples for the determination of heavy metals were collected using 500 mL double-capped polyethylene bottles, previously cleaned with 10% nitric acid, then rinsed with distilled water and dried, Sediment samples (1 kg) were collected from each station in January 2022 during the dry season using a hand shovel and stored in transparent polyethylene jars which were brought back to the Hydrobiology and Environment Laboratory (HEL) where they were dried at room temperature.

The dosages of the different metals contained in these samples were carried out using a PU 9200 metals in solution. This elementary analysis method requires that the measurement be made from an analyte (element to be measured) transformed into the state of free atoms. For this, the sample was brought to a temperature from 2000 to 3000°C so that the chemical combinations in which the elements are committed are destroyed. The determinations of the different metals (Cu,

Pb, Ni, Fe, Zn, Cd, Cr and Co) were carried out at the respective wavelengths of Cu = 387 nm, Pb = 283 nm, Ni = 232 nm, Fe = 248 nm, Zn = 213 nm, Cd = 228 nm, Cr = 387 nm and Co = 240 nm (AFNOR, 1999). The results are expressed in mg/L for water samples and in µg/kg for sediments, The physicochemical parameters measured in these sediments were pH (UC) and electrical conductivity (µS/cm) according to the techniques recommended by Rodier *et al.*, (2009).

II.5.5- Method of evaluation of contamination risk of underground water sources

The groundwater contamination risk assessment methodology was adopted by Boak and Packman (2001). It has been modified by integrating two (02) factors (the source of pollution and the level of anthropogenic activities), The risk of pathogen contamination has been divided into 12 categories or factors, such as the condition of the catchment well and the land use in the surrounding area, A choice was made about the area around each groundwater source, which was included in the risk assessment, It was decided that the areas considered are total watersheds of the source, For each category, a hierarchy of possible scenarios has been defined, in crossing order of groundwater contamination risks, A hint was given at each level of the hierarchy, with the highest number for the highest risk, A weight factor has been assigned to each category, to give it more critical importance, The weights take into account the highest index of the hierarchy in each category so that the relative importance of the categories is maintained between them. The twelve (12) categories, with hierarchy, indices and weights, are presented in Table XVIII below. The evaluation of factors also include the description of the station.

The application of the methodology then involves taking each groundwater source in turn, giving an index to each category according to the defined hierarchy (j), multiplying them by the corresponding weights, and adding all the weighted scores to have a weighted total score, The minimum and maximum weighted total scores for a station (i) are 35 and 120 respectively, giving a range of 85, The weighted total scores are then normalized (NWTS) or the risk level of contamination of the structure (RCS), so that the final minimum (min) score is 0 and the maximum (max) is 100, The method of normalizing scores is as follows: subtract 35 from the weighted total score for a Station (WTSS), divide the result by 85 and multiply by 100 to give an expressed normalized score percentage. The station's sanitation level sanitation index (I_S) is inversely proportional to the level of risk of contamination of the structures (wells and sources).

$$[(WTSS^{max} = \sum_{i-j}^{n} Wilimax = \mathbf{120}) - (WTSS^{min} = \sum_{i-j}^{n} Wilimin = \mathbf{35})] = \mathbf{85}$$

$$WTSSi = \sum_{i-j}^{n} \mathbf{WiIij} \text{ x } 100 = [0\text{-}100]\ \%$$

$$\mathbf{NWTSi} = \frac{\sum_{i(1-5)-j(,1-4)}^{12} \mathbf{Wilij-35}}{\mathbf{85}} \text{X } 100 = [0\text{-}100]$$

$$I_S = \frac{1}{\mathbf{NWTS}} \text{ X } 100 \quad \text{or} \quad I_S = \frac{1}{\mathbf{RCS}} \text{ X } 100$$

Sanitation index or Asi and Ajeagah index (I_S) belong to interval **(1-5)** with the appreciation of very low to very high sanitation or quality of water.

Risk assesment of groundwater is done by first developing out the contamination factors and putting them in different contamination weights, Index of contamination are now classified based on the different scenarios at each domestic water source considered (Table XVIII).

Table XVIII: Risk assessment of groundwater contamination according to Southern Water (Boak and Packman, 2001, modified).

Factors (fi)	Weight (wi)	Index (ii)	Scenarios
1/ / Land use (LU)	4	4	Intensive livestock buildings or non-partitioned slurry storage, or intensive spreading practice
		3	Extended pastures (in low density) dedicated to livestock
		2	Occasional pastures dedicated to breeding
		1	No breeding
2/Septic tanks (ST)	2	3	Dense development or presence of known septic tanks
		2	Low development or suspected presence of septic tanks
		1	Basin predominantly rural, no septic tanks
3/ Geology / hydrogeology (GH)	3	4	Cracked aquifer without cover of low permeability
		3	Cracked aquifer with low permeability cover
		2	Porous aquifer without cover of low permeability
		1	Porous aquifer with low permeability cover
4/Rapid bypass of tea unsaturated zone of the aquifer (RB)	5	3	Rapid infiltration of surface runoff into the aquifer, for example through soaks or losses after heavy rains
		2	Possibility of direct infiltration of surface runoff into the aquifer
		1	Direct infiltration of surface runoff to the aquifer unlikely
5/Induced recharge from	4	3	significant part of the groundwater resource comes from a supply from surface water

surface water (IR)		**2**	A small part of the groundwater resource could come from a supply from surface water
		1	By evidence of groundwater recharge from surface water
6/ Drainage of the catchment site (DC)	**1**	**3**	Poor drainage of the surface near the site
		2	Good drainage of the surface near the site, but the surroundings tend to bring runoff to the well
		1	Good drainage of the surface near the site, but the surroundings tend to bring water away from the wellhead, or no possibility of surface runoff
7/ Condition of the structure (CS)	**3**	**4**	Open well, or source with gallery(s)
		3	Maroon or brick well, closed or source without gallery
		2	Cased structure in known or suspected poor condition
		1	cased structure in good condition
8/ Head of the well / or source (HW)	**3**	**4**	Head of the well located outside and/or in a low position, sensitive to flooding
		3	Well head located outside but sealed and dry
		2	Well head with a close to the ground, or imperfectly sealed, but in a building
		1	Sealed well head, in a closed building
9/ Water quality (WQ)	**3**	**3**	Evidence of strong bacterial contamination or turbidity fluctuations
		2	Presumption of strong bacterial contamination or turbidity fluctuation
		1	No bacterial contamination or turbidity fluctuation
10/ Water treatment (WT)	**2**	**4**	No treatment (apart from chlorination)
		3	Activated carbon treatment
		2	Filtration (gravity or pressure filter, for example)
		1	Micro-filtration (1 micron)
11/ Sources of pollution (SP)	**3**	**3**	Presence of sources of pollution near the structure
		2	Sources of diffuse pollution
		1	Probable absence of sources of pollution
12/Level Anthropization (LA)	**2**	**3**	Strong urbanization or dense population demography
		2	Medium urbanization or low density demography
		1	Low urbanization or dispersed density demographics

The scenarios and the minimium and maximum weights analysed per domestic water stations to bring out the classified basis of index of contamination at each domestic water source considered as shown in Table XIX.

Table XIX: Representation of scenarios and weighting for sanitation index (example of NSW1 and NSSP1) by Researcher 2023

Station	Factors (n=12)	READ	ST	GH	RP	IR	D,C,	CS	H,W,	W,Q,	W,T,	SP	THERE	Total
NSW1	Weight i	4	2	3	5	4	1	3	3	3	2	3	2	/
	Index of scenario(j)	1	3	1	2	2	1	1	1	3	2	1	1	/
	Min Index of scenario (j Min)	1	1	1	1	1	1	1	1	1	1	1	1	/
	Max Index of scenario (j Max)	4	3	4	3	3	3	4	4	3	4	3	3	/
	WTS Min, D=1	**4**	**2**	**3**	**5**	**4**	**1**	**3**	**3**	**3**	**2**	**3**	**2**	**35**
	WTS Max	**16**	**6**	**12**	**15**	**12**	**3**	**12**	**12**	**9**	**8**	**9**	**6**	**120**
	Weighting (Wilij)	**3**	**2**	**1**	**2**	**2**	**1**	**1**	**1**	**3**	**2**	**1**	**1**	**54**
NSSP1	Weight i	4	2	3	5	4	1	3	3	3	2	3	2	/
	Index of scenario (j)	3	3	1	2	2	1	4	4	3	4	3	1	/
	Min Index of scenario (j Min)	1	1	1	1	1	1	1	1	1	1	1	1	/
	Max Index of scenario (j Max)	4	3	4	3	3	3	4	4	3	4	3	3	/
	WTS Min, D=1	**4**	**2**	**3**	**5**	**4**	**1**	**3**	**3**	**3**	**2**	**3**	**2**	**35**
	WTS Max	**16**	**6**	**12**	**15**	**12**	**3**	**12**	**12**	**9**	**8**	**9**	**6**	**120**
	Weighting (Wilij)	**2**	**3**	**1**	**2**	**2**	**3**	**4**	**4**	**3**	**4**	**3**	**1**	**82**

Determination of NSW1 sanitation index

[(WTSS min= 120)] - [(WTSS max =35)] = **85**

NWTS $^{(SS1)} = \frac{54-35}{120-35}$**X 100 = 22.35 % low risk** of contamination of NWTS; green color

$$\mathbf{I_S}^{(SS1)} = \frac{1}{22{,}35}\mathbf{X\ 100 = 4.47\ €\ [\ 2.5\text{-}5]\ High}$$ Sanitation index (high risk of water quality)

Determination of NSSP1 sanitation index

[(WTSSmin = 120)] - [(WTSSmax = 35)] = **85**

NWTS $(SS10) = \frac{82-35}{120-35}$ **X 100 = 55.29% High risk** of contamination NWTS; pink color

$$\mathbf{I_S}^{(SS10)} = \frac{1}{55{,}29}\mathbf{X\ 100 = 1.81\ €\ [\ 1.7\ \text{-}2.5\ ]}$$ poor Sanitation index (poor risk of water quality)

Weigth. WTSS min and WTSS max are Constants while "j" vary in the same where the product WiIij will also wary for each station.

II.6. Sampling. concentration and enumeration techniques for parasites

II.6.1. Sampling techniques

At each station, water sampling to identify the environmental forms of enteropathogenic protozoa and helminths was carried out at several points characterized by an accumulation of organic matter or the presence of herbarium, After gentle agitation to resuspend the particles, the water was collected in sterile 1000 mL polyethylene bottles and the organisms were fixed with 10% formalin (2 mL/Liter) (Sylla and Belghyti, 2008) and transported to the laboratory where they were left for sedimentation for 24 hours at room temperature, Then, the supernatant was poured out and the pellet was collected and measured. This pellet underwent several treatments to allow better identification and characterization of the parasites.

II.6.2. Concentration and staining techniques

Concentration techniques are used to concentrate resistance forms of intestinal protozoa and helminths in less diverse samples. These methods also make it easier to count parasites in a sample. The concentration methods used were the Kato-Katz technique for intestinal helminth eggs and larvae, the two-phase Ritchie technique modified with formalin-ether, the modified Faust technique or flotation with zinc sulfate and the direct sedimentation for all enteric pathogens, The modified Ziehl-Neelsen staining technique was used to demonstrate oocysts of intestinal protozoa.

II.6.3. Kato-Katz technique

Described by Katz *and al.*,(1979), it is a technique, which makes it possible to highlight the eggs of enteropathogenic helminths present in the pellet resulting from centrifugation. For this, the Kato-Katz solution (100 mL of glycerin, 1 mL of 3% Malachite green and 100 mL of distilled water) was prepared 24 hours before the manipulation and rectangles of cellophane paper were introduced into this solution, Glycerin promotes the lightening of helminth eggs while malachite green allows the coloring of these parasites. A pellet fragment was taken, placed in the center of a slide and covered with a rectangle of cellophane paper soaked in the Kato-Katz solution. Using a test tube, the pellet was spread between the slide and cellophane into a smear. The preparation thus obtained was directly observed under an optical microscope for the identification of hookworm eggs and 30 minutes later for that of the other eggs.

II.6.4. Ritchie formalin-ether technique

The modified Ritchie technique or two-phase formalolether sedimentation technique (Ajeagah *et al.*, 2014) makes it possible to highlight small helminth eggs and certain protozoan cysts (Flagellates and Amoebas), It is a qualitative technique complementary to the Kato-Katz technique which is based on the coagulation of proteins contained in the sample by formalin and the stabilization of fats by ether, After homogenization, 5 mL of the pellet was introduced into a test tube, then 2 mL of formalin to 10% (fixative) and 3 mL of ether (stabilizer) were added successively. The mixture was centrifuged at 1500 rpm for 3 minutes using a MINOR35 brand centrifuge, The contents of the tube separated into 4 layers: an upper layer containing the ether, a plug of fatty debris, a layer of formalin and the pellet containing the parasites (Figure 30), The 3 surface layers were removed and the fourth layer was mixed with a few drops of dyes and examined between slide and coverslip under an optical microscope and at 40x and 100x magnifications for identification and enumeration of parasites.

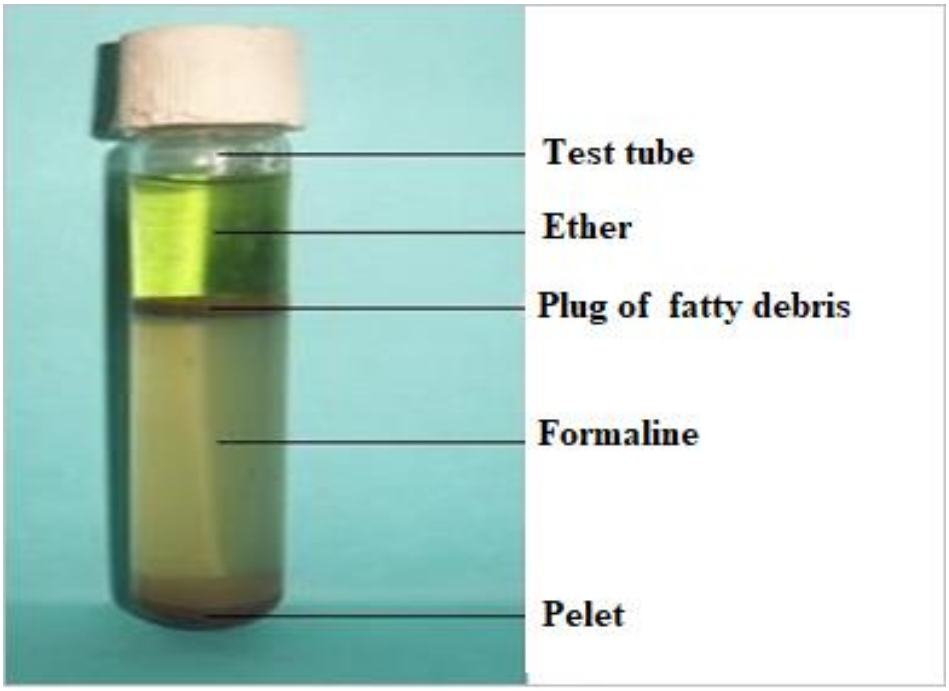


Figure 30: Appearance of the centrifuge tube after the Ritchie technique (Ajeagah *et al*,, 2014)

II.6.5. Modified Faust technique

The modified Faust technique or zinc sulfate concentration technique allows the flotation of Protozoan cysts and oocysts on the surface of test tubes (El Ouali *et al*.,2014), After homogenization, 5 mL of the pellet was taken and introduced into a test tube, To this, 1 mL of 10% formalin (fixative) and 3 mL of 33% zinc sulfate (for flotation of low density parasites) were added, The mixture was centrifuged at 1500 rpm for 3 minutes using a MINOR35 brand centrifuge, Then the surface layer of the supernatant was removed, placed on a slide, mixed with a few drops of dye and covered with a coverslip for identification and enumeration of parasites under an optical microscope at 40x and 100x magnifications.

II.6.6. Modified Ziehl-Neelsen technique

The Ziehl-Neelsen technique is a specific slide staining technique for detecting the oocysts of alcohol-acid-fast protozoa (Quintero *et al*., 2003). A 33% zinc sulfate solution was added to 5 mL of pellet to promote flotation, then the whole was centrifuged at 1500 rpm for 3 minutes using a MINOR35 brand centrifuge. The surface layer of the supernatant was collected using a micropipette and distributed onto slides. These slides were air dried to promote parasite adhesion,

then fixed and stained with methanol (fixative) and basic fuchsin (dye), respectively, Five minutes later, the slides were rinsed with distilled water and 2% sulfuric acid for 2 minutes to remove excess dye, Counterstaining was then carried out with 5% methylene blue (dye), then the slides were again rinsed with water, dried in the air and then observed under a microscope at 40x and 100x magnifications.

II.6.7. Direct sedimentation technique

This technique, which consists of concentrating the organisms at the bottom of the tube, makes it possible to identify both Protozoa and Helminths (Ajeagah and Karié Mouncharou, 2018), After homogenization, 5 mL of pellet was taken and introduced into a test tube. To that,

1 mL of 10% formalin (fixative) and 5 mL of distilled water mixed with a few drops of dyes are added and the mixture is centrifuged at 1500 rpm for 5 minutes using a MINOR35 brand centrifuge. After centrifugation, the pellet deposited at the bottom of the tube is removed, distributed on slides and covered with coverslips for observation under an optical microscope at 10x magnifications for Helminth eggs and larvae, 40x and 100x for Protozoan cysts and oocysts.

The dyes used in these different techniques were Lugol, methylene blue, cresyl violet, MIF (Merthiolate Iodine Formalin), hematocyline, basic fuchsin and saframine, The organisms are identified with branded optical microscopes Ivymen, Olympus CH and CYAN using the appropriate identification sheets (WHO, 1994) and cell sizes were measured using the ocular micrometer, Identification is based on criteria such as cell shape, size, wall thickness, structure and content of the cytoplasm, structure and number of nuclei.

II.6.8. Enumeration of intestinal protozoa and helminths

The enumeration of intestinal protozoa and helminths in the samples is done using the formula proposed by Ajeagah *et al.*, (2010). After decantation, the supernatant is discarded and the full volume (Vx) of the pellet measured, After homogenization of the pellet, a precise volume (Vy) is taken and used for identification. The final portion of each tube is spread onto slides, and then the number of organisms is counted, The total number of parasites (X) obtained in the sample is calculated by multiplying the value obtained (y) on all the slides by the fraction Vx/Vy and the result is finally reduced to the liter, The formula is as follows:

$$X = \frac{y, Vx}{\mathrm{Vy}}$$

With X (in Parasites/L) = total number of parasites, y = number of parasites observed on all slides, Vx = volume of the entire pellet and Vy (in L) = volume of the pellet taken for observation (in L). The results are then converted into parasites per unit volume (cysts, oocysts, eggs or larvae/L) according to the desired parasite function (Ajeagah *et al.*, 2010).

II.6.9. Evaluation of the maturation rate of environmental forms of parasites

The maturation rate was calculated in certain species of Protozoa and intestinal Helminths due to their high abundances and their different forms observed in the samples analyzed, The maturation rate of a species is the ratio expressed as a percentage (%) of the density of mature parasites to the total density of parasites (mature and immature) in a given sample, It is obtained according to the following formula:

$$T = \frac{\mathrm{Dm}}{Dt} \times 100$$

With T (in %) = maturation rate of a species, Dm (in Parasites/L) = average density of mature parasites of the species and Dt (in Parasites/L) = total average density (mature and immature parasites) of the species, The results obtained were processed using the Microsoft Office 2016 Excel program and the Origin Pro 8,0 software for producing the graphs, The photos were taken by screenshots of the microscopic observations at objective 40x using XPLOVIEWER software with an integrated camera on the microscope objective, The drawings were made using Photosop 4,1 and Dessin 3D version 2,4 software.

II.7. Statistical analysis of hydrological, physicochemical and biological data

II.7.1. Univariate analyzes

The Spearman rank correlation coefficient was calculated to measure the degrees of connection between the abiotic variables on the one hand, between the densities of intestinal Protozoa and Helminths and between the abiotic variables and the densities of intestinal Protozoa and Helminths on the other hand, This calculation made it possible to confirm the probable relationships between the different parameters, both biotic and abiotic, Two series of variables are more or less strongly linked depending on whether r is more or less close to 1. The analysis was

carried out using the SPSS version 20,0 program after checking the distribution of the data, The analysis were carried out in laboratory of Hydrobiology and Environment of university of Yaounde 1 and also in Standard Medical Diagnostic Center at Mile 3 Nkwen Bamenda.

II.7.2. Kruskal-Wallis H test

The non-parametric Kruskal-Wallis (H test) was used to verify, on a spatiotemporal level, the significance of differences (or similarities) in the variances of abiotic parameters and densities of intestinal parasites, relating to their distribution. To do this, two hypotheses were put forward: a null hypothesis according to which the medians of the samples to be compared do not differ significantly and a second alternative hypothesis according to which there is a significant difference between the medians of the samples to be compared, The analysis was carried out using the SPSS version 20,0 program which gives us the p-value (p-value), If this value is less than or equal to 0,05 ($p \leq 0.05$), the null hypothesis is rejected, Otherwise, ($p > 0,05$) it is verified. The variables being quantitative, this rank test is measured with at least one ordinal scale (ranks). The test is based on the hypothesis that the different samples to be compared follow the same distribution or that they have distributions around a median (StatSoft France, 2005). Whenever the Kruskal-Wallis test showed a significant difference between the variances of the samples compared, the multiple comparison test of ranks or the U test of Mann-Whitney was used for a pairwise comparison, to isolate samples that differ significantly.

II.8- Multivariate analyzes

II.8.1- Hierarchical Classification Analysis (ACH): The goal of Hierarchical Cluster Analysis (HCA) is to gather the means of variables into larger and larger classes, based on some measure of similarity or distance. The results of this type of classification are usually represented in the form of a dendrogram. This method differs from all others in that it uses an approximate analysis of variance to evaluate the distances between classes (Ward, 1963). In this work, ACH was used to group stations based on their abiotic similarities, and the similarity of parasites identified on the basis of average densities, Similarity was employed in this bottom-up classification analysis. The principle of this analysis is to group individuals according to their similarities and represent them in the form of a classification tree, The ACH was performed using XLSTAT 2014 software.

II.8.2. Principal Component Analysis (PCA)

In this study, Principal Component Analysis (PCA) was used to establish the abiotic typology of the sampling stations on the basis of all the physicochemical variables and the densities of intestinal parasites recorded at each station during the 'study. This method of factorial and descriptive statistics aims to present in graphic form the maximum of the information contained in a large data table (Philippeau, 1992), The data matrix is made up of samples “n” in rows on which quantitative variables “p” are measured arranged in columns, The matrix used in this study is a base having undergone a logarithmic transformation “Log (X + 1)” to have an approximate normality then standardized in order to obtain a comparable scale of the variables (Michael *et al*., 2004). The “n” × “p” data table thus forms a cloud of “n” points in a “p”-dimensional space, Each principal component (dimension) explains a more or less significant quantity of the initial information, The principal components are listed in descending order of the amount of information they explain, In general, the first two and three principal components are sufficient to explain 60 to 70% of the information contained in the initial matrix, The principal components are obtained by the diagonalization of a matrix which, depending on the nature of the initial variables, is either the correlation matrix or the covariance matrix (Legendre, 1979), As part of this study, the correlation matrix was used. The final phase of the PCA consists of a graphical representation which then provides an overview of the results. There are two types of representation; the dispersion diagram of the variables which is a correlation circle and the dispersion diagram of the stations, The percentage of initial information explained by each principal component is illustrated as a histogram. These analyzes were carried out using XLSTAT 2014 software.

CHAPTER III:

RESULTS AND DISCUSSION

III.1. Results

III.1.1. Physicochemical parameters

The seasonal values, averages, and standard deviations of physical and chemical parameters, and also Organic pollution Index were measured during the period of study and are presented in appendix too. The spatiotemporal variations of physico-chemical parameters are presented below and are grouped into parameters as well as those of the Organic pollution Index (OPI).

III.1.1.1 Physical Parameters

The physical parameters considered during this study varied from one quarter to another and from one water source to another. The overall mean values for all the physico-chemical parameters in each domestic water source evaluated and anlysed in study are summarised and presented in table XX.

Table XX: Data of mean values for physicochemical parameters and OPI for each collection source.

		UPT1	UPT2	UPW1	UPW2	UPSP1	UPSP2	NKT1	NKT2	NKW1	NKW2	NKSP1	NKSP2
Temp	Min-Max	19.8-23.2	20.4-23.4	19.1-21.1	19.2-21.5	18.1-22.3	20-22.8	20.1-24.5	20.4-23.7	20.8-22.6	22.1-24.6	20.2-22.2	20.8-22.8
	Mean ± σ	21.66±0.41	21.60±0.41	20.55±0.25	20.65±0.26	20.39±0.45	21.20±0.31	21.84±0.59	21.64±0.45	21.90±0.25	23.04±0.36	21.23±0.25	21.60±0.24
MES	Min-Max	0-18	0-13	0-17	0-16	0-21	0-26	0-18	0-31	0-74	0-38	0-34	0-18
	Mean ± σ	5.63±2.83	2.75±1.69	5.25±2.41	4.25±1.88	8.38±2.78	7.50±3.23	4.88±2.53	9.25±4.12	15.50±8.57	11.63±4.52	7.88±4.02	8.63±2.67
TDS	Min-Max	13.2-19.8	13.9-22.3	6.53-119	7.01-195	11.1-70.9	10.9-24.3	14.6-111	10.1-98.2	14.1-117	10.9-117	10.6-120	15-30.9
	Mean ± σ	15.96±0.88	15.65±0.98	33.93±13.67	33.73±23.06	22.50±7.04	13.81±1.53	76.29±13.37	53.16±14.84	78.8311.72	61.95±12.86	28.99±13.23	21.95±2.14
Col	Min-Max	0-161	0-35	0-85	0-86	0-121	0-92	0-59	0-151	0-337	0-51	19-470	0-102
	Mean ± σ	37.38±20.87	9.63±4.62	13.00±10.36	30.00±12.85	47.00±17.33	34.13±11.26	22.88±8.38	33.00±17.45	68.38±40.06	16.13±8.14	101±52.97	30.13±14.92
Turb	Min-Max	0-45	0-31	0-32	0-36	0-32	0-40	0-33	0-97	0-165	25569	0-52	0-36
	Mean ± σ	16.13±7.01	12.00±4.82	9.63±3.82	8.63±4.11	14.88±4.63	13.13±4.93	15.38±4.55	29.25±10.37	30.75±19.67	17.63±7.84	14.25±6.08	15.29±4.19
pH	Min-Max	5.76-7.04	4.6-6.55	5.59-6.81	5.44-6.46	5.86-7.01	5.9-7.17	4.95-6.91	5.42-7.01	5.23-7.01	5.67-7.11	5.9-7.39	5.64-7.62
	Mean ± σ	6.28±0.15	6.00±0.22	6.11±0.15	5.86±0.13	6.39±0.15	6.48±0.18	6.16±0.24	6.31±0.24	6.12±0.23	6.29±0.21	6.71±0.19	6.56±0.26
CO_2	Min-Max	11-41.00	1.76-66.88	4.56-56.6	3.52-33.44	1.76-31.68	8.8-44	12.21-67.56	1.76-52.8	14.08-47.7	8.8-44	21.23-64.4	35.2-70.4
	Mean ± σ	23.98±4.08	26.55±9.07	23.36±7.25	20.91±3.26	17.89±3.53	22.89±5.15	32.40±6.65	32.28±5.19	24.73±4.18	22.26±4.56	40.56±5.50	46.51±3.78
EC	Min-Max	27.2-39.5	27.9-45	13.6-236.9	13.89-207	22.1-167.8	21.8-48.8	29.1-222.1	29.2-201.1	28.2-234.6	18.2-233.3	22.1-238.6	30-61.8
	Mean ± σ	31.99±1.71	31.41±1.99	67.81±27.20	44.68±23.27	48.18±17.30	27.71±3.08	151.75±26.65	129.05±28.92	145.74±28.21	116.93±28.38	58.84±26.28	44.04±4.28
Alc	Min-Max	2-12.00	2-16.00	2-12.00	2-12.00	2-8.0	4-12.00	3-12.0	5-28.00	2-30.0	2-30.0	1-12.0	2-8.0
	Mean ± σ	5.00±1.24	6.13±1.76	6.95±1.17	5.38±1.32	4.65±0.74	5.88±0.93	8.66±2.87	11.68±3.08	12.19±3.96	6.88±1.14	5.00±0.87	5.13±0.69
	Min-Max	5.72-65.17	9.09-63.99	1.98-220.21	1.98-133.08	16.59-72.08	16.19-79.07	12.24-86.63	0.79-99.48	2.96-110.33	8.09-92.21	17.38-70.83	16.39-99.71

Oxyd	Mean ± σ	28.17± 7.77	28.15± 7.02	54.68± 26.12	31.48± 14.85	41.76± 6.86	35.83± 9.00	37.58±9. 18	44.83±1 2.48	31.53±1 3.30	35.00±1 0.95	35.87± 7.29	38.33± 12.31
DO	Min-Max	81.7-96.5	82-98.9	63.8-91.9	59.5-89	57.6-100	68.7-100.4	14.5-96.9	61-94.8	42.5-97.4	10.7-99.9	71.1-100.6	34.2-99.5
	Mean ± σ	89.01± 1.93	91.73± 2.59	77.39± 3.93	75.38± 4.14	85.74± 4.86	89.86± 3.65	75.65±9. 25	84.26±3. 97	77.80±6. 04	69.76±1 0.50	90.25± 3.21	77.49± 7.16
NO_3	Min-Max	0-12	0.1-16	0-8	0-10	0-4	0-12	0-8	0-16	0.5-28	0.4-18	0-6	0-6
	Mean ± σ	2.64±1. 25	3.78±1. 65	2.11±0. 84	2.44±1. 00	1.71±0. 41	2.80±1. 24	3.44±0.9 2	4.41±1.7 6	7.36±3.1 1	4.70±2.0 4	1.54±0. 67	2.39±0. 61
NO_2	Min-Max	0-0.01	0-0.013	0-0.126	0-0.014	0-0.058	0-0.046	0-0.045	0-0.027	0-0.027	0-0.034	0-0.023	0.005-0.036
	Mean ± σ	0.004± 0.001	0.007± 0.002	0.023± 0.015	0.008± 0.002	0.012± 0.007	0.008± 0.005	0.009±0. 005	0.010±0. 003	0.010±0. 003	0.009±0. 004	0.010± 0.003	0.010± 0.004
NH_4	Min-Max	0.01-1.05	0-1.4	0-1.97	0-1.32	0-1.18	0-1.98	0-1.4	0-1.23	0-2.64	0.01-1.04	0-1.53	0-1.89
	Mean ± σ	0.38±0. 15	0.53±0. 19	0.66±0. 24	0.57±0. 20	0.39±0. 14	0.71±0. 27	0.42±0.1 7	0.41±0.1 4	0.65±0.3 0	0.47±0.1 5	0.53±0. 18	0.46±0. 22
PO_4	Min-Max	0.38-0.15	0.53-0.19	0.66-0.24	0.57-0.20	0.39-0.14	0.71-0.27	0.07-2.40	0.16-2.82	0.13-1.43	0.16-3.09	0.12-3.45	0.23-2.12
	Mean ± σ	0.98± 0.40	0.89±0. 35	0.82±0. 32	0.74±0. 29	0.76±0. 22	0.96±0. 29	0.87±0.3 2	0.82±0.3 0	0.78±0.1 6	1.25±0.3 5	1.07±0. 38	0.65±0. 22
OPI	Min-Max	2.67-4.33	2.67-3.67	3.00-4.00	2.33-4.33	2.67-4.00	3.00-4.00	2.67-4.67	3.00-4.33	2.67-4.33	3.00-4.00	2.67-4.00	3.00-4.00
	Mean ± σ	3.67±0. 18	3.38±0. 15	3.29±0. 13	3.29±0. 25	3.42±0. 18	3.50±0. 13	3.58±0.2 2	3.42±0.1 5	3.25±0.2 2	3.29±0.1 2	3.25±0. 18	3.50±0. 11

		NST1	NST2	NSW1	NSW2	NSSP1	NSSP2	MAT1	MAT2	MAW1	MAW2	MASP1	MASP2
Temp	Min-Max	20.5-23	20.8-23.2	20.8-22.6	20.8-22.8	19-21.2	17.9-21.1	21.9-24.7	23-24.4	21.5-23	21.1-23.3	21.7-25	21.5-24.9
	Mean ± σ	21.51±0. 34	21.94± 0.32	21.43±0 .22	21.30± 0.25	20.18±0 .29	19.55± 0.51	23.09± 0.33	23.46± 0.17	22.25±0 .20	22.21± 0.25	22.94±0. 38	22.83±0. 41
SS	Min-Max	0-11	0-11	0-30	0-17	0-20	0-50	0-11	0-35	0-13	0-29	0-27	0-17
	Mean ± σ	2.38±1.4 0	3.88±1. 48	8.50±3. 42	7.38±2. 17	8.25±2. 53	14.63± 6.14	2.25±1. 52	10.13± 4.86	6.00±2. 13	8.25±3. 27	8.25±3.3 5	7.00±2.4 7
TDS	Min-Max	7.6-16.5	7.89-51.8	11.5-51.7	9.55-93.4	10.9-39.9	11.4-90.5	14-118	14.7-119	7.33-120	13.7-119	22.9-595	9.64-121
	Mean ± σ	13.96±0. 96	18.20± 4.89	22.89±4 .81	25.36± 9.77	20.99±3 .99	29.39± 9.25	32.20± 12.47	37.63± 12.40	43.38±1 2.76	42.30± 12.26	124.43±6 8.12	52.86±1 2.56
Col	Min-Max	0-41	0-107	0-42	0-153	0-155	0-78	0-51	0-44	0-69	0-121	0-83	0-231
	Mean ± σ	11±5.36	32.00± 15.58	19.38±6 .30	42.13± 18.47	42.25±1 8.62	34.25± 10.49	20.63± 7.73	9.25±6. 20	16.88±8 .03	28.63± 14.89	29.50±10 .05	54.00±2 7.54
Turb	Min-Max	0-27	0-23	0-38	0-31	0-39	0-51	0-25	26755	0-49	0-23	0-32	0-30
	Mean ± σ	6.38±3.6 5	7.88±3. 26	18.38±4 .74	14.38± 3.42	14.50±5 .07	25.13± 6.70	10.38± 3.57	24.63± 8.57	17.88±6 .08	11.88± 2.98	14.25±4. 38	12.50±3. 67
PH	Min-Max	5.74-7.57	5.7-7.52	5.31-7.49	5.47-7.48	5.8-7.49	3.79-7.32	5.88-7.34	5.2-7.01	5.34-7.01	5.36-7.06	3.16-7.06	5.68-7.09
	Mean ± σ	6.41±0.2 2	6.30±0. 24	6.14±0. 23	6.41±0. 21	6.49±0. 23	6.24±0. 39	6.52±0. 17	6.31±0. 23	6.18±0. 20	6.36±0. 19	6.00±0.4 3	6.44±0.1 7
CO_2	Min-Max	1.76-49.87	6.78-59.86	5.28-58.85	3.5-65.2	12.21-54.6	5.6-89.76	5.28-35.2	1.76-47.5	8.9-70.4	3.52-61.6	7.97-63.36	5.88-59.84
	Mean ± σ	25.97±6. 26	31.20± 7.37	31.53±6 .59	39.28± 6.61	30.65±4 .68	50.19± 9.26	19.96± 4.41	25.45± 5.53	28.88±6 .81	35.12± 8.03	33.83±8. 09	42.02±6. 83
EC	Min-Max	15.15-103.5	15.84-103.3	22.8-63.6	19.1-186.9	19.9-67.3	22.7-181.5	28.1-236.3	29.8-237.2	14.7-240.6	27.4-237.6	54.5-1189	19.31-249
	Mean ± σ	37.21±9. 67	36.39± 9.73	36.59±5 .08	51.04± 19.50	38.83±7 .45	54.71± 18.75	65.36± 24.83	74.91± 24.73	94.81±2 4.64	86.51± 24.30	251.41±1 35.58	106.40± 25.85
Alc	Min-Max	2-8.0	2-14.0	2-14.0	2-12.0	2-10.0	2-14.0	3-30.0	2-22.0	2-16.0	2-18.0	1-19.0	4-10.0
	Mean ± σ	6.25±1.3 5	6.50±1. 51	6.00±1. 60	5.88±0. 85	6.38±1. 70	10.00± 3.61	9.38±2. 12	7.38±1. 69	7.75±2. 02	7.50±2. 22	6.38±1.0 8	9.63±2.0 7
Oxyd	Min-Max	7.9-101.08	10.27-80.38	10.27-131.33	4.74-120.67	8.295-116.88	1.76-70.46	8.29-42.59	3.52-68.13	12.32-114.03	2.96-57.33	5.93-93.43	8.4-85.53
	Mean ± σ	38.55±1 1.86	34.29± 9.30	50.63±1 6.76	41.96± 14.11	41.40±1 4.70	28.08± 9.32	18.24± 4.20	26.95± 9.49	40.07±1 4.22	27.74± 7.82	38.04±12 .08	33.91±9. 30
DO	Min-Max	69.9-98.1	7.5-98.6	73.2-95.4	35.5-96.1	58.2-100.2	68.5-100.7	54-99.8	57.1-96.6	58.9-101.6	56.2-97.8	70.1-99.8	42.2-92.2
	Mean ± σ	86.24±3. 09	75.50± 10.44	82.95±2 .83	75.05± 6.92	86.45±5 .22	87.64± 4.49	83.71± 5.89	81.46± 4.55	77.30±4 .94	78.84± 5.37	84.81±3. 31	75.74±6. 00
	Min-Max	0.2-14	0-12	0-12	0-6	0.4-12	0-22	0.2-22	0-10	0.5-18	0.4-19	0-10	0.9-22

NO_3	Mean ± σ	2.42±1.46	2.80±1.20	2.78±1.21	1.62±0.61	2.77±1.24	3.71±2.35	3.73±2.30	2.60±1.03	4.62±1.94	3.76±1.93	3.22±1.03	5.81±2.31
NO_2	Min-Max	0.003-0.026	0.001-0.025	0.007-0.02	0.006-0.11	0.006-0.022	0.007-0.019	0.006-0.05	0-0.011	0.001-0.021	0.006-0.02	0.002-0.027	0.001-0.014
	Mean ± σ	0.010±0.002	0.009±0.003	0.012±0.002	0.036±0.015	0.013±0.002	0.010±0.001	0.012±0.005	0.006±0.001	0.009±0.002	0.010±0.002	0.008±0.003	0.009±0.002
NH_4	Min-Max	0-1.38	0.08-2.25	0-3.2	0.1-1.53	0-1.08	0.01-1.25	0.01-1.88	0-1.41	0-1.22	0.04-2.06	0-2	0.08-2.1
	Mean ± σ	0.53±0.21	0.66±0.27	1.10±0.41	0.56±0.20	0.42±0.12	0.61±0.18	0.81±0.26	0.56±0.20	0.40±0.17	0.57±0.24	0.75±0.25	0.84±0.24
PO_4	Min-Max	0.10-2.24	0.17-1.96	0.04-2.20	0.09-1.48	0.15-1.77	0.00-3.01	0.41-2.47	0.16-4.03	0.06-2.63	0.01-1.38	0.00-1.95	0.01-4.77
	Mean ± σ	0.83±0.29	0.67±0.20	0.76±0.25	0.77±0.20	0.87±0.21	1.34±0.35	1.29±0.28	1.41±0.44	1.13±0.38	0.57±0.14	0.55±0.22	0.99±0.55
OPI	Min-Max	2.67-4.00	2.67-4.00	2.33-4.00	2.33-3.33	2.67-3.67	2.67-4.00	2.67-3.67	3.00-4.00	2.67-4.67	3.00-4.33	2.67-4.33	2.67-3.67
	Mean ± σ	3.38±0.15	3.25±0.15	3.04±0.23	2.92±0.18	3.04±0.13	3.08±0.19	3.04±0.15	3.33±0.15	3.38±0.21	3.33±0.17	3.50±0.19	3.25±0.15

legend:

DO: Dissolved oxygen, **pH:** hydrogen concentration, **SS:** Suspended solid, **EC:** Electric conductivity, **NH_4:** Ammonium, **TDS:** Total dissolved solutes, **Alca:** alkalinity, **NO_2:** Nitrite, **PO_4:** Orthophosphates, **Turb:** Turbidity, **Col:** Colour, **OPI:** Organic Pollution Index, **NO_3:** nitrates, **Oxyd:** Oxydability, **CO_2:** Carbondioxide, **Temp:** Temperature

The measured temperature values fluctuated between 18,0 and 25°C, The highest value was recorded at Mankon spring 1 (MaSP1) and Nkwen well 2 (NKW2) in May and June respectively, The lowest value was noted at Nsongwa spring 1 (NSSP1) and Nsongwa spring 2 (UPSP2) in May and in Upstation well 1 (UPW1) in December showimg dry season, However, an average value of 21,66 ±0,20° C was noted (Figure 31 below). The rainy season showed avaerage temperature values slightly higher than in dry season (P≤0.05).

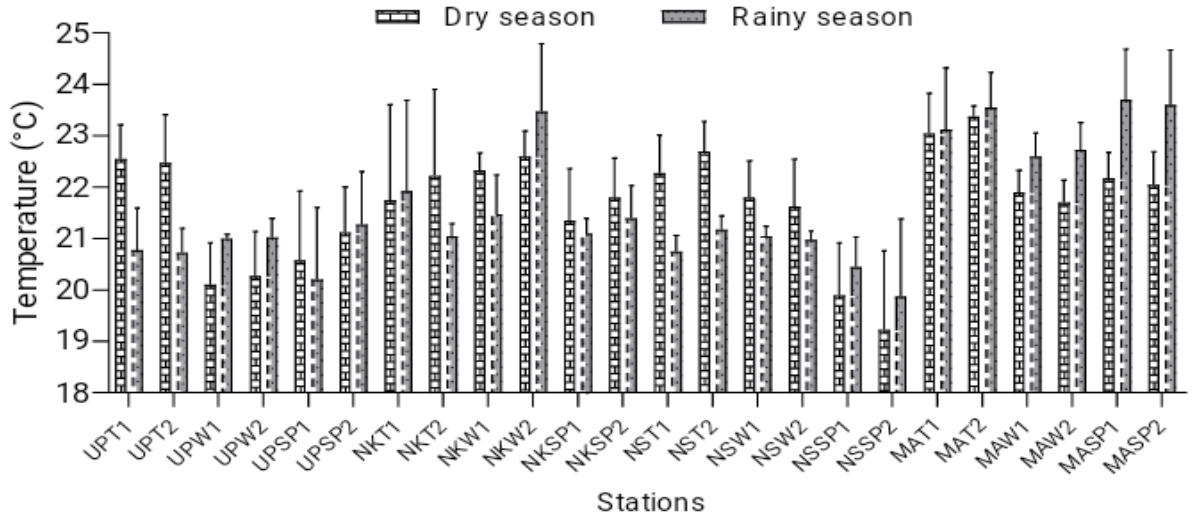


Figure 31: Spatio- temporal variation of annual mean value of temperature in domestic water sources during the study peroid

Overall, the water color values oscillated between 0 and 480 Pt.Co with an average value of 32.60 Pt.Co (32.60 ± 4.2). The highest values for colour was noted in Nkwen Spring 1 (NKSPI) and in Nkwen Well 1 (NKSPI) in February while most stations showed relatively low colour values especially in raiany season. There fore colour prevailed more slightly in dry season than rainy season (figure 32 below).

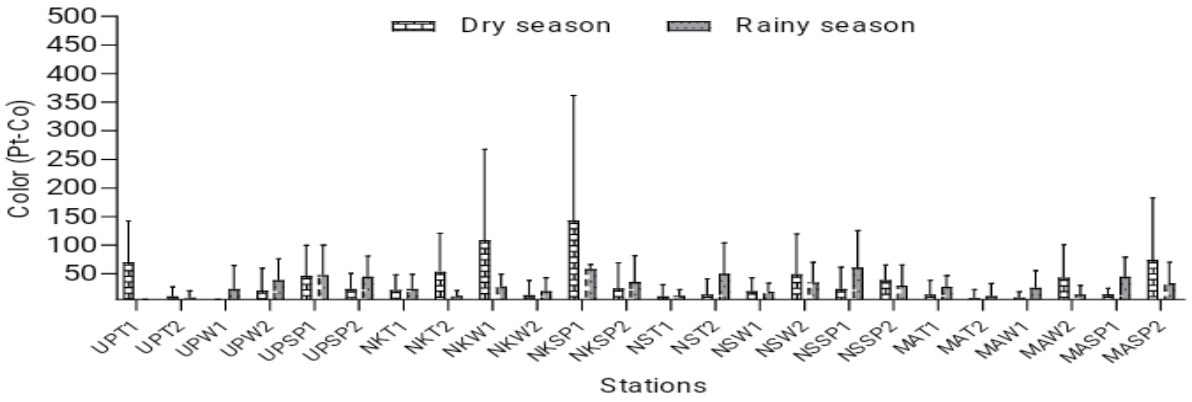


Figure 32: Spatio- temporal variation of annual mean value of colour in domestic water source stations,

The Total Dissolve solutes (TDS) values recorded during the study period varied between 12.8 and 180.4 mg/L, with an average value of 38.35 ± 5.32. The highest value was recorded for Mankon spring 1 (MASP1) of 180 mg/L in January of dry season, and the relatively low value was recorded for UPW2, NKT1, NKT2, NKW1, NKW2 and MankSP2 in dry season meanwhile the other stations recorded very low values (figure 33 below).

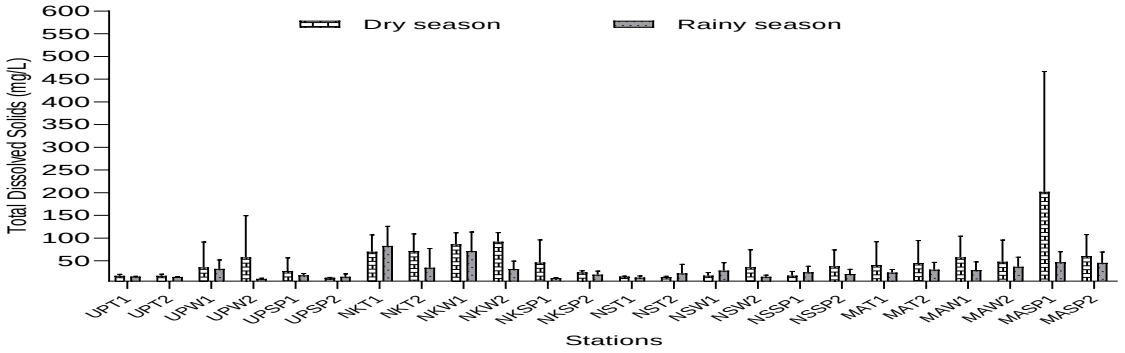


Figure 33: Spatio- temporal variation of annual mean value of Total Dissiolved Solutes in domestic water source stations

The Turbidity values recorded during the study period varied between 6,4 and 30,8 mg/L. The average rates was 15.63 ± 1.28. The highest value was recorded for NKW1 in February in dry season and the lowest value was recorded for the rest of the points in both seasons. However, an average significant value of 15.3 mg/L was noted (Figures 34).

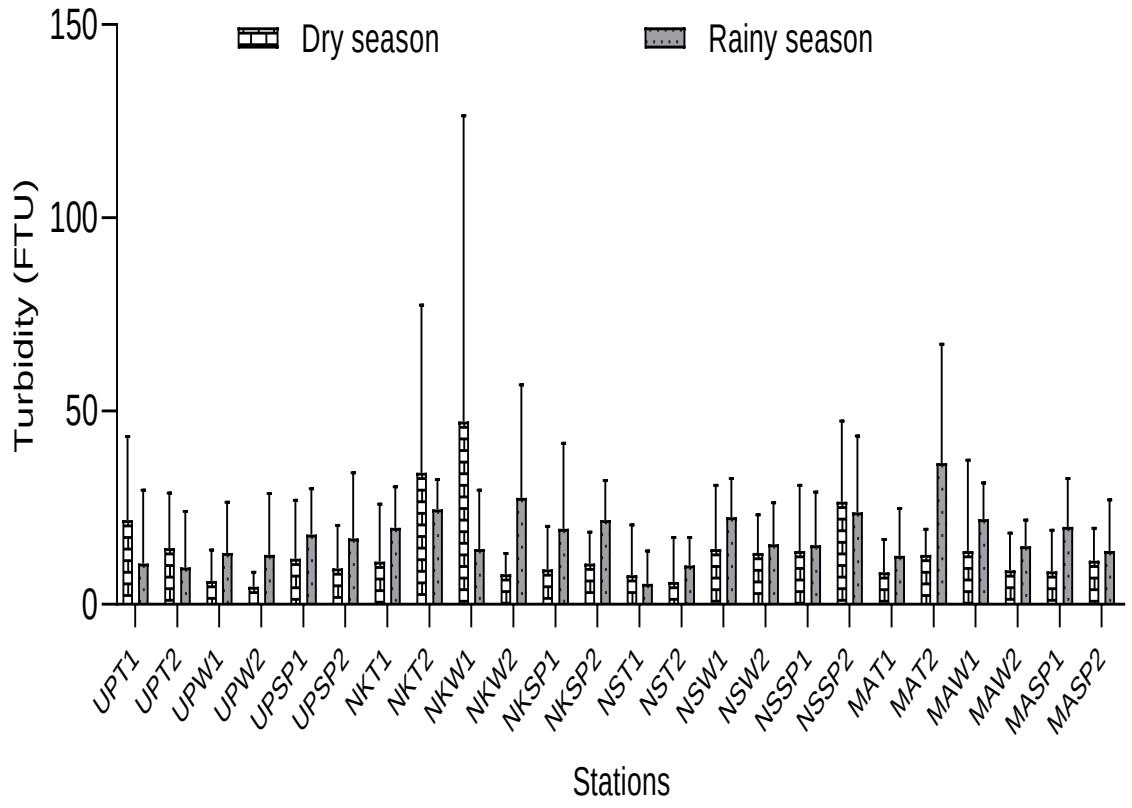


Figure 34: Spatio- temporal variation of annual mean value of turbidity in domestic water source stations

II,1,1,2- Chemical parameters

The chemical parameters considered throughout the study varied from one sampling point to another and from one month to another.

The pH values fluctuated overall between 5.7 and 7.5 UC for an average value of 6.29 ± 0.04 UC. The highest value was obtained at NKSP2 (7.62) in November dry season and the lowest at NSW1 (5.8) in rainy season (Figure 35).

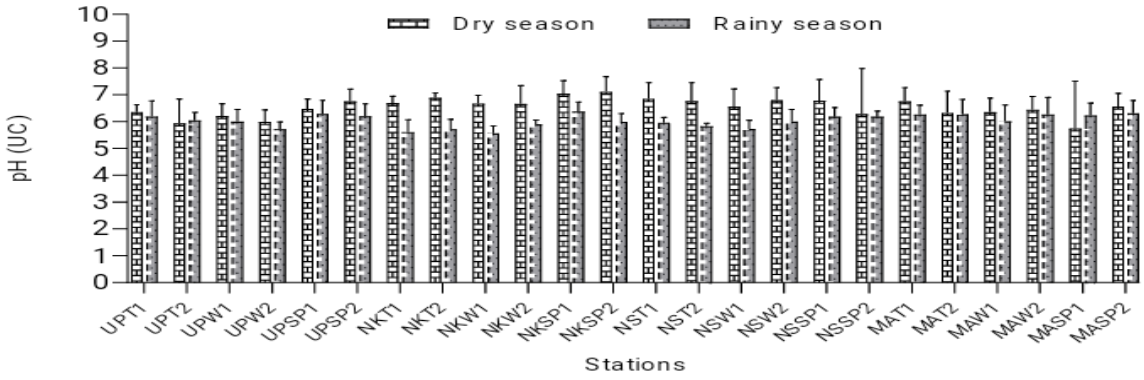


Figure 35: Spatio- temporal variation of annual mean value of pH in domestic water source stations

Electrical Conductivity values fluctuated between 27.7 and 251.4 µs/cm. The highest value was recorded for MASP1 (7.62) in January in dry season. Relatively low values were obtained for stations NKT1, NKT2, NKW1, NKW2, NKSP1, and MAW1 meanwhile very low values for electric conductivity were noted for most stations. An average value of 5 ± 10,75µs/cm was recorded 76.35 ± 10.75 (Figure 36 below).

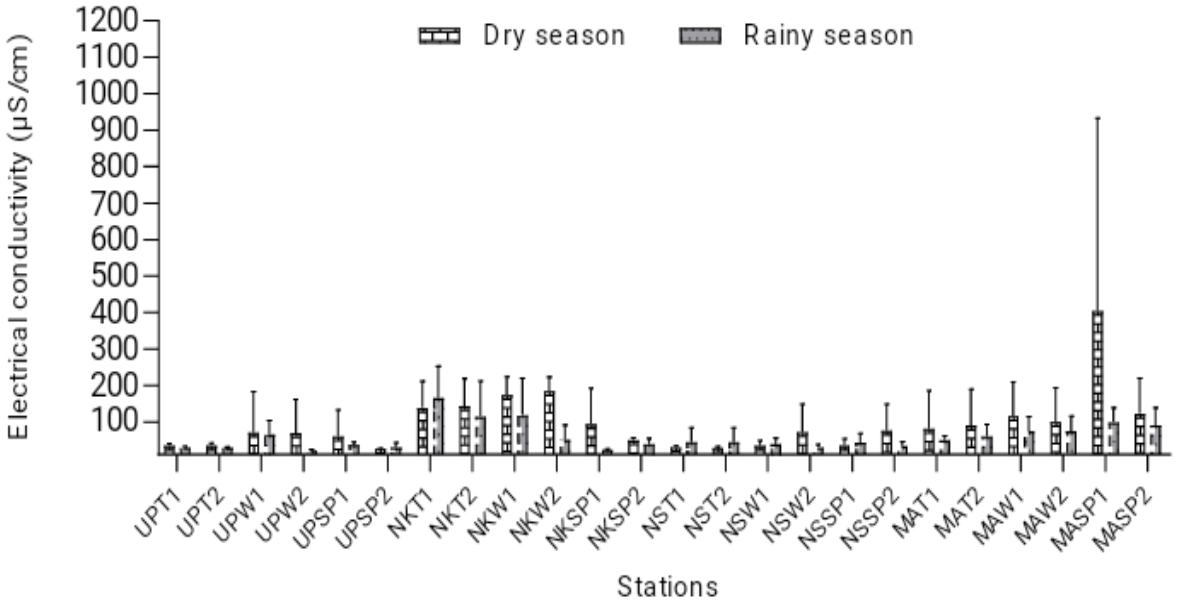


Figure 36: Spatio- temporal variation of annual mean value of electric conductivity in domestic water source stations

The Dissolved Oxygen levels fluctuated between 69,76 and 91,7 %. The relative high value was obtained in seven stations for UPW1, UPW2,UPSP1, NKW1, NST1, MASP1 MAW2 in dry seasons while in stations as NKT, NKW2, NKSP2, NST2 and NSW2 were relatively high in rainy season and the maximum value was recorded UPT1, UPT2, UPSP2, NKSP1, NSSPI. An average value of 81,762% was noted (Figure 37).

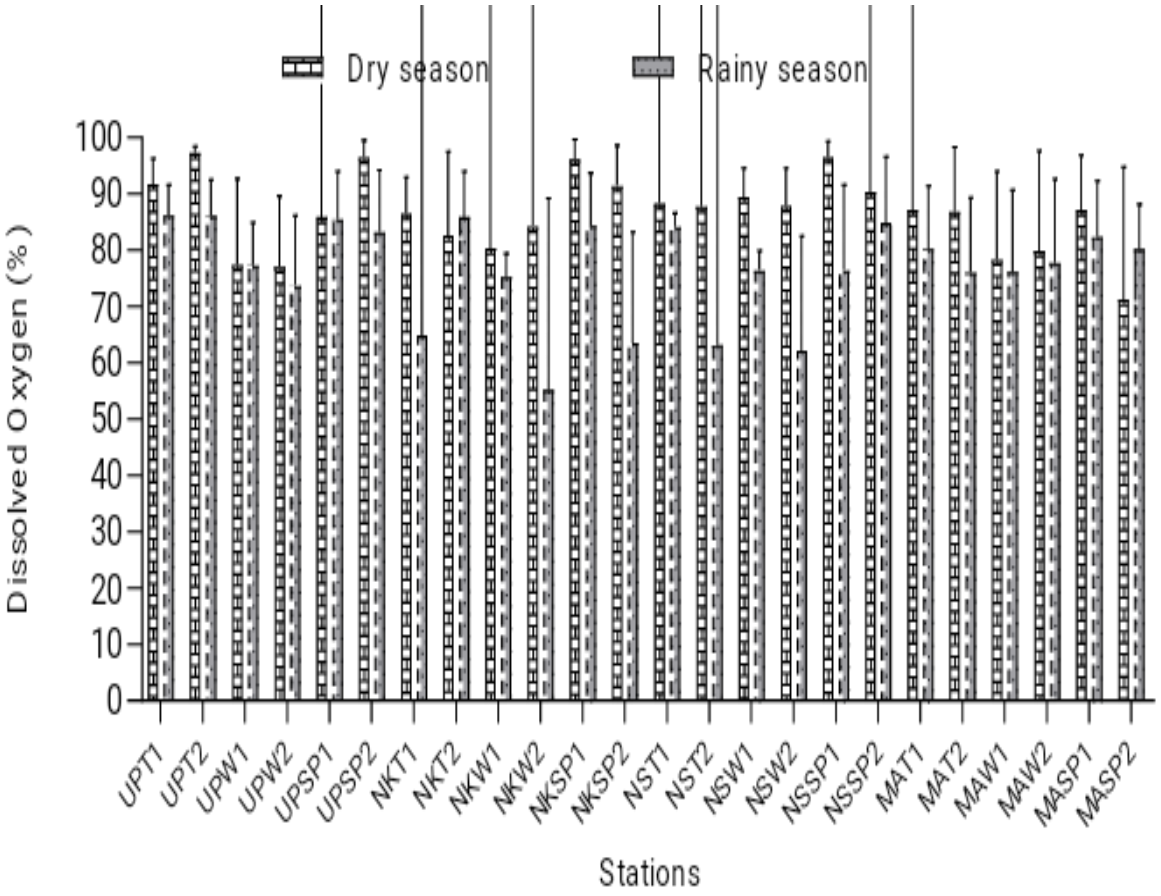


Figure 37: Spatio- temporal variation of annual mean value of dissolved oxygen in domestic water source stations

Overall carbon-dioxide values fluctuated between 17,89 and 50,18875mg/L with an average rate of (30.35 ± 1.74%). The highest value was recorded at NSSP1 (54,6) and in rainy season, Relatively high values were obtained in rainy season at MASP1 MAW2, NSW2, and NSW1, We obtained also relatively high values at stations UPT2, UPSP1, NKT2, NST1 and MankT2 respectively in the months of November, January, November and November. The lowest value was obtained in dry season at MAT1 in January (Figure 38).

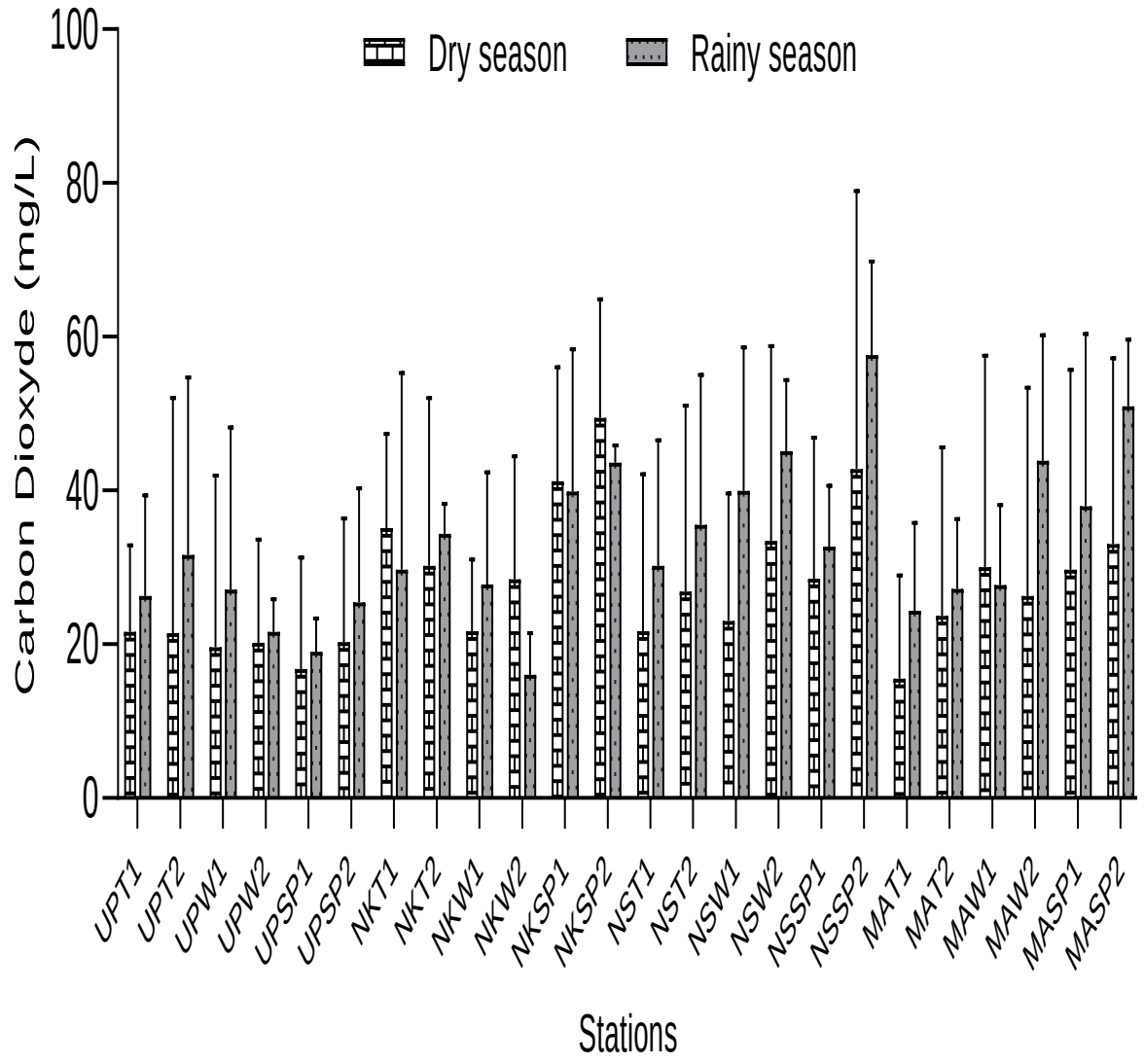


Figure 38: Spatio- temporal variation of annual mean value of carbondioxide in domestic water source stations

Oxidability values fluctuated between 18.2 and 54.12 mg/L of O_2 with an average value of 35.95 ± 1.6 mg/L of O_2, This parameter prevailed much more in rainy season than in dry season, The highest value was noted at UPW1 (54.6) in May of rainy season followed by NSW1, NKT2, NSW2 respectively, Medium rates of values in rainy season was recorded for MASP2, MASP1, MAW1 and MAT2, Generally the rates were very low in all stations in the dry season of November, December, January and February months (Figure 39).

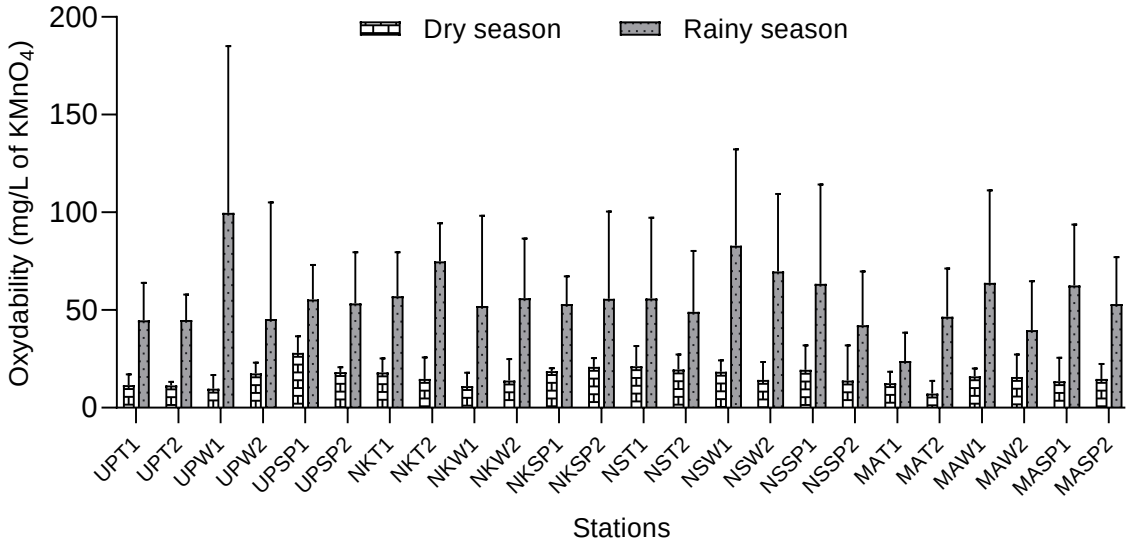


Figure 39: Spatio- temporal variation of annual mean value of oxydability ($KmnO_4$) in domestic water source stations

During the study period, Nitrate values varied between 1.55 and 7.3 mg/L NO_3^- a mean value of 3.29 ± 0.27 mg/L of NO_3^- was recorded. The highest value was obtained at NKW1 (7,3) in June followed by NKW1, MAW1 NKT1 in rainy season, while in dry season, only stations NKW2, MASP1, MASP2 had significant values for nitrates. The rest of the stations generally showed low values neither in dry or rainy season (Figure, 40).

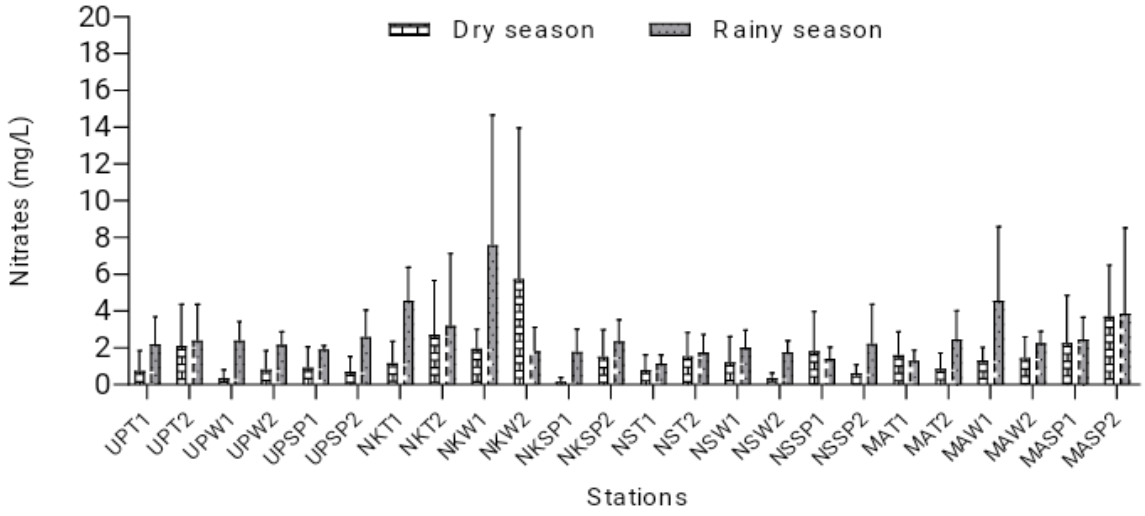


Figure 40: Spatio- temporal variation of annual mean value of nitrates in domestic water source stations

During the study period, nitrite values varied between 0.003 and 0.035 mg/L NO_2^- with mean value

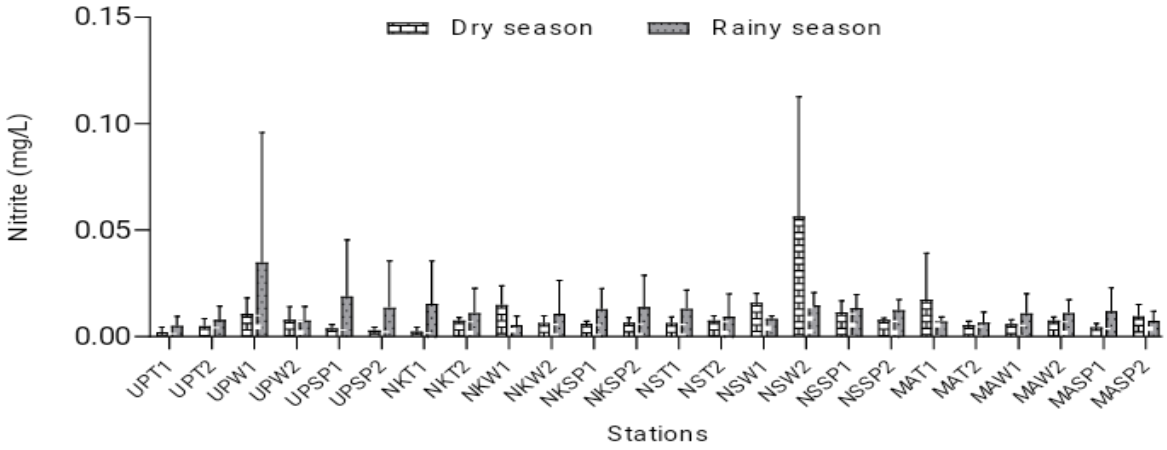


Figure 41: Spatio- temporal variation of annual mean value of nitrites in domestic water source stations

Throughout the study period, the ammoniacal nitrogen values fluctuated between 0.37 and 1.10 mg/L of NH_4^+ with average value of (0.58 ± 0.035). Hihgest value in rainy season in station NSW1 (1.10mg/l), Moderate values were recorded (0.5 and 1.0) in station MASP2, MASP1 MAT1, UPSP2 UPW1 all in dry season. While the other stations had values below 0.5 mg/l (Figure 42).

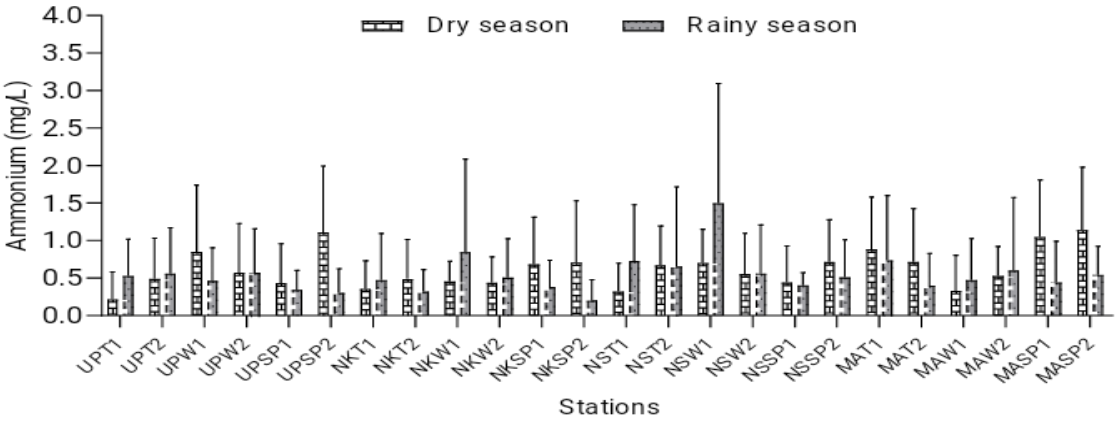


Figure 42: Spatio- temporal variation of annual mean value of ammonium in domestic water source stations

In this study period, the orthophosphates (PO_4^{3-}) values fluctuated between 0.54 and 1.41 mg/L of PO_4^{3-}, significant values for orthosphosphates were obtained in rainy season and in stations

NKSP1 (1.07 ± 0.38),) NKW2 (1.25 ± 0.35), NKT1 (0.87 ± 0.32), UPSP2 (0.96 ± 0.29), MAT21 (41 ± 0.44) UPT1 (0.98 ± 0.40), UPT2 (0.89 ± 0.35), MAT1 (1.29 ± 0.28) and UPW1 (0.82 ± 0.32) respectively in descending order. Highest value in dry season was recored in NSSP2, MAT1 and MAW1 in descending order respectively. While the other stations recored low rates or values (Figure 43).

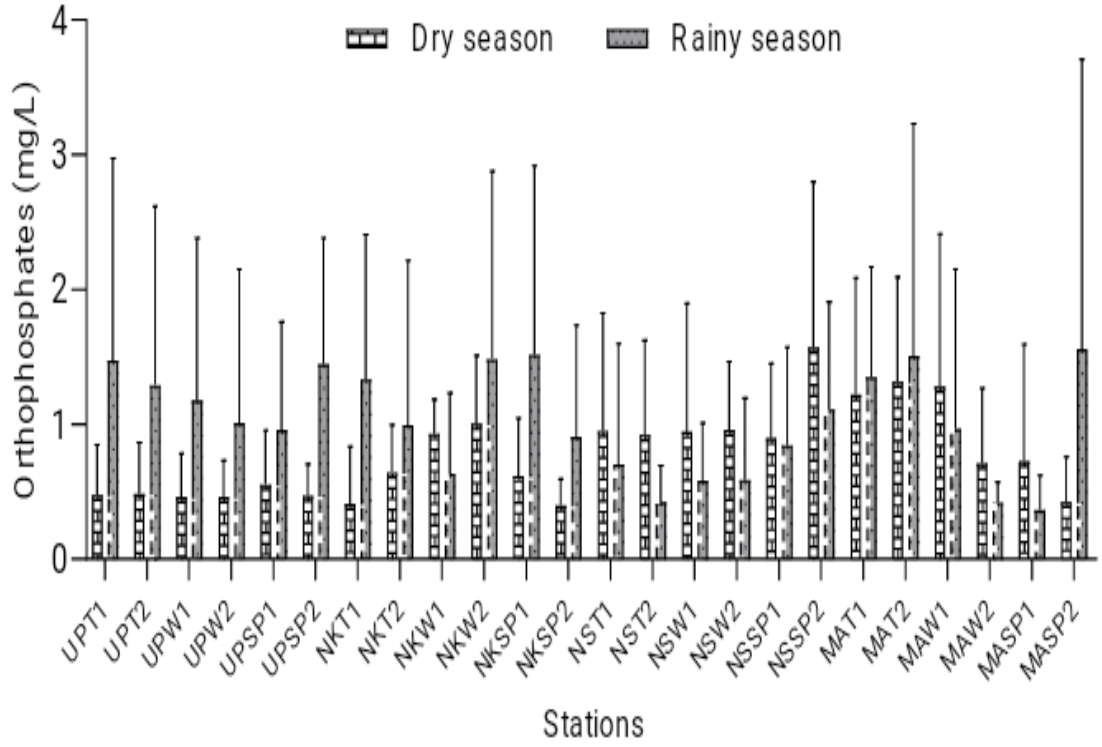


Figure 43: Spatio- temporal variation of annual mean value of orthophosphates in domestic water source stations

Throughout the study period, the Alkalinity values fluctuated between 5.38 and 15.60 mg/L. Highest value was obtained in station NSSP2 in rainy season, Relatively higher values were obtained in MASP2 (9.63 ± 2.07), MAW2 (7.75 ± 2.02), MAW1 (7.50 ± 2.22), NST1 (6.25 ±1.35), NST2 (6.50 ±1.51), UPW1(5.38 ± 1.32), UPT2 (6.13 ± 1.76), and UPT1 (5.38 ± 1.32), in rainy season respectively while in dry season the only significant vaules were recored in stations NKW1(12.19 ± 3.96), NKT2 (11.68 ± 3.08), and NKT1 (8.66 ± 2.87). The other staions had low values (figure 44).

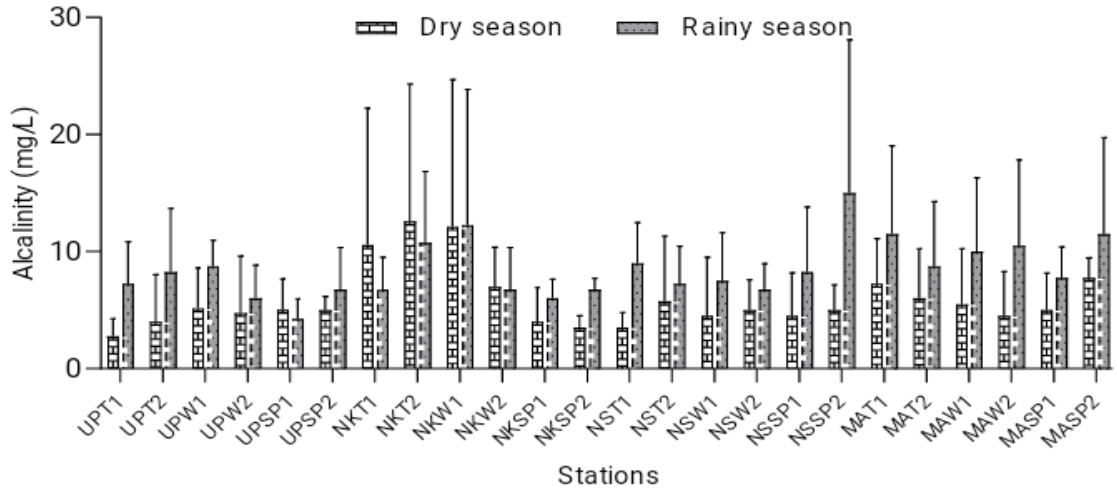


Figure 44: Spatio- temporal variation of annual mean value of alkalinity in domestic water source stations

In the study period, the Suspended Solids values fluctuated between 2.25 and 15.5 mg/L with a mean value of 7.43 ± 0.69. The highest value was obtained in station NKW1 (15,50 mg/l) in dry season. Other higher values were recorded in stations MAT2, NKSP1, NKW2 and MASP1 in rainy season with values ranging between 15 mg/l and 10 mg/l respectively. Very low values of below 5 mg/l were obtained NST1, NST1, UPW2, UPT2, UPT1, UPW2, NKW2, MAT2 MASP1, MAT2 and NKSP1 in dry season (Figure 45).

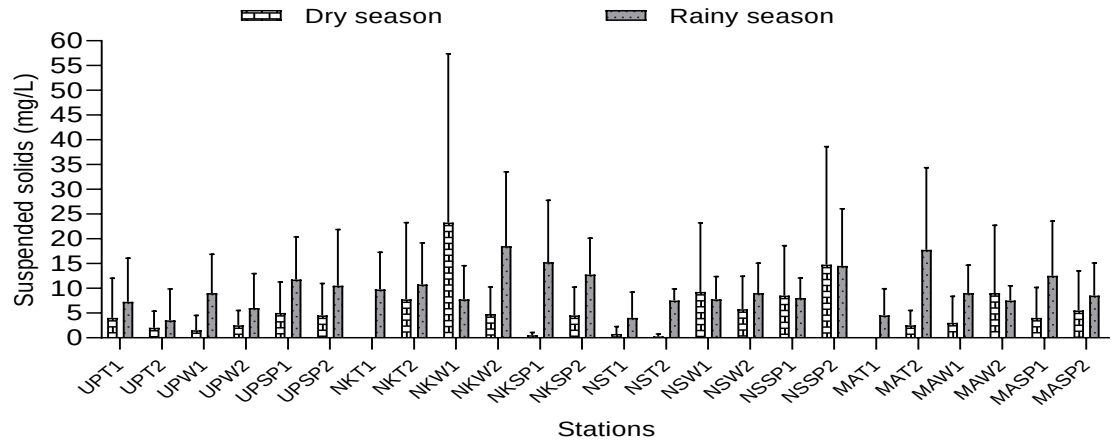


Figure 45: Spatio- temporal variation of annual mean value of Suspended Solids in domestic water source stations

The Organic Pollution Index varied from 2,92 to 3,67 which was generally within strong and moderate organic pollution of water sources in this study. The mean value for all was (3,32 ± 0,038), Stations NSW2 and NSW1 (2,3 and 3,4 respectively) had the strongest Organic Pollution Index showing that these domestic water sources were the most polluted, Station MASP2, MAT1, NSSP2, NSSP1 and UPW2 all had 2,5 index also showing that they were also of strong pollution, Apart from the above, the other water stations recorded moderate Organic pollution Index since their index ranged from 3 to 4 (Figures 46).

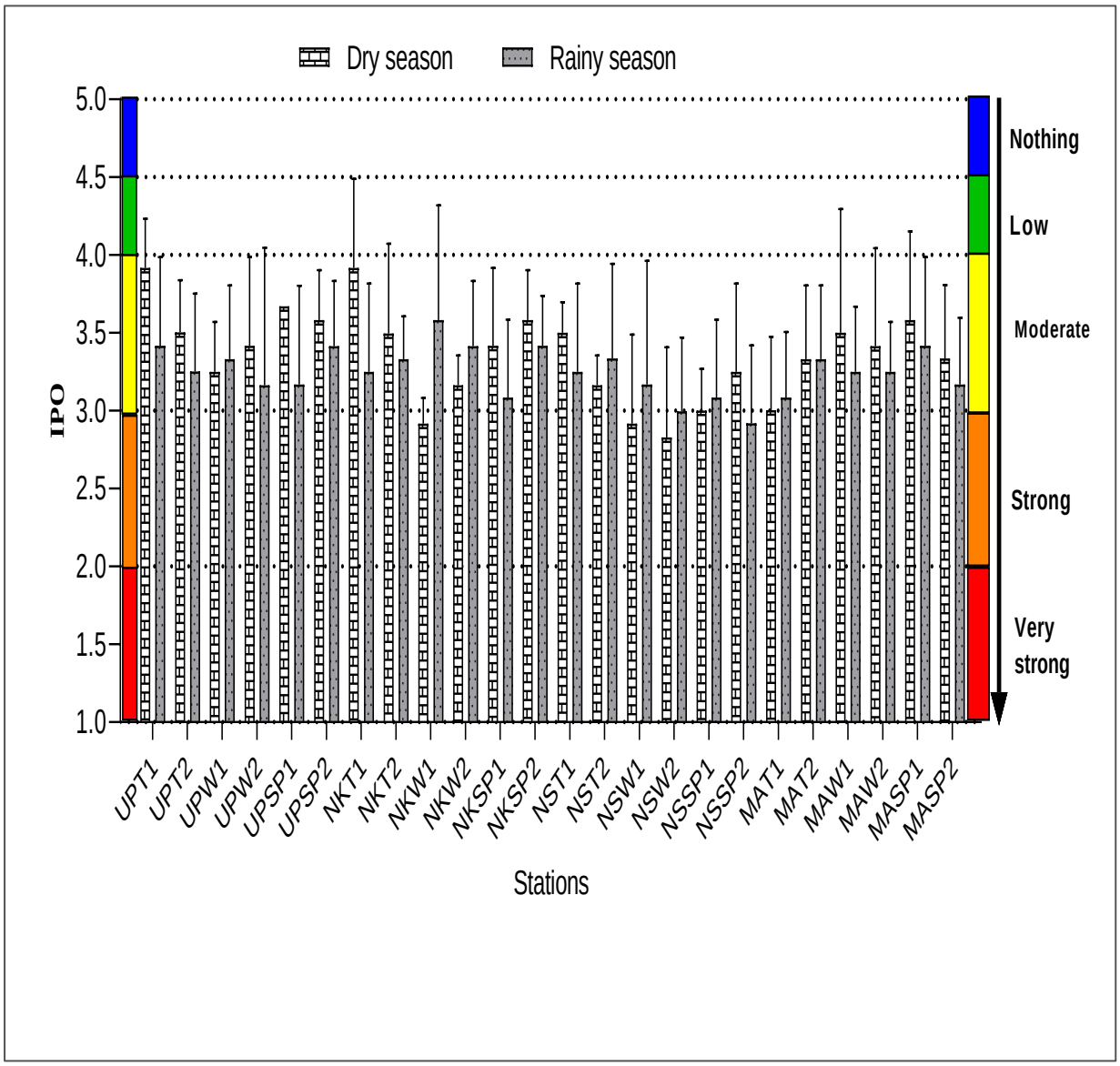


Figure 46: Spatio- temporal varaiation of Organic Polution Inedx in domestic water sources

A Principal Component Analysis (PCA) was performed to determine the physico-chemical parameters characteristic of the different sampling stations (Figure 47), Physico-chemical parameters measured at the 24 sampling stations. Principal Component Analysis (PCA) carried out from physicochemical data measured in the different stations showing the Scatter plot of variables. The first two factorial axes F1 (26,68%) and F2 (16,97 %) cumulating 44,00% (P≤0,05) expression variables were retained. The scatter plot of the variables shows that alkalinity (Alca), Hydrogen potential (pH), Electrical Conductivity (Cond), Total Dissolved Solids (STD), salinity (Sali), color (Coul), nitrates (NO_3^-), and Ammoniacal nitrogen (NH_4^+) are on the one hand, positively linked to each other, On the other hand, positively correlated with the F1 axis, Likewise, temperature (Temp), Ammoniacal nitrogen (NH_4^+), temperature, orthosphophates and Organic poulltion Index are positively correlated with each other, and negatively correlated with the F1 axis and the previous group of variables, Nitrites, Oxidability, colour, pH and Dissolved oxygen positively linked to each other on one hand, and positively correlated to the F2 axis, Furthermore, the other abiotic variable are not significantly linked to either axis. The first generally showed little or no correlation with respect to physico- chemical parameters as proven by the 66,00 % of variables whose expressions were mot retained.

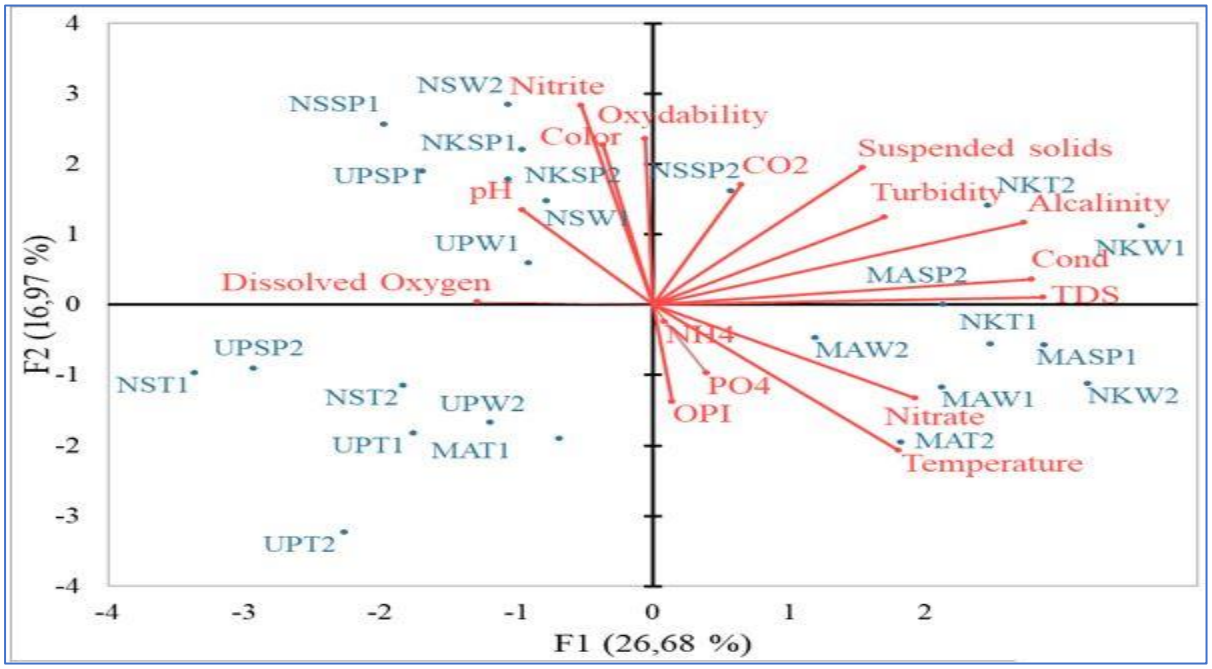


Figure 47: Principal Component Analysis (PCA) carried out from physicochemical data measured in the different stations.

The factorial map (Figure 47) which presents a distribution of the 24 stations sampling in relation to their physicochemical characteristics has defined 2 major sample groups, Group 1 is made up of the stations UPT1, UPT2, UPSP2, UPW2, NST1, NST2, and MATI little or no varaiation meawhile NSSPI, NSW1, NKSP1, UPSP1 NKSP2, NSW1 and UPW1 were averagely oxgenated , oxidazable , neutral Ph and nitrite , For NSSP2, NKT2, NKW1, MASP2, MAW2, NKLT1, MAW1, MASP1, NKW2 and MAT2, are characterized by well-oxygenated waters, high values of temperature, Total Dissolved Solids, electrical conductivity; contents high salinity, ions, nitrates, alkalinity and high values of pH and CO_2 and low to moderate organic pollution. These stations are for most located in the peri-urban area.

The Hierarchical Classification Analysis (CHA) carried out from physicochemical data (Figure 48) defined two classes of stations, Class 1(C1) made up of the UPSP2, NST1, UPT1, UPT2, UPSP1, NKSP2, NSSP2, NKSP1, UPW1, NSW1, NSW2, MAT1, UPW2 and NST2 while the others were grouped into class 2, Class 2(C2) consisting exclusively of the with characteristics abiotic different from those of other stations, presents similarities with class 1, Classes I and II group of stations are located in peri-urban areas and characterized by water well oxygenated and low organic pollution, Class 1, presents stations located in urban area and characterized by moderate to heavy organic pollution, high values of Suspended matter or solids, temperature, alkalinity and oxidizability.

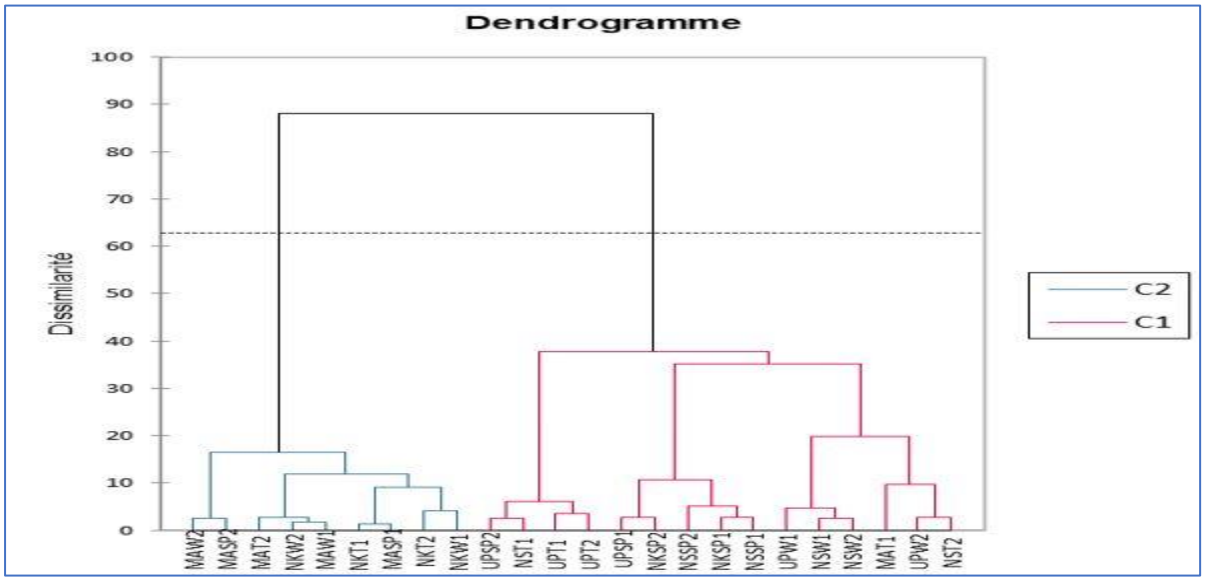


Figure 48: Hierarchical Classification Analysis (ACH) of sampling stations from values of physicochemical parameters

II.1.2. Correlations between the physicochemical and biological parameter

III.1.2.1 Correlations between abiotic variables of tap, well and spring water sources

The correlation between abiotic parameters in the tap waters shows very significant correlation ($P < 0,05$) for some parameters. There was positive correlations exist between Susoended Solids and parameters such as Turbidity (0.857 FAU), between Total Dissolved Solutes and Elecetric conductivity (0.857 µS/cm), and alkalinity (0.95 mg/L), between organic polution Index and ammonium, colour (0.970), between PO_4 with carbondioxide (0.71 mg/L) and oxidability (0,810 mg/L), and between oxidability and carbondioxide (0.71 mg/L).

The correlation between abiotic parameters in the well waters shows very significant correlation ($P < 0,05$) for some parameters, There was positive correlations exist between Temperature in °C and electric conductivity (0.786), between Suspended solids and turbidity (0.786), between Total Dissolved Solutes and (Electric conductivity (0.976 µs/CM), nitrates (0.833 mg/l) and alkalinity (0.929 mg/l), between Electric conductivity and alkalinity (0.952) and nitrates), While the rest of the abiotic parameters did not have significant correlation.

The correlation between abiotic parameters in the Spring waters shows very significant correlation at ($P < 0,05$) for some parametrs, There was positive correlations exist between Suspended Solids and Turbidity (0,982 FAU), between Total Dissolved Solutes and Electric conductivity (0,976 µs/cm), and also with alkalinity (0,952 mg/l), Positive significant correlation were recorded between Elecetric conductivity and alkalinity (0,976), between Nitrate and ammonium, Nitrites and ammonium, and between oxidability with ammoium and orthophosphates, (Tables XXI, XXII and XXIII for detailes about the correlations between the abiotic variables of tap, well and spring water sources).

Table XXI: Spearman correlations between abiotic varriables of water (physico-chemical parameters) in tap water sources in Bamenda and its environs

	Temp	SS	Turb	Color	TDS	PH	EC	NO3	NO2	NH4	PO4	DO	CO2	Oxyd	Alca	OPI
Temp (°C)	1.000															
SS (mg/L)	0.262	1.000														
Turb (NTU)	0.214	**.857****	1.000													
Color (Pt/Co)	-0.119	0.190	0.214	1.000												
TDS (mg/l)	0.548	0.524	0.619	0.190	1.000											
PH (CU)	0.167	-0.262	-0.190	-0.048	0.000	1.000										
EC (µS/cm)	0.333	0.357	0.405	0.024	**0.857****	0.310	1.000									
NO_3 (mg/L)	-0.095	-0.048	0.333	0.238	0.381	-0.167	0.119	1.000								
NO_2 (mg/L)	-0.143	-0.619	-0.429	-0.048	0.095	0.690	0.405	0.238	1.000							
NH_4 (mg/L)	0.524	-0.500	-0.571	-0.524	-0.095	0.476	-0.024	-0.167	0.405	1.000						
PO_4 (mg/L)	0.476	0.095	0.286	-0.452	0.048	0.048	-0.024	-0.190	-0.286	0.143	1.000					
DO (mg/L)	-0.690	-0.167	0.071	-0.048	-0.619	-0.143	-0.571	0.119	-0.167	-0.476	0.214	1.000				
CO_2 (mg/L)	-0.286	0.262	0.143	0.190	0.429	-0.429	0.405	0.357	0.071	-0.333	**-0.714***	-0.333	1.000			
Oxyd (mg/L)	-0.619	0.190	0.048	0.452	0.095	0.000	0.310	0.048	0.238	-0.524	**-.810***	-0.024	**0.714***	1.000		
Alca (mg/L)	0.476	0.548	0.643	0.262	**.952****	0.119	**.905****	0.214	0.119	-0.214	0.119	-0.524	0.310	0.167	1.000	
OPI (mg/L)	-0.491	0.443	0.467	0.491	0.108	-0.503	0.084	0.024	-0.383	**-.970****	-0.120	0.383	0.347	0.527	0.252	1.000

Table XXII: Spearman correlations between abiotic varriables of water (physico-chemical parameters) in well water sources in Bamenda and its environs

	Temp	SS	Turb	Color	TDS	PH	EC	NO3	NO2	NH4	PO4	DO	CO2	Oxyd	Alc	OPI
Temp (°C)	1.000															
SS (mg/L)	0.595	1.000														
Turb (NTU)	0.524	**.786***	1.000													
Color (Pt/Co)	-0.119	0.238	0.214	1.000												
TDS (mg/L)	0.619	0.452	0.333	-0.024	1.000											
PH (CU)	0.524	0.357	0.190	0.095	0.000	1.000										
EC (µS/cm)	0.643	0.524	0.405	0.000	**.976****	0.167	1.000									
NO3 (mg/L)	.786*	0.690	0.643	0.048	**.833***	0.000	**.786***	1.000								
NO_2 (mg/L)	-0.429	0.190	0.143	0.071	-0.381	0.286	-0.214	-0.476	1.000							
NH_4 (mg/L)	-0.643	0.048	0.024	0.071	-0.405	-0.571	-0.452	-0.238	0.429	1.000						
PO_4 (mg/L)	0.381	0.190	0.333	-0.524	0.524	0.024	0.571	0.357	-0.024	-0.405	1.000					
DO (mg/L)	-0,119	0,214	0,310	0,095	-0,167	-0,190	-0,190	0,119	0,214	0,667	-0,500	1,000				
CO_2 (mg/L)	0.095	0.214	0.286	0.310	-0.333	**.738***	-0.167	-0.238	0.571	-0.071	-0.333	0.357	1.000			
Oxyd (mg/L)	-0.381	-0.143	0.143	-0.476	-0.429	-0.071	-0.333	-0.452	0.643	0.310	0.429	0.024	0.143	1.000		
Alca (mg/L)	0.690	0.643	0.548	-0.048	**.929****	0.238	**.976****	.810*	-0.095	-0.381	0.595	-0.071	-0.048	-0.214	1.000	
OPI (mg/L)	0.415	-0.317	-0.268	-0.464	0.464	-0.073	0.366	0.342	-0.683	-0.464	0.146	0.000	-0.268	-0.390	0.293	1.0

Table XXIII: Spearman correlations between abiotic varriables of water (physico-chemical parameters) in spring water sources in Bamenda and its environs

	Temp	SS	Turb	Color	TDS	PH	EC	NO_3	NO_2	NH_4	PO_4	DO	CO_2	Oxyd	Alc	OPI
Temp (°C)	1.000															
SS (mg/L)	-0.455	1.000														
Turb (NTU)	-0.563	**0.982****	1.000													
Color (PT/Co	-0.214	-0.383	-0.252	1.000												
TDS (mg/l)	0.476	0.000	-0.108	0.048	1.000											
pH (CU)	-0.024	-0.228	-0.084	0.381	-0.571	1.000										
EC (µS/cm	0.571	-0.120	-0.216	0.143	**0.976****	-0.429	1.000									
NO_3^- (mg/L)	0.143	-0.168	-0.252	-0.262	0.452	-0.619	0.310	1.000								
NO_2^- (mg/L)	-0.643	0.515	0.635	0.286	-0.452	0.333	-0.476	-0.452	1.000							
NH_4 (mg/L)	0.571	-0.539	-0.635	-0.167	0.548	-0.357	0.524	**0.762***	**-0.881****	1.000						
PO_4^{3-} (mg/L)	-0.476	-0.156	-0.048	0.619	0.048	0.167	0.024	0.190	0.000	0.190	1.000					
DO (mg/L)	-0.548	-0.024	0.060	0.238	-0.381	0.286	-0.333	-0.405	0.000	-0.214	0.524	1.000				
CO_2 (mg/L)	0.095	0.323	0.323	-0.071	0.429	0.048	0.357	0.381	-0.071	0.333	0.381	-0.214	1.000			
Oxyd (mg/L)	-0.024	0.240	0.252	-0.071	-0.357	0.190	-0.286	-0.667	0.571	**-.762***	**-.714***	-0.167	-0.595	1.000		
Alca (mg/L)	0.476	-0.180	-0.263	0.214	**0.952****	-0.452	**0.976****	0.333	-0.429	0.500	0.071	-0.262	0.262	-0.262	1.000	
OPI (mg/L)	0.614	-0.074	-0.191	-0.602	-0.049	-0.098	-0.012	-0.110	-0.528	0.221	-0.626	-0.233	-0.209	0.147	-0.160	1

III.1.2.2. Presentation of protozoa and helminths organisms in domestic water sources

The parasitic evaluation considered during this study varied from one quarter to another and from one water source to another. The overall mean values for all the protozoa and helminths in each domestic water source evaluated and anlysed in study are summarised and presented the table XXIV.

Table XXIV: Data of mean values for Protozoa and Helminths for each collection source

Stations		cyst/L			Oocyst/L	egg/L				
		B. coli	E. histolytica	G. lamblia	C. pavum	A. lumbricoides	F. hepatica	T. cati	H. nana	D. latum
UPW1	Min-Max	0-8	0-6	0	0	0	0	0	0	0
	Mean ± σ	1.25 ± 0.99	2.5 ± 0.84	0	0	0	0	0	0	0
UPW2	Min-Max	0-8	0-4	0	0	0	0	0	0	0
	Mean ± σ	1.875 ± 1.076	0.5 ± 0.5	0	0	0	0	0	0	0
UPSP1	Min-Max	0-8	0-10	0	0	0	0	0	0	0
	Mean ± σ	2 ± 1.07	3.875 ± 1.59	0	0	0	0	0	0	0
UPSP2	Min-Max	0-8	0-4	0	0	0	0	0	0	0
	Mean ± σ	2.25 ± 1.16	0.5± 0.5	0	0	0	0	0	0	0
NKW1	Min-Max	0	0-5	0-2	0	0	0	0	0	0
	Mean ± σ	0	1 ± 0.681	0.75 ± 0.365	0	0	0	0	0	0
NKW2	Min-Max	0	0-5	0	0	0	0	0	0	0
	Mean ± σ	0	0.625 ± 0.625	0	0	0	0	0	0	0
NKSP1	Min-Max	0	0-6	0	0	0	0	0	0	0
	Mean ± σ	0	2.625 ± 0.99	0	0	0.25 ± 0.16	0	0	0	0
NKSP2	Min-Max	0	0	0	0-2	0	0	0	0	0
	Mean ± σ	0		0	0.75 ± 0.36	0	0	0	0	0
NSW1	Min-Max	0	0	0	0	0	0	0	0	0
	Mean ± σ	0	0	0	0	1.5 ± 0.73	0	0	0	0
NSW2	Min-Max	0-2	0	0	0	0	0	0	0	0
	Mean ± σ	0.75 ± 0.365	0	0	0	0	0	0	0	0
NSSP 1	Min-Max	0	0-8	0	0-2	0-10	0-2	0	0-12	0-

	Mean ± σ	0	2.75 ± 1.36	0	0.5 ± 0.327	3.625 ± 1.44	0.5 ± 0.327	0	4.25 ± 2.085	0
NSSP 2	Min-Max	0	0	0	0	0	0	0	0	0
	Mean ± σ	0	0	0	0	0	0	0	0	0
MAW1	Min-Max	0-10	0-3	0-5	0	0	0	0	0	0-3
	Mean ± σ	1.25 ± 1.25	0.375 ± 0.375	2.625 ± 0.80	0	0	0	0	0	1.25 ± 0.5
MAW2	Min-Max	0-12	0-4	0	0	0-5	0	0-2	0	0
	Mean ± σ	3.875 ± 1.91	1 ± 0.654	0	0	0.875 ± 0.64	0	0.25 ± 0.25	0	0
MASP1	Min-Max	0-6	0	0	0-3	0-0	0-0	0	0	0
	Mean ± σ	1.125 ± .79	0	0	0.375 ± 0.375	0	0	0	0	0
MASP2	Min-Max	0-6	0-5	0	0-2	0	0	0-2	0	0
	Mean ± σ	3.875 ± 0.91	1.875 ± 0.79	0	0.5 ± 0.327	0	0	0.5 ± 0.32	0	0

III.1.3- Presentation of Protozoa organisms in different domestic water sources

Figure 49, presents the spatio-temporal variations of the average densities of Protozoa organisms, and figures 50 presents the percentage abundance of each protozoa organism general identified in drinking water sources.

The highest density of protozoans was recorded by *Entamoeba histolytica* which had 32 Cysts/L in UPSP1 source while UPSP2, UPW2, NST1 and MAW1 had low density of *Entamoeba histolytica*, *Balantidum coli* also had high density values in MAW2 and MASP2 (32 Cysts/L) in each source respectfully while NSW2 was the lowest (6 Cysts/L) then followed by MankSP1, MankW1 and UPW1 (8, 10, 10 Cysts/L respectively), NKW1, UPW2 and UPSP2 densities for *B coli* were relatively high (17, 16, 16 Cysts/L respectively).

Balantidum coli also had high density values in MW2 and MASP2 (32 Cysts/L) in each source respectfully while NSW2 was the lowest (6 Cysts/L) then followed by MASP1, MAW1 and UPW1 (8, 10, 10 Cysts/L respectively), NKW1, UPW2 and UPSP2 densities for *B coli* were relatively high (17, 16, 16 Cysts/L respectively), MankW1 and NSW1 sources recorded relatively high densities (21 and 19 Cysts/L respectively) for *Gardia lambia*, while NKW1 had low density as 6 cyst/litre for *G, lambia,* NKSP2, NSSP1, MASP2, MASP1 (6, 4, 4, 3 Cysts/L respectively)

generally recorded low densities for *Cryptosporidium parvum*, Low density (7 Cysts/l) for Nematode larvae was nocticed MASP2.

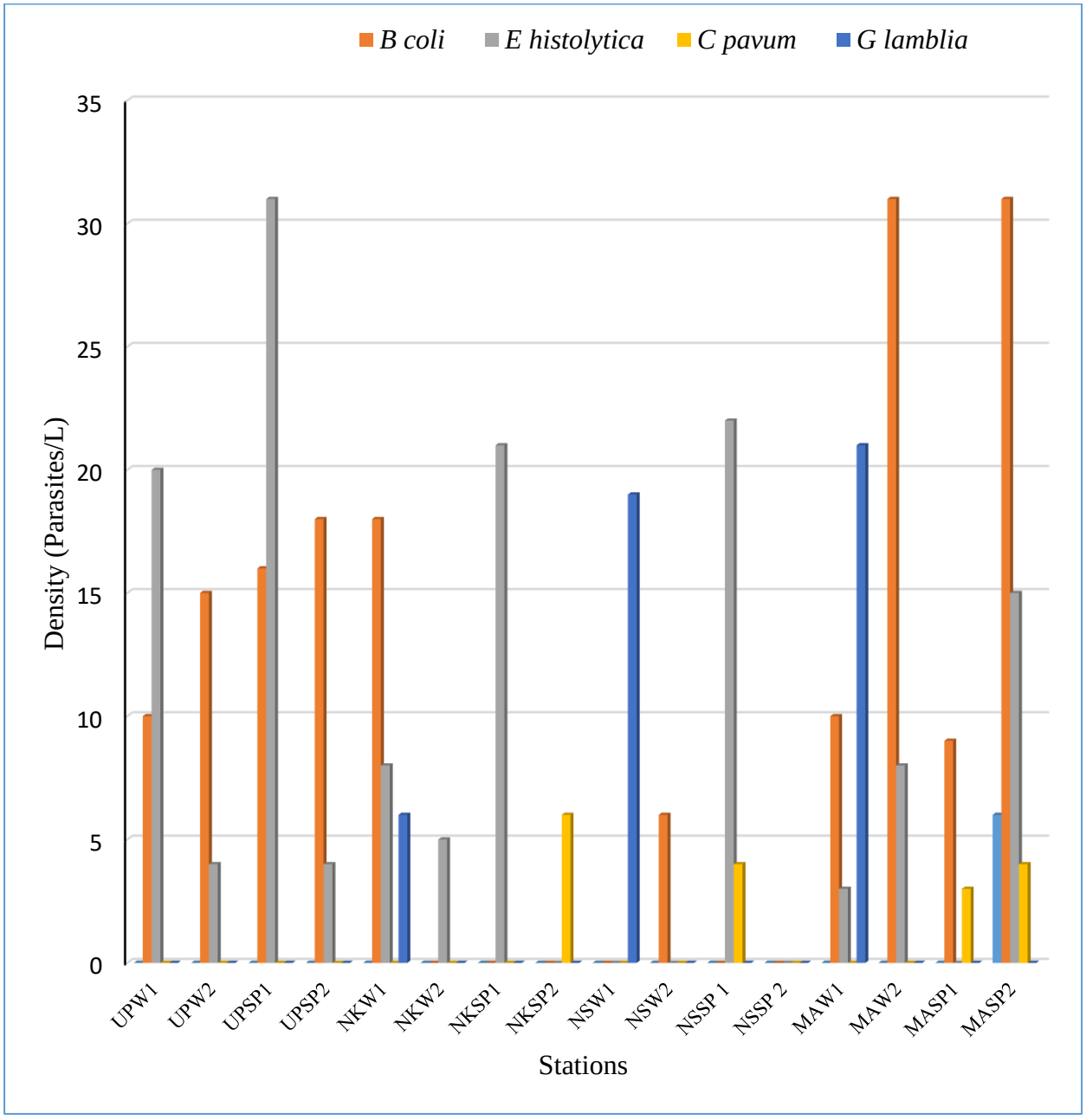


Figure 49: Spatio-temporal variations of the average densities of Protozoa

The highest density of protozoans was recorded by *Entamoeba histolytica* which had 34 Cysts/L in UPSP1 in Febrauary followed by *Balantidum coli* (32 Cysts/L) and (25 Cysts/L) in December and (27 Cysts/L) in March of dry season. In rainy season *Entamoeba histolytica* density was (23Cysts/L) in June, (17 Cysts/L) in May and (16 Cysts/L) in april while *Balantidum coli* (20

Cysts/L) in May and (19 Cysts/L) in April. The rest of the other protozoa densities were generally low in both seasons.

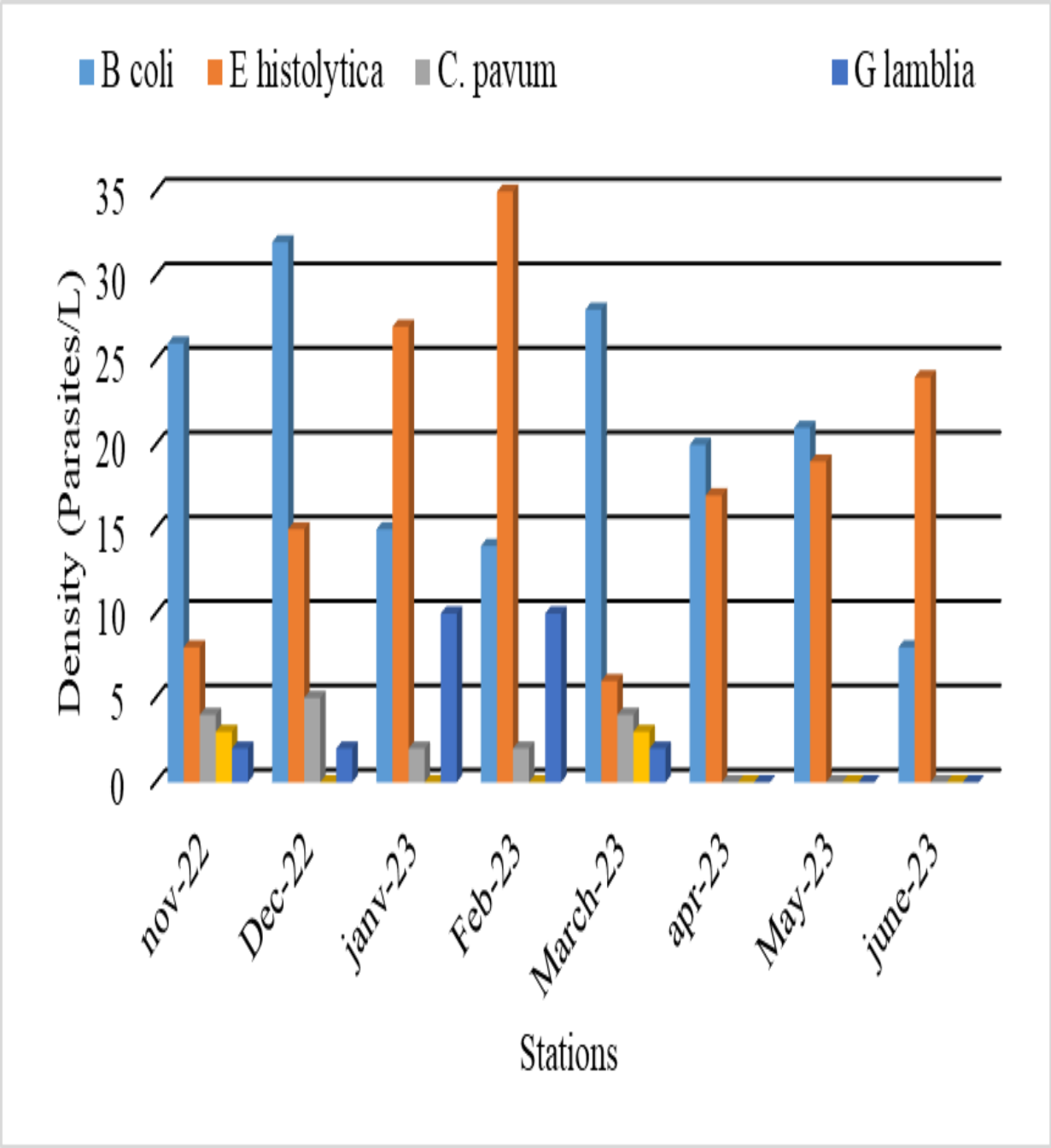
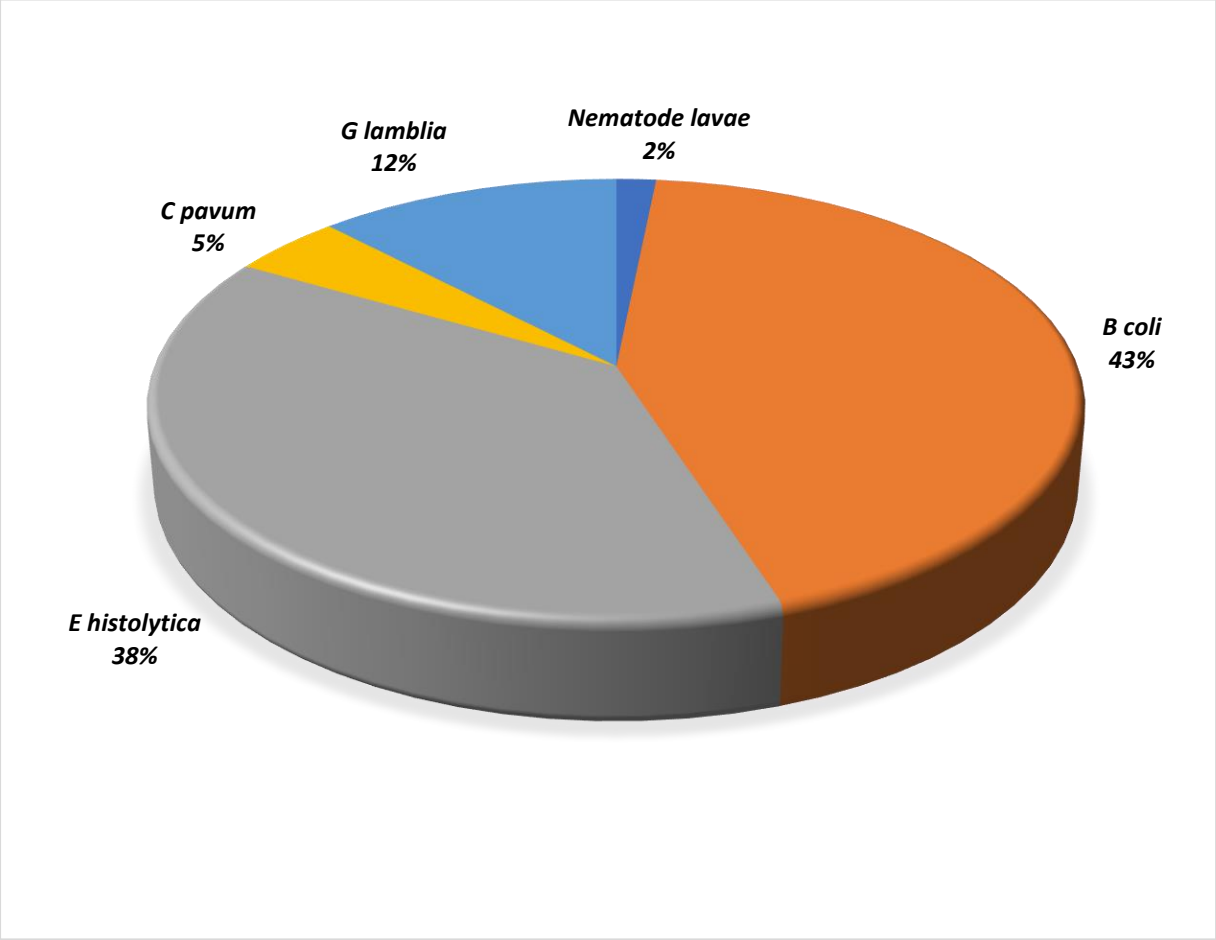


Figure 50: Spatio-temporal monthly variations of the average densities of Protozoa

With respect to percentage relative abundance of protozoa in various drinking water sources, *Balantidium coli* (43%) was the most abundant and then followed by *Entamoeba*

histolytica (38%), low percentages were recorded in *Gardia lamblia* (12%), *Cryptosporidium parvum* (5%) and *Nematode larvae* (2%), This is represented in the Pie chart in figures 51 below.



Figures 51: Relative abundance of protozoa species and Nematode larvae

III.1.4- Presentation of Helminthic organisms in different drinking water sources,

Figures 52, presents the spatio variations of the average densities of Helminthic organism, and figures 53 presents the temporal variations and 54 presents the percentage abundance of each Helminthic organism general identified in drinking water sources.

The highest density of Helminths was for *Hymenolepis nana* (34 Eggs/L) and was only identified in NSSP1, *Ascaris lumbricoides* density of eggs was relatively high in NSSP1 (28 Eggs/L) and low densities in NKT1 (14 Eggs/L), NSW1 (12 Eggs/L), MAW2 (7 Eggs/L) and NST2 (6 Eggs/L) for *Ascaris lumbricoides*, *Toxocara cati* abundance was very low in MankW2 (3 Eggs/L) and MankSP2 (4 Eggs/L) respectively, *Diphyllobothrium latum* abundance was only

recorded in MAW1 (10 Eggs/L) and it was low, *Fasciola hepatica* abundance was very low in NSSP1 (3 Eggs/L), *Tenia saginata* abundance was very low in NST2 (6 Eggs/L), *Schistosoma hematobium* abundance was very low in NKSP1 (2 Eggs/L).

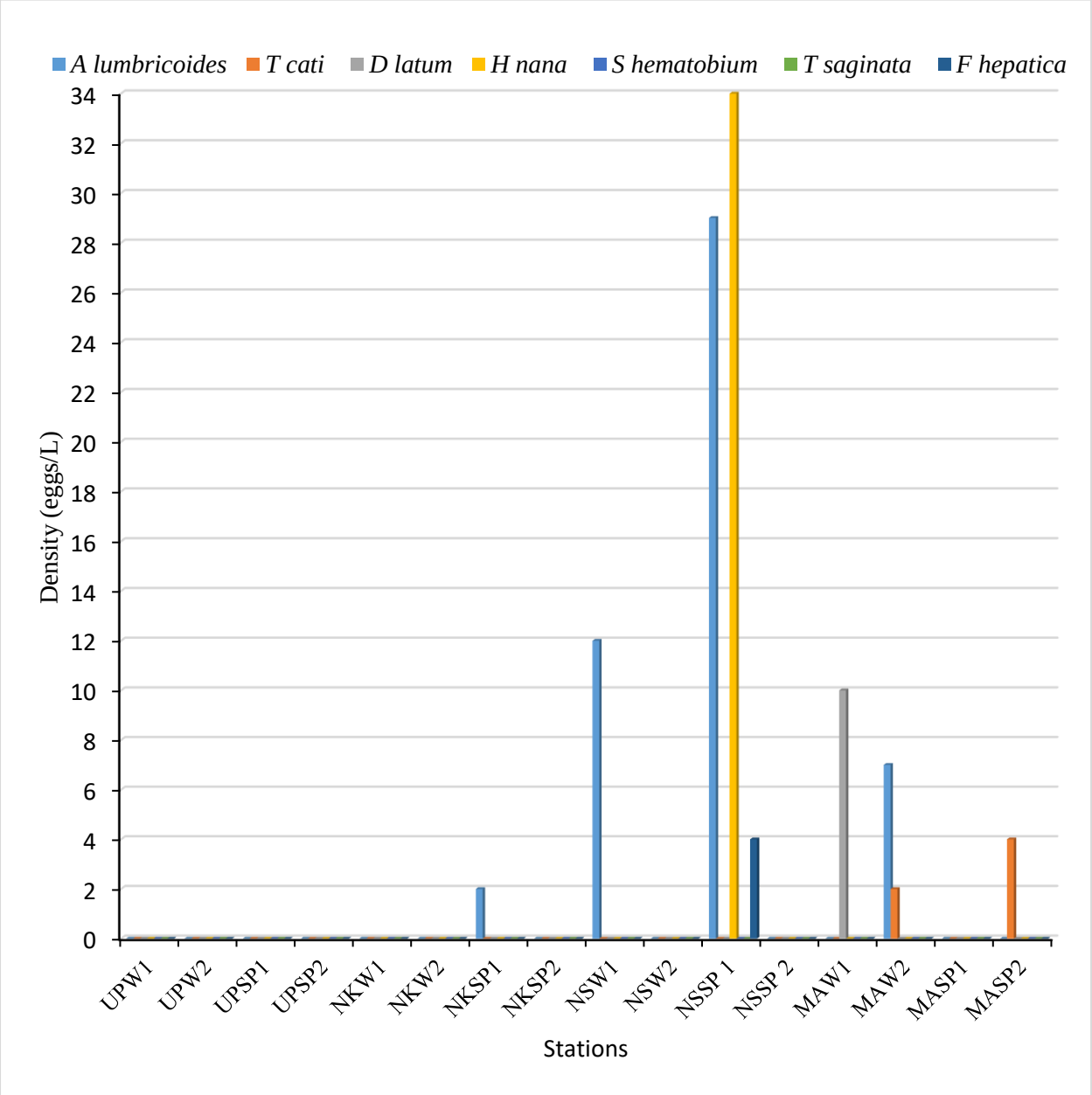


Figure 52: Spatial variations of the average densities of Helminths species

Highest densities were recored for *Hymenolepis nana* in December and November, for *Ascaris lumbricoides* in December and November respectively in dry season period, The other helmints had low densities in dry season, The rates were lower in rainy season where *Schistosoma*

hematobium, Ascaris lumbricoides and *Toxocara cati* were the only organism identified.

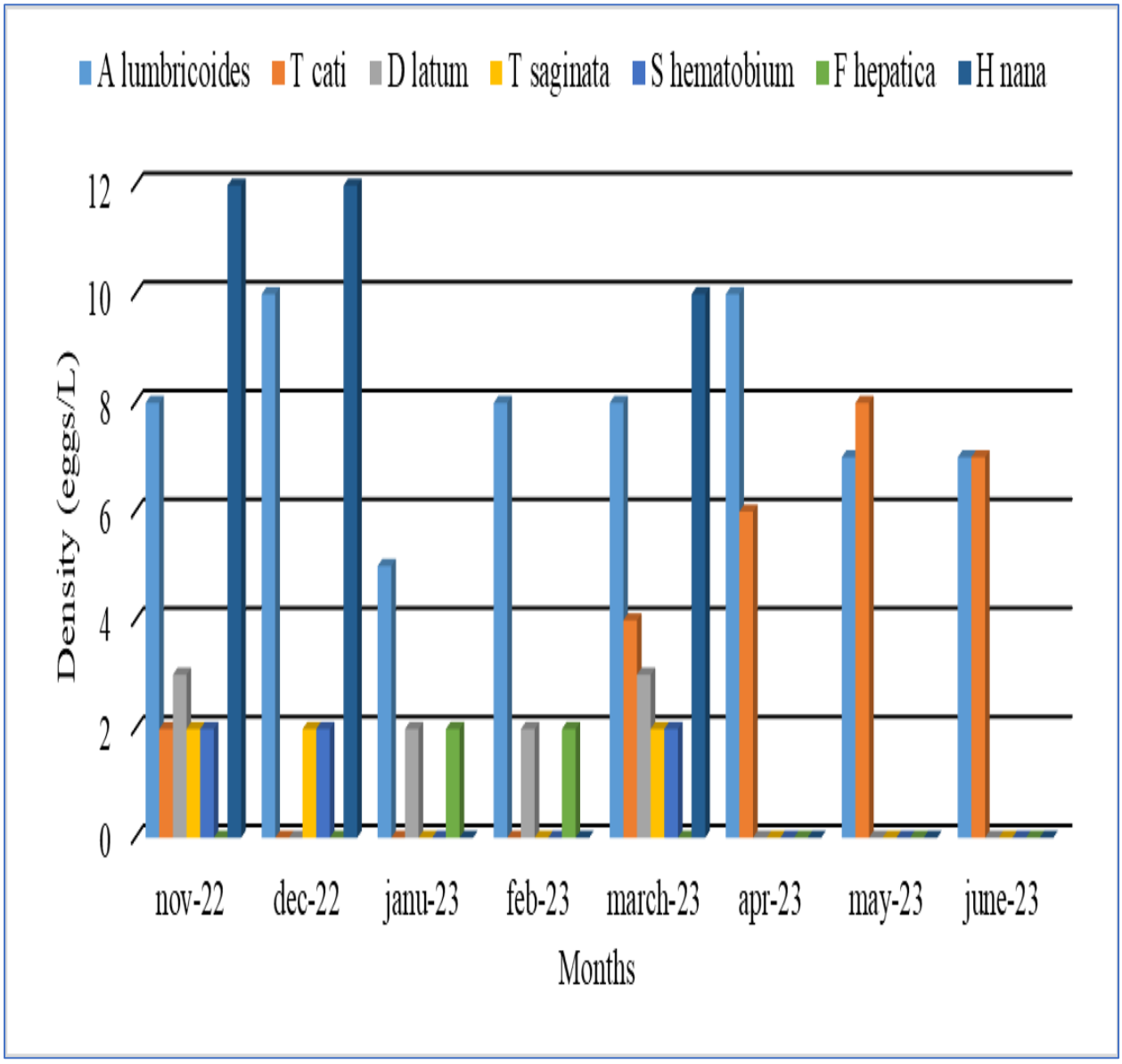
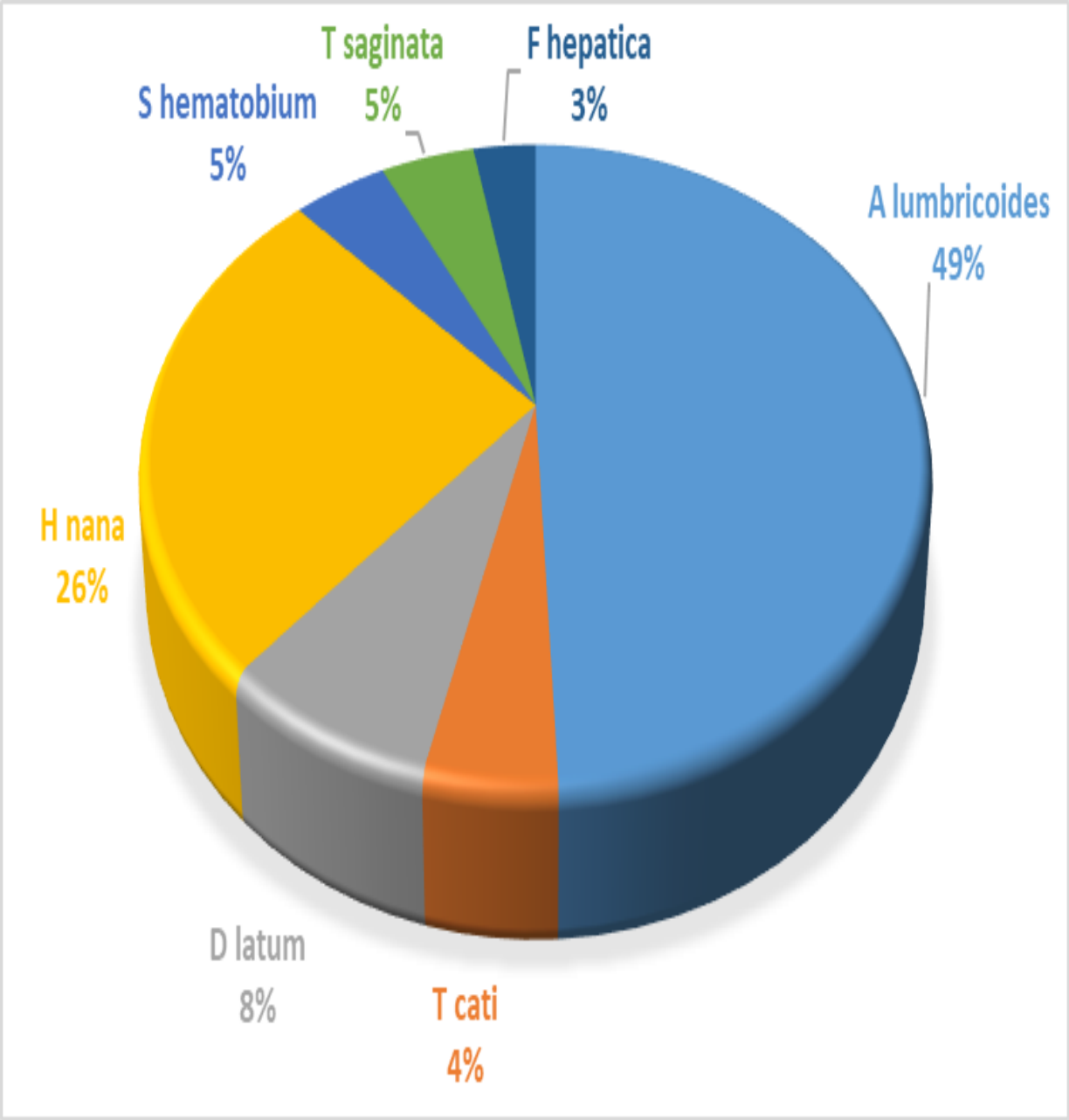


Figure 53: Temporal monthly variations of the average densities of Helminths species in all sample stations in Bamenda and its environs.

With respect to percentage relative abundance of Helminthic organisms in various drinking water sources, *Ascaris lumbricoides* (49%) was the most abundant and then followed by *Hymenolepis nana* (26%), Low percentages were recorded in *Diphyllobothrium latum* (8%), *Schistosoma hematobium* (5%), *Tenia saginata* (5%), *Toxocara cati* (4%) and *Fasciola hepatica* (3%), This is represented in the Pie chart in figures 54 below.



Figures 54: Relative abundance of Helminths species

A Principal Component Analysis (PCA) was carried out to determine the biological parameters (Protozoa and Helminthes) which characterize the different stations sampling or groups of stations. In intestinal protozoa (Figure 55), the PCA showed a grouping between the abiotic parameters and the densities of parasites on the first two factorial axes F1 (24,56%) and F2 (20,73%) accumulating 45,29%. On the dispersion diagram of the variables, the F1 axis discriminates in its positive part the physicochemical parameters such as temperature, MES,

conductivity electrical, total dissolved solids, nitrogen forms, turbidity and Sarcocystis species hominis, IPO, resistivity, dissolved oxygen and *Giardia* sp, are correlated negatively to the F1 axis, Species such as *Entamoeba histolytica*, *Balantidium coli,* and *Cryptosporidium spp* are positively correlated between them and to axis F2. The factorial map which presents a distribution of sampling stations relative to their physicochemical characteristics and the densities of the Protozoa defined in F1, is characterized by high densities of Protozoa and by waters rich in MES, dissolved CO2 and turbidity, Group 2 smaplying stations, constituted characterized by values high IPO, dissolved oxygen, resistivity and high densities of Giardia lambia, Stations such as MAW1, MAW2 and MASP2, characterized by values high abiotic parameters such as temperature, color, total dissolved solids, orthophosphates had low densities of Protozoa.

Principal Component Analysis (PCA) carried out in enteric helminths (Figure 55) showed dispersion diagram of the variables in the F1 axis discriminates in its positive part the physicochemical parameters such as temperature, pH, alkalinity and forms of nitrogen, The high egg densities of *Fasciola hepatica*, *Hymenolepis sp,* and *Taenia signata* are positively correlated ($P \leq 0.05$) with dissolved oxygen and resistivity, and negatively with the F1 axis, The eggs of Ascaris lumbricoides are positively correlated with the F2 axis, In the negative part of the F2 axis, found the Organic Pollution Index (OPI) and *Diphyllobothrium latum* eggs linked, The factor map defined 4 large groups of samples relative to their physicochemical characteristics and the densities of enteric helminth eggs and larvae, Group 1 is made up of MASP1, MAW2, UPW1, MASP2 and UPSP2 sampling stations, were characterized by well-oxygenated waters, high resistivity values, high densities of *Toxocara cati***.**

The group 2, made is made up of Nkwen tap1, Nsongwa tap1, Nsongwa well 1, Nsongwa Spring2, Nsongwa tap2 and Nkwen tap2, was having high densities eggs of *Schistosoma haematobium*, and *Tenia Saginata*, and large values of IPO and orthophosphates. The Mankon well 1, Upstation spring 2, Nsongwa well 2, Upstation tap2, and Nkwen well 1 characterized by low densities of helminth eggs and larvae enteropathogens and high values of physicochemical parameters such as temperature, dissolved CO_2, salinity and electrical conductivity form group 3, Group 4 concist if Nkwen spring 1, Nkwen spring 2, and Upstation tap2 characterised by Ascaris *lumbricoides, Fasciola hepatica,* and *Hymenolepis* sp. The physicochemical parameters such as oxydizability, color and forms of nitrogen were realated to high eggs densities for these parasites.

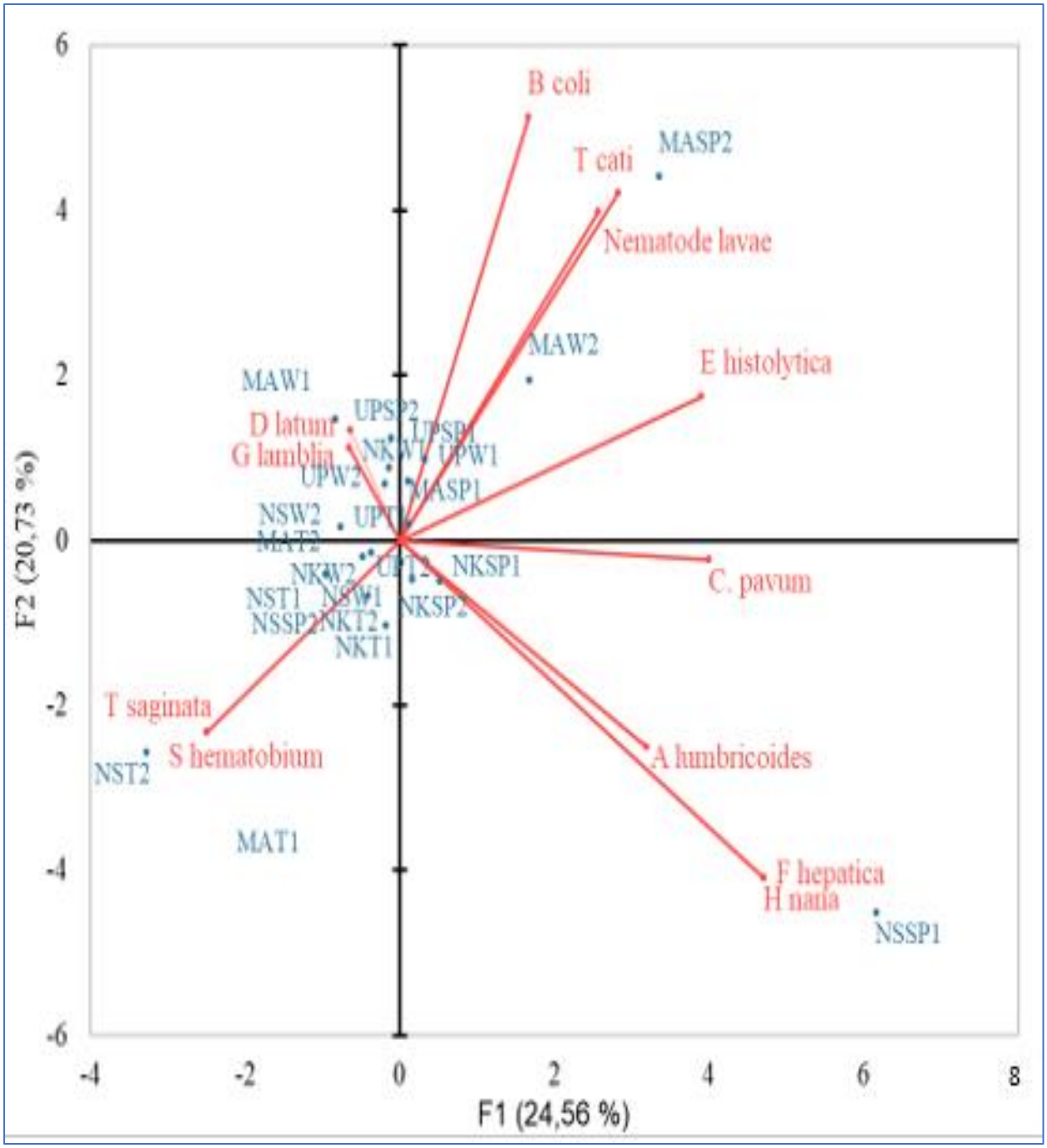


Figure 55: Principal Component Analysis (PCA) carried out from densities of enteropathogenic protozoa and Helminths

Hierarchical Classification Analysis (ACH) was carried out based on the results of the physicochemical parameters and densities of intestinal parasites in order to group these data according to their similarities and represent them in the form of a classification tree hierarchical (Figures 56). In intestinal protozoa, Hierarchical Classification Analysis (CHA) has defined 2

major classes, Class 1, is made up of the MAW2, NSW1, MAW2, NKSP1, UPW2, UPSP2, UPW1, and UPSP1 and presents 90 percent similarity with NSSP2, MAT2, MAT2, NKT1, NKW2, MASP1 and MASP2, While class 2 is NSSP1, Group class 2 showed with high densities of Protozoan cysts and intestinal oocysts; while class I stations show low densities of these parasites.

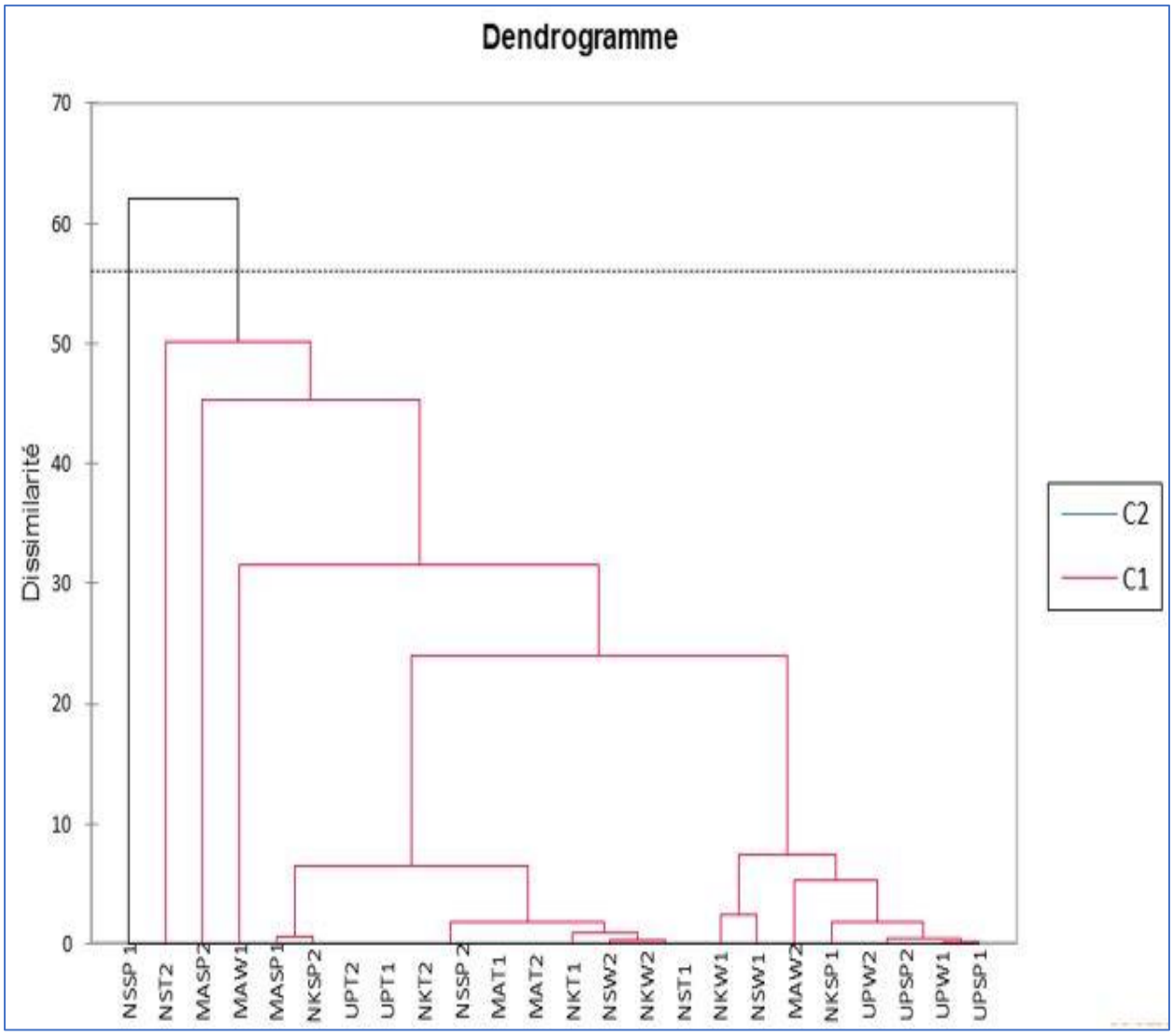


Figure 56: Hierarchical Classification Analysis (ACH) for densities of Protozoa and Helminths

The risk level of contamination of these domestic water sources escially for the well and springs, many scenarios were considered to evaluate the sanitation indices. Table XXIX belows shows that 8 stations (UPSP2, NKW2, NSW2, NSSP1, MAW1, MAW2, MASP1, MASP2) have poor quality of water and 16 stations having high quality of water.

Table XXIX: Risk level of contamination of structures according to scenarios showing the Sanitation indices (SI) gradings in domestic water sources

Factors	READ	ST	GH	RP	IR	D,C,	CS	H,W,	W,Q,	W,T,	SP	THERE	WTS	NWTS	RCS
weights	4	2	3	5	4	1	3	3	3	2	3	2			
UPT1	3	1	1	1	2	1	1	1	5	4	1	1	65	35.29	
UPT2	4	1	1	1	2	1	1	1	5	4	1	1	61	30.59	
UPW1	2	2	1	2	3	1	3	2	3	3	2	1	64	34.12	
UPW2	1	1	1	2	2	1	3	2	2	3	2	1	55	23.53	
UPSP1	2	1	1	1	1	2	3	2	3	4	3	1	63	32.94	
UPSP2	3	1	1	2	2	2	3	2	3	4	3	1	72	43.53	
NKT1	3	1	1	1	2	1	2	1	4	4	2	1	60	29.41	
NKT2	2	1	1	2	2	1	2	1	4	4	2	1	61	30.59	
NKW1	2	1	1	2	2	1	2	4	3	3	3	1	68	38.82	
NKW2	1	2	1	2	2	1	4	4	3	3	3	1	72	43.53	
NKSP1	1	1	1	1	2	0	4	3	4	3	2	1	61	30.59	
NKSP2	2	1	1	2	2	1	3	1	3	3	3	1	62	31.76	
NST1	2	2	1	1	2	0	2	4	4	4	1	1	63	32.94	
NST2	3	2	1	1	2	1	2	4	4	4	1	1	68	38.82	
NSW1	3	2	1	2	2	1	1	1	3	2	1	1	54	22.35	
NSW2	1	2	1	2	2	2	4	4	3	3	2	1	70	41.18	
NSSP1	2	3	1	2	2	3	4	4	3	4	3	1	82	55.29	
NSSP2	1	1	1	2	2	1	3	1	4	4	1	2	59	28.24	
MAT1	2	1	1	1	2	0	3	3	4	4	2	1	64	34.12	
MAT2	1	1	1	1	2	1	2	3	4	4	1	2	57	25.88	
MAW1	4	2	1	2	3	2	2	3	3	3	2	2	75	47.06	
MAW2	3	1	1	2	3	2	3	3	3	2	4	2	76	48.24	
MASP1	2	1	1	2	2	3	4	4	4	3	3	1	79	51.76	
MASP2	2	2	1	1	2	2	4	4	3	3	3	2	74	45.88	

Risk level of contamination of structures (NWTS or RCS)					
	VERY LOW [0-20[%	**LOW [20-40[%**	**POOR [40-60[%**	HIGH **[60-80[%**	VERY HIGH **[80-100[%**
Sanitation index (IS_I ; I $_S$ = 1/NWTS x100	**VERY HIGH** (I_S >5)	**HIGH** (2.5<I_S ≤5)	**POOR** (1.7<I_S ≤2.5)	**LOW** (1.25<I_S ≤1.7)	**VERY LOW** (1.25<I_S)

Legend: LU = Land use; **ST** = Septic tanks; **GH** = Geology / hydrogeology; **RP** = Rapid by pass of the unsaturated zone of the aquifer; **IR** = Induced recharge from surface water; **DC** = Drainage of the catchment site; **CS** = Condition of structure; **HW** = Head of the well / or springs;

WC = Water quality; **WT** = Water treatment; **SP** = Sources of pollution; **LA** = Level of Anthropization; **WTS** =Weighted Total Scores; NWTS = Normalized Weighted Total Scores and **RCS** = Risk level of Contamination of Structure (**CR**= Contamination Risk).

111.1.5- Correlations between the physicochemical and parasitic organsims (Protozoa and Helminths) in tap, well and spring water sources in Bamenda

The general correlation table analysed for all the water sources (tap, well and spring waters) in Bamenda and its environs shows a lot of variations at ($P < 0,01$) and also ($P < 0,05$). Positive correlation between electric conductivity and, Nematode larvae (0,097), *Balantidium coli* (0,115), *Toxocara cati* (0,046), *Diphyllobothrium latum* (0,006), *Cryptosporidium parvum* (0,064), *Gardia lamblia* (0,149) , with *Fasciola hepatica* (0,125). A positive correlation was also recorded between Ammonium (NH_4^{2+}) and Nematode larvae (0,008), *Ascaris lumbricoides* (0,055), *Balantidium coli* (0,102), *Entamoeba histolytica* (0,046), *Gardia lamblia* (0,149), *Hymenolepis nana* (0,024), *Schistosoma hematobium* (0,004) and *Tenia saginata* (0,004), A positive correlation was also recorded between total dissolved solutes and *Nematode larva* (0,100), *Ascaris lumbricoides* (0,028), *Balantidium coli* (0,020), *Toxocara cati* (0,122), *Diphyllobothrium latum* (0,010), *Cryptosporidium parvum* (0,113), *Gardia lamblia* (0,085), with *Fasciola hepatica* (0,020), A positive correlation was also recorded between orthophosphates (PO_4) and Nematode larvae (0,088), *Ascaris lumbricoides* (0,028), *Toxocara cati* (0,068), *Diphyllobothrium latum* (0,047), *Cryptosporidium parvum* (0,054), *Gardia lamblia* (0,029), *Fasciola hepatica* (0,095) with *Hymenolepis nana* (0,000), Total dissolved solutes and ionic compounds concentration like ammonium salts and orthophophates are related to to electric conductivity and they all for basis or good medium for subtances for metabolic activities for parasites.

Positive correlation were obtained between Turbidity and Nematode larvae (0,049), *Ascaris lumbricoides* (0,020), *Balantidium coli* (0,032), *Toxocara cati* (0,028), *Diphyllobothrium latum* (0,031), *Cryptosporidium parvum* (0,008), *Gardia lamblia* (0,175), with *Fasciola hepatica* (0,005), Positive correlation between colour and Nematode larvae (0,162), *Ascaris lumbricoides* (0,130), *Balantidium coli* (0,177), *Entamoeba histolytica* (0,058), *Toxocara cati* (0,084),

Cryptosporidium parvum (0,121), *Gardia lamblia* (0,041), *Fasciola hepatica* (0,027) with *Hymenolepis nana* (0,006). Positive correlation was recorded between Organic pollution Index and *Entamoeba histolytica* (0,039), *Diphyllobothrium latum* (0,016), *Cryptosporidium parvum* (0,019), *Schistosoma hematobium* (0,012) with *Tenia saginata* (0,012). Positive correlation between temperature and Nematode larvae (0,082), *Balantidium coli* (0,069), *Entamoeba histolytica* (0,052), *Gardia lamblia* (0,061), *Schistosoma hematobium* (0,069) with *Tenia saginata* (0,069), Organoleptic properties like colour, pH, Turbidity and temperature are also directly proportional to oxydability which has effects on the ambiant envirinment of the medium on which parasites can survive thus reason for the corelation of these parameters to parasitic content in water sources.

Positive correlation were obtained between NO_3 and Nematode larvae (0,071), *Balantidium coli* (0,047), *Entamoeba histolytica* (0,009), *Toxocara cati* (0,109), *Diphyllobothrium latum* (0,034), *Gardia lamblia* (0,213), *Hymenolepis nana* (0,002), *Schistosoma hematobium* (0,045) with *Tenia saginata* (0,045), Positive correlation between Oxydability and *Ascaris lumbricoides* (0,008), *Entamoeba histolytica* (0,085) with *Gardia lamblia* (0,007), Positive correlation between CO_2 and *Balantidium coli* (0,015), *Entamoeba histolytica* (0,052), *Entamoeba histolytica* (0,085), *Toxocara cati* (0,038), *Cryptosporidium parvum* (0,113), *Schistosoma hematobium* (0,033) with *Tenia saginata* (0,033), Positive correlation between alkalinity and *Balantidium coli* (0,069), *Toxocara cati* (0,086), *Diphyllobothrium latum* (0,064), *Cryptosporidium parvum* (0,005), with *Gardia lamblia* (0,061). The nitrate content and oxydability melieu also determine the alkalinity of a mileiu and thus they make confortable surviaval conditions for most parasites especially *Ascaris lumbricoides.* While the others showed negative correlation-ship amongst the physicochemical parameters and parasitic organisms. Most of these parasitic organisms be them protozoa or Helminths needs particular aboatic and or chemical composition in any milieu for their survival and these include dissolved oxygen environment, suspended solids and nitrites which they need to serve as food materials and growth conditions for their survival. Most of the abiotic parameters showing the correlation with the parasites were chemical paramaters than physical parameters. These details are below in Table XXVI

Table XXVI: General correlations between the physicochemical variables and organisms (Protozoa and Helminths)

	DO	pH	MES	NO_2	CE	NH_4	TDS	PO_4	Turb	Col	OPI	NO_3	Oxyd	CO_2	Temp	Alca
Nematode larvae	-.098	.068	.136	.033	.097	.008	.100	.088	.049	**0.162***	-.025	.071	-.016	-.019	.082	-.011
Ascaris lumbricoides	-.012	-.016	.031	.115	-.030	.055	.028	.028	.020	.130	-.089	**-0.183***	.008	-.014	-.037	-.124
Balantidium coli	**-0.151***	.062	.051	-.042	.027	.102	.020	-.016	.032	**0.177***	-.014	.047	-.092	.015	.069	.044
Entamoeba histolytica	.078	.044	-.002	.023	-.113	.034	-.101	**-0.162***	-.076	.058	.039	.009	.085	.052	**-0.158***	.038
Toxocara cati	**-0.146***	.055	.116	.046	.120	-.009	.122	.069	.028	.084	-.016	.109	-.081	.038	.086	-.055
Diphyllobothrium latum	-.057	-.076	.006	-.102	.038	-.003	.010	.047	.031	-.039	.016	.034	-.058	-.061	.064	-.127
Cryptosporidium parvum	-.067	**0.142***	.003	.064	.137	-.013	.113	.054	.008	.121	.019	-.001	-.096	.113	.005	-.023
Gardia lamblia	-.132	-.107	**0.166***	**0.149***	.088	.046	.085	.029	**0.175***	.041	**-0.149***	**0.213****	.007	-.047	.061	.057
Fasciola hepatica	-.013	-.010	.069	.125	.067	-.080	.020	.095	.005	.027	-.109	-.073	-.029	-.024	**-0.158***	-.007
Hymenolepis nana	**0.159***	.136	-.049	.038	-.121	.024	-.122	.000	-.074	.006	-.084	.002	-.067	-.008	-.138	**-0.154***
Schistosoma hematobium	.021	.083	-.065	-.100	-.029	.004	-.030	-.034	**-0.146***	-.009	.012	.045	-.022	.033	.096	-.089
Tenia saginata	.021	.083	-.065	-.100	-.029	.004	-.030	-.034	**-0.146***	-.009	.012	.045	-.022	.033	.096	-.089

Legend:

DO: Dissolved oxygen**, pH:** hydrogen concentration, **MES:** Suspended solid, **NO2:** Nitrites**, EC:** Electric conductivity, **NH_4:** Ammonium, **TDS:** Total dissolved solutes, **Alc:** alkalinity, **PO_4:** Orthophosphates, **Turb:** Turbidity, **Col:** Colour, **OPI:** Organic Pollution Index, **NO_3:** nitrates, **Oxyd:** Oxydability, **CO_2:** Carbondioxide, **Temp:** Temperature.

Most of the physico-chemical parameters have insignificant and or negative correlation with Helmths and protozoa organsims at ($P < 0.01$) and also ($P < 0.05$) for most parametrs in all the tap water samples. The only positive though insignificant correlations existed bewteen *A. lumbricoides* and abiotic parameters as (Electric conductivity (0.577), Carbondioxide (0.577), oxydability (0.247), alkalinity (0.577), and Organic polution index. *Entameoba histolytica* was

also correlated to oxydabilty (0.412) while the other organism identified in theses tap waters cources revealed a negative and insignifant correlationship with physico-chemical parameter as seen in Table XXVII.

Table XXVII: Correlations between the physico-chemical and (Protozoa and Helminths) in " tap" waters in Bamenda and its environs.

	A. lumbroides	*E. histolytica*	*S. haematobium*	*T. saginata*
Temperature	0.082	-0.577	0.247	0.247
Suspended Solods	0.082	-0.412	-0.082	-0.082
Turbidity	0.082	-0.577	-0.412	-0.412
Colour	0.082	-0.247	0.247	0.247
Total Dissolved Solutes	0.577	-0.577	-0.082	-0.082
pH	-0.412	0.412	-0.082	-0.082
Electric Conductivity	0.577	-0.082	-0.247	-0.247
NO_3^-	0.082	-0.577	-0.082	-0.082
NO_2^-	0.082	0.412	-0.082	-0.082
NH_4^+	-0.247	0.082	0.412	0.412
PO_4^{3-}	-0.082	-0.247	-0.577	-0.577
Dissolved oxygen	-0.412	0.247	-0.577	-0.577
CO_2	0.577	-0.082	0.247	0.247
Oxydability	0.247	0.412	0.082	0.082
Alkalinity	0.577	-0.412	-0.247	-0.247
OPI	0.415	0.000	-0.415	-0.415

The correlation of abiotic parameters with that of biotic parameters in well water sources in Bamenda and its environs ranged form negative correlations noticed in most of these abiotic parameters with the parasites at ($P < 0.01$) and also ($P < 0,05$). The only striking significant relationship in these well waters was noticed only between *A. lumbricoides* and dissolved oxygen (0.764) and also between Turbidity and *G. lambia* (0.764) as seen in table XXVIII.

Table XXVIII: Correlations between the physico-chemical and (Protozoa and Helminths) in "Well" waters in Bamenda and its environs

	A. lumbricoides	*B. coli*	*Toxocara cati*	*D. latum*	*E. histolytica*	*G. lambia*
Temperature	0.094	-0.096	0.247	0,412	-0,072	0,327
Suspended solods	0.265	-0.145	0.082	-0,247	0,036	0,245
Turbidity	0.187	-0.241	-0.247	0,247	-0,265	**0,764***
Colour	-0.016	0.434	0.082	-0,247	-0,241	0,027
Total Dissolved solutes	-0.436	0.361	0.082	0,247	0,578	0,109
pH	0.203	-0.205	0.412	0,082	-0,337	-0,109
Electric conductivity	-0.436	0.289	0.082	0,247	0,518	0,109
NO_3^-	-0.016	0.181	0.082	0.247	0.265	0.436
NO_2^-	0.156	-0.265	-0.082	-0.412	-0.036	-0.136
NH_4^+	0.436	0.048	-0.082	-0.577	0.205	0.027
PO_4^{3-}	-0.592	-0.482	-0.577	0.412	0.108	0.218
Dissolved oxygen	**0.764***	0.337	0.412	-0.082	0.157	0.436
CO_2	0.483	0.000	0.412	0.082	-0.398	0.191
Oxydability	-0.031	-0.675	-0.577	0.082	-0.229	0.218
Alkalinity	-0.296	0.181	0.082	0.247	0.458	0.218
OPI	-0.080	0.420	0.423	0.592	0.407	0.084

The correlation of abiotic parameters with that of biotic parameters in "Spring" water sources in Bamenda and its environs ranged form negative correlations noticed in most of these abiotic parameters with the parasites at ($P < 0.01$) and also ($P < 0.05$). The only striking positive significant relationship in these "spring" waters was noticed only between *E, histolytica* and Colour

(0.732). A very negative significant correlation was also noticed between B. coli and Turbidity (-0.708) and also between C. parvum and Dissolved oxygen (-0.753) as seen in table XXIX below.

Table XXIX: Correlations between the physico-chemical and (Protozoa and Helminths) in "Spring" waters in Bamenda and its environs

	ALUM	BCOLI	TCATI	EHIST	CPAV	FHEP	HNANA
Temperature	-0.296	0.381	0.412	-0.317	0.434	-0.412	-0.412
Suspended solods	-0.165	-0.644	-0.581	-0.307	-0.006	0.000	0.000
Turbidity	-0.039	**-0.708***	-0.581	-0.196	-0.019	0.083	0.083
Colour	0.452	0.089	0.412	**0.732***	-0.268	0.082	0.082
Total Dissolved solutes	-0.296	0.127	0.412	-0.317	0.013	-0.412	-0.412
pH	0.592	-0.368	-0.082	0.293	0.230	0.247	0.247
Electric conductivity	-0.187	0.127	0.412	-0.220	0.013	-0.412	-0.412
NO_3^-	-0.452	0.419	0.577	-0.488	0.192	-0.082	-0.082
NO_2^-	0.436	-0.495	-0.247	0.512	0.192	0.577	0.577
NH_4^+	-0.405	0.507	0.577	-0.537	0.051	-0.412	-0.412
PO_4^{3-}	0.203	-0.089	0.247	0.098	-0.472	-0.082	-0.082
Dissolved oxygen	0.452	-0.342	-0.577	0.195	**-0.753***	0.082	0.082
CO_2	-0.156	-0.419	0.247	-0.659	0.319	-0.247	-0.247
Oxydability	0.296	-0.178	-0.412	0.512	0.243	0.412	0.412
Alkalinity	-0.047	0.127	0.412	-0.098	-0.026	-0.247	-0.247
OPI	-0.619	0.360	-0.170	-0.415	0.053	-0.595	-0.595

III.1.6- Principal Component Analysis of correlation between abiotic and biotic parameters

A Principal Component Analysis (PCA) was also performed to determine the correlation between the physico-chemical parameters or abiotic parameters with the biotic densities of Protozoa and Helminths (Figure 57). This showed positively correlated variation of the parameters both from one station to another and from one season to another. The factorial map which presents a distribution of the sampling stations relative to their physico-chemical characteristics and to the densities of Protozoa and Helminths has defined 3 large groups of samples (Figure 55). It showed clustering between the abiotic parameters and the densities of the parasites on the first two factorial axes F1 (16.87%) and F2 (2.77 %) cumulating 19.64%. On the scatterplot of variables, axis F1 discriminates in its positive part the physico-chemical parameters such as temperature, Suspended solids, conductivity, electricity, total dissolved solids, nitrogen forms, turbidity with parasites such

as Entamoeba histolytica, Hymenolepis nana, and *Fasciola hepatica* while ammonium salts and orthophosphates were correlated negavtively to the axis F1. Organic Pollution Index, temperature, ammonium salts and orthophosphates were positively correlated to *Balantidium coli, Cryptosporidium parvum, Gardia lamblia, Toxocara cati,* and *Diphyllobothrium latum* in F2 axis.

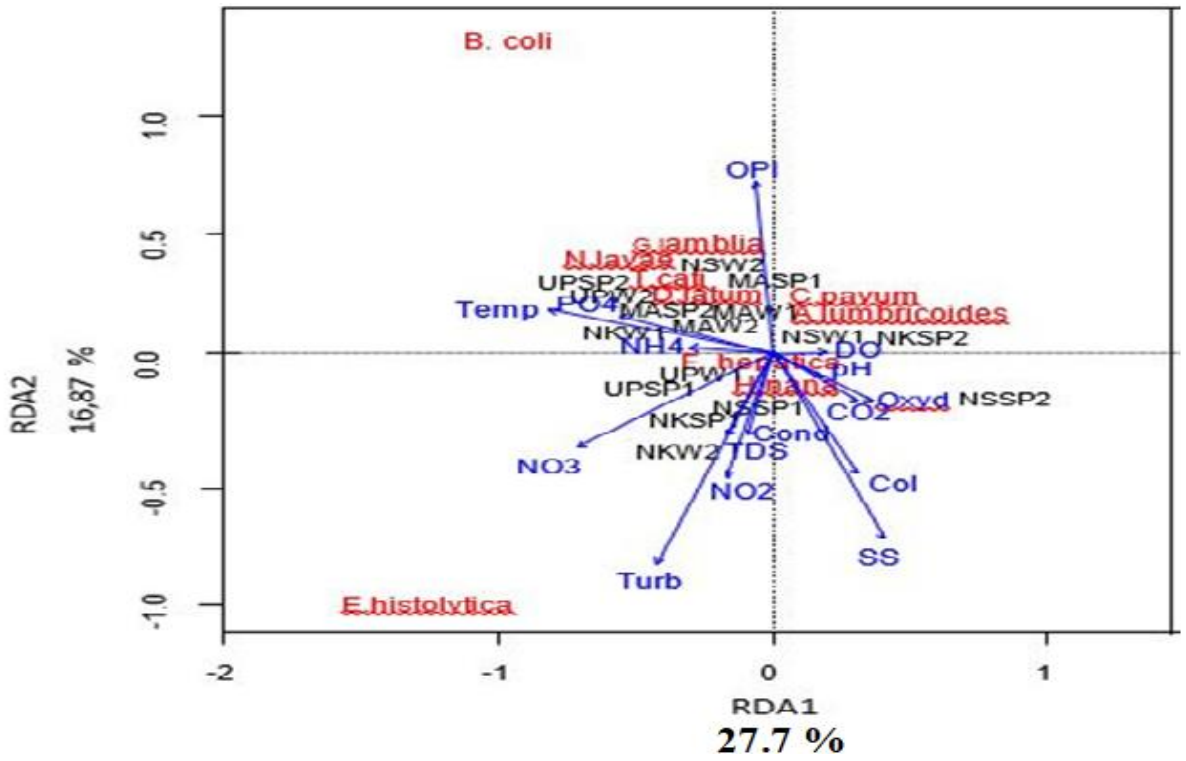


Figure 57: Principal Component Analysis (PCA) of physicochemical data and densities of enteropathogenic Protozoa and Helminths

III.1.7- Correlations between the different variables of parasites (Protozoa and Helminths).

There was positive correlations exist between Nematode larvae and *Balantidium coli* (0.250), *Toxocara cati* (0.814) with *Cryptosporidium parvum* (0.489). While there are instead negative correlation of Nematode larvae with the other organsims, *Ascaris lumbricoides* had a positive correlation only with *Cryptosporidium parvum* (0.124) and *Fasciola hepatica* (0.336). While the rest of the organisms instead had a negative correlation to *Ascaris lumbricoides,* Positive correlation was also noted between *Balantidium coli* and *Entamoeba histolytica* (0.091). *Toxocara cati* (0.187). *Cryptosporidium parvum* (0.137) and *Gardia lamblia* (0.121). While the rest of the organisms instead had a negative correlation to *Balantidium coli,* Positive correlation was also noted between *Entamoeba histolytica* and *Hymenolepis nana* (0.331). While the rest of the

organisms instead had a negative correlation to *Entamoeba histolytica* Positive correlation was between *Toxocara cati* and *Cryptosporidium parvum* (0.0392) while the other organism did not show any correlation, Positive correlation between *Diphyllobothrium latum* and *Gardia lamblia* (0.121) only while the others were negative, Positive correlation between *Cryptosporidium parvum* and *Fasciola hepatica* (0.489) was noted meanwhile the others showed negative correlation. The variations and appropraite relationships between the entheropathogenic for of parasites of Protozoa and Helminths is presented in Table Table XXX.

Table XXX: Correlations between the different variables of parasites (Protozoa and Helminths)

	Nematode arvae	*A. lumbricoide*	*B. coli*	*E. histolytica*	*T. cati*	*D.latum*	*C.parvum*	*G. lamblia*	*Fasciola hepatica*	*H. nana*	*S. hematobium*	*T. saginata*
Nematode larvae	1.000											
Ascaris lumbricoides	-.030	1.000										
Balantidium coli	**0.250****	-.002	1.000									
Entamoeba histolytica	-.044	-.020	.091	1.000								
Toxocara cati	**0.814****	-.037	**0.187****	-.054	1.000							
Diphyllobothrium latum	-.015	-.042	-.061	-.062	-.018	1.000						
Cryptosporidium parvum	**0.489****	.124	.137	-.089	**0.392****	-.030	1.000					
Gardia lamblia	-.028	-.078	.121	-.115	-.034	**0.261****	-.056	1.000				
Fasciola hepatica	-.011	**0.336****	-.043	-.044	-.013	-.015	**0.489***	-.028	1.000			
Hymenolepis nana	-.013	-.037	-.053	**0.331***	-.016	-.018	-.026	-.034	-.013	1.000		
Schistosoma hematobium	-.013	-.037	-.053	-.054	-.016	-.018	-.026	-.034	-.013	-.016		
Tenia saginata	-.013	-.037	-.053	-.054	-.016	-.018	-.026	-.034	-.013	-.016	**1.000****	1.000

III.1.8 - The Susceptible-Infection- Susceptible (SIS) SIS Model for estimataion of dissemination of parasitic waterborne pathogens in domestic water sources

In this case, an extension of the networked SIS model is done by adding a water compartment W by taking into consideration the different domestic water sources that was evaluated for enteropathogens, in which both person-person and person-water-person transmissions exist, and thus we call it the networked SIWS model. The way to model and interpret a networked SIS model is to regard each agent of gastroenteritis as a group of fully connected individuals and each agent's variable represents the proportion of infected individuals in the corresponding group of enteropathogenic otganisms. The variables take values between zero and one. Since we are interested in studying the epidemic spreading of a waterborne disease over multiple groups of individuals, the interpretation and its corresponding model derivation fits our purpose.

The main contributions of this model are three-fold. First, we propose a networked model for SIS-type waterborne diseases, called networked SIWS model, for a system consisting of multiple groups of individuals (Upstation, Nkwen, Nsongwa and Mnakon) with a shared water resource, Second, we obtain a sufficient condition for the healthy state to be globally asymptotically stable. Third, we compare the basic reproduction number per quarter of domestic water source of the networked SIWS model with that of the networked SIS model for non-waterborne diseases, and provide a set of simulations to demonstrate the behavior of the networked SIWS model differing from the networked SIS model.

III.1.9. Assumptions and Notation of modelling in Bamenda urban area

The population of Bamenda and its environs under consideration is divided into disjoint classes which change with time *t.* The susceptible class to gastrointestinal water borne infections consists of those individuals who can incur the disease but are not yet infective. The infective class consists of those who are transmitting the disease to others. The removed class consists of those who are removed from the susceptible-infective interaction by recovery with immunity, isolation, or death. The fractions of the total population in these classes are denoted by S(l), /(t) and R(t), respectively.

In the epidemiological models here, the following assumptions are made:

The population of Bamenda and its environs considered has constant size *N* which is sufficiently large so that the sizes of each class is considered as continuous variables. If the model is to include vital dynamics, then it is assumed that births and natural deaths occur at equal rates and that all newborns are susceptible.

1-Individuals are removed by death from each class at a rate proportional to the class size with proportionality constant μ which is called the daily death removal rate. This corresponds to a negative exponential age structure with an average lifetime of I/μ.

2. The population Bamenda and its environs is homogenously mixing. The daily contact rate λ, is the average number of adequate contacts per infective per day. An adequate contact of an infective is an interaction which results in infection of the other individual if he is susceptible. Thus the average number of susceptibles infected by an infective per day is λS, and the average number of susceptibles infected by the infective class with size *NI* per day in *Λsni*. The daily contact rate λ is fixed and does not vary seasonally. The type of direct or indirect contact adequate for transmission depends on the specific disease or reservoir characteristics of the causative agents. The number of cases per day $\lambda SN I$, which is called the incidence, is a mass action law since it involves the product of S and *I*.

3. Individuals recover and are removed from the infective class at a rate proportional to the number of infectives with proportionality constant y, called the daily recovery removal rate. The latent period is zero (it is defined as the period between the time of exposure and the time when infectiousness begins). Thus the proportion of individuals exposed (and immediately infective) at time t0 who are still infective at time t_0 +tis exp (- yt), and the average period of infectivity is l /y. The removal rate from the infective class by both recovery and death is y + μ so that the death-adjusted average period of infectivity is l/(y +μ).Thus the average number of adequate contacts (with both susceptibles and others) of an infective during the infectious period is α= λ/(y + μ), which is called the contact number (basic reproductive rate).

Since the average number of susceptibles infected by an infection during the infectious period is αS, the quantity αS is called the replacement number. Since recovery these water borne pathogens in Bamenda domestic water sources can easily propagate to affect uninfected individuals and the fact that there is little or no immunization of the population for these water borne pathogens, then the model is called an SIS model, since individuals move from the susceptible class (exposed to

biological and physico- chemical pollution or contaminating agents) to the infective class (those who ingested the contaminated water and or food to acquire the infection) and then back to the susceptible class upon recovery.

III.1.10. Scientific application of SIS model in dissemination of waterborne diseases

Consider an SIS type waterborne disease spreading over a network consisting of $n > 1$ groups of individuals, labeled 1 to n, and a water compartment shared among the n groups. The water compartment can be contaminated by infected individuals shedding the pathogen into it. We simulate the water compartment was a reservoir-like water system with homogeneous water quality, assuming instantaneous pathogen diffusion process in W. An individual may be infected either by contact with contaminated water or by contact with infected individuals only in its own and neighboring groups around the domestic water sources in Upstation, Nkwen, Nsomgwa and Mankon considered Neighbour relationships among the n groups are described by a directed graph G on n vertices with an arc (or a directed edge) from vertex j to vertex i whenever the individuals in group i can be infected by those in group j. Thus, the neighbour graph G has self-arcs at all n vertices, and the directions of arcs in G represent the directions of epidemic contagion. It is assumed that G is strongly connected. We also assume that each group has bi-directional connection with the water compartment, which implies that each group can contaminate the water if it has infected individuals, and the individuals in each group can in turn get infected by the water if it is contaminated. Let $I_i(t)$ and $S_i(t)$ respectively denote the number of infected and susceptible individuals in group i at time $t \geq 0$. We assume that the total number of individuals in each group i, denoted by N_i, does not change over time. In other words, $S_i(t) + I_i(t) = N_i$ for all $i \in [n]$ and $t \geq 0$, which implies that the birth and death rates for each group are equal. Such an assumption simplifies the model and has been adopted. We leave the relaxed, and more realistic, scenarios without this assumption as future work. Associate with each group i several parameters: curing rate γ_i , birth rate μ_i , death rate $\bar{\mu}_i$, person-to-person infection rates α_{ij} (with the understanding that $\alpha_{ij} > 0$ whenever group j is a neighbor of group i and $\alpha_{ij} = 0$ otherwise), and water-to-person infection rates α_{iw}, Since N_i is constant, there holds $\bar{\mu}_i = \mu_i$. We assume that individuals are susceptible at birth even if their parents are infected. The evolution of the numbers of infected and susceptible individuals in each quarter of Bamenda and its environs i is as follows: 360 for *Entamoeba histolytica*, 178 for *Balantidium coli*, 199 for *Gardia lamblia* and 210 *Cryptosporidium*

parvum for Protozoa infections while for Helminthic infections 218 for *Ascaris lumbricoides,* 219 for *Hymenolepis nana,* 192 for *Diphyllobothrium latum,* 178 for *Schistosoma haematobium,* 256 for *Tenia saginata,* 159 for *Toxocara cati and* 108 for *Fasciola hepatica.*

$$\begin{aligned}
\dot{S}_i(t) &= \mu_i N_i - \bar{\mu}_i S_i(t) + \gamma_i I_i(t) - \sum_{j=1}^{n} \alpha_{ij} \frac{S_i(t)}{N_i} I_j(t) \\
&\quad -\alpha_{iw} W(t) S_i(t) \\
&= (\mu_i + \gamma_i) I_i(t) - \sum_{j=1}^{n} \alpha_{ij} \frac{S_i(t)}{N_i} I_j(t) \\
&\quad -\alpha_{iw} W(t) S_i(t), \qquad (1) \\
\dot{I}_i(t) &= -\gamma_i I_i(t) - \bar{\mu}_i I_i(t) + \sum_{j=1}^{n} \alpha_{ij} \frac{S_i(t)}{N_i} I_j(t) \\
&\quad +\alpha_{iw} W(t) S_i(t) \\
&= (-\gamma_i - \mu_i) I_i(t) + \sum_{j=1}^{n} \alpha_{ij} \frac{S_i(t)}{N_i} I_j(t) \\
&\quad +\alpha_{iw} W(t) S_i(t), \qquad (2)
\end{aligned}$$

where $W(t)$ denotes the pathogen concentration in the water reservoir which evolves as

$$\dot{W}(t) = -\delta_w W(t) + \sum_{k=1}^{n} \zeta_k I_k(t) \qquad (3)$$

where δ_w denotes the decay rate of pathogen in the water, and ζ_k denotes the person to water contact rate of group k. Note that (1) and (2) implies that $\dot{S}_i(t) + \dot{I}_i(t) = 0$, which is consistent with the assumption that N_i is a constant.

To simplify the model and for the purpose of analysis, we change the variables of the model as follows. First, we denote the portion of infected individuals in each group i by $x_i(t)$, and thus.

$$x_i(t) = \frac{I_i(t)}{N_i}$$

Second, define a new variable as

$$z(t) = \frac{\delta_w}{\sum_{k=1}^{n} \zeta_k N_k} W(t),$$

which can be regarded as an index describing the waterborne pathogen concentration. Set the following parameters:

which can be regarded as an index describing the waterborne pathogen concentration. Set the following parameters:

$$\delta_i = \gamma_i + \mu_i, \quad \beta_{ij} = \alpha_{ij}\frac{N_j}{N_i}, \quad \beta_{iw} = \frac{\alpha_{iw}}{\delta_w}\sum_{k=1}^{n}\zeta_k N_k ,$$

Then, from (1) and (2), it follows that

$$\dot{x}_i(t) = -\delta_i x_i(t) + (1 - x_i(t))\left(\sum_{j=1}^{n}\beta_{ij}x_j(t) + \beta_{iw}z(t)\right) \quad (4)$$

To proceed, let

$$c_i = \frac{\zeta_i N_i}{\sum_{k=1}^{n}\zeta_k N_k}, \quad (5)$$

Then, from (3), it follows that

$$\dot{z}(t) = \delta_w\left(-z(t) + \sum_{k=1}^{n} c_k x_k(t)\right), \quad (6$$

We impose the following assumptions on the system parameters,

Study the following continuous-time networked system with specified initial conditions:

$$\dot{x}_i(t) = -\delta_i x_i(t) + (1 - x_i(t))\left(\sum_{j=1}^{n}\beta_{ij}x_j(t) + \beta_{iw}z(t)\right) \quad (7)$$

$x_i(0) \in [0,1], \quad i \in [n],$

$$z^{\cdot}(t) = \delta_w - z(t) + \sum_{k=1}^{n} c_k x_k(t), \quad z(0) \in [0,\infty), \qquad (8)$$

where δi, δw, βij, βiw, and ci are model parameters satisfying Assumption 1. The above n + 1 differential equations can be combined into one equation in a compact form. Toward this end, let x(t) be the state vector in IRn whose ith entry is xi(t), D be the n × n diagonal matrix whose ith diagonal entry is δi , B be the n × n matrix whose ijth entry is βij , X(t) be the n × n diagonal matrix whose ith diagonal entry is xi(t), b be the vector in IRn whose ith entry is βiw, and c be the vector in IRn whose ith entry is δwci. Then, from (7) and (8), it can be verified that:

$$x^{\cdot}(t) = (-D + B - X(t)B)x(t) + (I - X(t))bz(t), \quad (9)$$

$$z^{\cdot}(t) = -\delta_w z(t) + c^{>} x(t), \quad (10)$$

3.2.11 – Interpretation of the suited SIS model according to scenario in Bamenda

The chosen applicable SIS model with regards to study were presented in form of an illustration showing the twoway contamination scenarios where healthy individuals were susceptible to water borne enteropathogenic protozoa and Helminths when exposed to contaminated domestic water sources. While on the other hand, the infected individuals keep on contaminating other water bodies and making other members of the community vulnerable to waterborne infections as seen in illustration in figure 60.

Figure 58 : Schematic illustration of SIS model that was applicable for this study

Shaded circles represent activated individuals in each domestic water samplying point, Arrows mean the possibility of propagation of infections. If the nodes to which the arrows point are susceptible and the source nodes are infected, then the propagation of gastroenteritis due to enterpathogenic Helminths and protozoa occurs.

Table XXXI: Properties of SIS Model

Model	**Contacts**	**Active individual**	**Outbreak threshold**	**Equilibrium density of infected**
1a	all neighbors	sender	vanish	same as Epidemic Spreading in Scale-Free Networks,
1b	all neighbors	receiver	vanish	lower than Model 1a
1c	all neighbors	hybrid	vanish	intermediate of 1a and 1b
2a	one neighbor	sender	finite	lower than Model 2b
2b	one neighbor	receiver	finite	same as well-mixed case
2c	one neighbor	hybrid	vanish	

We have analyzed the spreading phenomena on scale-free networks using six SIS models with different contact and propagation mechanisms. Figure 59 **s**hows a decent match between theoretical predictions and numerical results, In Models 1a, b, c, the theory is not so accurate as in Models 2a, b, c. This is because the theory neglects the probability of an individual to re-infect the neighbor that had previously infected it (Parshani, 2010). This probability increases with the rate λ,

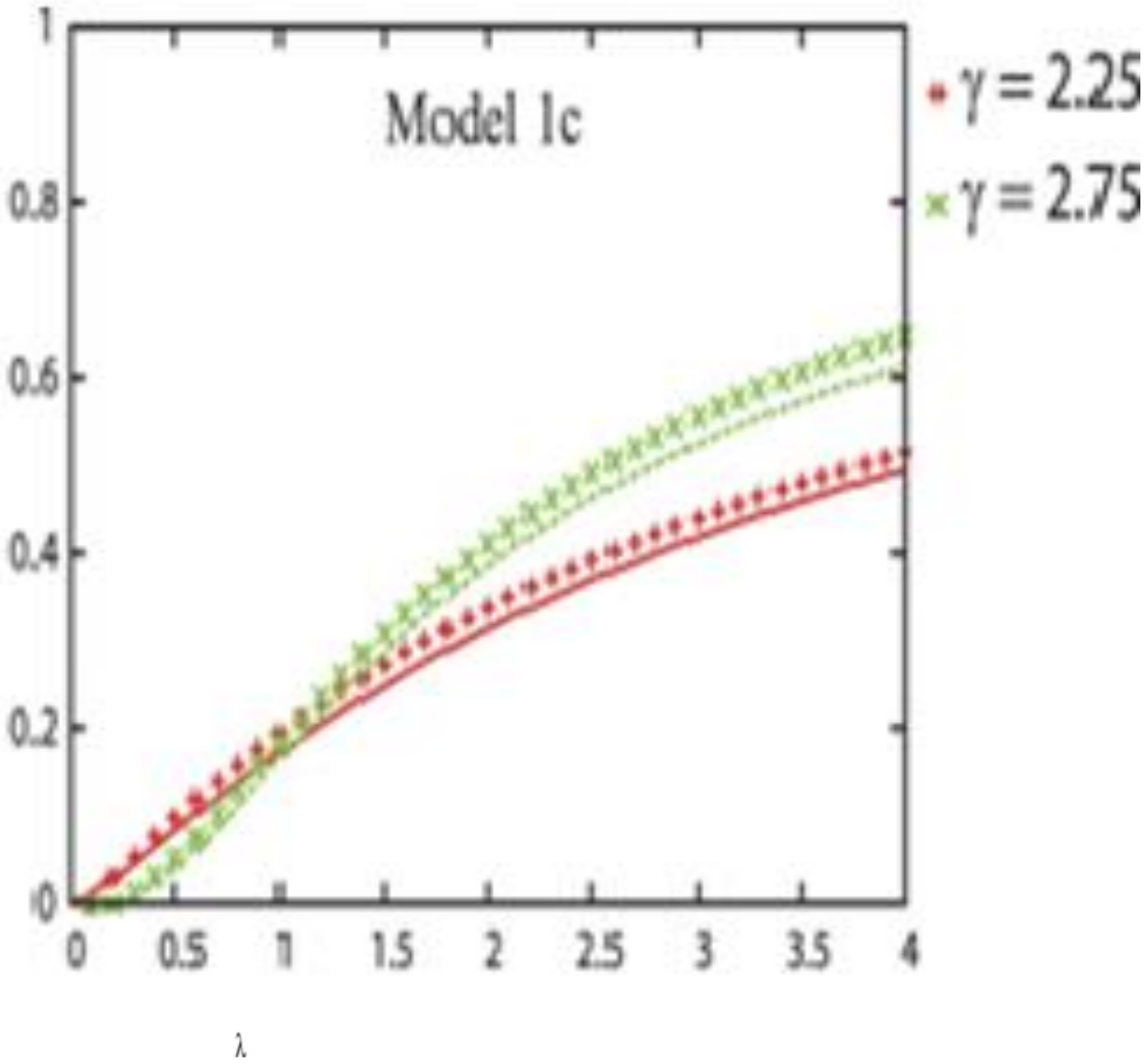


Figure 59: The density of infected individuals ρ* is plotted as a function of λ for the six different models, when γ is 2.25 (red) or 2.75 (green)

The curves show the theoretical predictions, while the crosses represent the numerical results, In the numerical simulations, the system size is set to N = 100000 and each point is obtained by averaging over 10000 unit time after 10000 relaxation time on 10 different network realizations, Error bars are smaller than the size of the data point symbols.

In this study, we formulated a model for water borne diseases using system of differential equations. We divided the human population into five compartments and took a sixth

compartment for pathogen population, Relation for basic reproduction number, R0, is established and disease-free equilibrium is analysed, Analysis result shows that the disease free equilibrium is locally asymptotically stable if R0<1. Sensitivity analysis is done using parametric values for typhoid. This tells us that the most crucial parameters which escalate disease spread are environment-to-person transmission rate and pathogen population. The parameters that have negative impact on the disease spread are pathogen death rate and the rate moving out from symptomatically infected class.

We have obtained the basic reproduction number for the networked model and shown that the healthy state is globally asymptotic for gastreoenteritis, stable if the number is less than or equal to one as reflected on the 360 for *Entamoeba histolytica*, 178 for *Balantidium coli*, 199 for *Gardia lamblia* and 210 *Cryptosporidium parvum* for Protozoa infections while for Helminthic infections 218 for *Ascaris lumbricoides,* 219 for *Hymenolepis nana,* 192 for *Diphyllobothrium latum,* 178 for *Schistosoma hematobium,* 256 for *Tenia saginata,* 159 for *Toxocara cati and* 108 for *Fasciola hepatica.*

Sensitivity analysis results indicate that contaminated environment is more responsible for the spread of these diseases. Simulation results show that population in infected (I) class increases very fast and parallel to it, pathogen population also shoots up, So, it concludes that we need to take special care of the individuals in this class by means of starting treatment as soon as we identify them, proper and extra careful sanitation and disinfection of patient's belongings, room and toilet. We also need to treat the water and drainage of the area where patient reside so that the disease bacteria will not contaminate the environment of that area.

III.2. DISCUSSION

III.2.1- Physico-chemical parameters

For the physical parameters, the measured temperature values fluctuated between 18,0 and 25°C. The highest value was recorded at Mankon spring 1 (MASP1) and Nkwen well 2, (NKW2) in May and June respectively. The high temperature values (23 - 27°C) observed in certain of these sources could be explained on the one hand by the absence of the canopy exposing the bodies of water directly to sunlight (Panel *et al.*, 2021) and on the other hand, by the discharge into water courses of waste from all natures whose degradation contributes to the increase of temperature. On the other hand the lowest value was noted at wells NSSP1 and UPSP2 in May and this could be due to the surrounding characteristics of these stations. Indeed, these stations are characterized by a significant plant cover which stands on the banks of watercourses and forms a canopy which constitutes a barrier reducing the impact of solar radiation on the beds of these waters thereby determining the temperature of water bodies as noticed in Nkwen well 1 and 2. The low sunlight due to this riparian vegetation also influenced the physico-chemical properties these domestic water sources due to the temperature of these waters by absorbing part of the incoming radiation. In this regard, sunlight conditions, the sampling period and the environment determine the temperature of surface waters. Throughout the study period, the Suspended Solids values fluctuated between 15.60 and 61,54 mg/L. The maximum value was recorded at NKW1 in December. The minimum value was noted at seven different points through out the peroid (Figure 33). This values could be explained by the presence of the canopy exposing the bodies of water directly small particles and on the other hand, by the discharge into water courses of waste from all natures whose degradation, surrounding characteristics of these stations increase suspended solids (Auby *et al.*, 1994).

Overall, the water colour values oscillated between 0 and 480 Pt.Co with an average value of 32.60 Pt.Co. The lowest value were recorded in dry season in most of the stations and the highest value was recorded at Nkwen spring 2 in February of dry season (Figure 34). This could be due to humic and fulvic materials leaching from peat or other decaying vegetation and by naturally occurring salts of iron or manganese. The characteristic of the color of water is variable and often shows a strong seasonal effect, with concentrations being greatest in late late rainy season and dry season. Water derived from lowland areas can similarly show a seasonal increase in colour following autumn leaf fall (Eunjin *et al.*, 2023). Water may appear coloured because of material in

suspension and true colour can only be determined after filtration. This also explains why there was positive correlation ($P < 0.05$) between Dissolve oxygen and parameters such as pH (0.316). colour (0.020). Organic pollution Index (0.052) and temperature (0.004) to an extend. Water may appear coloured because of material in suspension and true colour can only be determined after filtration. Water can be coloured by humic and fulvic materials leaching from peat or other decaying vegetation and by naturally occurring salts. The characteristic brown colour of such water is variable and often shows a strong seasonal effect, with concentrations being greatest in dry season. Water derived from lowland areas like Mankon and Nkwen can similarly show a seasonal increase in colour following leaf fall in rainy seasons too. High colour also reduces the efficiency of dysinfection by UV radiation, chlorination and ozonation thereby reducing the quality of the drinking water source (Panel *et al.*, 2021).

The Total dissolved solids values recorded during the study period varied between 12.8 and 124,4 mg/L. The highest value was recorded for the Mankon spring 1 in June in rainy season and the lowest value was recorded for the MAW2 and MASP2 in Januray of dry season. However, an average value of 38,3 mg/L (Figure 33). The Turbidity values recorded during the study period varied between 6,4 and 30,8 mg/L. The highest value was recorded for Nkwen well 1 and the lowest value was recorded for the rest of the points in both seasons. However, an average value of 15,3 mg/L was noted. Turbidity is caused principally by inorganic matter in suspension including mineral sediments and organic matter including algae can also cause significant turbidity. Most surface waters show particularly high turbidity following periods of heavy rainfall, while groundwater generally shows low to very low turbidity (Figure 35). However, variations following heavy rainfall, for example, may indicate rapid recharge bringing in contaminants from the surface (Panel *et al.*, 2021). High-altitude areas like upstaion mile 1, and Nsongwa have steep slopes and rapidly flowing water. This can lead to increased erosion and sedimentation, resulting in higher turbidity levels in water sources. Altitude also affects the deposition and accumulation of certain chemical contaminants, such as pesticides and heavy metals thus atmospheric circulation patterns and precipitation can transport these contaminants to high-altitude areas (Jones *et al.,* 2022). This is why there were fluctuations of turbidity of water points in this study due the the contaminants in various seasonal peroids. The high value of Total Dissolved solutes during rainy season may be due to addition of domestic sewage along with waste waters, garbage and materials from run-offs in the natural surface of water body, Total dissolved solids (TDS) including phosphate, organic

ions and other ions determine the general nature of water quality. They affect the taste of drinking water if found at concentrations above the WHO recommended value. Consequently the Total dissolved solutes in all the water sources were below the WHO maximum allowable limit of 1000 mg/l (World Health Organisation, 2006), hence making these water sources suitable for drinking. The variation profiles of Total Dissolved Solutes are similar to those of turbidity and color and all these could be due to the reason that by the discharge into water courses of waste from all natures whose degradation contributes to the values of Total Dissiolved Solutes (TDS). Turbidity and colour of drinking water sources. (Figures 32, 33, and 34).

The low values of suspended solids (15.60 to 61.54mg/L), color (0 - 480 Pt.Co) and turbidity (2 - 67 NTU) recorded in these drinking water sources during the study period could be explained by the low load of organic matter in the water and the low contribution of allogenic materials into the water sources. Indeed, the presence of abundant plant cover around some of these drinking water limits the phenomena of soil erosion and water runoff, the main natural factors responsible for turbidity. On the other hand, the high levels of suspended solids, color and turbidity recorded would be an indicator of anthropogenic pollution (Boyd *et al.,* 2020,). This is the reason why there existed a positive correlation between MES. Suspended solids and Carbondioxide (0.333), total dissolved solids (0.011), orthophosphates -PO_4 (0.057), turbidity (0.666), colour (0.275), nitrates- NO_3 (0.228), Oxydability (0.386), and alkalinity (0.142). This correlation bewtwen abiotic parameters was more noticed in Well water sources since then few correlataion in spring water sources and no major correlation amongst abiotic parameters in tap waters showing that these tap waters chemical contents were under control by the authorities incharged. These measures are helpful to the operators of the wastewater treatment plant because they roughly approximate the amount of organic matter existing in the total solids of wastewater, activated sludge, and industrial wastes describes the interrelationship of solids found in water.

Some of these drinking water sources are located near areas where there is an intensification of livestock breeding activities, vehicle washing and daily sand extraction. These activities lead to the resuspension of particles in the water and increase the turbidity of this water. Furthermore, in these areas, watercourses constitute the major receptacle for various wastes which are either dumped directly into the body of water by local residents or drained by runoff water. Panel *et al,* (2021) point out that watercourses having received various urban effluents are rich in particles and other suspended matter and have high values of color and turbidity (Smith., 2023). The observed

peaks of these three parameters (SS, color and turbidity) during the rainy season in these water sourses would essentially be linked to the resuspension of particles by rainwater and water flow during this season. Auby *et al.*, (1994) in fact assert that rain promotes the erosion of particles from the watershed and their transport in the water, thus causing their enrichment in organic matter and their mixing. According to the WHO (2011), the color and turbidity of water are linked to the presence of organic matter associated with humus and suspended particles in the water.

Electrical conductivity values fluctuated between 27.7 and 251.4 µS/cm, The lowest value was recorded at Mankon well 2 (MAW2) in January and the highest value Mankon well 2 (MASP2) in January of dry season. An average value of 76.3 µs/cm was recorded (Figure 36). High conductivity was recorded from tap water sources and is attributable to the corrosion of metals leading to accumulation of heavy metals. This showed similar remarks by same study carried out in Ethiopia (Yasin, 2015). High concentration of charged ions resulting from leaching and run off into the drinking water sources particularly from latrines and landfills including the underlying rocks could have also contributed. The high temperature of (23.45˚C) could have increased the dissolution of the ions leading to high TDS and conductivity as supported by the overall significant positive correlation ($p < 0.05$) of temperature with TDS and conductivity.

The pH of water is a useful parameter as most biological activities take place only within a narrow range. As a result, any pH variations beyond an acceptable limit could be fatal to a particular organism (Trivede *et al.*, 2010). The average pH value (6.29 ± 0.04 UC) obtained during the study (higher value was obtained in NKSP2 in November and the lowest at well MASP1 in the month of January while the other stations had relative closely neutral pH) showing that the drinking water waters sources in Bamendaand its environs are slightly basic to neutral (Figure 35). The mean pH values of spring and shallow well drinking water sources were within the pH range for drinking water sources (6.5 – 9.5) by World Health Organisation (2006) while the rest of the water sources had mean pH values below the minimum guide line value (6.5). Ground water sources (boreholes, springs) including the well in the present study also had slightly acidic pH values consistent with the findings of that show that ground water is acidic and this is associated with the low pH values in most wells and springs to carbon dioxide saturation in the groundwater. The physico-chemical nature of the soil of the sampling sites partly dictates the final pH of the water samples. The high pH values obtained in the dry season would be attributable to the high levels of organic matter recorded during this season, In the dry season, there is an accumulation of organic matter and their

degradation contributes to raising the Ph. These pH values do not differ significantly from those obtained in studies carried out by Rodier *et al.*, (2009) who stated to this effect that the pH of surface water is generally linked to the nature of the soil crossed. The high pH value obtained in NKSP2 in November would be due to the washing activities carried out near or on said stations and to the high levels of organic matter.

The high values in percentage of dissolved oxygen saturation observed in the water points and fluctuated between 69.76 and 91.7 %. The minimum value was obtained in seven stations in various months and the maximum value was recorded NST2 in August. This maximum value could be due to the fact that upstream of water sourses usually show well-oxygenated waters (Panel *et al.*, 2021). The steep slopes observed in the town of Bamenda as well as the substrates which are mostly composed of large stones and rocks, create turbulence allowing the rapid circulation of water, thus promoting their re-oxygenation. The low Dissolved oxygen in the shallow well in Bamenda can be attributed to increased decomposition of organic material from the closely situated surrounding crop lands (1 m from the water source). High photosynthetic rates in the water which reduce the available carbon dioxide (increasing the pH) would liberate oxygen leading to positive correlation between dissolved oxygen and Ph. This can be expected to take place during the growing season. On the other hand, the drop in oxygen levels observed during the rainy season in the other stations could be attributed to the quantity of organic matter which increases in these stations during this season. On this subject Panel *et al*., (2021) point out that high loads of biodegradable organic matter in a river increase the biological, biochemical and chemical demand for oxygen, therefore, greater oxygen consumption in the processes of degradation of organic matter by decomposer microorganisms. Indeed, high values of nitrates and orthophosphates contribute to raising the pH of. This would explain the positive correlations obtained between pH and nitrates. The high pH values obtained in the dry season would be attributable to the high levels of organic matter recorded during this season. In the dry season, there is an accumulation of organic matter and their degradation contributes to raising the Ph. Excessively high and low pHs can be detrimental for the use of water. A high pH makes the taste bitter and decreases the effectiveness of the chlorine disinfection, thereby causing the need for additional chlorine. The amount of oxygen in water increases as pH rises. Low-pH water will corrode or dissolve metals and other substances,

The alkalinity contents (15.60 and 61.54 mg/L of $CaCO_3$) reveal a weakly alkaline character of the waters of the Bamenda hydrographic network (Figure 44). These alkalinity values are characteristic of water bodies located in regions with an acidic substrate (Rodier *et al*., 2009), These alkalinity results therefore corroborate those of pH, hence the positive and significant correlation observed between these two parameters. The low alkalinity values obtained in NKSP1 and MASP1 in February could be essentially due to the weakly basic nature of these waters and to the low values of oxidizable organic matter. Rodier *et al.,* (2009) state that the variation in the alkalinity of water is directly linked to its state of mineralization and the oxidation of the organic component. According to Mara *et al.*, (2003), the nature of the soil in the watershed also influences the concentration of hydrogen carbonates and bicarbonates, and therefore, the alkalinity of the water, Bamenda soils are composed of fine sand, fine clays and silt; which would give these soils a weakly alkaline character.

There is continuous discharge into these waters of urban and domestic waste rich in organic matter which increases mineralization of these organic materials by microorganisms thereby contributes to increasing the electrical conductivity of these waters. According to Rodier *et al*, (2009), these electrical conductivity values would reflect medium to moderately accentuated mineralization. Electrical conductivity of water could also depend on that of the terrain crossed by it. The low oxidizability values observed in the 11 water sources in months of November, December, January and February are indicative of low contents of oxidizable organic and inorganic matter, and therefore low metabolic activity of the decomposers in these waters (Matilainen *et al.,*2006). On the other hand, the high oxidizability values observed in upstation well 1 (UPW1) in May could be explained by the excessive contribution of organic and inorganic materials of anthropogenic origin to these different sampling points.

In fact, the water from these run-offs into drinking water sources receives domestic and urban waste from heavily populated areas of the city. This would show a synergy of domestic and urban pollution in the increase of oxidizable organic matter in water and hence its pollution. To this end, Rodier *et al.,* (2009) point out that an oxidizability value above 6 mg/L is indicative of high organic pollution and poor water quality. These oxidizability values were higher during the dry season compared to the rainy season. Indeed during this season, the low speed of water flow encourages an accumulation of organic matter and their degradation by

microorganisms contributes to increasing oxidizability (Matilainen *et al.,* 2006). The low levels (figures 40, 41, 42, and 43) of mineral nitrogen (ammonium, nitrites and nitrates) and orthophosphates (PO_4^{3-}) in the watercourses studied could be attributed on the one hand to the low use of agricultural inputs in this area, for crops, and to the precipitation of these elements in sediments on the other hand. To this end, Panel *et al.*, (2021), emphasizes that adsorption and precipitation reactions in sediments reduce orthophosphate contents in the aquatic environment. These results are similar to those obtained in the waters of the Kpassa dam on the Okpara in Benin (Boukari, 2018). The average value of the Organic Pollution Index (0.052 ± 0.54) obtained during the study period shows strong to moderate organic pollution of the waters. This could be explained by the relatively low values of nitrates, orthophosphates and oxidizability obtained in the drinking water sources of Bamenda.

III.2.2 Biological parameters of the waters studied

Biological analyzes of Bamenda drinking water sources show that they are contaminated by 4 species of protozoa and 7 species of Helminths. This variety of parasites found in these waters would be linked to the prevalence and intensity of infestation of the human and animal population served. In fact, these species of parasites are excreted in the form of cysts or eggs eliminated with feces. Of the species of parasites identified. Protozoa species dominated with an average density of protozoa compared Helminthes. This domination of Protozoa could be justified not only by their mode of reproduction (asexual and sexual multiplication), but also, by their morphological characteristics (presence of a rigid membrane, sometimes double) which give them strong resistance to environmental constraints. They also present greater diversity compared to that of Helminths.

III.2.3- Cysts and oocysts of enteropathogenic protozoa

Identified cysts and oocysts of enteropathogenic Protozoa in the drinking water sources were analyzed were *Balantidium coli* (43%) which was the most abundant and then followed by *Entamoeba histolytica* (38%). Low percentages were recorded in *Gardia lamblia* (12%), *Cryptosporidium parvum* (5%) as seen in figure 51. This predominance would probably be linked to their morphological characteristics (small size, presence of a rigid shell), their biology (mode of reproduction) and their low infective dose. Indeed, these species are characterized by relatively small sizes, the presence of a rigid shell and their resistance to common disinfectants. The small

size would allow these parasites to most often escape the filtration process; while the rigid shell facilitates them with strong resistance to environmental conditions. Their mode of reproduction (asexual and sexual) would also favor their excretion in large quantities into the external environment. Their high occurrence in these waters could also be explained by their resistance to usual treatment methods such as chlorination and ozonation (Ajeagah *et al.,* 2007). The high densities of the species such as *Balantidium coli, Entamoeba histolytica, Gardia lamblia,* and *Cryptosporidium parvum* (Figures 49 and 50) in stations upstaion spring 1. Mankon well 2 and Mankon spring 2 (UPSP1, MAW2 and MASP2) would probably be attributable to the proximity of these stations to livestock farms and to the high Suspended Solids levels noted in these two sampling stations. This would explain the positive correlations obtained between suspended solids and *protozoa* showing the strong adhesion of these species to suspended matter in water (Thabet *et al*., 2017).

The relatively occurrence of cysts of *Giardia* sp, in the drinking water sources of Bamenda would be justified by the large quantity of cysts excreted in the feces on the one hand, and their strong resistance in the environment on the other hand, *Giardia* cysts are excreted in large quantities in the feces of infected people (7x10 8 cysts per day in an adult) and infected animals (e,g, infected cattle excrete up to at one million cysts per gram of feces). These cysts can survive in the environment for weeks or even months, depending on certain abiotic factors such as temperature (as the temperature increases, the survival period of the cysts decreases (Thabet *et al.,* 2017). Indeed, these ampling stations showed low temperature values during the study period, unlike the other stations which presented low densities of these parasites with relatively high temperatures thus showing a correlation with temperature variations.

The concentrations of *Entamoeba histolytica* and *Balantidium coli* and other protozoa recorded would be due to their rigid shells, which give them strong resistance to environmental stress. This could also be explained by the proximity of these stations to sources of pollution (cannon latrines with discharge of products into waterways or livestock farms). The high values of color. Carbondioxide turbidity and suspended matter which are carriers of cysts in water explain the positive correlations with protozoa and helminths parasites in well water sources while no sigifican relationship was observed between these parameters and parasites in tap water and springs showing their low organic mineralization. In fact, high densities of *Balantidium coli cysts* were

noted downstream of the stations which are contaminted with waste from pigsties. Indeed, pigs are the majority reservoirs of *Balantidium coli cysts* (Bourée *et al*., 2016).

The reduction in densities of protozoan cysts in the other sampling stations could be justified by high values of certain physicochemical parameters. Thus, organic materials in ionic form and certain ions have the capacity to penet rate parasite cells, leading to their destruction or inactivation. Significant and negative correlations ($p \leq 0.05$) were also obtained between the density of some of these species of enteropathogenic protozoa and the ions in the waters studied. These low parasite loads observed in certain stations could also be explained by the high temperature values observed in said stations, the phenomenon of predation and/or self-purification. Some authors (Thabet *et al.*, 2017), have shown that high temperatures, exposure to UV rays or predation by other organisms can also shorten the time survival of certain Protozoan cysts in the aquatic environment. Temporally, the rainy season showed the highest average densities of enteropathogenic protozoa. This could be explained by the fact that in the rainy season, runoff water drains various wastes rich in organic matter from the bleed latrines and barrel latrines open during this season (Ajeagah *et al*., 2016). This is confirmed with high values of physico-chemical parameters recorded during this rainy season such as color. Carbon-dioxide, turbidity and suspended matter, carriers of cysts in water (Thabet *et al.*, 2017). This would explain the positive correlations obtained between Suspended solids, carbondioxide, color and densities of enteropathogenic Protozoa cysts ($p \leq 0.05$). These high densities were observed particularly in the month of March. Indeed, it is during this month that the rains return to the city of Bamenda. Spatially, maturation rates were remarkable at stations that had high dissolved oxygen percentages. This would show the role of dissolved oxygen in the sporulation of Protozoan oocysts (Ortega and Robertson, 2017). Significant and positive correlations were also obtained between mature oocysts of protozoa and dissolved oxygen.

III.2.4- Helminth eggs and larvae

The eggs of entero-pathogenic helminths encountered in these drinking waters of the Bamenda and its environs hydrographic network were *Ascaris lumbricoides* (49%) was the most abundant and then followed by *Hymenolepis nana* (26%). Low percentages were recorded in *Diphyllobothrium latum* (8%), *Schistosoma haematobium* (5%), *Tenia saginata* (5%), *Toxocara cati* (4%) and *Fasciola hepatica* (see figure 54), The high densities of larvae and eggs of *Ascaris*

lumbricoides observed in the analyzed samples (figure 52 and 53) could be justified by their ecology, their biology, as well as by the high resistance of these two parasites in the aquatic environment, *Ascaris lumbricoides* eggs have a thick, nippled shell made up of 3 membranes: the nippled outer membrane, the chitinous middle membrane and the inner membrane. This shell would allow them to resist factors that are harmful to them (high temperatures, desiccation, acidic or basic pH, salts and chemicals) and therefore to survive in unfavorable conditions. The abundance of these eggs would also be due to their high egg production potential. According to (Layla *et al*., 2018) a female of *Ascaris lumbricoides* produces 200.000 eggs per day.

Compared to the eggs and larvae of Nematodes, the low concentrations of eggs of Trematodes (*Schistosoma haematobium* and *Fasciola hepatica*) could be attributable not only to the fact that these species have low resistance in the environment, but also to their mode of transmission which is indirect. Indeed, these parasites have life cycles that necessarily require passage through an intermediate host. The eggs of Schistosomes hatch quickly (after 24 hours) in an aquatic environment and release the miracidia which will penetrate an intermediate host (mollusk). The same goes for the eggs of *Fasciola hepatica* which hatch in the aquatic environment to release the miracidium which swims in search of an intermediate host. The presence of these eggs in the samples analyzed indicates recent contamination of these waters.

On a spatio-temporal level, the high densities of helminth eggs and larvae observed during the rainy season would be due to the physicochemical characteristics of these stations and their proximity to sources of pollution. In addition, the good oxygenation of the waters as well as the low temperatures obtained in certain stations are the cause of these high densities by providing favorable conditions for the survival of helminth eggs (WHO, 1989). The high densities of helminth eggs and larvae obtained during the rainy season are also justified by the action of runoff water which carries overflow from barrel latrines as well as domestic waste into watercourses during this season. These results corroborate that of Layla *et al*., (2018) which indicated that the content of helminth eggs is higher in the rainy season than in the dry season. On the other hand, the low densities of eggs and larvae of enteropathogenic helminths found in certain stations could be attributed to the high values of certain ions and organic matter in ionic form

present in the domestic water sources. These mineral elements could have a negative impact on the densities of these organisms. This is how negative and significant correlations were found between ions, nitrates, orthophosphates, ammoniacal nitrogen and the densities of these parasites ($p<0.05$). This would show that high levels of mineral elements and dissolved salts can reduce parasite densities through their great capacity to penetrate cell walls (Layla *et al.*,2018). The most important conditions that favor the optimal development of these eggs are temperature, humidity, nutrients, the presence of other microorganisms, solar radiation and Ph. On the other hand, the low maturation rate of larvae of could be explained by the fact that these organisms continue their reproduction cycle in the aquatic environment, thus giving birth to second generation rhabditoid larvae. Indeed, humidity provides storage conditions favorable to the survival of helminth eggs (Vaz *et al.,* 2019).

III.2.5. Influence of abiotic variables on the distribution and maturation of parasites

The high values of hydrological parameters obtained during the rainy season, would be the cause of the high densities of parasites as well as the high maturation rates recorded during this season. Indeed, during the rainy season, runoff water drains domestic waste from various effluents and the contents of septic tanks which are emptied into water sourses (Ajeagah *et al.*, 2016). The increase in the volume of water would also promote the maturation of helminth eggs in the sense that humidity provides storage conditions favorable for the survival of helminth eggs (Vaz Nery *et al.,* 2019). High parasite densities in the rainy season would be a signal of a high health risk, Ascaris *lumbricoides* had a positive correlation only with *Cryptosporidium parvum* (0.124) and *Fasciola hepatica* (0.336), Significant and negative correlations are noted between the eggs of *Ascaris lumbricoides* and *Hymenolepis* sp, (r=-0.182) and of *Fasciola hepatica* (r=- 0.155). This would show that increasing the levels of these ions and solute contents in the water could slow down the maturation of parasites and reduce their densities through their ability to penetrate and destroy cells (Layla *et al.,* 2018). The positive and significant correlations obtained between *Hymenolepis* sp., *Fasciola hepatica*, and dissolved oxygen would show that these parasites favor oxygenated environments with a low level of organic pollution.

CONCLUSION, RECOMMENDATIONS AND PERSPECTIVES

The evaluation of domestic water quality in this study was based on the determination of the Biological (more specifically Protooa and Helminths) and physico-chemical contents of the water sources, The factors that influenced the quality of domestic water sources in Bamenda and its envions were, runoff from urban areas, debris littering the streets, sediments, animal wastes (fecal coliform and pathogens), farming and industrial activities.

During this study, biological analyzes made it possible to identify, characterize and to count different environmental forms of intestinal protozoa and helminths, with a clear predominance of Protozoan cysts and larvae. The presence of these parasites in the intestinal tract shows contamination of water by fecal matter. The Protozoa identified in water sources included *Entamoeba histolytica, Giardia lambia, Balantidium coli and Cryptosporidium parvum*. On the spatiotemporal level, the high parasitic loads as well as mature forms of intestinal protozoa were noted during the rainy season. The stations UPSP1, MAW2, MASP2, and UPW1 were the most contaminated by these parasites, while the stations of drinking water sources showed low parasite loads, Statistical analyzes presented significant and positive correlations between the densities of Protozoa and the suspended solids ($p<0.05$); and between mature forms of parasites and dissolved oxygen showing the role of dissolved oxygen in the maturation of Protozoa.

Intestinal helminth eggs and larvae comprised of *Ascaris lumbricoides, Taenia saginata, Diphyllobothrium latum, Hymenolepis nana, Schistosoma haematobium, Fasciola hepatica* and *Toxocara cati*, Spatially, the NSSP1 source was the most contaminated by eggs and larvae of intestinal helminths; while rest of the domestic water sources presented low loads of these parasites, April during the rainy season recorded the highest densities as well as mature forms of helminth eggs and larvae. The high maturation rate of *Ascaris lumbricoides* eggs reflects the role of humidity in the maturation of these eggs. The negative correlations ($p\leq0.05$) obtained between the salinity, ions, temperature and helminth eggs on the one hand, and positive oxygen between dissolved, the Organic Pollution Index and the density of these eggs on the other hand, show that these parasites are of well-oxygenated waters with low temperature values and low organic pollution.

Generally, the domestic waters sources of Bamenda and its environs are used for several purposes by the population and are contaminated by cysts and oocysts of Protozoa as well as than by helminth eggs and larvae. The distribution of parasites in these waters depends sources of pollution (cannon latrines, livestock farms, runoffs rain water) and also under the influence of

physicochemical characteristics of each station. The origin of most common waterborne pathogens can be traced to the fecal wastes of animals and humans. The potential for increased pathogen loads in source waters used as a drinking water supply presents a challenge in designing and operating domestic water treatment to efficiently remove a high number of the pathogens due to their organoleptic and morphometric characteristics, Shallow groundwater wells are likely to be more vulnerable to fecal contamination as they are most influenced by surface runoff.

Based on the results of physical and chemical evaluation of these domestic water souirces, all the sample locations, were subjected to varying levels of pollution. The station of Nkwen showed significant values of chemical composition as shown by the high Organic pollution Index in the area. From this study it can be deduced that the mismanagement of our waters through unrestrained and unrestricted dumping of contaminants into it has caused these water bodies to have poor quality and should not be used for the purpose of consumption unless properly treated. The results show that several parameters, including Disolved Oxygen, electric conductivity. Organic pollution Index, and turbidity, have concentration levels that were higher than the WHO standards, rendering the water unfit for human consumption. The poor condition of water distribution system exacerbates the depletion of water resources.

In this study, we noticed a correlation between the parasites and the physico-chemical paramaters. It was realized that mature forms of dissemination of intestinal protozoa and helminths were having a relationhip to the physicochemical quality of drinking water sources in Bamenda and its environs. The analysis of the physicochemical parameters showed that some of the drinking water sources, had low values of temperature, pH, good oxygenation, low mineralization and low organic pollution. This shows that these drinking waters sources were of acceptable quality. Meanwhile, in the Upstaion, Nkwen and and some parts of Mankon of domestic water sources located in urban areas, the domestic waters sorces show moderate to heavy organic pollution, high values of temperature, pH, more colored waters, strong mineralization and high contents of metallic elements in the sediments proofing that these waters are therefore of poor quality.

This study is a premium in the investigation of pathogen load in domestic water and is suitable for ameliorating the health and drinking water quality situation of the municipality. Given the high densities of these parasites as well as that the mature forms of parasites found in these waters, also in recognizance of the physico-chemical properties of these domestic water sources, it

is imperative to make recommendations to public authorities, the population in collaboration with researchers, to take the necessary measures to limit the contamination of these bodies of water and thus limit the spread of these parasites.

Recommendations to the population comprises, building of wells with curbs (0.5 to 1 m) respecting WHO standards and at least 15 m from potential sources of pollution; treating all the domestic water sources by boiling or chlorination methods before consumption or any sensitive use; and adequately respect hygiene rules in order to avoid water-related diseases. Recommendation to public authorities include, Extending the drinking water supply network throughout the locality in order to limit the use of water of dubious quality for sensitive purposes by the population, implementing public hygienic rules and involve partners concerned and intensification of sensibilization of the population in the prevention and control of water born diseases.

Perspectives of this study are as follows:

1-The effect of climate change and environmental degradation on the water quality in the area has not been thoroughly examined. The maturation of environmental forms of organisms including the mobility of cyst, larval and eggs stages are aspects of interest which needs to be evaluated also. Thus wish further study can be done in these areas. Future studies could examine the link between these elements and the criteria governing domestic water quality.

2-Maturation of environmental forms of pathogens with physico-chemical parameters.
3-Evaluation of the dynamics of cysts and larvae of pathogens with respect to seasonality.
4-Molecular characterization of environmental forms.
5-Elements of resistance of *Ascaris lumbricoides* and *Cryptosporidium parvum* which have a high prevalence in the stream.
6-Extend this research to other areas of the town.
7-Impact of altitude and geomorphology on the dissemination of intestinal pathogens.
8-Characterisation of the viablilty of enteropathogenic Protozoa and Helminths.
9-Asssess trophic status of enteropathogens in the environment of Bamenda.

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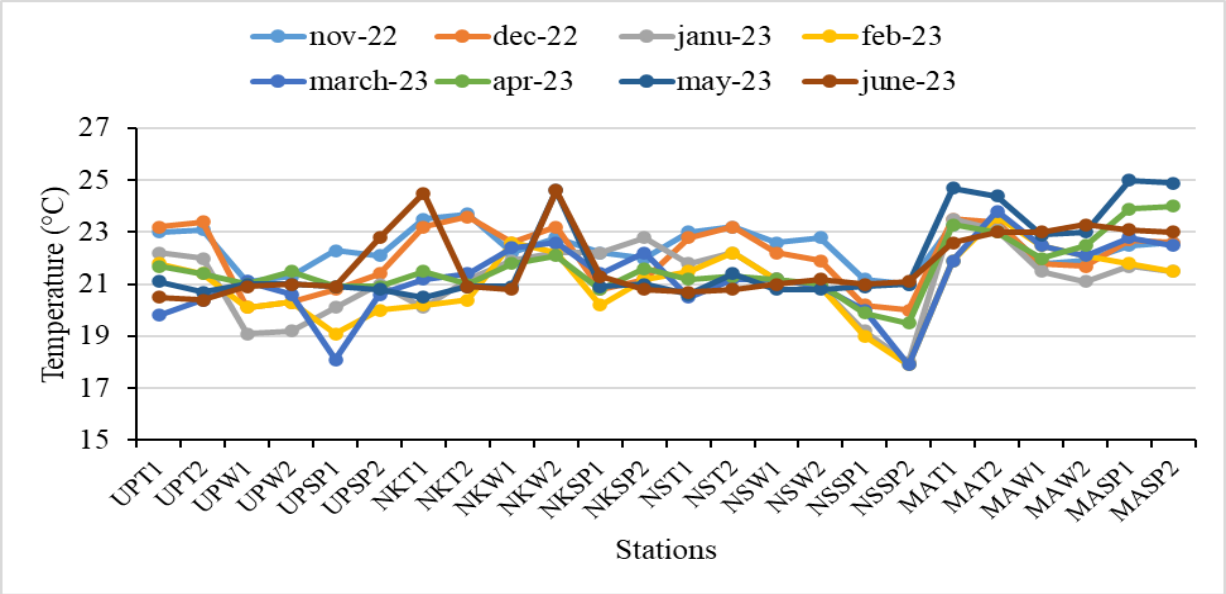
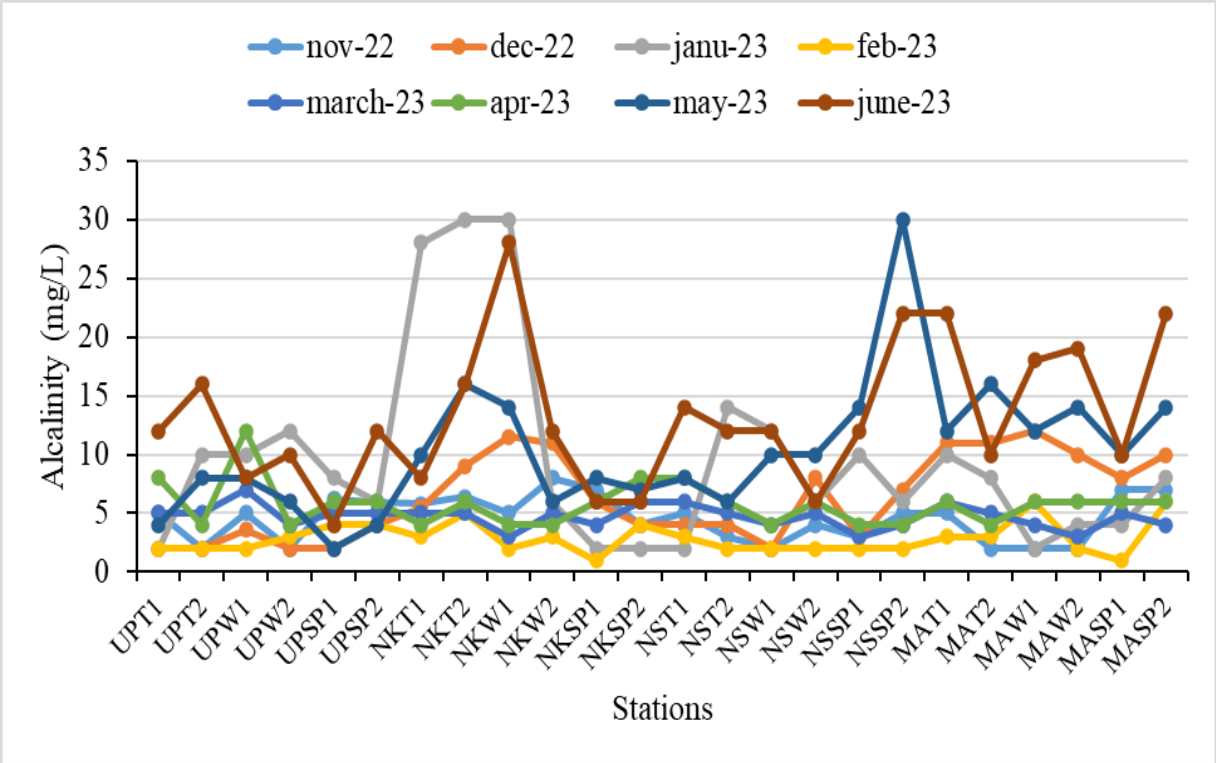
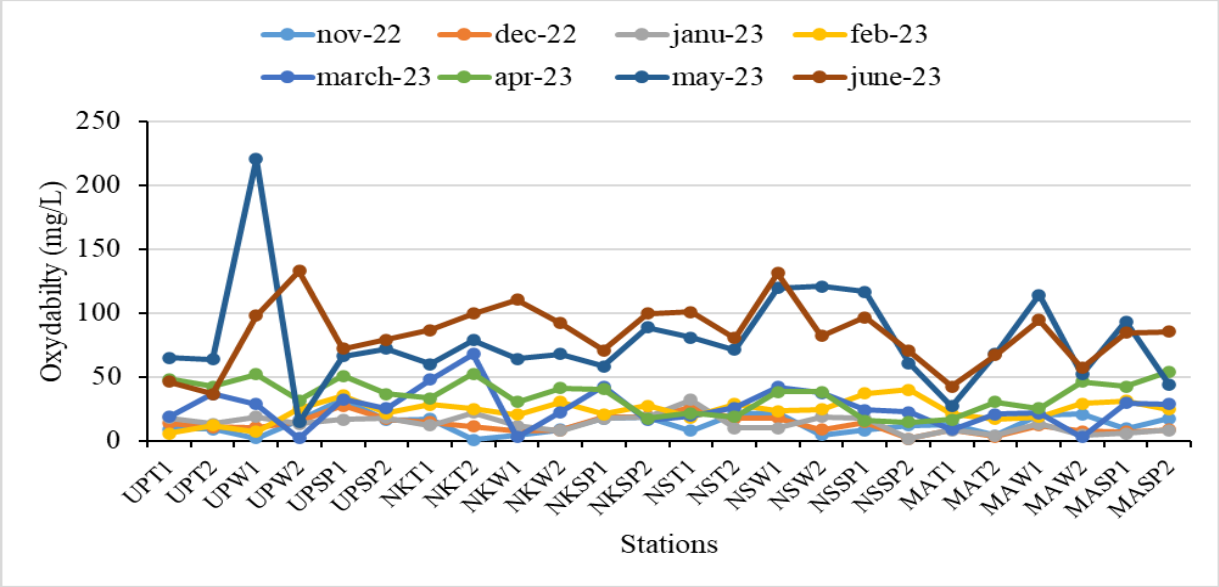
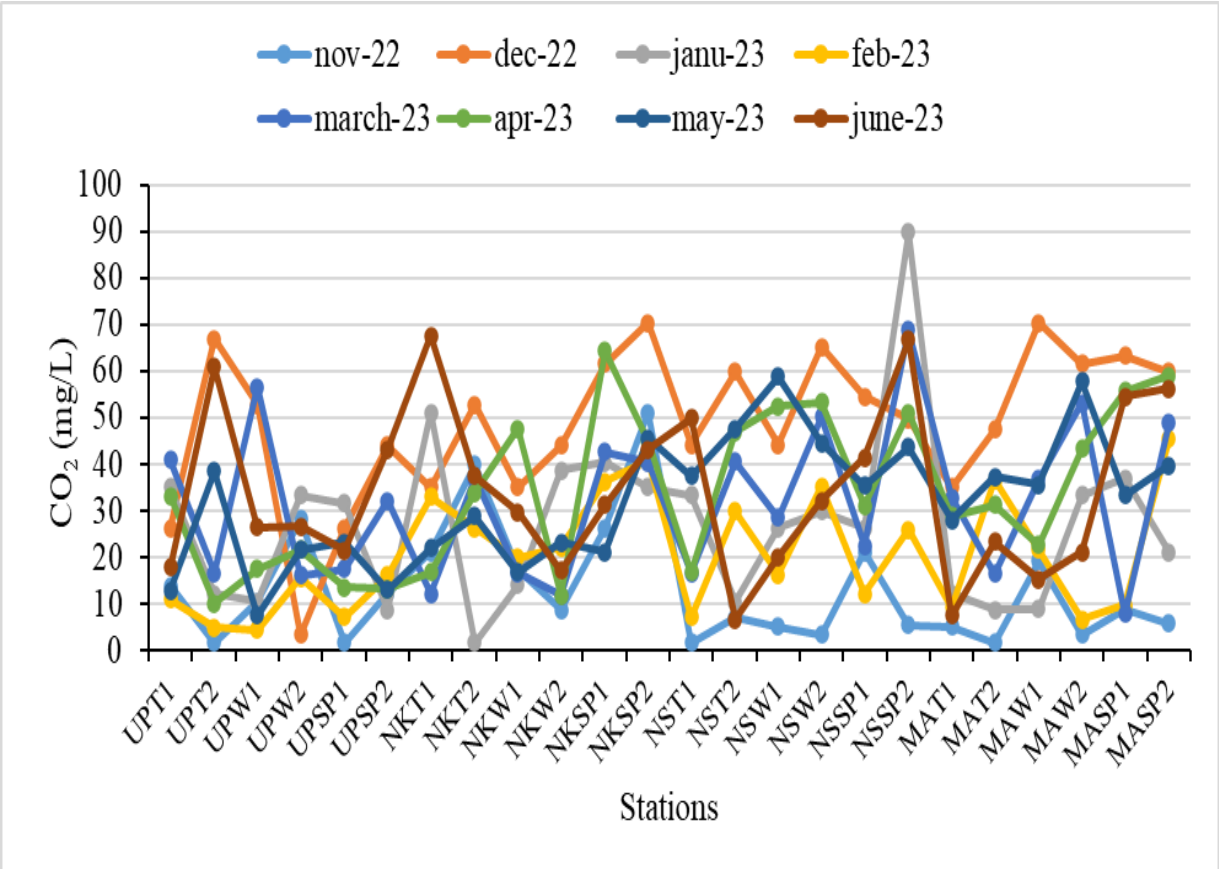
ANNEXES

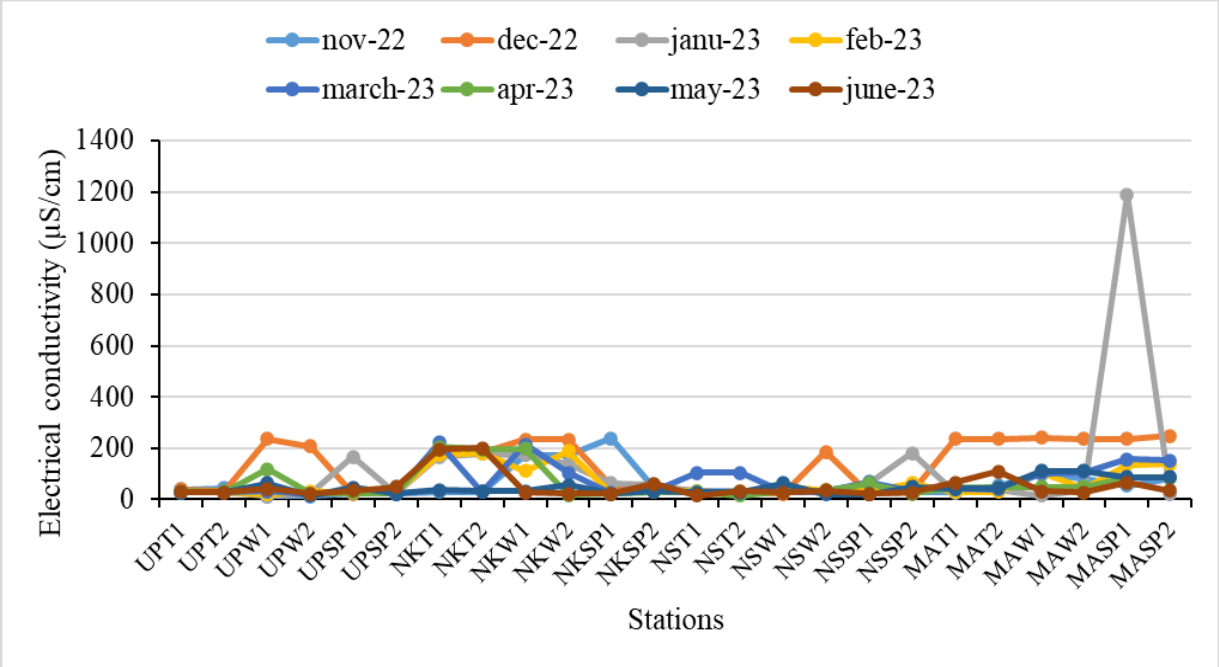
Annex 1: Figures showing spatio- temporal illustration of physic-chemical parameters

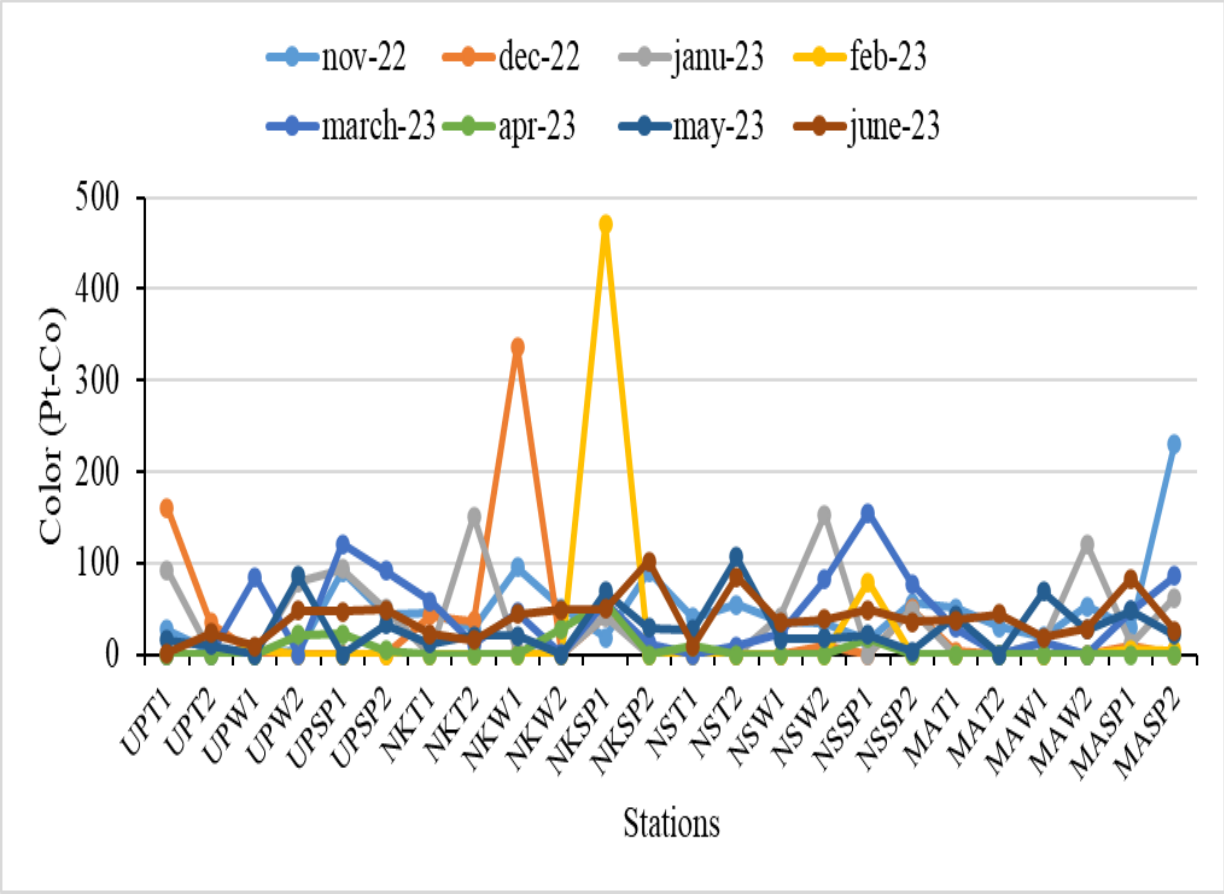


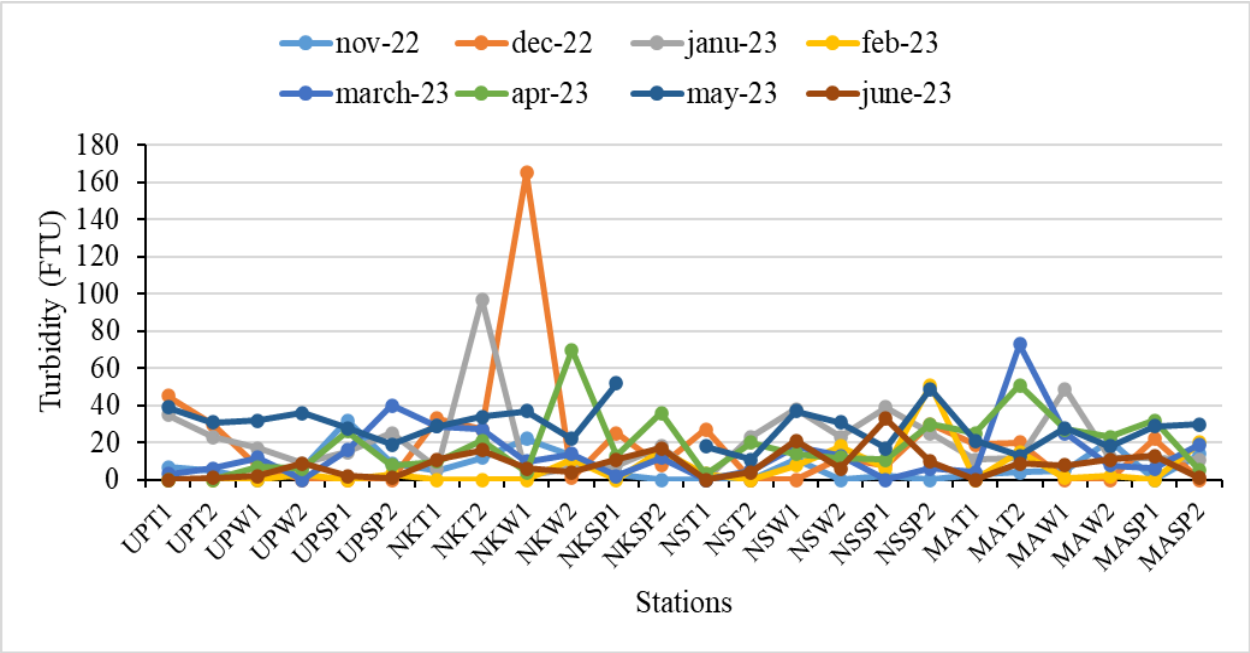


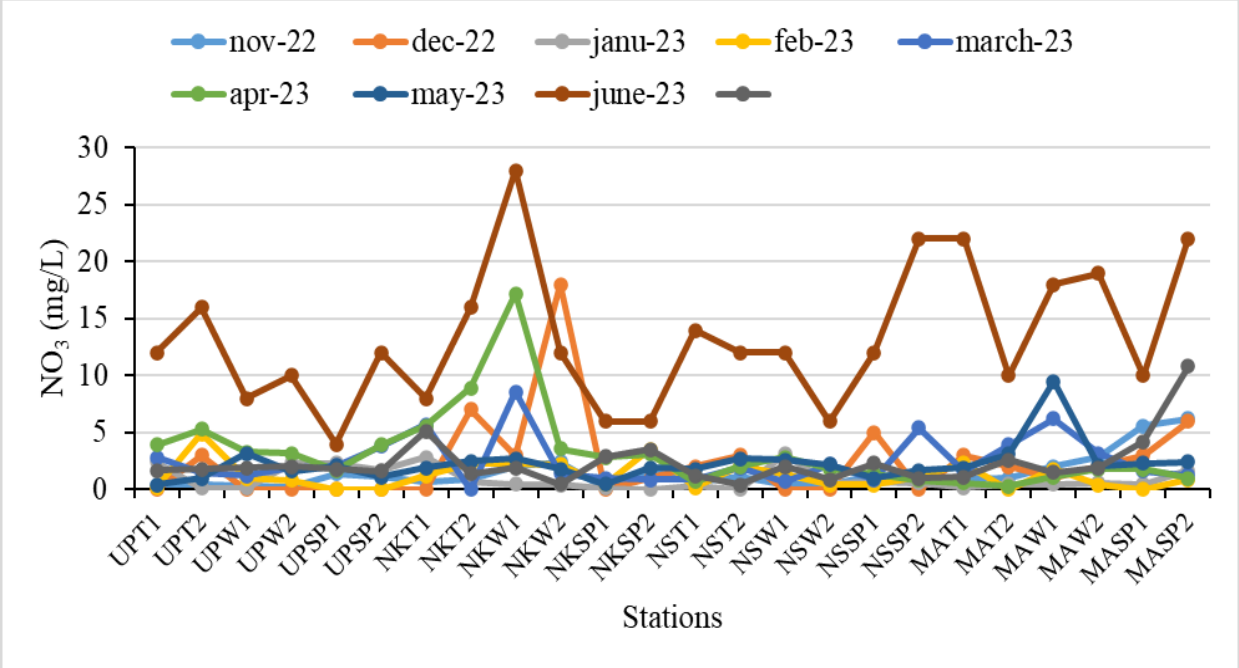

nov-22
dec-22
janu-23
feb-23
march-23
apr-23
may-23
june-23
Oxydabilty (mg/L)
250
200
150
100
50
0
UPT1
UPT2
UPW1
UPW2
UPSP1
UPSP2
NKT1
NKT2
NKW1
NKW2
NKSP1
NKSP2
NST1
NST2
NSW1
NSW2
NSSP1
NSSP2
MAT1
MAT2
MAW1
MAW2
MASP1
MASP2
Stations

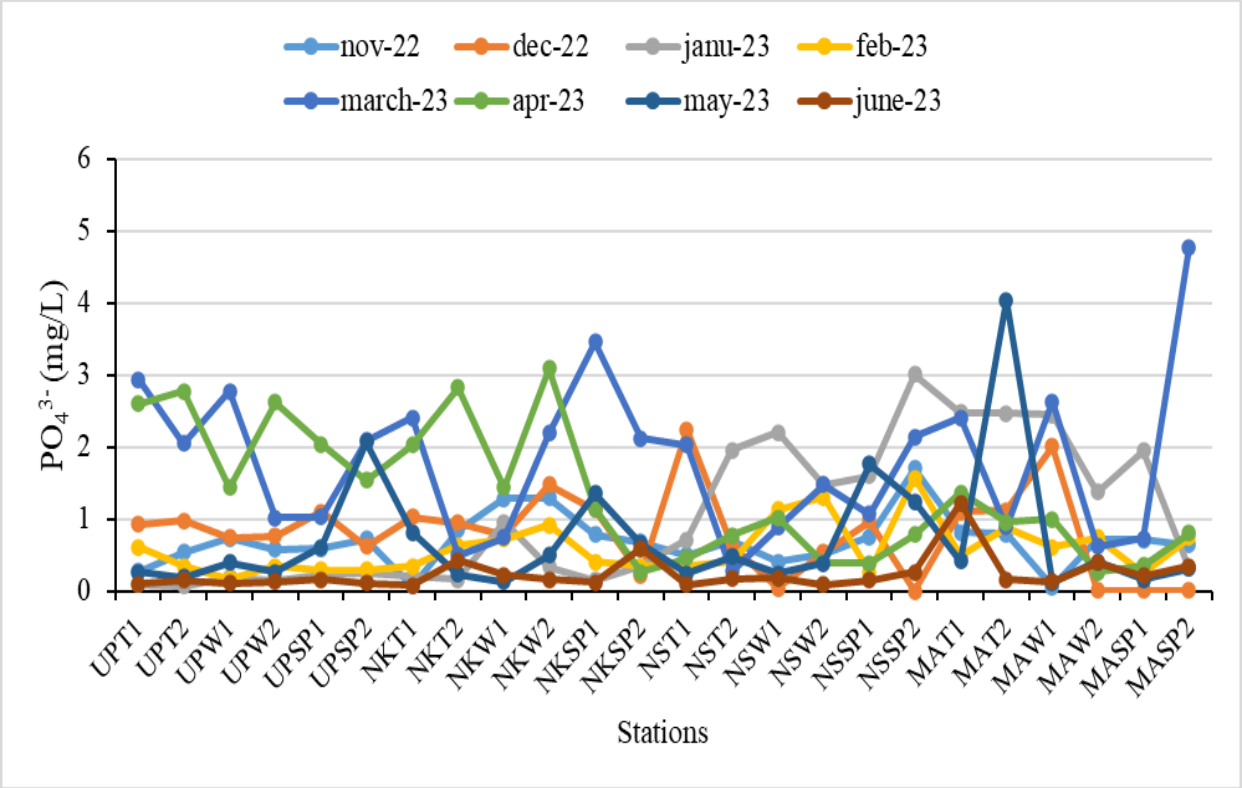

nov-22
dec-22
janu-23
feb-23
march-23
apr-23
may-23
june-23
CO_2 (mg/L)
100
90
80
70
60
50
40
30
20
10
0
UPT1
UPT2
UPW1
UPW2
UPSP1
UPSP2
NKT1
NKT2
NKW1
NKW2
NKSP1
NKSP2
NST1
NST2
NSW1
NSW2
NSSP1
NSSP2
MAT1
MAT2
MAW1
MAW2
MASP1
MASP2
Stations

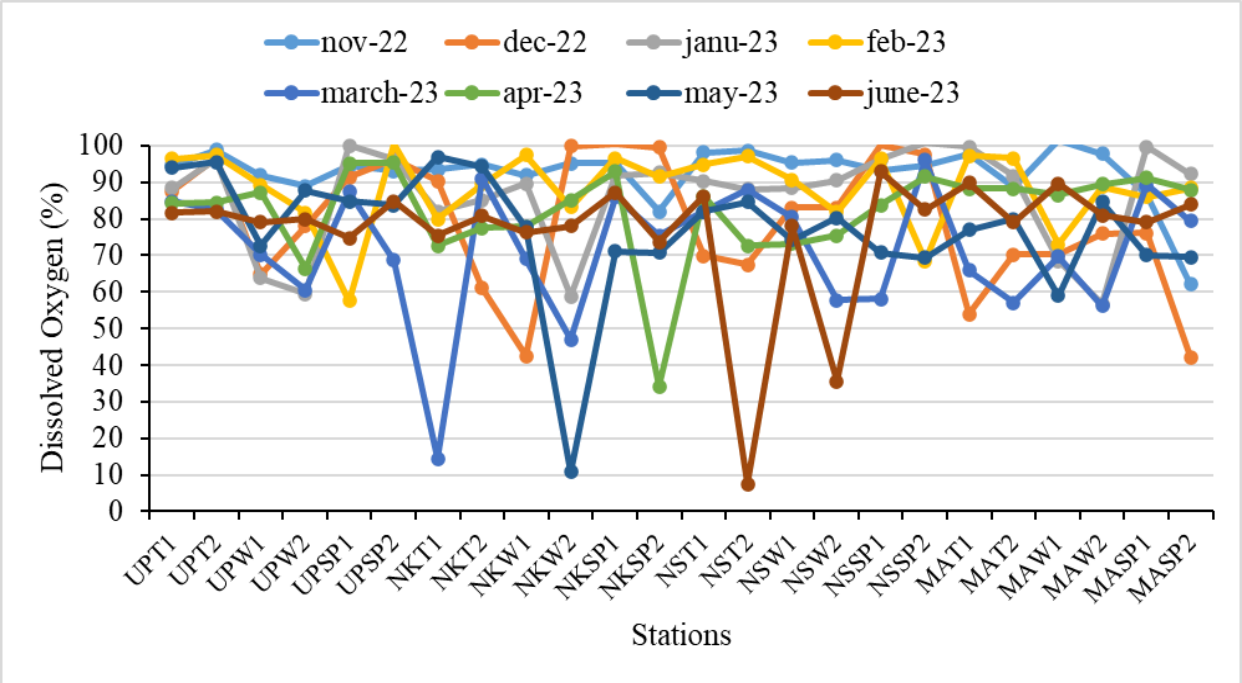

nov-22
dec-22
janu-23
feb-23
march-23
apr-23
may-23
june-23
Electrical conductivity (µS/cm)
1400
1200
1000
800
600
400
200
0
UPT1
UPT2
UPW1
UPW2
UPSP1
UPSP2
NKT1
NKT2
NKW1
NKW2
NKSP1
NKSP2
NST1
NST2
NSW1
NSW2
NSSP1
NSSP2
MAT1
MAT2
MAW1
MAW2
MASP1
MASP2
Stations

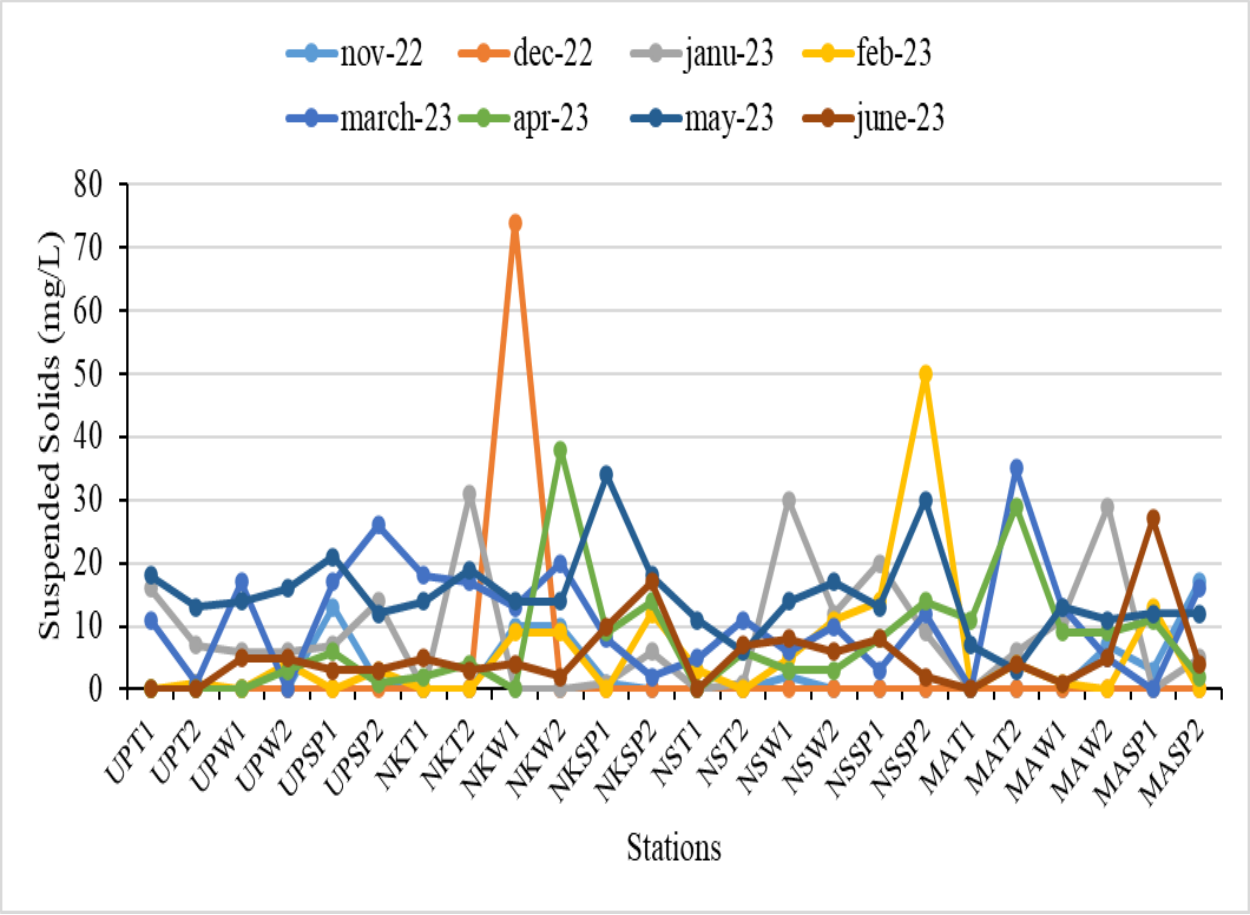

nov-22
dec-22
janu-23
feb-23
march-23
apr-23
may-23
june-23
Color (Pt-Co)
500
400
300
200
100
0
UPT1
UPT2
UPW1
UPW2
UPSP1
UPSP2
NKT1
NKT2
NKW1
NKW2
NKSP1
NKSP2
NST1
NST2
NSW1
NSW2
NSSP1
NSSP2
MAT1
MAT2
MAW1
MAW2
MASP1
MASP2
Stations


nov-22
dec-22
janu-23
feb-23
march-23
apr-23
may-23
june-23
Turbidity (FTU)
180
160
140
120
100
80
60
40
20
0
UPT1
UPT2
UPW1
UPW2
UPSP1
UPSP2
NKT1
NKT2
NKW1
NKW2
NKSP1
NKSP2
NST1
NST2
NSW1
NSW2
NSSP1
NSSP2
MAT1
MAT2
MAW1
MAW2
MASP1
MASP2
Stations


nov-22
dec-22
janu-23
feb-23
march-23
apr-23
may-23
june-23
NO_3 (mg/L)
30
25
20
15
10
5
0
UPT1
UPT2
UPW1
UPW2
UPSP1
UPSP2
NKT1
NKT2
NKW1
NKW2
NKSP1
NKSP2
NST1
NST2
NSW1
NSW2
NSSP1
NSSP2
MAT1
MAT2
MAW1
MAW2
MASP1
MASP2
Stations


nov-22
dec-22
janu-23
feb-23
march-23
apr-23
may-23
june-23
PO_4^{3-} (mg/L)
0
1
2
3
4
5
6
UPT1
UPT2
UPW1
UPW2
UPSP1
UPSP2
NKT1
NKT2
NKW1
NKW2
NKSP1
NKSP2
NST1
NST2
NSW1
NSW2
NSSP1
NSSP2
MAT1
MAT2
MAW1
MAW2
MASP1
MASP2
Stations


nov-22
dec-22
janu-23
feb-23
march-23
apr-23
may-23
june-23
Dissolved Oxygen (%)
0
10
20
30
40
50
60
70
80
90
100
UPT1
UPT2
UPW1
UPW2
UPSP1
UPSP2
NKT1
NKT2
NKW1
NKW2
NKSP1
NKSP2
NST1
NST2
NSW1
NSW2
NSSP1
NSSP2
MAT1
MAT2
MAW1
MAW2
MASP1
MASP2
Stations


nov-22
dec-22
janu-23
feb-23
march-23
apr-23
may-23
june-23
Suspended Solids (mg/L)
0
10
20
30
40
50
60
70
80
UPT1
UPT2
UPW1
UPW2
UPSP1
UPSP2
NKT1
NKT2
NKW1
NKW2
NKSP1
NKSP2
NST1
NST2
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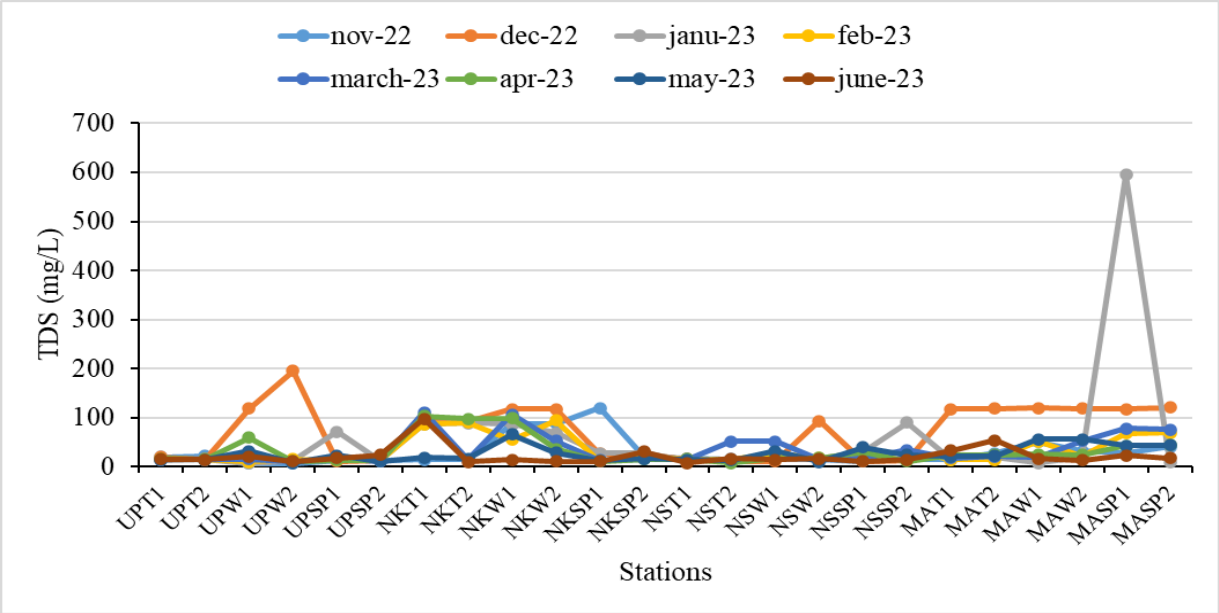
NSW2
NSSP1
NSSP2
MAT1
MAT2
MAW1
MAW2
MASP1
MASP2
Stations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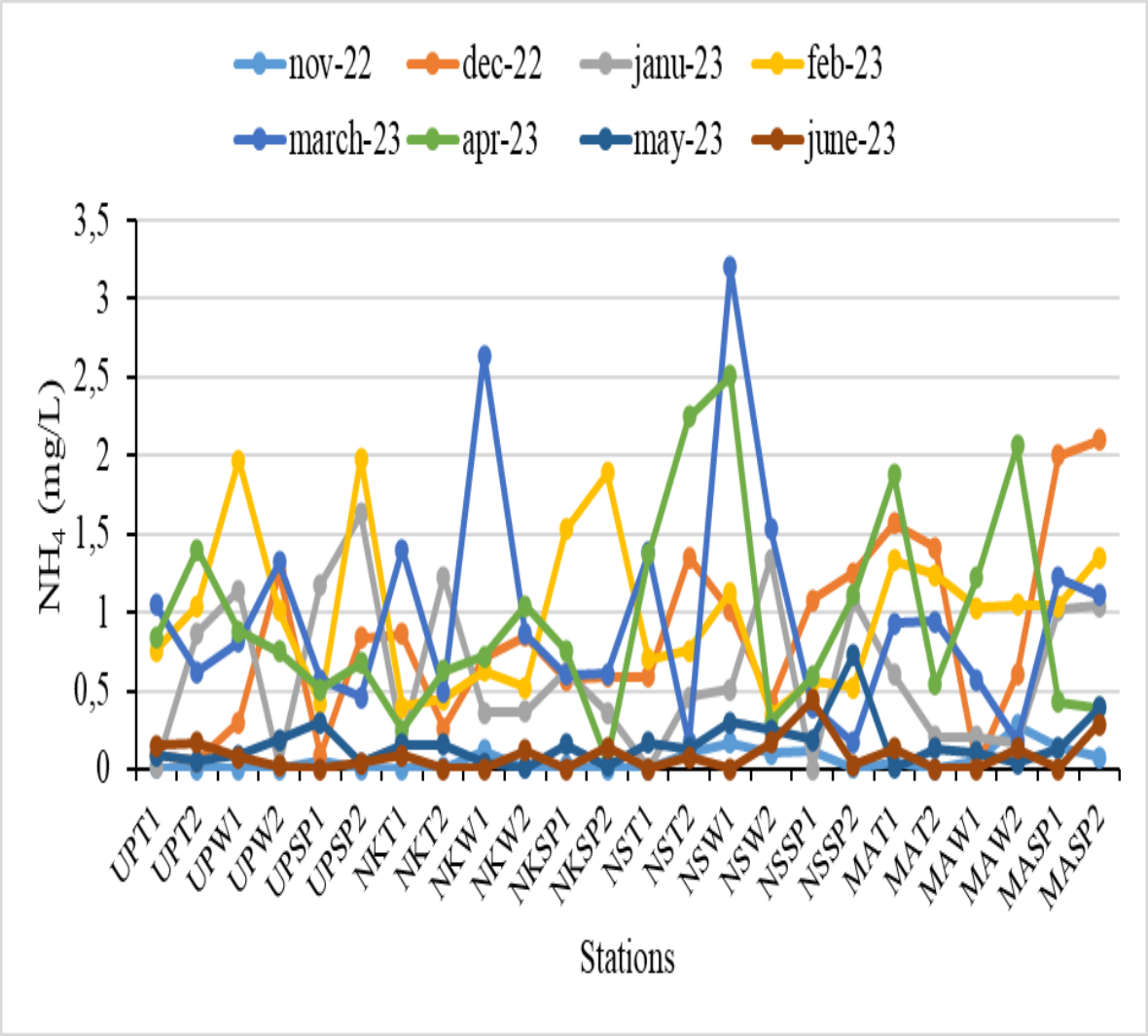
dec-22
janu-23
feb-23
march-23
apr-23
may-23
june-23
TDS (mg/L)
0
100
200
300
400
500
600
700
UPT1
UPT2
UPW1
UPW2
UPSP1
UPSP2
NKT1
NKT2
NKW1
NKW2
NKSP1
NKSP2
NST1
NST2
NSW1
NSW2
NSSP1
NSSP2
MAT1
MAT2
MAW1
MAW2
MASP1
MASP2
Stations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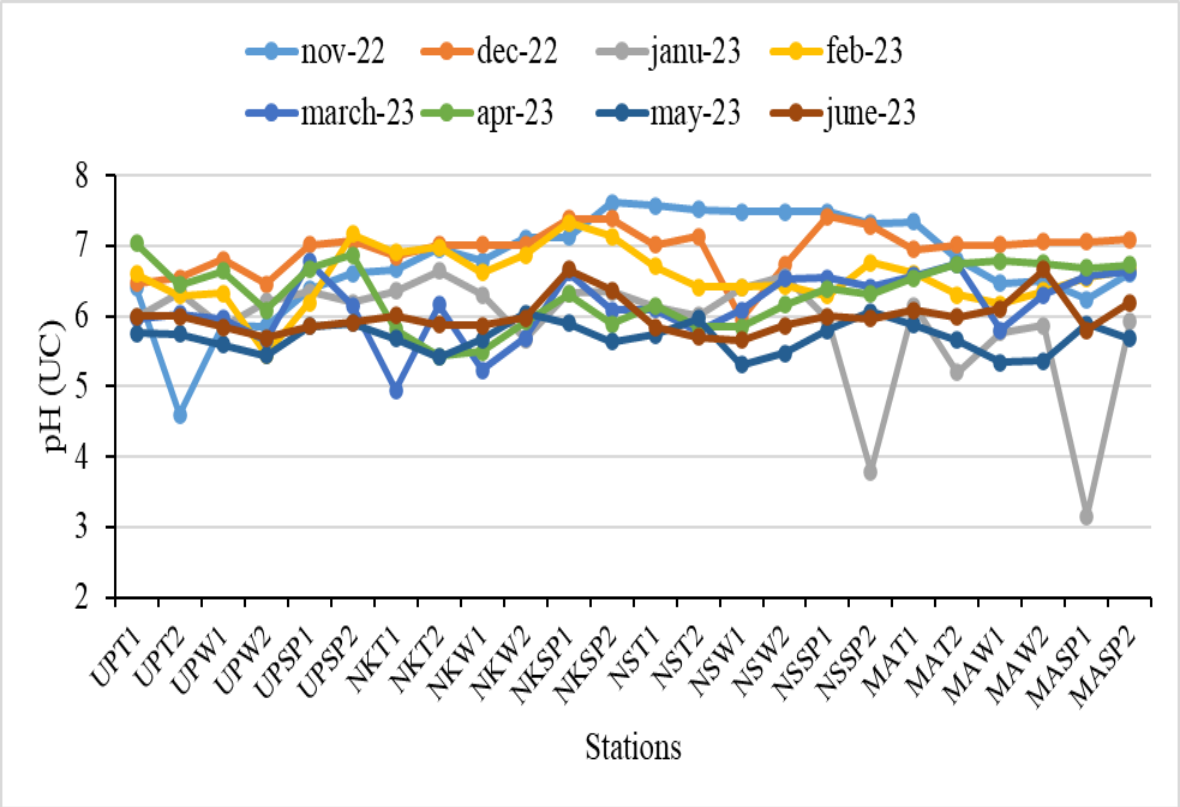
janu-23
feb-23
march-23
apr-23
may-23
june-23
3,5
3
2,5
2
1,5
1
0,5
0
NH4 (mg/L)
UPT1
UPT2
UPW1
UPW2
UPSP1
UPSP2
NKT1
NKT2
NKW1
NKW2
NKSP1
NKSP2
NST1
NST2
NSW1
NSW2
NSSP1
NSSP2
MAT1
MAT2
MAW1
MAW2
MASP1
MASP2
Stations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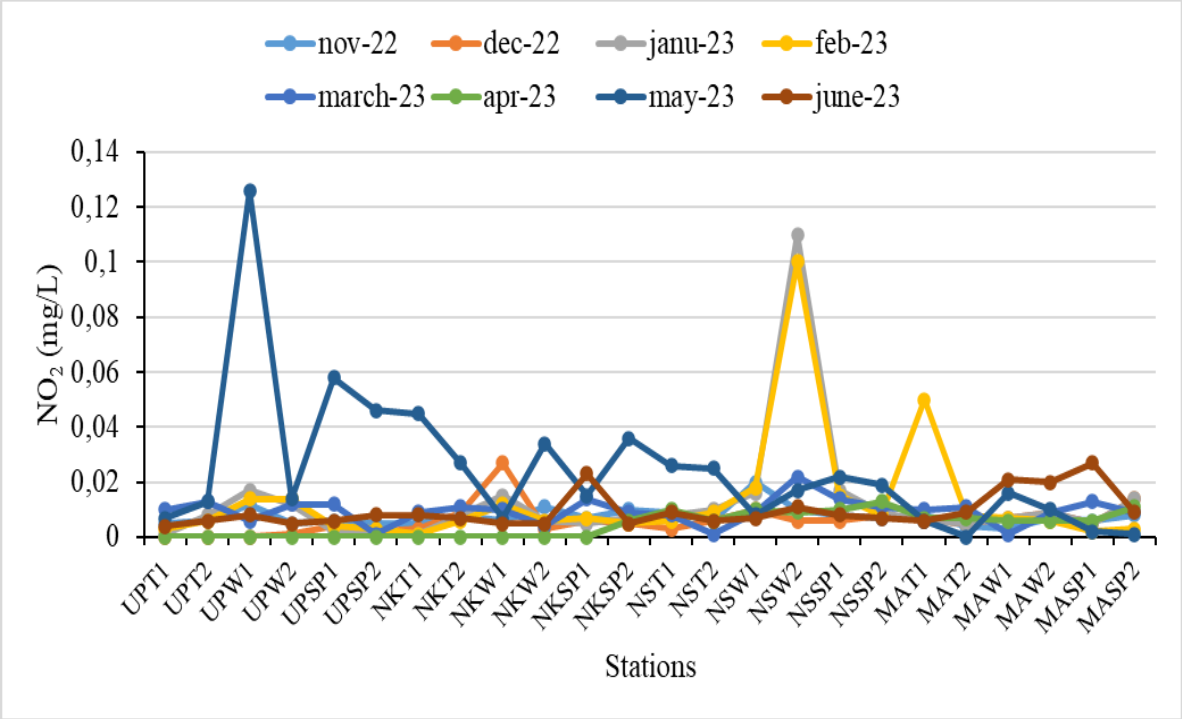
janu-23
feb-23
march-23
apr-23
may-23
june-23
pH (UC)
8
7
6
5
4
3
2
UPT1
UPT2
UPW1
UPW2
UPSP1
UPSP2
NKT1
NKT2
NKW1
NKW2
NKSP1
NKSP2
NST1
NST2
NSW1
NSW2
NSSP1
NSSP2
MAT1
MAT2
MAW1
MAW2
MASP1
MASP2
Stations


nov-22
dec-22
janu-23
feb-23
march-23
apr-23
may-23
june-23
NO2 (mg/L)
0,14
0,12
0,1
0,08
0,06
0,04
0,02
0
UPT1
UPT2
UPW1
UPW2
UPSP1
UPSP2
NKT1
NKT2
NKW1
NKW2
NKSP1
NKSP2
NST1
NST2
NSW1
NSW2
NSSP1
NSSP2
MAT1
MAT2
MAW1
MAW2
MASP1
MASP2
Stations

Annex 2: Spearman correlations betwen aboitic variables of water sources

	Temp	SS	Turb	Color	TDS	PH	EC	NO_3	NO_2	NH_4	PO_4	DO	CO_2	Oxyd	Alca	OPI
Temp (°C)	1.000															
SS (mg/L)	0.595	1.000														
Turb (NTU)	0.524	**.786***	1.000													
Color (Pt/Co)	-0.119	0.238	0.214	1.000												
TDS (mg/L)	0.619	0.452	0.333	-0.024	1.000											
PH (CU)	0.524	0.357	0.190	0.095	0.000	1.000										
EC (µS/cm)	0.643	0.524	0.405	0.000	**.976****	0.167	1.000									
NO3 (mg/L)	.786*	0.690	0.643	0.048	**.833***	0.000	**.786***	1.000								
NO_2 (mg/L)	-0.429	0.190	0.143	0.071	-0.381	0.286	-0.214	-0.476	1.000							
NH_4 (mg/L)	-0.643	0.048	0.024	0.071	-0.405	-0.571	-0.452	-0.238	0.429	1.000						
PO_4 (mg/L)	0.381	0.190	0.333	-0.524	0.524	0.024	0.571	0.357	-0.024	-0.405	1.000					
DO (mg/L)	-0.119	0.214	0.310	0.095	-0.167	-0.190	-0.190	0.119	0.214	0.667	-0.500	1.000				
CO_2 (mg/L)	0.095	0.214	0.286	0.310	-0.333	**.738***	-0.167	-0,238	0,571	-0,071	-0.333	0.357	1.000			
Oxyd (mg/L)	-0.381	-0.143	0.143	-0.476	-0.429	-0.071	-0.333	-0.452	0.643	0.310	0.429	0.024	0.143	1.000		
Alca (mg/L)	0.690	0.643	0.548	-0.048	**.929****	0.238	**.976****	.810*	-0.095	-0.381	0.595	-0.071	-0.048	-0.214	1.000	
OPI (mg/L)	0.415	-0.317	-0.268	-0.464	0.464	-0.073	0.366	0.342	-0.683	-0.464	0.146	0.000	-0.268	-0.390	0.293	1.0

Annex 3: Spearman correlations between physico- chemical variables and parasites

	DO	PH	MES	NO_2	EC	NH_4	TDS	PO_4	Turb	Color	OPI	NO_3	Oxyd	CO_2	Temp	Alca
Nematode larvae	-.098	.068	.136	.033	.097	.008	.100	.088	.049	**0.162***	-.025	.071	-.016	-.019	.082	-.011
Ascaris lumbricoides	-.012	-.016	.031	.115	-.030	.055	.028	.028	.020	.130	-.089	**-0.183***	.008	-.014	-.037	-.124
Balantidium coli	**-0.151***	.062	.051	-.042	.027	.102	.020	-.016	.032	**0.177***	-.014	.047	-.092	.015	.069	.044
Entamoeba histolytica	.078	.044	-.002	.023	-.113	.034	-.101	**-0.162***	-.076	.058	.039	.009	.085	.052	**-0.158***	.038
Toxocara cati	**-0.146***	.055	.116	.046	.120	-.009	.122	.069	.028	.084	-.016	.109	-.081	.038	.086	-.055
Diphyllobothrium latum	-.057	-.076	.006	-.102	.038	-.003	.010	.047	.031	-.039	.016	.034	-.058	-.061	.064	-.127
Cryptosporidium parvum	-.067	**0.142***	.003	.064	.137	-.013	.113	.054	.008	.121	.019	-.001	-.096	.113	.005	-.023
Gardia lamblia	-.132	-.107	**0.166***	**0.149***	.088	.046	.085	.029	**0.175***	.041	**-0.149***	**0.213****	.007	-.047	.061	.057
Fasciola hepatica	-.013	-.010	.069	.125	.067	-.080	.020	.095	.005	.027	-.109	-.073	-.029	-.024	**-0.158***	-.007
Hymenolepis nana	**0.159***	.136	-.049	.038	-.121	.024	-.122	.000	-.074	.006	-.084	.002	-.067	-.008	-.138	**-0.154***
Schistosoma hematobium	.021	.083	-.065	-.100	-.029	.004	-.030	-.034	**-0.146***	-.009	.012	.045	-.022	.033	.096	-.089
Tenia saginata	.021	.083	-.065	-.100	-.029	.004	-.030	-.034	**-0.146***	-.009	.012	.045	-.022	.033	.096	-.089

Annex 4: Matrix of Spearman correlation between different variables of Protozoa

	Nematode larvae	*A. lumbricoide*	*B. coli*	*E.histolytica*	*T. cati*	*D.latum*	*C.parvum*	*G. lamblia*	*Fasciola hepatica*	*H. nana*	*S. hematobium*	*T. saginata*
Nematode larvae	1.000											
Ascaris lumbricoides	-.030	1.000										
Balantidium coli	**0.250****	-.002	1.000									
Entamoeba histolytica	-.044	-.020	.091	1.000								
Toxocara cati	**0.814****	-.037	**0.187****	-.054	1.000							
Diphyllobothrium latum	-.015	-.042	-.061	-.062	-.018	1.000						
Cryptosporidium parvum	**0.489****	.124	.137	-.089	**0.392****	-.030	1.000					
Gardia lamblia	-.028	-.078	.121	-.115	- 034	**0.261****	-.056	1.000				
Fasciola hepatica	-.011	**0.336****	-.043	-.044	-.013	-.015	**0.489****	-.028	1.000			
Hymenolepis nana	-.013	-.037	-.053	**0.331****	-.016	-.018	-.026	-.034	-.013	1.000		
Schistosoma hematobium	-.013	-.037	-.053	-.054	-.016	-.018	-.026	-.034	-.013	-.016		
Tenia saginata	-.013	-.037	-.053	-.054	-.016	-.018	-.026	-.034	-.013	-.016	**1.000****	1.000

Annex 5: Table showing Drinking Water Quality Standard (who, 2006)

Parameter	**Existing Standard**	**Parameter**	**Standard for the Reprovisioned Sha Tin WTW South Works**	**Explanations**
pH at 25°C	8.2 – 8.8	pH at 25°C	8.2 – 8.8	The pH guideline for drinking water is 6.5 to 8.5. This is based on the fact that pH can affect the taste, smell and appearance of water and can also corrode pipes with its acidity. When alkaline it can cause skin irritations and bitter taste.
Colour	Not exceeding 5 Hazen units	Colour	Not exceeding 5 Hazen units	The World Health Organization (WHO) also has a colour guideline of 15 Hazen units for drinking water. This guideline is based on the fact that colour can affect the acceptability of water to consumers. Water that is too coloured may be perceived as being dirty or contaminated. even if it is safe to drink.
Turbidity	Not exceeding 1.5 NTU	Turbidity	Not exceeding 1.0 NTU. and not exceeding 0.3 NTU in 95% of daily samples in any month	The World Health Organization (WHO) also has a turbidity guideline of 5 NTU for drinking water. This guideline is based on the fact that turbidity can affect the taste, smell, and appearance of water. It can also be an indicator of the presence of contaminants, such as bacteria, viruses, and parasites.
Iron as Fe	Not exceeding 0.1 mg/L	Iron as Fe	Not exceeding 0.1 mg/L	The World Health Organization (WHO) also has a guideline value for iron in drinking water of 0.3 mg/L. This guideline value is based on the fact that iron can cause taste and odor problems in water, and can also stain laundry and fixtures.
Manganese as Mn	Not exceeding 0,05 mg/L	Manganese as Mn	Not exceeding 0.05 mg/L	The World Health Organization (WHO) also has a guideline value for manganese in drinking water of 0.4 mg/L. This guideline value is based on the fact that manganese can cause neurological problems in humans. even at low levels.
Aluminium as Al	Not exceeding 0.10 mg/L	Aluminium as Al	Not exceeding 0,10 mg/L	The World Health Organization (WHO) also has a guideline value for aluminium in drinking water of 0,05

				mg/L, This guideline value is based on the fact that aluminium can cause a variety of health problems in humans, even at low levels,
Free residual chlorine	0.5 – 1.5 mg/L	Free residual chlorine	0,5 - 1,5 mg/L	The World Health Organization (WHO) also has a guideline value for free residual chlorine in drinking water of 5 mg/L, This guideline value is based on the fact that free residual chlorine is an effective disinfectant that can kill bacteria and other microorganisms in water, However, free residual chlorine can also react with organic matter in water to form disinfection by products (DBPs), some of which are known carcinogens
Fluoride as F	± 10% of norminal level (current 0.5 mg/L)	Fluoride as F	± 10% of norminal level (current 0,5 mg/L)	The World Health Organization (WHO) also has a guideline value for fluoride in drinking water of 1,5 mg/L. This guideline value is based on the fact that fluoride is an essential nutrient for humans, but that excessive levels of fluoride can cause dental fluorosis and other health problems.
Taste and odour	Unobjecti onable	Taste and odour	Unobjectionable	The World Health Organization (WHO) also has a guideline value for free taste and odor of drinking water of 3 TON. This guideline value is based on te fact that taste and odor can affect the acceptability of water to consumers, Water that has a strong taste or odor may be perceived as being dirty or contaminated, even if it is safe to drink.
Total Coliforms & E.coli (no./100mL)	Absent	Total Coliforms & E.coli (no./100mL)	Absent	The World Health Organization (WHO) also has a guideline value for total coliforms and E, coli in drinking water, The WHO guideline value for total coliforms is 0 CFU/100 mL of water, and the WHO guideline value for E, coli is also 0 CFU/100 mL of water, E. coli is a type of total coliform that is found in the intestines of humans and animals, The presence of total coliforms and E, coli in drinking water can indicate that the

				water has been contaminated with sewage or animal waste.
-	-	Enteropathogenic Protozoa	4-log (99.99%) reduction or inactivation	The WHO guideline value for Giardia lamblia and Cryptosporidium parvum is 0 cysts/oocysts per 100 mL of water. The presence of enteropathogenic protozoa in drinking water can indicate that the water has been contaminated with sewage or animal waste.
-	-	Enteropathogenic Helminths		he World Health Organization (WHO) has established the following standards for enteropathogenic helminths in domestic drinking water: The drinking water should be free from any detectable helminths, including: • Roundworms (Ascaris lumbricoides, Necator americanus, Ancylostoma duodenale) • Whipworms (Trichuris trichiura) •Hookworms (Ancylostoma duodenale) • Strongyloides (Strongyloides stercoralis)
-	-	Viruses	4-log (99.99%) reduction or inactivation	The World Health Organization (WHO) has established the following standard for viruses in domestic drinking water: The drinking water should be free from any detectable viruses, including • Hepatitis A virus (HAV) • Norovirus • Rotavirus • Adenovirus

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Asakizi Nji Augustine[1,2]and*Ajeagah Gideon Aghaindum*[1]