REPUBLIQUE DU CAMEROUN
Paix – Travail – Patrie
****
UNIVERSITE DE YAOUNDE I
FACULTE DES SCIENCES
DEPARTEMENT DE BIOLOGIE ET PHYSIOLOGIE ANIMALES
****
LABORATOIRE D'HYDROBIOLOGIE ET ENVIRONNEMENT

REPUBLIC OF CAMEROUN
Peace – Work – Fatherland
****
UNIVERSITY OF YAOUNDE I
FACULTY OF SCIENCE
DEPARTMENT OF ANIMAL BIOLOGY AND PHYSIOLOGY
****
LABORATORY OF HYDROBIOLOGY AND ENVIRONMENT

Characterisation of benthic macroinvertebrates indicators of organic pollution in the Bamenda urban city (North West Region-Cameroon)

THESIS
Presented and defended in partial fulfillment for the award of a Doctorate/Ph.D. in Biology of Animal Organisms.

Par : **ENAH DICKSON ACHUO**
Master of Science

Sous la direction de
AJEAGAH Gideon AGHAINDUM.,
Associate Professor, University of Yaoundé I
FOTO MENBOHAN Samuel,
Associate Professor, University of Yaoundé I

Année Académique : 2019

UNIVERSITÉ DE YAOUNDÉ I

UNIVERSITY OF YAOUNDE I

FACULTÉ DES SCIENCES

FACULTY OF SCIENCE

DEPARTEMENT DE BIOLOGIE ET PHYSIOLOGIE ANIMALES
DEPARTMENT OF ANIMAL BIOLOGY AND PHYSIOLOGY

ATTESTATION DE CORRECTION DE THESE DE DOCTORAT/Ph.D

Nous soussignés membres du jury de la soutenance de thèse de Doctorat/Ph.D en Biologie des Organismes Animaux, option **Hydrobiologie et Environnement**, de Monsieur **ENAH DICKSON ACHUO**, Matricule **10Q1203**, soutenance autorisée par la correspondance N° 19/00059/UYI/VREPDTIC/QAAC/SPD de Monsieur le Recteur de l'Université de Yaoundé I, en date du 13 mai 2019, attestons que les corrections exigées au candidat lors de cette évaluation faite le 07 juin 2019 ont été réellement effectuées et que le présent document peut être déposé sous sa forme actuelle.

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

Yaoundé le..... 19 FEB 2020 .....

Membres

Président du jury

M. NOLA

Chef de Département

Professeur

UNIVERSITE DE YAOUNDE I

UNIVERSITY OF YAOUNDE I

FACULTE DES SCIENCES

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DEPARTMENT OF ANIMAL BIOLOGY AND PHYSIOLOGY

DÉPARTEMENT DE BIOLOGIE ET PHYSIOLOGIE ANIMALES

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Option: Hydrobiology and Environment

By

ENAH DICKSON ACHUO

Matricule: 10Q1203

Master of Science

Publicly defended on the 07th of June 2019 in the presence of a jury constituted of :

President: NOLA Moïse, Professor, University ofYaoundé I;

Supervisors: AJEAGAH Gideon AGHAINDUM., Associate Professor, University of Yaoundé I;

FOTO MENBOHAN Samuel, Associate Professor, University of Yaoundé I;

Members: DJIETO LORDON Champlain, Professor, University of Yaoundé I;

FONKOU Theophile, Associate Professor, University of Dschang;

ZÉBAZÉ TOGOUET Serge Hubert, Associate Professor, University of Yaoundé I.

Academic year: 2019

UNIVERSITÉ DE YAOUNDÉ I **Faculté des Sciences** Division de la Programmation et du Suivi des Activités Académiques		*THE UNIVERSITY OF YAOUNDE I* ***Faculty of Science*** *Division of Programming and Follow-up of Academic Affaires*

ANNÉE ACADEMIQUE 2018/2019

(Par Département et par Grade)

DATE D'ACTUALISATION 19 Février 2019

ADMINISTRATION

DOYEN : TCHOUANKEU Jean- Claude, *Maitre de Conférences*
VICE-DOYEN / DPSAA : DONGO Etienne, *Professeur*
VICE-DOYEN / DSSE : AJEAGAH Gideon AGHAINDUM, Maître *de Conférences*
VICE-DOYEN / DRC : ABOSSOLO Monique, Maitre de Conférences
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Chef Division des Affaires Académiques, de la Scolarité et de la Recherche DAASR : MBAZE MEVA'A Luc Léonard, *Professeur*

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N°	NOMS ET PRÉNOMS	GRADE	OBSERVATIONS
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2	MBACHAM FON Wilfried	Professeur	En poste
3	MOUNDIPA FEWOU Paul	Professeur	Chef de Département
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5	OBEN Julius ENYONG	Professeur	En poste
6	ACHU Merci BIH	Maître de Conférences	En poste
7	ATOGHO Barbara Mma	Maître de Conférences	En poste
8	BELINGA née NDOYE FOE M. C. F.	Maître de Conférences	Chef DAF / FS
9	BIGOGA DIAGA Jude	Maître de Conférences	En poste
10	BOUDJEKO Thaddée	Maître de Conférences	En poste
11	EFFA NNOMO Pierre	Maître de Conférences	En poste
12	FOKOU Elie	Maître de Conférences	En poste
13	KANSCI Germain	Maître de Conférences	En poste
14	NANA Louise épouse WAKAM	Maître de Conférences	En poste
15	NGONDI Judith Laure	Maître de Conférences	En poste
16	NGUEFACK Julienne	Maître de Conférences	En poste
17	NJAYOU Frédéric Nico	Maître de Conférences	En poste
18	AKINDEH MBUH NJI	Chargée de Cours	En poste
19	AZANTSA KINGUE GABIN BORIS	Chargée de Cours	En poste
20	BEBOY EDZENGUELE Sara Nathalie	Chargée de Cours	En poste
21	DAKOLE DABOY Charles	Chargée de Cours	En poste
22	DJOKAM TAMO Rosine	Chargée de Cours	En poste
23	DJUIDJE NGOUNOUE Marcelline	Chargée de Cours	En poste
24	DJUIKWO NKONGA Ruth Viviane	Chargée de Cours	En poste
25	DONGMO LEKAGNE Joseph Blaise	Chargé de Cours	En poste
26	EWANE Cécile Anne	Chargée de Cours	En poste
27	FONKOUA Martin	Chargé de Cours	En poste
28	BEBEE Fadimatou	Chargée de Cours	En poste
29	KOTUE KAPTUE Charles	Chargé de Cours	En poste
30	LUNGA Paul KEILAH	Chargé de Cours	En poste
31	MANANGA Marlyse Joséphine	Chargée de Cours	En poste

32	MBONG ANGIE M. Mary Anne	Chargée de Cours	En poste
33	MOFOR née TEUGWA Clotilde	Chargée de Cours	Ip Service MINESUP
34	PACHANGOU NSANGOU Sylvain	Chargé de Cours	En poste
35	Palmer MASUMBE NETONGO	Chargé de Cours	En poste
36	TCHANA KOUATCHOUA Angèle	Chargée de Cours	En poste
37	MBOUCHE FANMOE Marceline Joëlle	Assistante	En poste
2- DÉPARTEMENT DE BIOLOGIE ET PHYSIOLOGIE ANIMALES (BPA) (44)			
1	BILONG BILONG Charles-Félix	Professeur	Chef de Département
2	DIMO Théophile	Professeur	En Poste
3	DJIETO LORDON Champlain	Professeur	En Poste
4	ESSOMBA née NTSAMA MBALA	Professeur	*VDoyen/FMSB/UYI*
5	FOMENA Abraham	Professeur	En Poste
6	KAMGANG René	Professeur	*C.S. MINRESI*
7	KAMTCHOUING Pierre	Professeur	En poste
8	NJAMEN Dieudonné	Professeur	En poste
9	NJIOKOU Flobert	Professeur	En Poste
10	NOLA Moïse	Professeur	En poste
11	TAN Paul VERNYUY	Professeur	En poste
12	TCHUEM TCHUENTE Louis Albert	Professeur	*Inspecteur de service* *Coord.Progr./MINSANTE*
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14	DZEUFIET DJOMENI Paul Désiré	Maître de Conférences	En poste
15	FOTO MENBOHAN Samuel	Maître de Conférences	En poste
20	JATSA BOUKENG Hermine épse MEGAPTCHE	Maître de Conférences	En Poste
16	KEKEUNOU Sévilor	Maître de Conférences	En poste
17	MEGNEKOU Rosette	Maître de Conférences	En poste
18	MONY Ruth épse NTONE	Maître de Conférences	En Poste
19	NGUEGUIM TSOFACK Florence	Maître de Conférences	En poste
21	TOMBI Jeannette	Maître de Conférences	En poste
22	ZEBAZE TOGOUET Serge Hubert	Maître de Conférences	En poste
23	ALENE Désirée Chantal	Chargée de Cours	En poste
24	ATSAMO Albert Donatien	Chargé de Cours	En poste
25	BELLET EDIMO Oscar Roger	Chargé de Cours	En poste
26	BILANDA Danielle Claude	Chargée de Cours	En poste
27	DJIOGUE Séfirin	Chargée de Cours	En poste
28	DONFACK Mireille	Chargée de Cours	En poste
29	GOUNOUE KAMKUMO Raceline	Chargée de Cours	En poste
30	KANDEDA KAVAYE Antoine	Chargé de Cours	En poste
31	LEKEUFACK FOLEFACK Guy B.	Chargé de Cours	En poste
32	MAHOB Raymond Joseph	Chargé de Cours	En poste
33	MBENOUN MASSE Paul Serge	Chargé de Cours	En poste
34	MOUNGANG LucianeMarlyse	Chargée de Cours	En poste
35	MVEYO NDANKEU Yves Patrick	Chargé de Cours	En poste
36	NGOUATEU KENFACK Omer Bébé	Chargé de Cours	En poste
37	NGUEMBOK	Chargé de Cours	En poste
38	NJUA Clarisse Yafi	Chargée de Cours	Chef Div. UBA
39	NOAH EWOTI Olive Vivien	Chargée de Cours	En poste
40	TADU Zephyrin	Chargé de Cours	En poste
41	YEDE	Chargé de Cours	En poste
43	ETEME ENAMA Serge	Assistant	En poste

44	KOGA MANG DOBARA	Assistant	En poste
3- DÉPARTEMENT DE BIOLOGIE ET PHYSIOLOGIE VÉGÉTALES (BPV) (27)			
1	AMBANG Zachée	Professeur	Chef Division/UYII
2	BELL Joseph Martin	Professeur	En poste
3	MOSSEBO Dominique Claude	Professeur	En poste
4	YOUMBI Emmanuel	Professeur	Chef de Département
5	ZAPFACK Louis	Professeur	En poste
6	ANGONI Hyacinthe	Maître de Conférences	En poste
7	BIYE Elvire Hortense	Maître de Conférences	En poste
8	DJOCGOUE Pierre François	Maître de Conférences	En poste
9	KENGNE NOUMSI Ives Magloire	Maître de Conférences	En poste
10	MALA Armand William	Maître de Conférences	En poste
11	MBARGA BINDZI Marie Alain	Maître de Conférences	CT/Uds
12	MBOLO Marie	Maître de Conférences	En poste
13	NDONGO BEKOLO	Maître de Conférences	*CE / MINRESI*
14	NGONKEU MAGAPTCHE Eddy L.	Maître de Conférences	En poste
15	TSOATA Esaïe	Maître de Conférences	En poste
16	GOMANDJE Christelle	Chargée de Cours	En poste
17	MAFFO MAFFO Nicole Liliane	Chargé de Cours	En poste
18	MAHBOU SOMO TOUKAM. Gabriel	Chargé de Cours	En poste
19	NGALLE Hermine BILLE	Chargée de Cours	En poste
20	NGOUO Lucas Vincent	Chargé de Cours	En poste
22	NOUKEU KOUAKAM Armelle	Chargé de Cours	En poste
23	ONANA JEAN MICHEL	Chargé de Cours	En poste
24	NSOM ZAMO Annie Claude épse PIAL	Chargée de Cours	*Expert national/UNESCO*
25	TONFACK Libert Brice	Chargé de Cours	En poste
26	DJEUANI Astride Carole	Assistante	En poste
27	NNANGA MEBENGA Ruth Laure	Assistante	En poste
4- DÉPARTEMENT DE CHIMIE INORGANIQUE (CI) (32)			
1	AGWARA ONDOH Moïse	Professeur	*Vice RecteurUniv ,Ba*
2	ELIMBI Antoine	Professeur	En poste
3	Florence UFI CHINJE épouse MELO	Professeur	*Recteur Univ.Ndre*
4	GHOGOMU Paul MINGO	Professeur	*Ministre Chargé deMiss.PR*
5	NANSEU Njiki Charles Péguy	Professeur	En poste
6	NDIFON Peter TEKE	Professeur	*CT MINRESI/Chef de Departement*
7	NDIKONTAR Maurice KOR	Professeur	*Vice-Doyen Univ. Ba*
8	NENWA Justin	Professeur	En poste
9	NGAMENI Emmanuel	Professeur	*DOYEN FS Uds*
10	BABALE née DJAM DOUDOU	Maître de Conférences	*Chargée Mission P.R.*
11	DJOUFAC WOUMFO Emmanuel	Maître de Conférences	En poste
12	KAMGANG YOUBI Georges	Maître de Conférences	En poste
13	KEMMEGNE MBOUGUEM Jean C.	Maître de Conférences	En poste
14	KONG SAKEO	Maître de Conférences	*En poste*
16	NGOMO Horace MANGA	Maître de Conférences	*Vice Chancelor/UB*
17	NJIOMOU C. épse DJANGANG	Maître de Conférences	En poste
18	NJOYA Dayirou	Maître de Conférences	En poste
19	YOUNANG Elie	Maître de Conférences	En poste
20	ACAYANKA Elie	Chargé de Cours	En poste
21	BELIBI BELIBI Placide Désiré	Chargé de Cours	CS/ ENS Bertoua

22	CHEUMANI YONA Arnaud M.	Chargé de Cours	En poste
23	EMADACK Alphonse	Chargé de Cours	En poste
24	KENNE DEDZO GUSTAVE	Chargé de Cours	En poste
24	KOUOTOU DAOUDA	Chargé de Cours	En poste
25	MAKON Thomas Beauregard	Chargé de Cours	En poste
26	MBEY Jean Aime	Chargé de Cours	En poste
27	NCHIMI NONO KATIA	Chargé de Cours	En poste
28	NDI NSAMI Julius	Chargé de Cours	En poste
29	NEBA nee NDOSIRI Bridget NDOYE	Chargée de Cours	Ip/Service MINFEM
30	NYAMEN Linda Dyorisse	Chargée de Cours	En poste
31	PABOUDAM GBAMBIE A.	Chargée de Cours	En poste
32	TCHAKOUTE KOUAMO Hervé	Chargé de Cours	En poste
5- DÉPARTEMENT DE CHIMIE ORGANIQUE (CO) (32)			
1	DONGO Etienne	Professeur	Vice-Doyen / PSAA
2	GHOGOMU TIH Robert Ralph	Professeur	Dir. IBAF/UDS
3	NGOUELA Silvère Augustin	Professeur	En poste
4	NKENGFACK Augustin Ephreïm	Professeur	Chef de Département
5	NYASSE Barthélemy	Professeur	*Directeur/UN*
6	PEGNYEMB Dieudonné Emmanuel	Professeur	*Directeur/ MINESUP*
7	WANDJI Jean	Professeur	En poste
8	Alex de Théodore ATCHADE	Maître de Conférences	*DEPE/ Rectorat/UYI*
9	EYONG Kenneth OBEN	Maître de Conférences	*Chef Service DPER*
10	FOLEFOC Gabriel NGOSONG	Maître de Conférences	*En poste*
11	KEUMEDJIO Félix	Maître de Conférences	En poste
12	KEUMOGNE Marguerite	Maître de Conférences	En poste
13	KOUAM Jacques	Maître de Conférences	En poste
14	MBAZOA née DJAMA Céline	Maître de Conférences	En poste
15	MKOUNGA Pierre	Maître de Conférences	En poste
16	NGO MBING Joséphine	Maître de Conférences	S/Direct. MINERESI
17	NOUNGOUE TCHAMO Diderot	Maître de Conférences	En poste
18	TABOPDA KUATE Turibio	Maître de Conférences	En poste
19	TCHOUANKEU Jean-Claude	Maître de Conférences	*Doyen /FS/ UYI*
20	TIH née NGO BILONG E. Anastasie	Maître de Conférences	En poste
21	YANKEP Emmanuel	Maître de Conférences	En poste
22	AMBASSA Pantaléon	Chargé de Cours	En poste
23	FOTSO WABO Ghislain	Chargé de Cours	En poste
24	KAMTO Eutrophe Le Doux	Chargé de Cours	En poste
25	MVOT AKAK CARINE	Chargé de Cours	En poste
26	NGOMO Orléans	Chargée de Cours	En poste
27	NGONO BIKOBO Dominique Serge	Chargé de Cours	En poste
28	NOTE LOUGBOT Olivier Placide	Chargé de Cours	Chef Serv/MINESUP
29	OUAHOUO WACHE Blandine M.	Chargée de Cours	En poste
30	TAGATSING FOTSING Maurice	Chargé de Cours	En poste
31	ZONDENDGOUMBA Ernestine	Chargée de Cours	En poste
32	NGNINTEDO Dominique	Assistant	En poste
6- DÉPARTEMENT D'INFORMATIQUE (IN) (25)			
1	ATSA ETOUNDI Roger	Professeur	*Chef Div.MINESUP*
2	FOUDA NDJODO Marcel Laurent	Professeur	*Chef Dpt ENS/Chef IGA.MINESUP*
3	NDOUNDAM Réné	Maître de Conférences	En poste
4	AMINOU Halidou	Chargé de Cours	En poste
5	DJAM Xaviera YOUHEP KIMBI	Chargé de Cours	En Poste

6	KOUOKAM KOUOKAM E. A.	Chargé de Cours	En poste
7	MELATAGIA YONTA Paulin	Chargé de Cours	En poste
8	MOTO MPONG Serge Alain	Chargé de Cours	En poste
9	TAPAMO Hyppolite	Chargé de Cours	En poste
10	ABESSOLO ALO'O Gislain	Chargé de Cours	En poste
11	KAMGUEU Patrick Olivier	Chargé de Cours	En poste
12	MONTHE DJIADEU Valery M.	Chargé de Cours	En poste
13	OLLE OLLE Daniel Claude Delort	Chargé de Cours	C/D Enset. Ebolowa
14	TINDO Gilbert	Chargé de Cours	En poste
15	TSOPZE Norbert	Chargé de Cours	En poste
16	WAKU KOUAMOU Jules	Chargé de Cours	En poste
17	BAYEM Jacques Narcisse	Assistant	En poste
18	DOMGA KOMGUEM Rodrigue	Assistant	En poste
19	EBELE Serge	Assistant	En poste
20	HAMZA Adamou	Assistant	En poste
21	JIOMEKONG AZANZI Fidel	Assistant	En poste
22	KAMDEM KENGNE Christiane	Assistante	En poste
23	MAKEMBE. S . Oswald	Assistant	En poste
24	MEYEMDOU Nadège Sylvianne	Assistante	En poste
25	NKONDOCK. MI. BAHANACK.N.	Assistant	En poste
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2	DOSSA COSSY Marcel	Professeur	En poste
3	AYISSI Raoult Domingo	Maître de Conférences	Chef de Département
4	EMVUDU WONO Yves S.	Maître de Conférences	*CD Info/ Chef division MINESUP*
5	NKUIMI JUGNIA Célestin	Maître de Conférences	En poste
6	NOUNDJEU Pierre	Maître de Conférences	En poste
7	TCHAPNDA NJABO Sophonie B.	Maître de Conférences	Directeur/AIMS Rwanda
8	AGHOUKENG JIOFACK Jean Gérard	Chargé de Cours	Chef Cellule MINPLAMAT
9	CHENDJOU Gilbert	Chargé de Cours	En poste
10	DJIADEU NGAHA Michel	Chargé de Cours	En poste
11	DOUANLA YONTA Herman	Chargé de Cours	En poste
12	FOMEKONG Christophe	Chargé de Cours	En poste
13	KIANPI Maurice	Chargé de Cours	En poste
14	KIKI Maxime Armand	Chargé de Cours	En poste
15	MBAKOP Guy Merlin	Chargé de Cours	En poste
16	MBANG Joseph	Chargé de Cours	En poste
17	MBEHOU Mohamed	Chargé de Cours	En poste
18	MBELE BIDIMA Martin Ledoux	Chargé de Cours	En poste
19	MENGUE MENGUE David Joe	Chargé de Cours	En poste
20	NGUEFACK Bernard	Chargé de Cours	En poste
21	NIMPA PEFOUNKEU Romain	Chargée de Cours	En poste
22	POLA DOUNDOU Emmanuel	Chargé de Cours	En poste
23	TAKAM SOH Patrice	Chargé de Cours	En poste
24	TCHANGANG Roger Duclos	Chargé de Cours	En poste
25	TCHOUNDJA Edgar Landry	Chargé de Cours	En poste
26	TETSADJIO TCHILEPECK M. E.	Chargée de Cours	En poste
27	TIAYA TSAGUE N. Anne-Marie	Chargée de Cours	En poste
28	MBIAKOP Hilaire George	Assistant	En poste
8- DÉPARTEMENT DE MICROBIOLOGIE (MIB) (12)			

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2	ETOA François Xavier	Professeur	Chef de Département/FS/UYI Recteur Université de Douala
3	BOYOMO ONANA	Maître de Conférences	En poste
4	NWAGA Dieudonné M.	Maître de Conférences	En poste
5	NYEGUE Maximilienne Ascension	Maître de Conférences	En poste
6	RIWOM Sara Honorine	Maître de Conférences	En poste
7	SADO KAMDEM Sylvain Leroy	Maître de Conférences	En poste
8	ASSAM ASSAM Jean Paul	Chargé de Cours	En poste
9	BODA Maurice	Chargé de Cours	En poste
10	BOUGNOM Blaise Pascal	Chargé de Cours	En poste
11	ESSONO OBOUGOU Germain G.	Chargé de Cours	En poste
12	NJIKI BIKOÏ Jacky	Chargée de Cours	En poste
13	TCHIKOUA Roger	Chargé de Cours	En poste
9. DEPARTEMENT DE PYSIQUE(PHY) (40)			
1	BEN- BOLIE Germain Hubert	Professeur	En poste
2	ESSIMBI ZOBO Bernard	Professeur	En poste
3	KOFANE Timoléon Crépin	Professeur	En poste
4	NDJAKA Jean Marie Bienvenu	Professeur	Chef de Département
5	NJANDJOCK NOUCK Philippe	Professeur	*S/ Directeur/ MINRESI*
6	NJOMO Donatien	Professeur	En poste
7	PEMHA Elkana	Professeur	En poste
8	TABOD Charles TABOD	Professeur	Doyen Univ/Bda
9	TCHAWOUA Clément	Professeur	En poste
10	WOAFO Paul	Professeur	En poste
	BIYA MOTTO Frédéric	Maître de Conférences	DG/HYDRO Mekin
14	BODO Bertrand	Maître de Conférences	En poste
12	DJUIDJE KENMOE épouse ALOYEM	Maître de Conférences	En poste
15	EKOBENA FOUDA Henri Paul	Maître de Conférences	*Chef Division. UN*
16	EYEBE FOUDA Jean sire	Maître de Conférences	En poste
17	FEWO Serge Ibraïd	Maître de Conférences	En poste
18	HONA Jacques	Maître de Conférences	En poste
19	MBANE BIOUELE César	Maître de Conférences	En poste
20	NANA ENGO Serge Guy	Maître de Conférences	Director/ UB
21	NANA NBENDJO Blaise	Maître de Conférences	En poste
22	NOUAYOU Robert	Maître de Conférences	En poste
23	SAIDOU	Maître de Conférences	S/Directeur/Minresi
24	SIEWE SIEWE Martin	Maître de Conférences	En poste
25	SIMO Elie	Maître de Conférences	En poste
26	VONDOU Derbetini Appolinaire	Maître de Conférences	En poste
27	WAKATA née BEYA Annie	Maître de Conférences	*S/ Dir/* MINESUP
28	ZEKENG Serge Sylvain	Maître de Conférences	En poste
29	ABDOURAHIMI	Chargé de Cours	En poste
30	EDONGUE HERVAIS	Chargé de Cours	En poste
31	ENYEGUE A NYAM épse BELINGA	Chargée de Cours	En poste
32	FOUEDJIO David	Chargé de Cours	Chef Cell. MINADER
33	MBINACK Clément	Chargé de Cours	En poste
34	MBONO SAMBA Yves Christian U.	Chargé de Cours	En poste
35	MELI'I Joelle Larissa	Chargée de Cours	*En poste*

36	MVOGO ALAIN	Chargé de Cours	*En poste*
37	NDOP Joseph	Chargé de Cours	En poste
38	OBOUNOU Marcel	Chargé de Cours	DA/Univ Inter Etat/Sangmalima
39	WOULACHE Rosalie Laure	Chargée de Cours	En poste
40	CHAMANI Roméo	Assistant	En poste
10- DÉPARTEMENT DE SCIENCES DE LA TERRE (ST) (43)			
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2	FOUATEU Rose épse YONGUE	Professeur	En poste
3	KAMGANG Pierre	Professeur	En poste
4	MEDJO EKO Robert	Professeur	*CT/UYII*
5	NDJIGUI Paul Désiré	Professeur	Chef de Département
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BPA	12 (1)	10 (5)	20 (07)	2 (0)	**44 (13)**
BPV	5 (0)	10(2)	9 (04)	2(02)	**26 (9)**
CI	9(1)	9(2)	14 (3)	0 (0)	**32 (6)**
CO	7 (0)	14 (4)	10 (4)	1 (0)	**32(8)**
IN	2 (0)	1 (0)	13 (0)	10 (3)	**26 (3)**
MAT	2 (0)	4 (1)	19 (1)	2 (0)	**27 (2)**
MIB	2 (0)	5 (2)	5 (1)	0 (0)	**12 (3)**
PHY	10 (0)	17(2)	11 (3)	1 (0)	**39 (5)**
ST	7 (1)	15 (1)	21 (5)	1 (0)	**43(7)**
Total	**61 (4)**	**97 (25)**	**141 (39))**	**19(6)**	**318 (75)**

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DEDICATION

To

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LIST OF ABBREVIATIONS AND ACRONYMS

ACC: Canonical Correspondence Analysis

ACH: Hierarchical Classification Analysis

ACP: Principal Components Analysis

AE: Water Agencies

AFD: Discriminant Factor Analysis

APHA: American Public Health Association

BCC: Bamenda City Council

BOD_5: Biochemical Oxygen Demand for 5 days

BUC: Bamenda Urban Community

CBA: Center Business District

CB: Chironomidae Bassomatophora

CEAEQ: Center of Expertise in Environmental Analysis of Quebec

DNM: National Direction of Meteorology

DO: Dissolved oxygen

EC: Electrical conductivity

EPT: Ephemeroptera, Plecoptera, Trichoptera

ETC: Ephemeroptera, Trichoptera, Coleoptera

ETOC: Ephemeroptera – Trichoptera – Odonata- Coleoptera

EPTD: Ephemeroptera, Plecoptera, Trichoptera, Diptera

EPTH: Ephemeroptera, Plecoptera, Trichoptera, Hemiptera

ETM: Traces Metallic Elements

EXCEED: Excellent Centers for Exchange and Development

GPS: Global Positioning System

HYSACAM: Hygiene and Health of Cameroon

INRA: National Institute of Agronomic Research

InVal: Indicator Value

IPO: Organic Pollution Index

SS: Suspensed Solids

MINEPDED: Ministry of the Environment, Nature Protection and Sustainable Development

NTU: Nephelometric Turbidity Units

OPI: Organic Pollution Indice

WHO: World Health Organization

PNDP: National Participatory Development Program

POP: Persistent Organic Pollutants

RCC: River Continuum Concept

GCPH: General Census of Population and Housing

GRA: Government Residential Area

SOM: Self-Organizing Maps

TDS: Total Dissolved Solids

TE: Topographic Error

VBDL: Vector Borne Diseases Laboratory

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ABSTRACT

Freshwater resources are increasingly being subjected to organic pollution because of the escalating growth of human population which is accompanied by urbanization and the increasing demand for food (Agriculture) and habitat. Consequently, freshwater quality and aquatic ecosystem structure and function are severely affected. The Mezam River drainage, which flows across the city of Bamenda, North West Region of Cameroon is no exception.

This study, seeks to evaluate the biological and physicochemical state of the Mezam River and it's affluent streams that flows across the city of Bamenda. Very little data is available on water quality and diversity of benthic macroinvertebrates of these hydrosystems. Moreover, the real impact of urban and agricultural wastes on these invertebrates remains to be determined. The main aim of this study was to evaluate the influence of urbanization on the physical and chemical qualities of streams and the diversity of macroinvertebrate's community as indicators of organic pollution in some urban aquatic ecosystems in the Bamenda municipality. The specific objectives are: to determine the physico-chemical parameters of the drainage system; the bio-identification of benthic macroinvertebrate communities, indicators of aquatic pollution in Mezam river; to determine the structural adaptations of some macro-invertebrates, bioindicators of aquatic pollution levels in the savana high lands of the North West Region and to evaluate the relationship between physicochemical and biological community structure and water quality. A total of 13 sampling stations were selected in 5 streams that flow across the center city of Bamenda. In each of the stations, sampling were carried out each month over a 13-month period (from January 2017 to January 2018).

Analysis of abiotic variables showed that, the Mufueh and Mezam streams that are located at the periphery of the city, presented a high vegetation cover and were of good ecological status. They are well oxygenated, of low temperatures with very low mineralization and have a very low organic pollution load. Conversely the Furmuki, Mankon and Ayabah streams which goes across the main urban settlement, prove to be highly polluted according to OPI and reveal higher values of heavy metals, high temperatures, with high mineralization. These urban streams are subjected to domestic, municipal and agricultural pollution as they constitute the main receptors of the different types of wastes.

Regarding the biotic communities, 115 taxa of benthic macroinvertebrates distributed into 3 phyla, 4 classes, 10 orders and 56 families were identified in all the streams studied. The biotic community of the Mufueh River is the most diversified with 94 taxa, whereas just

60, 57, 55 and 36 taxa were identified in the Furmuki, Mankon, Ayabah and Mezam rivers respectively.

The Mufueh River was dominated by Insects which were the most diversified class with 97 taxa that were essentially composed of sensitive species especially *Limnometra* sp. and *Aeshna* sp. that where totally absent in the other four streams. On the ecological point of view, this invertebrate community is mainly constituted by predators and organisms with gills, highlighting an unpolluted medium. *Limnometra ciliata May* 1965 (Heteroptera-Gerridae), a species known to be endemic in Northern zones of America, was found in the Mufueh stream. The species *Aeshna* sp. is reported for the first time in freshwater in Cameroon which indicate average pollution. The high occurrence of sensitive taxa and the great diversity of benthic macroinvertebrates in the Mufueh River reveals high levels of biodiversity and ecological integrity.

Contrarily to the Mufueh river, the other three rivers of the drainage basin (Furmuki, Mankon and Ayabah), showed an abundance of tolerant insects groups. The benthic fauna is less diversified and comprised essentially of Dipterans, Molluscs and Annelids, which are, in their majority, tolerant to pollution. From a functional point of view, these taxa are primarily saprophytes, filterers, and rely on their tegument for breathing. These overall results shows a high polluted urban waterways within the Bamenda municipality.

The genera and species within the family Chironomidae in the present study presented varying degrees of sensitivity to water quality deterioration and therefore provided evidence of their bio-indication of high organic pollution in the Bamenda streams. An evaluation of the mouth part deformities in Chironomidae, revealed 19 % mentum deformity and 8% mandible deformity as a result of organic pollution. This is particularly useful because, it provided evidence of the adverse effects of pollution in the different streams on the chironomid communities and may serve as biological impact of deteriorating water quality in this aquatic ecosystems. Morphological deformities also provide indication of species health and fitness of Chironomids, which could impact on their ability to feed, and to perform ecological roles such as linking other food chains and webs, utilization of energy and nutrients cycling in the Bamenda drainage system.

Keywords: Urbanization, pollution, benthic macroinvertebrates, Bamenda, Indicator species, mouth part deformities.

RÉSUMÉ

Les ressources en eau douce sont de plus en plus soumises à la pollution en raison de la croissance démographique exponentielle qui s'accompagne de l'urbanisation et de la demande accrue en nourriture (agriculture). Par conséquent, la qualité de l'eau douce, la structure et la fonction des écosystèmes aquatiques ont été gravement affectées. Le bassin versant du cours d'eau Mezam, qui draine les eaux de la ville de Bamenda dans la Région du Nord-Ouest du Cameroun, ne fait pas exception. Le but de la présente étude est de déterminer l'influence de l'urbanisation sur la qualité physicochimique et sur la diversité des peuplements des macroinvertébrés, bioindicateurs de la pollution organique, dans quelques cours d'eau de la ville de Bamenda.

Pour mener à bien cette étude, 13 stations ont été sélectionnées de facon aléatoire sur la rivière Mezam et ses affluents dan la ville de Bamenda. Elle avait pour objectifs : 1) de déterminer les variables physico-chimiques de ces eaux ; 2) d'analyser la diversité des communautés de macroinvertébrés benthiques ; 3) déterminer les adaptations structurelles de certains macroinvertébrés benthiques au niveau des zones de hautes altitudes dans la Région du Nord-Ouest et 4) d'évaluer les relations entre les paramètres physicochimiques, la structure de la communauté biologique et la qualité des eaux. Les échantillons ont été recoltés suivant une fréquence mensuelle de janvier 2017 à janvier 2018 suivant les méthodes standards.

L'analyse des variables abiotiques a montré que les cours d'eau Mufueh et Mezam, situés à la périphérie de la ville de Bamenda présente un couvert végétal très abondant, présentent un bon état écologique. Leurs eaux sont bien oxygénées, avec des températures moyennes faibles, une minéralisation très faible et une faible charge de pollution organique. À l'inverse, les cours d'eau Furmuki, Mankon et Ayabah, qui traversent le centre urbain, se sont révélés très pollués et présentent des valeurs plus élevées en métaux lourds, des températures moyennes élevées et une forte minéralisation. Ces eaux urbaines sont soumises à des pollutions domestiques, municipales et agricoles, car ils constituent les principaux récepteurs des différents types de déchets.

En ce qui concerne les variables biotiques, 115 taxons de macroinvertébrés benthiques répartis dans 3 phylums, 4 classes, 10 ordres et 56 familles ont été recoltés et identifiés dans tous les cours d'eau étudiés. La communauté biotique de la rivière Mufueh est la plus diversifiée avec 94 taxons, alors que seuls 60, 57, 55 et 36 taxons ont été identifiés dans les rivières Furmuki, Mankon, Ayabah et Mezam respectivement.

La classe des insectes est la plus abondante dans la rivière Mufueh et est représente également le groupe zoologique le plus diversifié avec 97 taxons composés essentiellement d'espèces sensibles, en particulier *Limnometra* sp.et *Aeshna* sp. qui sont totalement absents dans les quatre autres cours d'eau. Sur le plan écologique, cette communauté d'invertébrés suburbains est principalement constituée de prédateurs et de taxons respirant avec des branchies, mettant en évidence un milieu non perturbé. *Limnometra ciliata* May 1965 (Heteroptera- Gerridae), une espèce connue pour être endémique dans les zones de l'Amérique du nord, a été trouvée à Mufueh. L'espèce *Aeshna* sp. (Odonata-Aeshnidae) est signalé pour la première fois dans les eaux de surface au Cameroun. La présence accrue de taxons sensibles et la grande diversité des macroinvertébrés benthiques dans la rivière Mufueh témoignent de sa bonne intégrité écologique.

Contrairement au cours d'eau Mufueh, la faune benthique des trois autres cours d'eau du bassin versant de la Mezam (Furmuki, Mankon et Ayabah) est moins diversifiée et comprend essentiellement des diptères, des mollusques et des annélides, qui sont majoritairement tolérants à la pollution organique. Les insectes qui sont très abondants dans ces cours d'eau utilisent d'autres méthodes de respiration que les branchies. Du point de vue fonctionnel, les taxons récoltés lors de la présente étude sont principalement des saprophytes, des filtreurs et utilisent leur tégument pour la respiration. De manière globale, les résultats montrent que les cours d'eau urbains sont fortement polluées dans la ville de Bamenda.

Dans cette étude, les genres et les espèces de la famille des Chironomidae ont montré divers degrés de sensibilité face à la détérioration de la qualité de l'eau et ont donc démontré leur potentiel de bio-indication dans les cours d'eau de Bamenda. L'examen des déformations des pièces buccales chez les Chironomidae, a montré une déformation du mentum de 19% et une déformation de la mandibule de 8% due à la pollution organique. Cela est particulièrement utile car il a permis la mise en évidence des effets néfastes de la pollution sur les communautés des chironomes.

Les déformations morphologiques des pièces buccales des chironomidés pourraient avoir un impact sur leur capacité à se nourrir et à jouer des rôles écologiques tels que : la liaison à d'autres chaînes alimentaires et l'utilisation de l'énergie et des substances dans les eaux du bassin versant de Bamenda. Ces déformations morphologiques pourraient donc être utilisées pour avoir des indications sur la santé de l'écosystème.

Mots-clés: Urbanisation, pollution, macroinvertébrés benthiques, Bamenda, espèces indicatrices, déformations de la partie buccale.

INTRODUCTION

Rivers are ecosystems with great ecological value, with a rich fauna that consists of complex community structures and a high biological value. However, their special typology makes them fragile and vulnerable to environmental changes especially, those related to anthropogenic perturbations which often imply the reversible degradation of their biota (Beasley and Kneale, 2003; Dahl *et al*., 2004). As a consequence, the biodiversity of most rivers will be reduced and their biogeochemical cycles will be altered (Jenkins *et al*., 1993). One of the major problems affecting rivers is pollution from both domestic and industrial wastes (Benetti and Garrido, 2010).

Pollutants from both urban and agricultural activities exert considerable pressure on aquatic ecosystems which results in the deterioration of the water and habitat's quality on which the aquatic organisms depend (Wang *et al.,* 2012). Aquatic organisms integrate various types and degrees of environmental impacts which occur on a variety of spatial and temporal scales (Colas *et al.*, 2014). The word "urbanization" is defined as the movement of people from the royal areas to towns and cities accompanied by an increase habitant in a precise location. It leads to an increase in the proportion of national or regional population living within cities (Abbott, 2003). The rapid pace of urbanization in Bamenda ultimately affects its wetland ecosystem as urban development is gradually encroaching into the wetlands to secure space for multiple urban functions. Anthropogenic activities such as settlement, conversion of wetlands into farm land, waste dump sites reduces this ability (Balgah and Kimengsi, 2016). Urbanization in this city is anarchical with precarious sanitation systems, housing facilities and industrial buildings are blended in the same place. This leads to high promiscuity, and consequently to high pollution sources (Feumba *et al.,* 2011; Schuetze and Chelleri, 2013).

Among the fauna of rivers that should be highlighted are macro-invertebrates. This group which shows great diversity and ecological importance consists of invertebrates of macroscopic size that are approximately greater than 1mm; living permanently or during certain periods of their life cycle in water. They include insects, crustaceans, annelids, molluscs, leeches, etc (Tachet *et al,* 2010). Different groups of macroinvertebrates are excellent indicators of human actions, especially contamination. Most of them have quite narrow ecological requirements and are very useful as bio-indicators in determining the characteristics of aquatic environments (Benetti and Garrido, 2010; Fernández-Díaz *et al*., 2008), as well as identify the segments of the polluted river which undergo the process of self-purification (Chatzinikolaou and Lazaridou 2007).

Bamenda city has experienced a progressive deterioration in its environmental quality as a result of rapid and unplanned urbanization that took off since the early 80's (Kometa and

Ndi, 2012). The increased pollution of freshwater ecosystems has negatively affected their capacity to provide clean and reliable sources of freshwater, to maintain the natural hydrological cycle and biological food webs, and to provide food and to recycle nutrients. Hydro biological studies done so far in and around Cameroon, were carried out mostly along the different hydro systems of the Centre and Littoral regions geared towards; evaluating their healthy state based on their community structure (Foto Menbohan and Njine, 1998; Foto Menbohan *et al.* 2012; Ajeagah *et al.,* 2010; Tchakonte, 2014). However, the town of Bamenda which has an important hydrographic network has little or no data on the physico-chemical qualities of its water bodies and the biodiversity of the various macro invertebrates found in the aquatic systems of the Bamenda municipality. Furthermore, the impact of urbanization on the diversity and the spatio-temporal variation of these groups of organisms have been ignored.

The main aim of this study is to determine the influence of urbanization on the physical and chemical characterisation of streams and to evaluate the diversity of macro invertebrate's community in some urban streams in the town of Bamenda.

The specific objectives are to 1) determine the physico-chemical parameters of the drainage system in relation to human disturbance; 2) assess the benthic macroinvertebrate communities, in Mezam river, 3) identify the structural adaptations of some macro-invertebrates indicators of aquatic pollution in the savana high lands of the North West Region and 4) evaluate the relationship between physicochemical and biological community structure and water quality.

After the introduction, this thesis is arranged under three chapters; with the first being literature review, which seeks to explain the various processes affecting the deterioration of rivers and the methods used to evaluate pollution. In the second chapter, comes the material and the methods used for this study. The presentation of the results obtained, their interpretation and the discussion are covered in the third chapter. After the above chapters, follows a conclusion, recommendations and the perspectives for future research

CHAPTER I
LITERATURE REVIEW

I-1- GENERAL CONTEXT

The social context of Bamenda is characterized by rapid urbanization which is typical of towns in developing countries. The rate of urbanization in Bamenda like in other towns of the south is alarming (Fodouop and Mougoué, 1997). According to Mougeot, (2000), urbanization within developing countries is occurring at an unprecedented rate. This rapid increase results from ruralexodus and natural increase of the population size. The rapid population growth in Bamenda is causing problems of unemployment, poverty, food insecurity and hunger leading to adoption of urban agriculture with its consequences on the landscape (Kimengsi, 2011).

I-1-1- Wetlands usage in Bamenda

Wetlands occupy a central position as far as the earth's natural resource base is concern. They offer numerous ecosystem services as spelt out by the 1971 Ramsar Convention (Ramsar Information Sheet 2009-2012). A result of urban development, affects the management of wetlands. The causal mechanisms associated with land-use change remain relatively poorly understood in part because of the complexity of urban systems. Consequently, urban planners and policy makers are often faced with a difficult task in making land-use decisions without sufficient analyses or vision (Sun *et al.*, 2009).This is the case with the town of Bamenda which is witnessing rapid urbanization that is characterized by the multiplication of her major land uses (agricultural, settlement and administrative land uses) . Bamenda is home to major wetlands such as in Ngomgham, Mulang and Menda-Nkwen. As the town continues to witness rapid multiplication of land uses due to her primacy status, wetland encroachment and degradation has been aggravated. In other words, this rapid pace of urbanization in Bamenda ultimately affects its wetland ecosystem as urban development is encroaching onto the wetlands to secure space for multiple urban functions. Anthropogenic activities such as settlement, conversion of wetlands into farm land, waste dump sites reduces the ability of wetlands to build resistance and resilience leading to eventual collapse. Previous studies on land use dynamics have focused on its connection with population growth and their effect on the environment (Kimengsi, 2011; Lambi and Balgah, 2010; Balgah *et al.*, 2008), and land use conflicts (Kimengsi, 2009; Kimengsi, 2008). In addition, the hydro-geomorphological implications of urbanization have also been researched upon including the causes and effects of land use changes (Kometa and Ndi, 2012). However, their implications on wetland management have received little attention. This is particularly necessary at a time when the Bamenda City Council has embarked on moves towards

conserving, restoring and revitalizing wetland environments in Bamenda against the backdrop of increasing land use dynamics precipitated by human activities – agriculture, settlement, commerce and waste disposal.

I-1-2- Straightening river channels

Urban population dispose solid waste at random in towns where only little government effort can possibly remove the garbage from such build up points that are urban and no man's land such as bridges and stream banks leading to floods. Such areas have emerged to gain some significance in some quarters along the River Mezam tributaries in Bamenda (Lambi and Fogwe, 2001; Fogwe, 2016). This urban inhabitants along River Mezam tributaries in Bamenda and those who occupy the flood plains have put in numerous but failed strategies to combat flood hazard situation, with most constructing embankments, raising foundations, doing channel widening and land reclamation along the streams (Fogwe, 2016) as presented in figure 1.

Figure 1: Channel straightening, embankment and channel reduction for land reclamation purposes (*Source*: Fogwe, 2016).

It is widely recognized that channelization for land use and flood control has profound effects on stream communities (Swales, 1982; Brookes, 1988). In particular, the practice of

channel straightening eliminates morphological features of natural streams such as: meanders and pool-riffle sequences. Numerous studies have reported that losses of habitat heterogeneity caused by channelization decrease abundance and species diversity of fish and macro invertebrates
(Quinn *et al*., 1992; Toyoshima *et al*., 1996).

I-1-3- The effect of land use and activities on water quality

Perennial rivers provide a steady and readily available source of water for people living within that area. However, depending on the purpose of the water usage, this might impact the water quality in a negative way. Firstly, Sand mining talk of; which is the action of removing sand from a river bed for further use that is; for construction and other related purposes. The most common sources are river channel deposits, flood plains, alluvial deposits and residual soil deposits. Tan Peck Yen and Rohasliney (2013) reported effects such as negative change of water quality in theriver, especially regarding suspended solids (SS), turbidity, nitrate concentration as well as river bank erosion and degradation of the river bed. One effect of this; is poor and stressful conditions for the aquatic life. Sand and other smaller particles stirred up during sand mining activities can be transported a long way, depending on the nature of the stream and the size of the particles, resulting to high turbidity and the deposition of sediments downstream. Furthermore, Sreedharan and Damodaran (2011) conclude that the lack of adequate information on the environmental impact of sand river mining is a major challenge regarding regulatory efforts and management in many developing countries. This means that a satisfactory scientific assessment is a pre-requisite in formulating management in such areas.

Again, water is used in carrying out laundry activities which involves the washing of clothes, as well as personal hygiene, directly in, or nearby rivers and streams is common in many parts of the world. Often some sort of soap or detergent containing surfactants is used, meaning soapy water being expelled directly inside water often results in the observation of high concentrations of surfactant within urban streams close to their emission points. Jönsson *et al.* (2005) studied the concentration of the commonly used anionic surfactant; linear alkylbenzene sulphonate (LAS) in a small South African river. The study showed that LAS concentration was very variable, both spatially and temporally, although generally very low (<11 µg L-1), suggesting that the molecule was dissipated rapidly by a combination of dilution and degradation. A way of decreasing the chemical load of a river is to discard the laundry water on the river banks rather than directly in the water to permit for its infiltration

in the soil. A big impact of detergents inside natural waters is with respect to their high content of phosphates (sodium tripolyphosphate), leading to eutrophication. Many countries have banned or are about to ban the use of these in favor of zeolites (Yamane and Nakazawa, 1986).

Furthermore, the use of fertilizers in agriculture: inorganic and commercial fertilizers are commonly used to increase yield in crops. The major inorganic fertilizers used in agriculture are nitrogen, phosphorus, potassium and sulphur fertilizers. If insufficiently absorbed by plants and soil or washed away by heavy rains, these fertilizers can enter ground and surface water possibly causing eutrophication or pose a threat to drinking water sources (Farhadinejad *et al*., 2014).

Moreover, the use of domestic waste water that is; mixture of all household wastewater from a community, including toilet water, showers, dish washing and laundry. This means that the content will vary from large floating material such as toilet paper, to small suspended

particles and dissolved substances. Besides the fats, proteins and carbohydrates that primarily make up faeces and urine, waste water also contains great quantities of intestinal bacteria and parasites. Some varieties of these can cause health problems for people if they end up in a water source. Waste water contains elevated concentrations of nutrients, such as different forms of nitrogen, phosphorous, sulphur and potassium (Jönsson *et al.*, 2005, Svenskt Vatten 2010).

Also, water quality is of uttermost importance when taking water from a river for irrigation purposes, with the most important parameter considered being, that of soil health and quality that is; salinity. Saline water can accumulate salt in the soil profile if the precipitation is not sufficient and regular. If the salt content is higher than the recommended value, the crop’s ability to absorb these water and nutrients is interfered. The main concern of the water course is however the change in flow rate and water discharge, which can be considerable within a small stream, causing problems downstream (Laycock, 2007) (figure 2).

Figure 2: Dumping of domestic waste into river channel (*Source*: Fogwe, 2016).

I-2 PARAMETERS OF WATER QUALITY

I-2-1- Physical and chemical characteristics

The physico-chemical nature and ecological characteristics of rivers confirm the presence or absence of certain animal species and their development (Tufféry, 1980). In other words, biological diversity and rivers structure is closely related to the abiotic integrity of the medium (Moisan and Pelletier, 2008). In fact, each organism is very sensitive to various abiotic factors within its living milieu (temperature, pH, salinity, dissolved oxygen, current velocity, etc.) and present minimum and maximum tolerance levels for each of these factors. The difference between the minimum and maximum levels of tolerance is called ecological valence. This represents the adaptation of the organism to its biotope (Gaujous, 1993; Ramade, 2005). Considerably, physicochemical variables are taken into account in the evaluation and follow-up of rivers quality.

I-2-2 Physical variables

Temperature, Suspended Solids (SS), Turbidity and Color are the principal physical variables used for the lotic characterization of a medium. Temperature is the key factor influencing the biology and distribution of running water species which are mostly poikilothermic organisms (Giller and Malmqvist, 1999). Within the lotic system, altitude and the sun's intensity affect the temperature which in turn conditions the solubility of gases and the speed of chemical and biochemical reactions (Hecky, 2000). Generally, for an aquatic environment, the surface water temperature is influenced by the surrounding temperature,

especially when the depth is low. It depends on: latitude, altitude, weather conditions, time and the rate of the river flow (Rodier *et al.*, 2009). For each river, the contents of SS vary with the type of catchment area, nature of the soil, the season and the contributions of effluents (Rodier *et al.*, 2009). However, a high concentration of SS in streams has harmful effects on aquatic fauna; it constitutes a limiting factor for the installation and development of benthic fauna, it causes the death of these organisms by filling their respiratory organs (Camacho, 1992). Turbidity and color increases with SS; they reduces the quantity of light which penetrates the water column and consequently, decrease the productivity of autotrophic organisms: phytoplankton (Dajoz, 2000).

I-2-3 - Chemical variables

pH is one of the first indicators of chemical alteration of water quality because, it varies with the geological nature of the catchment area, bed, industrial and domestic effluents and also biological activity (Jullian *et al.*, 2005). Its variations are inversely proportional to dissolved CO_2 content in water. However, the buffer solution which can be determined by all the reactions in the water system: insoluble carbonates, dissolved CO_2, soluble bicarbonates, constitute a stable vital medium able to maintain a pH favorable for the development of living organisms (Angelier, 2003).

As for electrical conductivity, it is proportional to the quantity of dissolved ionizable salts and its measurement constitutes a good indication of the degree of mineralization taking place in water. It varies with the origin of water, the geological nature of the substrate, the underground flow and the pollution of aqueous support (Camacho, 1992; Jullian *et al.*, 2005).

Dissolved oxygen is a chemical as well as a biological variable whose content has a clear significance in relation to the biological quality of the aqueous support (Rodier *et al.*, 2009).The normal ecological equilibrium conditions requires an oxygen saturation rate of 75 %, the situation becomes critical at 50% (Foto Menbohan and Njiné, 1991). Rodier *et al.* (2009) stress that the variation of dissolved oxygen concentration in water is inversely proportional to that of fermentable organic matter: hydrocarbons, detergents and a number of aerobic organisms and germs. However, a better oxygenation of water particularly at the water/sediment interface is favorable for the installation of benthic communities (Devidal *et al.*, 2007).

Within hydro-systems, nitrogen is in the form of organic nitrogen, of ammonum ion (NH_4^+), nitrites (NO_2^-), nitrates (NO_3^-), or associated to other compounds (CEAEQ, 2007). In

natural water, nitrogen comes from the ground and from the mineralization process. However, human activity accelerates the process of enrichment of water in this element by their contribution through urban and industrial effluents, domestic waste water discharge, scrubbing of agricultural soils highly rich in manure and pesticides (Jullian *et al.*, 2005; Jain, 2012; Bhat *et al.*, 2013). According to CEAEQ (2007), NH_4^+ ions are very high in water rich in organic matter, when the percentage of saturation of oxygen is insufficient to ensure its oxidation to nitrate. Moreover, an excessive increase in temperature transforms the NH_4^+ into NH_3 which is toxic to many organisms (Kourradi, 2005). As for nitrites, it is an intermediate form of nitrogen which is maintained in running waters only when the medium is insufficiently oxygenated. The reminiscence of these elements indicates a state of organic pollution (Foto Menbohan and Njiné, 1991). Orthophosphates or "reactive phosphorus" represents the bio-available phosphate forms in aquatic environments (CEAEQ, 2007). A high concentration of these elements in water is an indication of pollution originating from industrial effluents which contains organic phosphates and synthetic detergents (INRA, 2005). The high content in orthophosphates generally involve algal blooms with a consequence: the reduction of in-depth illumination, night anoxia, diurnal pH and long-term variations of eutrophication (Devidal *et al.*., 2007).

The alkalinity of water testifies the combined presence of hydrogen carbonates (HCO_3^-), carbonates (CO_3^-) and hydroxides (OH^-) ions. The variation of these components are to be brought closer to those on the degrees of mineralization of water and oxidation of the organic compounds, but also for the content of carbon dioxide (Lévêque and Balian, 2005).Water coming from the ground lime-stones and especially from gypsium has very high degree of hardness, while those which run out on the crystalline grounds e.g., metamorphic or schist minerals show very low degrees of hardness (Rodier *et al.*, 2009).

The Biochemical Demand for Oxygen (DBO_5) and Oxydability make it possible to appreciate the content of water for biodegradable organic matter which, within a natural environment, comes primarily from the scrubbing of the grounds, ripisylve and for the metabolism of aquatic organisms (Lecerf, 2005).The high content of these variables generally translates anthropic organic matter contribution in the river (Derwich *et al.*, 2010).

I-3- AQUATIC MACROINVERTEBRATES

I-3-1- Diversity and biology

Classified as aquatic macro-invertebrates, are members of invertebrate fauna which: do not possess a bony skeleton, are visible to the naked eye and carry out at least part of their life cycle in aquatic environment. They have a body size superior to 0.5 mm, this facilitates their collection, handling and their recognition (Tachet *et al,* 2010). Within these inland waters, this large group is composed of very diverse organisms with an ubiquitous character. They are mainly Annelids, Molluscs, Shellfish and arthropods (Monique, 1987; Tachet *et al.*, 2010).

I-3-1.1. Annelids

Annelids belong to the group of Metazoans with three germ layers possessing a coelom, with a bilateral symmetry. Their metamerized body is divided into three main sections: the prostomium, the soma and the pygidium (Tachet *et al,* 2010; Martin and Aït Boughrous, 2012). According to Beaumont and Cassier (1981), this phylum is divided into three classes: Polychaetae, Oligochaetae and Achaetae or Hirudinae. Only the two last classes are present in fresh water (Monique, 1987). Both are hermaphrodites and deprived of parapodia. Oligochaetae differ from Achaetae by the absence of suckers and the presence of capillary silks on their body. Achaetae are deprived of silks and are characterized by the presence of an oral and posterior sucker (Beaumont and Cassier, 1981; Lecointre and Guyader, 2001; Tachet *et al.,* 2010).

I-3-1-2- Molluscs

Molluscs are hyponeurians protostomian metazoans whose bodies are composed of three germ layers and a coelom. They show a bilateral symmetry, possessing a soft unsegmented body deprived of articulated appendages. Molluscs can be divided into two classes based on the number of articulated valves which make up their shell: in case of two articulated valves such as Bivalves or Lamellibranches or if only one, as in the Gastropods (Lioris and Rhcababo, 1984). Bivalves show a primitive bilateral symmetry which is absent in Gastropods which have a helicoidal rolling up of their shell from the visceral mass (Lecointre and Guyader, 2001). Bivalves are characterized by a shell made up of two calcified valves articulated on the level of the hinge by a ligament. The opening and the closing of the valves are ensured by the presence of adductor muscles. Bivalves can either be gonochoric or hermaphroditic according to their different families. in all fresh water Gastropods, reproduction is primarily sexual, one however notices some rare cases of parthenogenesis in

some taxa; sexes are generally separate at Prosobranches, contrary to Pulmonae who show evidence of haemaphroditism (De Moor and Day, 2002).

I-3-1-3- Crustaceans

Like all Arthropods, the crustaceans have an external skeleton (exoskeleton) and a body made up of several segments each of which bears, a pair of appendages (Day *et al.*, 2001). During their evolution, these segments and certain parts of the body become specialized performing specific function. The appendages are used for respiration, swimming, crawling, feeding and reproduction. Certain appendages have been strongly modified into jaws, reproductive organs etc. if they do not regress or disappear (Tachet *et al*, 2010). In crustaceans, sexes are separate and reproduction is generally sexual. One however notices the phenomenon of parthenogenesis in some taxa like the Branchiopods (Gasparini, 2004). Three crustacean subclasses are represented in fresh water. They are: Branchioura, the Branchiopoda and Malacostraca. In the subclass of Malacostraca which is most significant (in term of diversity and biomass), the body can be divided into three regions: the cephalic or head region which consist of the fusion of the first five segments each bearing a pair of appendages, the pereion or thoracic region which has eight segments each bearing a pair of pereiopodia, and the pleon or abdominal region made up of six segments bearing each a pair of pleopodia. This subclass consists of three orders which are: Amphipods, Isopods and Decapods.

Amphipods are characterized by the lateral flatness of their body and the presence of two pairs of antennae which are slightly identical in length The first pair of pereiopodia is linked to their mouth parts (maxillipedes), pereiopodia 2 and 3 are transformed into claws and the remaining 5 perform the function of locomotion organs (Day *et al.,* 2001).The difference between the pereion and the pleon is not very clear. Pleonites are free with the 3 first bearing each a pair of pleopodia, while the last 3 bear each a pair of uropods.

For Isopods, their bodies are dorso-ventrally flattened and bear two pairs of antennae with the first appearing much longer than the second. Their first pair of pereiopodia has been transformed into maxillipedes or mouth parts, while the remaining 7 which appear similar perform the function of lomotion. The pleon is short while plehonites (abdominal segments) can be free or presents variable fusions according to their taxon. The sixth pleonite is generally plain linked to a telson and forms with him the pleotelson. The latter bears laterally a pair of fourchus uropods which are more or less lengthening (Tachet *et al.*, 2010).

Decapods are characterized by the presence of a carapace around their cephalo-thorax which completely encloses the base of their pereiopodia. The first three pairs of the pereiopodia have been modified into mouth parts (maxillipedes). Most often, the fourth and/or the fifth pairs of pereiopodia have been modified into claws. Their eyes are hanging. Macroures (i.e., shrimps and crayfish), have an extended abdomen which is laterally flattened and their sixth pair of pleopodia join with the telson, a swimming palette. Brachyoura (crabs) has a much more reduced abdomen which is folded up under their thorax (Day *et al.,* 2001).

I-3-1-4- Insects

Insects are Arthropods which possess three pairs of jointed legs at the adult stage and in certain larvae forms. There also exist vermiform larvae that do not possess legs. One however notices that, the presence of false legs (pseudopodia or pygopodia) or locomotive pads at the level of the thorax and/or the abdomen in the latter (Tachet *et al*., 2010).Their body is divided into three segments which are: head, thorax and abdomen. Insects show a significant share (in term of diversity) of macro-invertebrates with eleven fresh water orders known (Merritt, 2008; Song *et al*., 2009).The larvae of five of these orders are exclusively aquatic namely: Ephemeroptera, Plecoptera, Trichoptera, Odonates and Megaloptera. Certain Coleopters and Hemipterans carry out their total life cycle in aquatic environment (De Moor *et al*.., 2003; Tachet *et al*, 2010). According to Diomandé (2001), fresh water Dipterans represent the most diversified species within these families and only their larvae are aquatic. In Insects, their sexes are separate, but they can sometimes reproduce by means of parthenogenesis (Zahradnik and Chvala, 1991).

I-3-2- Evaluation of benthic macro-invertebrates

The integrity of biological health on a hydro-system can be defined by its capacity to accommodate, integrate and maintain an equilibrium among a community of organisms which are capable of adapting themselves to the various changes affecting a given eco-region and possessing a specific composition, diversity and a functional organization comparable with those of a natural ecosystem (Karr, 1999; Moisan and Pelletier, 2008). The different biological methods used in evaluating the quality of water rest on the use of bio-indicators. A bio-indicator is an organism, or a group of organisms (plants or animal) whose ecological characteristics form the basis for both an abiotic and a biotic modification index of the environment caused by a particular type of human action (Ramade, 2005). If the system experiences a disturbance, there will first be the appearance and proliferation of certain species which will be attracted to a particular condition and on the one hand, a rapid disappearance of part or all of the initial

community of these organisms (Ramade, 2005; Davies *et al.*, 2010; Cabral-Oliveira *et al.*,, 2014).The aquatic biological communities of these organisms are thus influenced by many human activities which do not directly intervene on the quality of water (Chessman, 1995).The follow-up on this ecological integrity can thus contribute to evaluate the functionality of certain processes which ensures that, biodiversity is maintained and thus, manages to counter its degradation.

The choice of macro-invertebrates as bio-indicators can be justified by: their sedentary nature, their varied life cycle, their great taxonomical diversity, their varied tolerance to all sorts of pollution and the degradation of their habitat. The use of macro-invertebrates in the evaluation of water quality presents many advantages. This enables one to use their biological effectives i.e. their capacity to integrate a certain number of physical and chemical conditions. It also takes into account on the one hand, the reminisce of the organisms which represents their ability to attests for a more or less ancient type of pollution and, on the other hand, the conditions of intermittent toxic and moderate organic pollution (Friedrich *et al.*, 1992). It is capable of detecting the changes within the most subtle sources of diffuse pollution (Barbour *et al.*, 1999).

These organisms constitute a very important link within a food chain in an aquatic environment; because they form a primary source of food for several fish species, amphibians and birds. Apart from their sedentary nature, they react to distortions which occur within the stream either by dying or resisting to the difficult conditions hence, they also integrate the synergic cumulative effects within a short run of a multiple physical, chemical and biological disturbance on the river (Colas *et al..*, 2014). Macro-invertebrates provide very significant information due to the fact that they can integrate data which proves the existence of pollutants, i.e. their type, their quantity, their availability within the medium and on their effects, no matter their nature (Basu *et al.*, 2007). Moreover, their ecology which is not well known, is abundant within several rivers hence, are relatively very easy to collect and their sampling leaves the biocenose with very little harmful effects (Barbour *et al.*, 1999). On the other hand, Moisan and Pelletier (2008) stress that the follow-up of these benthic macro-invertebrates is of great importance permitting: for the evaluation of health status within a given river, the follow up of its temporal evolution, the estimation of the impacts on the efforts of restoration (habitat and quality of water) and finally bringing in a biological complement to the program which monitors the bacteriological and physico-chemical quality of the milieu. The protection and restoration of these aquatic

environments is essential for the maintenance of human activities and the ecological processes which support their life.

I-3-2-1- The role of Chironomidae community in water quality characterization

Among families of aquatic macroinvertebrates, Chironomidae are probably the most widely distributed and species rich family. It constitute between 10 % and 50 % of aquatic macroinvertebrates biomass (Armitage *et al*., 1995; Cranston, 1996; Harrison, 2002; Porinchu and MacDonald, 2003; Ajeagah *et al.,* 2016). They occupy extremely varied biotopes. They are tolerant to a wide array of environmental water quality gradients and their extraordinary ecological range and environmental sensitivity make them particularly useful for assessing and interpreting changes in water quality of aquatic ecosystems (Bhattacharyay *et al.*, 2006). Consequently, several studies have used them as indicators of environmental water quality changes (Janssens de Bisthoven and Gerhardt, 2003; Mousavi *et al*., 2003; Adriaenssens *et al*., 2004; Janssens de Bisthoven *et al*., 2005, Luoto, 2010). Changes in chironomid community composition may reveal evidence of industrial, agricultural, organic pollution and habitat degradation in aquatic ecosystems (Diggins and Stewart, 1993; Luoto, 2010; Ajeagah *et al*., 2017). Adriaenssens *et al*. (2004) examined the diversity of chironomid communities and their role as indicators of water quality changes for the assessment of particular river types and water quality in Flanders, Belgium. These authors, grouped chironomid populations into three indicator groups, which include indicators of good water quality, indicators of waters enriched with nutrients and organic matter and taxa that were indifferent to changes in water quality.

I-3-2-2- Morphological deformity in Chironomidae

The term “deformity” refers to morphological features that depart from the normal Chironomidae larval configuration (Warwick, 1985; Nazarova *et al.,* 2004). Effects produced by mechanical wear, breakage or abrasion are usually not included in deformity screening and are recognised by their “chipped” or “rough” edges (Vermeulen, 1995; Bird, 1997; Nazarova *et al.,* 2004). Because chironomid larvae live in close association with sediments and often feed on organic detritus and associated algae, deformities in chironomids can be used as biomonitoring tool for assessing sediment toxicity and environmental water quality deterioration (Vermeulen, 1995). Morphological deformities in chironomids represent sublethal effects of exposure to contaminants and are considered an early warning indicator of environmental water quality deterioration caused by chemical contaminants. Assessments of these deformities offer an effective and cost friendly means of assessing impacts of environmental stressors on aquatic ecosystems (Meregalli *et al.,* 2002). The earliest reports of deformities in the mouthparts and the

thickening of the body wall in chironomids exposed to a wide array of chemical contaminants came from the sediments of Lake Erie and Lake Ontario in Canada (Hamilton and Saether, 1971).

I-3-2-3- Ecology and functional feeding groups

Benthic macro-invertebrates carryout first degree ecological functions. They are essential for the transformation of organic matter; that is, they ensure the shredding and recycling of a good part of plant and/or animal matter within these hydro-systems (Olivier *et al*, 2004; Lecerf, 2005; Monoury, 2013). They filter organic particles found inside water and graze on the algal vegetation therein. Also, they form an essential link of the food chain and are used as food by many fish, amphibians and birds species (Moisan, 2010). They also intervene in the biological cycle of certain parasites, as they serve as intermediate and/or definite hosts. Macro-invertebrates are also very interesting organisms which strongly contribute to the biodiversity of streams. The different species become adapted to diverse ecological conditions. Some taxa known as polio-sensitive (example the larvae of Ephemeroptera, Plecoptera and Trichoptera) need good quality water of whereas, polio-tolerant species (Chironomidae, Tubificidae, Physidae) support very high organic matter loads or resist pollutants (Hilsenhoff, 1988; Bode *et al.*, 1996; Bode *et al.*, 2002). Certain species show affection to zones with strong currents (rheophiles), while limnophiles prefer calm waters. Others known as heliophilous species prefer calm and clear zones (e.g., some Odonat larvae), on the contrary, Sciaphilous species known to be shades-loving (e.g., Ephemeroptera, Plecoptera, Planarians) find refuge under stones, rocks, herbs, dead sheets, or in cracks, and are active only at night (Dajoz, 2000; Tachet *et al*, 2010). Others are generalists (eurytopes) and can adapt to different types of media. The occupation of a niche by these organisms will depend on: their basal metabolism, the environmental conditions and the specificity of the different taxons (Schuwirth and Reichert, 2012).

The trophic ecology and feeding modes of aquatic macro-invertebrates varies among the different groups. One thus distinguishes: grazers/scrapers who feed on algae that grow on substrates; collectors, filterers and sediment feeders who recover organic matter contained in water and alluvia. The species which feed on cytoplasmic and tissue contents aquatic plants and animals have been classified under the group of drillers/suckers, whereas those which split up dead sheets and vegetable remains are known as shredders. One also distinguishes; predators who feed on other invertebrates and finally, omnivores (Lecerf, 2005; Schuwirth and Reichert, 2012; Monoury, 2013). A more synthetic classification adopted by Cummins and Wilzbach

(1985), Merritt *et al.* (2008) and Tachet *et al.* (2010), permits us to identify omnivores, predators, shredders, grazers, filterers, gatherers or decomposers and detritivores.

I-4- BIBLIOGRAPHICAL SYNTHESIS OF MACRO-INVERTEBRATES FOUND IN RIVERS OF CAMEROON

Documentation on fresh water macro-invertebrates in Cameroon relates to the recent studies carried out by Foto Menbohan (2012), Foto Menbohan *et al.* (2012 and 2013), Ajeagah *et al.*. (2014), Nyamsi Tchacho (2014), Tchakonté *et al*. (2014; 2015a, b) Ajeagah *et al*. (2017 and 2018). The studies carried out by Foto Menbohan (2012) within the urban zone of Yaoundé partly concerned macro-invertebrates found in 11 rivers of the hydrographic network of Mfoundi. This permitted the identification of 96 taxa of macro-invertebrates belonging to 5 phyla (Arthropods, Molluscs, Annelids, Nematodes and Platyhelminthes), 7 classes, 18 orders and 52 families. Crustaceans were absent in all the stations located within this urban environment and only three species of Atyidae Decapods (*Atyaephrya africana, Atyaephrya desmarestii* and *Caridina africana*) were sampled downstream of river Byémé, within the semi-urban zone. The class of Insects dominated with 8 orders, 30 families and 52 taxa. Within this class, Dipterans Chironomidae, Psychodidae and Syrphidae were the most frequent and abound in all of the rivers studied. Gastropods follow with 2 orders, 8 families and 17 taxa. Amongst all the Gastropods sampled; Pulmonae, *Physa acuta* (Physidae) and Prosobronchia, *Hydrobia accrensis* (Hydrobiidae) were the most frequently observed in the quasi totality of the prospected rivers. Within these urban rivers, Annelids were primarily represented by Oligochaetae Aeolosomatidae (*Aeolosoma hemprichi, Heamopis sanguisuga*), Tubificidae (*Tubifex tubifex*) and Lumbriculidae (*Lumbriculus* sp.). Nematodes were exclusively represented by the Aphelenchoides *microlaimus species* (Aphelenchoidae), while Platyhelminthes were principally represented by the *Dugesia tigrina species* (Dugesiidae).

Foto Menbohan *et al.* (2012 and 2013) worked in the peri-urban zones of the Western periphery in the town of Yaounde that is; in the Mefou and Nga rivers (i.e., the affluents of Mefou).These studies permitted them to identify 4 Phyla which are: Arthropods (99.25 %), the Molluscs (0.39 %), Annelids (0.20 %) and Nematodes (0.16 %). These individuals were divided into 7 classes, 15 orders, 74 families and 117 taxa. The class of the Insects prevailed with 63.85 % out of total the abundance and accounts for 8 orders, 66 families and more than 111 taxa; it was followed by crustaceans (35.41 %) with a single order, 2 families and 2 taxa. The five other classes: Oligochaetae, Achaetae, Gastropods, Bivalves and Gordiacae represented 0.74 % of total abundance. Of the 15 censored orders, 9 were found in all the sampling stations. These

were the: Decapods (35.41 %), Coleopters (21.19 %), of Odonates (14.02 %), of Hemipterans (10.46 %), of Ephemeropterans (9.09 %), of Plecopterans (3.76 %), of Dipterans (2.27 %), of Trichopterans (1.87 %) and Dictyopterans (1.21 %). The six other orders were collected in a sporadic manner and represented only 0.75 % of the total abundance. Out of the 74 families sampled, 13 belong to the order of Ephemeropterans and 11 were celuides Coleopters. The orders of Odonates and Dipterans each counted 10 families; those of Trichopterans and Hemipterans counted 9 families each; whereas, the Plecopterans and Decapods counted 3 and 2 families each respectively. The seven other orders (Dictyopterans, Lumbriculidaes, Haplotaxidaes, Rhynchobdellidaes, Basommatophora, Eulamellibranchia and Gordioidaes) were each being represented by only one family.

Ajeagah *et al.* (2014; 2017 and 2018) on their own part studied a group of benthic fauna and were based on the morphology and the abundance of the developmental stage of Heteroptera-Naucoridae, *Ilyocoris cimicoïdes* Linné 1758, within the pond of Obili, Community structure of Chironomidae (Diptera) in Olezoa and the diversity of Crustaceans in the Yaoundé forest zones. While Tchakonté *et al*. (2014; 2015a, b) worked in the sub-urban and urban zones of Douala, were a total of 178 macroinvertebrate taxa were inventoried, of which 149 were identified as genus and / or species, 3 as sub-family, 25 as family and 1 at the rank of the order. These taxa were distributed in 5 phyla (Arthropods, Molluscs, Annelids, Nemathelminthes and Platyhelminthes), 7 classes (Crustaceans, Insects, Gasteropods, Achaetes, Oligochaetes, Gordias and Turbellarians), 18 orders and 69 families. Arthropods are the most diversified with 2 classes, 10 orders, 54 families and 150 morphotypes (84.27% of taxa). They are followed by the Annelids which have 2 classes, 4 orders, 8 families and 16 morphotypes, then the Molluscs represented only by the class of Gastropods which counts 2 orders, 5 families and 10 species. The Nemathelminthes and Platyhelminthes each contain only one class, one order, one family and one morphotype.

CHAPTER II
MATERIAL AND METHODS

II-1- MATERIAL

II-1-1- GENERAL PRESENTATION OF THE CITY OF BAMENDA.

Bamenda is the head quarter of the Mezam division in the Northwest Region of Cameroon. It is made of three subdivisions (Bamenda I, II and III) with 391 km² as total surface area. This study concerns the urbanized part known as the city of Bamenda (mainly Bamenda II and III sub-divisions) which according to Fogwe 2006, the zone covers about 12.49% of this surface (4 880 hectares). Figure 3 shows the location of Bamenda city between 5°56-6°00N and 10°08-10°12E. Its relief consists of interspersed plateaus with deep valleys. Its vegetation is the Guinea Savana type with moderate temperatures (Neba, 1999). There are two topographic units separated by a high scarp oriented NE – SW (Neba 2011). Above the cliff, stands the upper plateau which is mainly Bamenda 1 and represents 10% of the total area of the city (Sahe & Tchindjang, 2017). Altitudes here vary between 1472m and 1573 m. The minimum altitude of the lower plateau is 1201m with the climate being the humid tropical highland type characterized by two seasons; the rainy and the dry season. The rainy season is generally longer and lasts for eight months (mid-March to mid-October) with a short, dry season of four months (mid October to mid-march) (Tita *et al*., 2012). The Mezam River and its tributaries drains all runoff from the city of Bamenda and flows down to the Menchum River (figure 3).

II-1-2 Description of study sites and sampling points

The dendritic drainage pattern of running water in the town of Bamenda permits the evaluation of the effects of urbanization in this town. Five streams which flow across the urban settlements and drain all the wastes were chosen: three urban streams located in Bamenda II sub-division (Mankon, Ayabah and Mezam streams) and two others located in the Bamenda III sub-division (the Mufueh and Furmuki streams).

II-1-2-1- Mufueh stream (Mf)

The Mufueh stream extends for 1.5 km upstream of Mile 4 Bridge along the Mughoro village and flows down through the mile 4 Nkwen into the upper part of river Mezam. It has an altitude range of 1172 and 1163 m and situated on Longitude 05^0 52’ 07” / 05^0 59’ 19.6” N and Latitude 010^0 10’ 39.3” / 010^0 10’ 17.9” E For this studies, three sampling stations where chosen along this stream (Mf1, Mf2 and Mf3) as shown on figure 3 and figure 4.

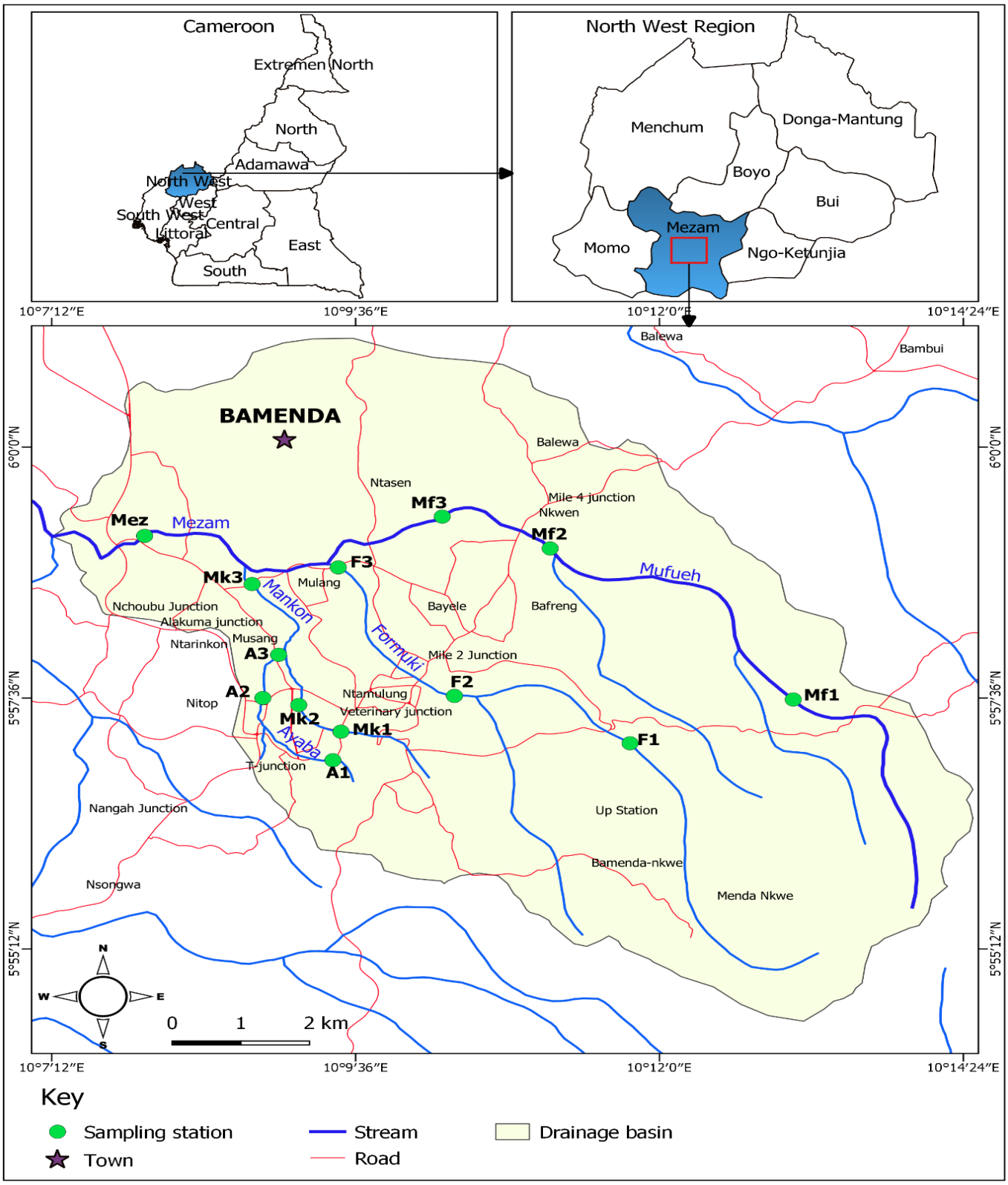


Figure 3: Location of sampling points on the streams in the city of Bamenda (source I. N C)

Mf1 is the first station on the mufueh with geographic coordinates 05^0 52’ 07” N and 011^0 30’ 39.3” E, with an altitude 1172 m. It is located in the upper course, about 1 km from

the source. Access to this place is facilitated by a track put in place by local populations as they go about their activities of construction and farming. The stream bed is relatively small and shallow. The vegetation is dense along the banks and in some places forms a real shading that keeps the bed in relative darkness (Figure 4A).

Mf2 is the second point with coordinate 05^0 59' 13.8" N and 010^0 30' 55.4" E, and altitude 1163 m, is located on the middle course of the mufueh stream about 7.5 km from the source. Access is facilitated by the road linking Bamenda 1 and Bamenda 2 just beside the mile 4 Nkwen Bridge. Vegetation, also abundant along the banks, is dominated by the herbaceous species. The river bed is relatively large and deep (Figure 4B).

The station Mf3 has as coordinates of 05^0 59' 19.6" N and 010^0 10' 17.9" E, with an elevation of 1162 m, It is located about 2.5 km downstream of the mile 4 Nkwen bridge. Riparian vegetation is abundant and largely dominated by undergrowth, food crop plantations and palm trees. The water at this point has a very low velocity, dark in appearance and very deep (Figure. 4C).

Figure 4: Photos of the different sampling points on the mufueh stream, mf1 (A), mf2 (B) and mf3 (C).

II-1-2-2- Furmuki stream (F)

This stream originates on the hills of Bamendankwen village which is an intensive agricultural area in a semi-rural/semi-urban setting and flows pass the government residential quarters up the station hill before falls it over the escapement of the Bamenda town into the Bayelle flood plain. The stream has as altitude of 1194 and 1229m and situated on Longitude 05^0 57' 37.6" / 05^0 58' 51.1" N and Latitude 010^0 10' 36.5" / 010^0 09' 27.9" E. Its shoreline presents some degree of disturbance by habitation, cultivation, animal farming, land reclamation and eroded soil. Three sampling stations where chosen along this stream (F1, F2 and F3)

F1 is the first station on this stream and situated just below the escarpment in the Nnitop neighborhood. This point has as geographical coordinates 05^0 57' 37.6" N and Latitude 010^0 10' 36.5" E. Access is facilitated by a fairly busy secondary road which link the houses of inhabitants. The particularity of this station is that, water flow over metamorphic rocks, market gardening, intense pig and goat farms. The banks are reduced by inhabitant to construct toilets which empty into the stream during floods. The vegetation is scanty and the water colomn is exposed to direct sun rays (figure 5A).

F2 is located downstream some 2 km from the first station. This point is located few meters downstream from the mile 2 Nkwen Bridge and receives runoffs from the Nkwen market, the mobile Nkwen area and the other neighborhood. It has as coordinates 05^0 57' 52.0" N and Latitude 010^0 9' 56.3" E. Inhabitants along this stream dump all their waste into the stream (Figure 5B)

The third station (F3) with coordinates 05^0 58' 51.1" N and Latitude 010^0 09' 27.9" E is located between the mulang quarters and the below Foncha neighborhood. Water at this point has gone through the ndamukong swampy area which is characterized by high agricaltural activities and land reclamation for construction. The banks of the stream are shallow, straight and relatively wild and covered with sun flower vegetation (Figure 5C).

Figure 5: Photos of the different sampling points on the Furmuki stream, F1 (A), F2 (B) and F3 (C).

II-1-2-3- Mankon stream (Mk)

This stream takes its source below the Bamenda escarpment at mugheb quarters, old town just below the government high school of the area. The water flows and drains all the waste of the "hausa" quarter, Sonac Street, Commercial Avenue and small mankon into the Ngomgham where it joins the Ayabah stream. The stream has as altitude range of 1263 and 1234m and situated on Longitude range of 05^0 57' 16.7" / 05^0 58' 41.4" N and Latitude 010^0

9’ 29.0” / 010^0 08’ 46.9” E. Three sampling sites were chosen on this stream based on the effluent inlet (Mk1, Mk2 and Mk3).

Mf1 is the first station which is about 800m from the source at mugheb in the old town quarter. It is located between 05^0 57’ 16.7” N and Latitude 010^0 9’ 29.0” E. this point receives domestic waste from all the government offices, schools in old town. It is the main point for washing of motor bikes by aera boys. The stream is covered by dense sun flower bush (Figure 6A).

Mk2 is situated some 2 km away from the source and collect waste from Sonac and commercial avenues precisely below “rendez-vous” quarter. It has as coordinates 05^0 57’ 16.7” N and Latitude 010^0 9’ 29.0” E. most of the household waste are dump into this stream and it has scanty vegetation (Figure 6B).

The third point (Mk3) is in the Ngomgham quarters and here, the stream join with the Ayabah stream. Besides the indiscriminate waste disposal on the channel, the water here is turbid due to sand mining activities. The vegetation has greatly disappeared and has been replaced by houses, toilets or animal farms and other urban activities (Figure 6C).

Figure 6: Photos of the different sampling points on the Mankon stream, mk1 (A), mk2 (B) and mk3 (C).

II-1-2-4- Ayabah stream (A)

This stream source on the hills of Akum sub-urban settlements on the upper part of the escarpment and flows down the escarpment behind the catholic cathedral and Ayabah hotel. The stream is located between altitude 1270 and 1242 m, Longitude range of 05^0 57’ 00.3” / 05^0 58’ 00.8” N and Latitude 010^0 09’ 25.2” / 010^0 08’ 59.5” E. This stream goes through Meta quarters, food market, Bamenda main market, small-mankon and Ngomgham quarters. All the wastes from the markets are dumped into this stream. To better understand the impact on this stream, three sampling points were chosen (A1, A2 and A3).

The first point (A1) is located about 2.5 km from the source at the foot of the escarpment behind the Ayabah hotel at an altitude of 1270m and between longitude 05^0 57' 00.3" N and Latitude 010^0 09' 25.2" E. the water here is shallow, flows on stones and under a dense vegetation of trees and herbs (figure 7A).

The second station A2, is situated about 4 km from the source at the area called fish pond hill after the food market. The area collects all the perishable and nonperishable wastes from the markets. There are embankment walls on the stream bed constructed by the city council to protect the commercial centers. The vegetation is scanty and characterized by sun flowers put in place by the inhabitants to hold the stream banks from collapsing (figure 7B).

A3 is the third point located downstream at an altitude of 1242m and between longitude 05^0 58' 00.8" N and Latitude 010^0 08' 59.5" E in the small mankon neighborhood before the junction between Ayabah stream and mankon stream. It has little or no vegetation and the water colomn is exposed to direct sun rays (figure 7C).

Figure 7: Photos of the different sampling points on the Ayabah stream, A1 (A), A2 (B) and A3 (C).

II-1-2-5- Mezam (Mz):

This point is located on the Mezam River itself. Geographically, it is situated at an altitude of 1226m and between longitude 05^0 59' 09.2" N and Latitude 010^0 7' 49.0" E. It is the area below Ngomgham and around the mile 8 mankon quarters and this river drains the Municipal open waste discharge at Mile 8. At this area, all the other streams that flow through the Bamenda capital city join into Mezam River. It has stiff banks and the water goes over igneous rocks and at high velocity due to its high volume (figure 8)

Figure 8: Photo of the sampling point on the Mezam stream

II-2-METHODS

II-2-1- Hydromorphometric variables

The hydromorphometric parameters considered in this study are: water flow rate, width of the wetted cross section and depth of the river or stream. For each one of these parameters, five series of measurements were taken *in situ* within each station and the average values were considered.

The rate of water flow was measured at each station by an indirect method which consists of determining the flow rate using a stop watch, the time put by a nonpolluting neutral dye (methyl blue) to cross a known distance without obstacle. The speed (**V**) of water run-off expressed in m/s is obtained by a ratio of the distance covered (**D)** expressed in m over time (**T)** in s

$$V = \frac{d}{t}$$

The width of the wetted cross section is expressed in meters and was measured by tightening the decameter across the river from one bank to another, at water limits.To take measurements (expressed in m) on the heights of the river and the movable substrate, a wooden ruler of 2 m long, graduated in millimeters was plunged vertically in the river and the measurements taken according to a regular step of 20 cm from one bank to another.

II-2-2-Measurements of physico-chemical parameters

Physico-chemical parameters measurements proceeded at the simultaneously on the field and in the laboratory following the recommendations of APHA (1998) and Rodier *et al.* (2009). The measurement and water sampling were first effectuated before the sampling of macro-invertebrates to avoid any disturbance within the medium which could likely skew the results.

II-2-2-1- Measurements of physico-chemical parameters (in situ)

The temperature (^{o} C) of the river, pH (CU) and the percentage saturation of dissolved oxygen (% of saturation) were measured *in situ*, respectively using an alcohol thermometer graduated 1/10C, a pH-meter of mark HACH HQ11d and precision 0,1 CU, and an Oxymeter of mark HACHHQ14d. Also salinity (PSU), Electric Conductivity (µS/cm) and Total Dissolved Solids (TDS in mg/L) were measured *in situ* using a TDS-conductimeter instrument of mark HACH HQ 14d, with precision 0,1.

To achieve this, the measuring apparatus were first standardized or calibrated, their probes were then plunged inside the sample water and the selection of the desired function of the different parameters made it possible for us to read the values on the screen of our apparatus.

II-2-2-2- Measurements of physico-chemical parameters in the laboratory

For the physico-chemical parameters measured in the laboratory (Suspended solids, turbidity, color, NH_4^+, NO_2^-, NO_3^-, PO_4^{3-}, alkalinity, oxydability and DBO_5), the water samples were collected without bubbles, at each station and for every sampling period using polyethylene bottles with double corks with a capacity of 250 and 1000 ml. These were then transported in inside a cool shielded cell of approximately 4^{o} C to the laboratory.

Suspended solids, turbidity and color were measured by the colorimetric method with the help of a spectrophotometer of mark HACH DR2800, at the wavelengths of: λ= 810 nm, λ = 450 nm and λ = 455nm respectively. The values were expressed in mg/L, FTU and Pt-Co respectively.

Measurements of the orthophosphate contents of water and the different forms of nitrogen (NH_4^+, NO_2^- and NO_3^-) were done using the spectrophotometry method, with the help of a spectrophotometer of mark HACH DR. 2010. The ammonia concentration (expressed in mg/L of $NH4^+$) was measured using the Nessler's method which was done on

25 ml of our water sample and the reading was effectuated at a wavelength of, ƛ= 425nm. As for the contents of nitrites (NO_2^-), nitrates (NO_3^-) and out orthophosphates (PO_4^{3-}), they were measured using 10 ml of the water sample with reagents such as: Nitriver III, Nitraver V and Phosver III respectively. The readings were effectuated at the wavelengths of: ƛ = 500 nm, ƛ = 507nm and ƛ = 530nm respectively and the results were expressed in mg/L of NO_2^-, NO_3^- and PO_4^{3-} respectively.

Alkalinity was determined by volumetric analysis. 50ml of sample of water was titrated against sulphuric acid N/50, in the presence of the green-red methyl bromo-cresol indicator. The results were expressed in mg/L of HCO_3^- are calculated by the formula:

Alkalinity (mg/L of HCO_3^-) = (difference in burette's reading) × 20

Oxydability was measured by volumetric analysis method. Into a 500ml conical flask was introduced 200 ml of the water sample was introduced into a 500 ml conical flask, 2 ml of monosodic carbonate was added to the contents of the flask which was then left to boil. During boiling, 20 ml of $KMnO_4$ N/80 was introduced into the conical flask. Ten minutes after, the conical flask containing the solution is then cooled under a running tap and 5 ml of H_2SO_4 25 % and 20 ml of Mohr's salt was added simultaneously. The constituted solution will be titrated against potassium permanganate solution of conc. N/80 until the persistence of the pink coloration. The results were expressed in mg/L of O_2 gas whose volume was calculated by the formula:

$$\text{Oxydability (mg/L of } KMnO_4) = \frac{qi - q0}{2} \times 3{,}95$$

Where, q_i = difference in burette's reading of the test sample, q_o = difference in burette's reading of the control experiment

II-2-2-3- Calculation of the Organic Pollution Index (O.P.I)

Organic pollution Index (Leclercq, 2001) was calculated in order to give a precise account on the degree of organic pollution across the different sampling stations of the river during the period of study. The calculation of this index is based on three parameters (NH_4^+ (mg/L)), NO_2^- (µg/L) and PO_4^{3-} (µg/L)) generally resulting from organic pollution and a synthetic parameter (DBO_5 (mg/L). For each parameter measured, 5 classes of constituents having an ecological significance were defined (Table I). The OPI corresponds to the average figure of each parameter measured for the different classes defined; the values obtained were classified under 5 different levels of pollution (Table II).

Table I: Classes of OPI with respect to the limiting values of each parameter

Classes	Parameters			
	DBO_5 (mg/L)	**NH_4^+ (mg/L)**	**NO_2^- (µg/L)**	**PO_4^{3-} (µg/L)**
5	< 2	< 0.1	≤ 5	≤ 15
4	2-5.0	0.1 – 0.9	6-10.0	16 - 75
3	5.1-10	1 – 2.4	11-50.0	76 - 250
2	10.1 – 15	2.5 - 6	51 - 150	251 - 900
1	>15	> 6	> 150	> 900

Table II: Classification of the degree of pollution with respect to the classe intervales of O.P.I

Class mean	5.0 – 4.6	4.5 – 4.0	3.9 – 3.0	2.9 – 2.0	1.9 – 1.0
Level of organic pollution	Null	Low	Moderate	High	Very high

II-2-3- Benthic Macro-invertebrates

II-2-3-1- Sampling of the benthic fauna

The sampling of macro-invertebrates was done following the multi-habitat approach proposed by Stark *et al.* (2001). It consists of carrying out at each station, a total of 20 hauls in various micro-habitats characterized by a ratio between the substrate and speed of flow of the river. The material used for the collection of this macro-fauna was a benthic sampler net, made from a metal framework with a dimension of 30 cm × 30 cm, mounted on a steel handle which is 150 cm long, and provided with a taper thread of 400 µm of mesh and 50 cm of depth. To this effect, the net was deposited inside water and made to touch the bottom of the stream and it is hauled over a distance of 50 cm upstream, in the direction opposite to the water current. The surface sampled for 20 hauls is equal to a distance of about 3 m^S, for a station which is approximately equal to100 m in length. Each time, the contents of the net was washed in a square sieve which measures 40 cm on each side and 400 µm mesh. The specimens were collected using a pair of fine pincers and a hand lens, then fixed in a small bottle containing 10 % formalin solution.

II-2-3-2- Sorting identification and counting of the organisms collected

In the laboratory, the contents of the bottles were transferred into another sieve of 400 µm mesh, and then rinsed with water to remove the formalin. The organisms were then collected using fine probes, gathered in limp of Petri on the basis of their morphological nature, then identified, counted and preserved in labeled pill machines containing ethanol at 95^0.The specimens were identified to the least possible taxonomic level, under a binocular magnifying lens of mark Olympus SZ30 under an episcopic lighting system as well as an optical microscope of the ZEISS mark and an inverted microscope of mark Olympus CK 2 UL WCD, this using the different Identification keys. Among the keys used were those of: Durand & Lévêque (1981); Tachet *et al.* (2010) which characterizes invertebrates in a global manner. The other keys give a detail method or manner for the characterization of Insects (Dejoux *et al.*, 1981; Diomandé *et al.,,* 2000; Day *et al.,,* 2002; De Moor *et al.,,* 2003; Stals & De Moor, 2007), crustaceans (Day *et al.*, 2001), Molluscs (Binder, 1955, 1957, 1958; Samé Ekobo, 1984; Brown, 1994; De Moor & Day, 2002).

II-2-3-3- Sampling, mounting and identification of Chironomid larvae and nymph exuviae of Chironomidae

On the field with the help of a hand net with very fine mesh about 300µm the aquatic vegetation of the stream was swept across upstream and downstream. The specimens were then picked out and conserved in 100ml polythene bottle containing 10% formalin before transportation to the laboratory (Soumi *et al.*, 2012). In the laboratory the specimens brought from the field were washed in a 250µm mesh sieve with tap water and conserved in 70 % alcohol. The preserved larvae were transferred to a petri dish containing 10% KOH solution and left in the solution for 24 - 48 h to digest the larval muscles. Thereafter, the permanent slide mounts of the larvae were prepared following the method of Epler (2001). The slide mounted larvae were identified to genus and species level using appropriate taxonomic keys (Kikuchi *et al*. 1985, Hasegawa and Sasa 1987, Morse *et al*. 1994, Merritt and Cummins 1996, Epler 2001, Cranston 2004).

Contrary to the larvae and the adults, the approach used for the identification of the nymph exuviae appears simpler (Wilson & Mc Gill, 1982). Indeed, the nymph exuviae possess systematic characteristics which assures for the easy identification of the different genera and species. Moreover, they are easy to sample and their collection does not have an effect on the Chironomidae population. Moreover, they can be easily mounted between slides and cover slides due to their fine structure or thinness.

Owing to the fact that the development of the different stages of the Chironomidae species proceeds at night, the collection of their nymph exuviae was done within the early hours of the morning (between 06 and 07 am). A rectangular drift net measuring 25 cm large by 15 cm long, made from a cloth having a pyramid form with mesh measuring 400 µm and 90 cm of depth was used for the collection of these nymph exuviae of the chironomidae species. In order to achieve this, the net was immersed with half way inside the stream against the water currents and was maintained in equilibrium thanks to the iron bars inserted at each side of the net, for a period of 30 minutes within each station. The exuviae and floating debris were collected inside the net and preserved in polyethylene bottles containing ethanol at 70^0.

In the laboratory, the contents of each bottle were poured into Petri dishes and exuviae were sorted under a binocular magnifying lens using a pair of fine pincers, they were then regrouped according to their morphological similarities. On each slide, two exuviae were mounted on their dorsal surfaces between slide and the slide cover in a drop of glycerin and under a binocular magnifying lens. A Canada bump was used to glue the slides and cover slides together. A total of 250 slides were observed. Their identification was done under an optical microscope, using the keys proposed by: Wilson & Mc Gill (1982), Wiederholm (1986), Langton (1991) and Jacobsen (2008).

II-2-4- Analysis of community structure of macroinvertebrates

II-2-4-1-Taxonomic richness, abundance and population density of macro-invertebrates

The specific richness (S) indicates the number of species present within a given medium and at a given time. It tells us about the variability of the ecological niches of a given station (Alliaume *et al*, 1990).

Abundance on its part indicates the number of individuals (N) presented within each given species or sampled taxonomic group.

Density is the number of individuals per species or taxonomic group collected per unit volume or surface. For this study, the surface density (Di) expressed in ind./m2 was calculated according to the formula (4) where Ni represents the number of individuals belonging to species i while S corresponds to the surface area sampled.

$$D_i = \frac{N_i}{S} \qquad (4)$$

II-2-4-2- Frequency of occurrence for each taxa

The frequency of occurrence (f) expressed as a percentage, tells us about the consistency of a species or a taxon within a given habitat without any indication on their quantitative importance (Dajoz, 2000).One distinguishes the omni-present species which appear in all the stations (100 %); regular species, present within a 75 and < 100 % interval of the different stations; constant species, present within a 50 and < 75 % of the stations; access species present within a 25 and < 50 % period on the different points on the stations and rare species present in less than 25% collected (Dufrêne & Legendre, 1997).This index is based on the presence/absence ratio and is calculated according to the equation (5) in which Pt is the total number of samples collected and Pi the number of samples collected in which species i was present.

$$F = \frac{P_i \times 100}{P_t} \qquad (5)$$

II-2-4-3- Diversity index of Shannon and the Piélou Equitability index

The diversity (H ') index of Shannon-Weaver (1963) was used to bring into evidence the total diversity of the population of aquatic macro-invertebrates. It permits us to measure the degree of organization within the population of organisms (Krebs, 1989; Dajoz, 2000; Tonkin *et al*, 2013). According to Ramade (2005), an appropriate comparative study on the population was done using this index because relatively, it is independent of the sample size. This index is calculated according to formula (7). Where; pi is the proportion of each species or taxon within a given population and S the total number of species or of taxa. H' is expressed in units of information per individual or bits per individual (bits/ind.) and its values lie between 0 and Log2S. Diversity is large when H' tends towards Log2S (Lévêque and Balian, 2005).

$$H' = -\sum_{i=1}^{S} (p_i \log_2 p_i) \qquad (7)$$

As regards the equitability index (E) of Piélou (1969) which make it possible for us to study their regularity and the distribution of species. This index varies between 0 and 1 and translates the quality of the organization of a population (Amanieu & Lasserre, 1982; Dajoz,

2000). It is close to 1 when all the species tend to have the same abundance and close to 0 when one or some species dominate within the population. It is calculated according to equation (8) where H' is an indication of the Shannon and Weaver diversity and S the number of species.

$$E = \frac{H'}{Log_2 S} \qquad (8)$$

II-2-4-4- EPT, EPTD, EPTC, EPTH indices and the ratio between EPT/density of chironomidae

EPT, EPTD, EPTC and EPTH indexes correspond respectively to the total number of the Ephemeroptera, Plecoptera, Trichoptera, Decapoda, Coleopters and Hemiptera taxa sampled within a station (Dolédec & Statzner, 2008; Moisan & Pelletier, 2008; Song *et al.*., 2009; Feio & Dolédec, 2012). It is about the taxonomic richness of the different groups of macro-invertebrates which represents the most sensitive taxa to aquatic organic pollution. The high values of these indices indicate that the medium is more or less undisturbed, with a non-perceivable level of pollution and whose water is of good ecological quality. As regards the ratio between the densities of EPT/chironomidae species which constitutes; the abundance of the EPT per unit of area fetched against that of the chironomidae species collected per unit of surface area within each station. The calculation of this ratio makes it possible to evaluate the degree of environmental stress which the river is undergoing. According to Rothrock *et al.* (1998), chironomidae would tend to increase their relative density as well as dominate the community where there is enrichment of organic matter.

II-2-4-5- Functional traits on mode of nutrition and respiration

The classification of macro-invertebrates according to their feeding modes was adopted by several authors: Vannote *et al.* 1980; Cummins & Wilzbach, 1985; Tachet *et al.* 2010. Vannote *et al.* (1980) used four trophic modes for the application of Riveting Continuum Concept (RCC).They are: predators, decomposers, the scrapers-grazers, collectors, filterers and detritivores. On the other hand, the classifications of Cummins & Wilzbach (1985) and that of Tachet *et al.* (2010), allow us to define six food functional groups which are: choppers, filterers, detritivores, grazers, predators and omnivores. It is this classification method on the

mode of feeding among macro-invertebrates that was used in this our study. This method of classification makes it possible for us to avoid the loss of necessary information related to the regrouping of the filterers-detritivores species as proposed by Vannote *et al.* (1980) whereas, these two groups have quite distinct functions (Edia, 2008).

The use of biological features to indicate ecological function of a species is beneficial for bio-surveillance of a river (Charvet *et al.* 1998; Tomanova & Usseglio-Polatera, 2007), but its application within tropical zones is rare, because of the insufficiency (or the absence) of data relating to the auto-ecology of many species (Usseglio-Polatera *et al.*, 2000; Tomanova *et al.* 2006). In this study, the dynamism of taxonomic richness and abundance of benthic macro-invertebrates within the four respiratory systems (tegument, gills, drill plate and spiracles) as described in the literature by: Durand & Lévêque, 1981; Usseglio-Polatera *et al.*, 2000; De Moor *et al.* 2003a, b; Tomanova *et al*, 2006; Stals & De Moor, 2007; Merritt *et al*, 2008; Tachet *et al.*, 2010) were studied and compared across the different stations.

II-2-4-6- Univariate analyses

The coefficient of correlation of the rho of Spearman was effectuated in order to measure the degree of similarity between the abiotic variables on one hand, and the abiotic and biological variables on the other hand. This coefficient is calculated according to the formula (11).

$$\rho = 1 - \frac{6 \sum_{i=1}^{n} d_i^2}{} \qquad (11)$$

With; n= total number of observations; d_i= difference between the rows of the two series of measurements considered.

The non-parametric test of Kruskal-Wallis (test H) was used to evaluate spatial and seasonal variation in the significance between the differences or similarities for the variances of the abiotic parameters, the taxonomic richness and the Shannon and Weaver diversity index, relating to the distribution of benthic macro-invertebrates. In this case, two assumptions are put forth: a null assumption; according to which, the medians of the samples to be compared do not differ significantly and a second, alternative assumption according to which, there is a significant difference between the medians of the samples to be compared. The analysis is carried out using the Statistical 7.1 program which gives us the value of p (p-been worth). If this value is lower than 0, 05 ($p < 0, 05$), the null assumption is rejected. On

the contrary when (p=0.05) it is accepted. This test considers that the studied variable is quantitative and that it was measured with at least an ordinal scale (ranks). The test is based on the assumption that the various samples compared follow the same distribution or that they have distributions with the same median value. This is why; the interpretation of the test of Kruskal-Wallis is very close to the parametric ANOVA to a factor, knowing that it is based on rows and not averages (Stat Soft France, 2005).

Each time the test of Kruskal-Wallis shows a significant difference between the variances of the compared samples, the multiple test of comparison of ranks or the test U of Mann-Whitney was used for the comparison of a two by two data, in order to isolate the samples which differ significantly.

II-2-4-7- Analyses of Principal Components (ACP)

In this study, ACP was used to establish the abiotic typology of the different sampling stations on the basis of their entire environmental parameters measured within each station throughout the study period. This descriptive factorial statistical method aimed at presenting in a graphic form, the maximum information contained within the table of figures with significant size (Philippeau, 1992). The matrix of data is made up of samples "n" on which are measured the quantitative variables "p" laid out in columns. The matrix used in this study is a base which has undergone a logarithmic transformation following the equation "Log (X + 1)" to have an approximate normality which is then standardized to obtain a comparable scale of variables (Michael *et al.* 2004).The table of figures "n" × "p" thus forms a cloud of "n" points in a space of "p" dimensions. Each principal component (dimension) explains a more or less significant quantity of the starting information. The principal components are classified by in a descending order of the quantity of information which they explain. In general, the second and third principal components are sufficient to explain 60 to 70% of the information contained within the starting matrix (Ouro-Boya, 2004). The principal components were obtained from a diagonal matrix which according to the nature of the initial variables is either a correlation or the covariance matrices (Legendre & Legendre, 1979). Within the framework of this study, it is the matrix of correlation which was used. The final phase of the ACP consists of a graphical representation which makes it possible for one to have an overview of the results. There are two types of representations: the scatter chart of the variables which is a circle of correlation and the scatter chart of the sites. The percentage on the initial information explained by each principal component is illustrated in the form of a histogram. The XLSTAT software version 11.0 was used for this analysis.

CHAPTER III

RESULTS AND DISCUSSION

III-1- RESULTS

III-1-1- Physico-chemical characterization of streams studied

The minimum, maximum, annual mean and standard deviation of physicochemical parameters measure during the study period as well as those of the Organic Pollution Indice (OPI) are presented per sampling stations on Appendix 1. While spato-temporal variations (per sampling station and per month) and seasonal variations of the physico-chemical parameters.

III-1-1-1- Characterization of physical parameters

III-1-1-1-1. Temperature

In the Mufueh stream, temperatures were almost constant throughout the study period with a minimum value of 16°C observed at Mf2 and Mf1 in January 2017 and January 2018 respectively. A maximum value of 22°C was observed in May at the stations Mf1 and Mf2 (figure 9 A). This values oscillated around 19.35±0.45 with a thermal amplitude of 6°C. No significant difference was noted between the stations of the Mufueh stream.

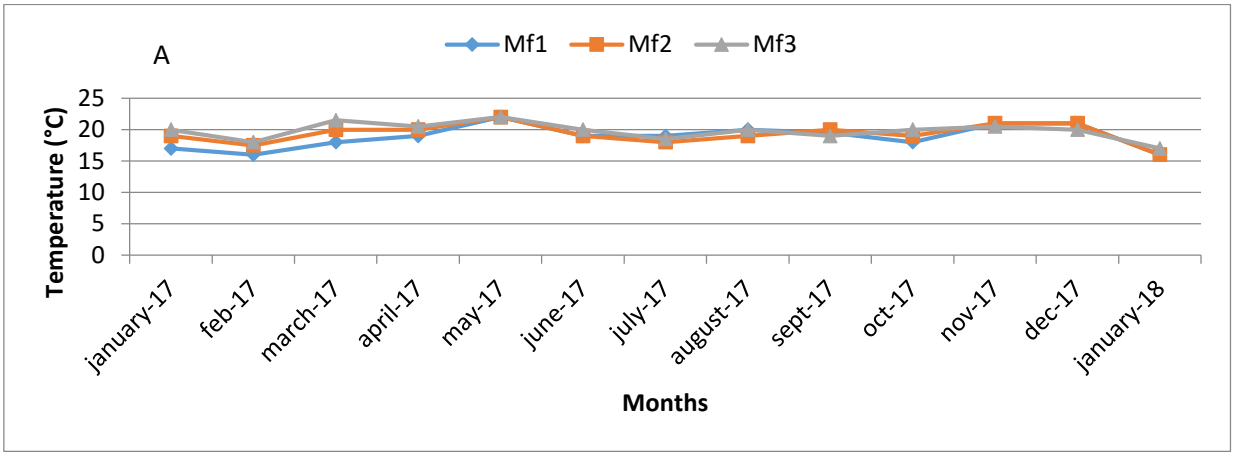
In the Furmuki stream, the lowest temperature value was 16°C obtained in January 2018 at the station F1, while the highest temperature value was 24°C obtained in the month of December 2017 at the station F3 (figure 9 B). These stations had a thermal amplitude of 8°C and the mean at the level of every sampling station of the stream shows that, temperature increases from upstream to downstream on the Furmuki. Amongst the stations, a very significant difference was observed between F1 and F3 ($P= 0.0031$; $\alpha = 0.01$).

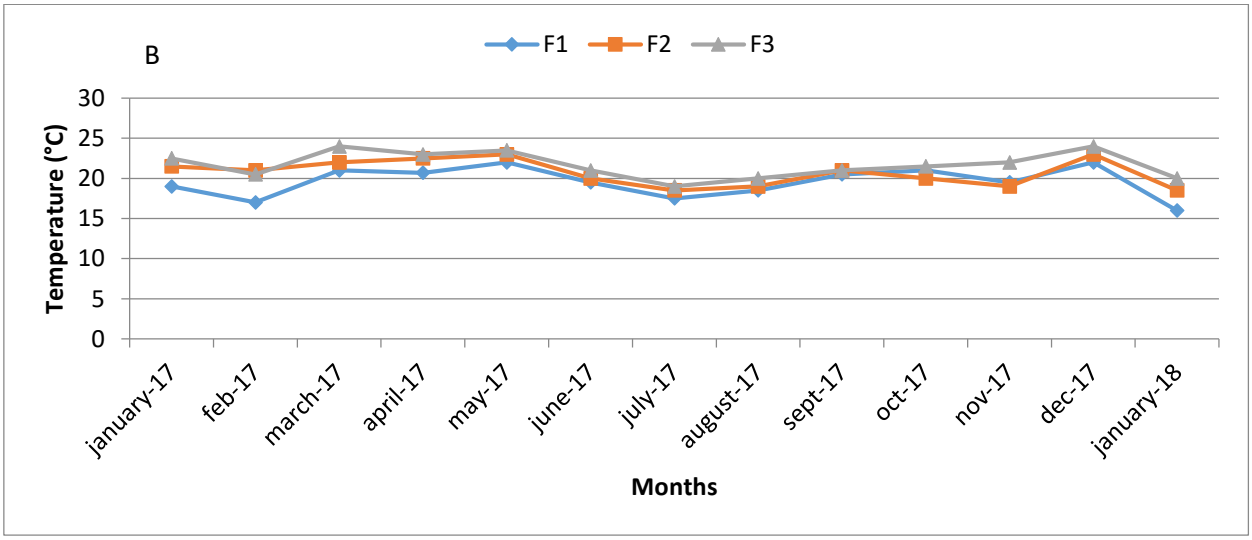
Temperature of Mankon stream lies between 19°C (mk2, October 2017) and 26.5°C (mk2, March 2017) (figure 9 C), for a thermal amplitude of 7.5°C. Just like in the Furmuki, significant differences were observed between sampling stations. Significant differences were noted between mk1 and mk2 ($P = 0.022$, $\alpha = 0.05$) and very significant between Mk1 and Mk3 ($P = 0.0013$, $\alpha = 0.01$).

The temperature of Ayabah and Mezam showed a minimum value of 19°C at A1 in June 2017, A2 in October 2017, and at A3 in February 2017 and January 2018 and a maximum value of 27°C at A1 and A2 respectively in March 2017. It showed a thermal amplitude of 8°C (figure 9). Significant differences were noted between the different stations between A1 and A2 ($P= 0.002$, $\alpha = 0.01$), A1 and A3 ($P = 0.003$, $\alpha = 0.01$) and A3 and A2 ($P = 0.007$, $\alpha = 0.01$).

At river mezam, temperatures varied between 19°C in Ferbruary 2017 and 23°C in October 2017 for a mean of 21.19±1.33 and a thermal amplitude of 4°C. There was no significant difference between the months.

Seasonally, temperature varied from one sampling station to another and from one stream to another. The lowest temperature was obtained in the dry season at mf1 (18.17±2.32) and the highest value was also obtained in the dry season at A2 (25.28±1.43) as shown on table IV below. From this stations, temperatures varied much in the dry season then in the rainy season with a variance coefficient of (12.75). Significant differences where noted between the different seasons at mk1 (P= 0.002) and A3 (P = 0.008) respectively at $\alpha = 0.01$. The difference in temperature between the two seasons was very significant at mk2 (P= 0.0005) and A2 (P= 0.0008) respectively at $\alpha = 0.001$ (table III).





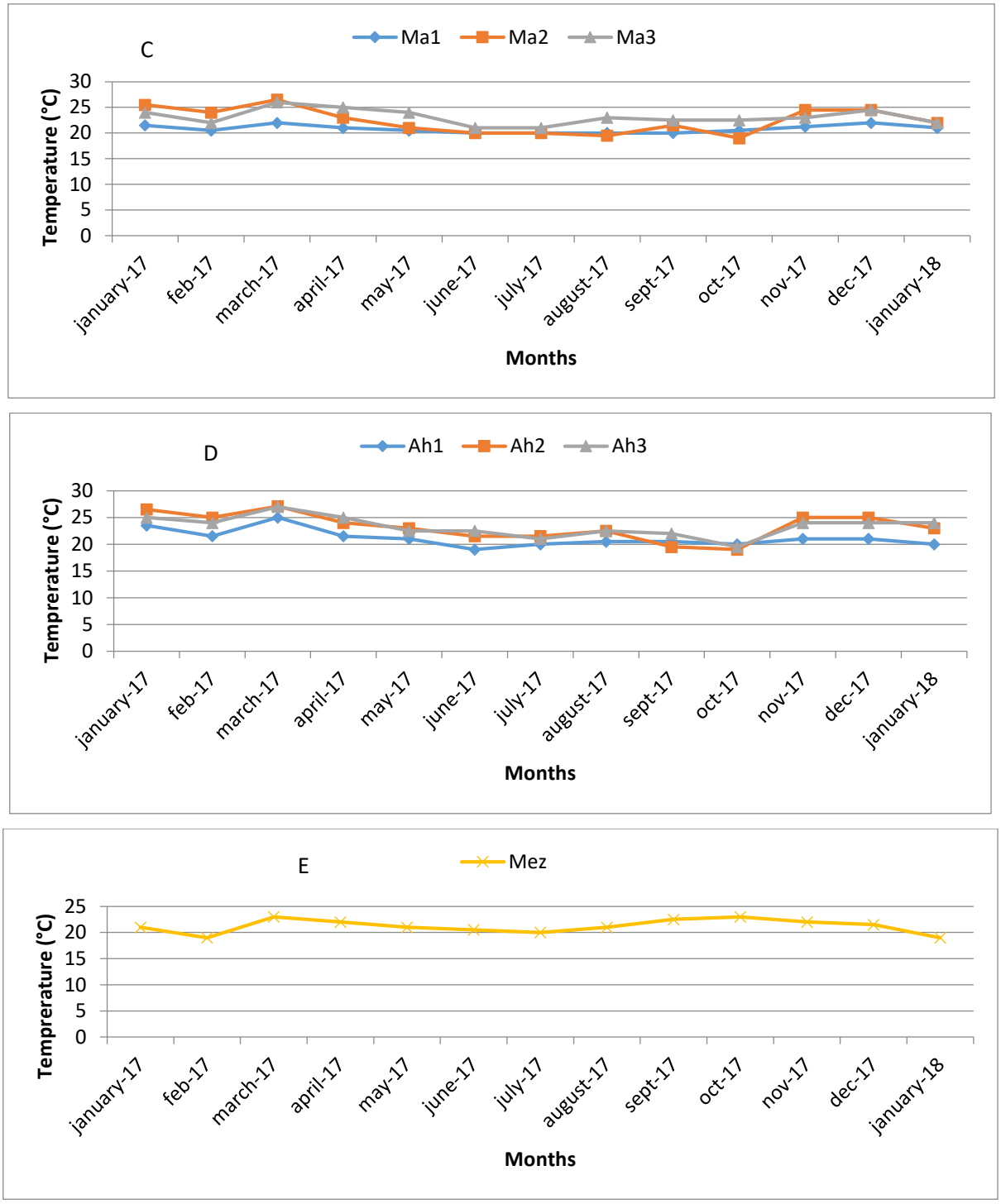


Figure 9: Spatiotemporal variation of temperature in the different streams studied (A = Mufurh, B = Furmuki, C = Mankon, D = Ayabah and E = Mezam).

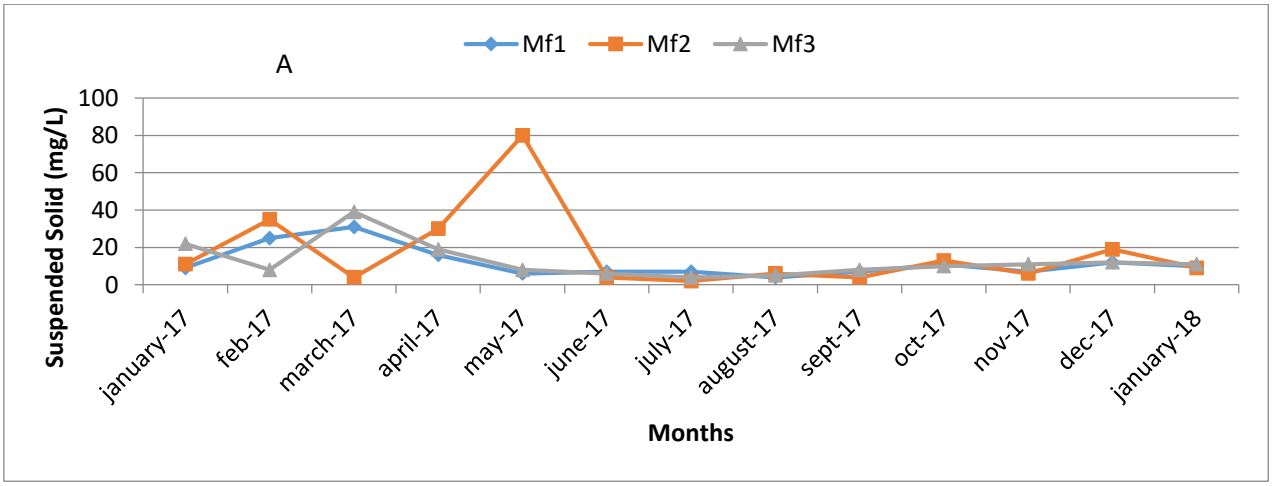
III-1-1-1-2. Suspended Solids

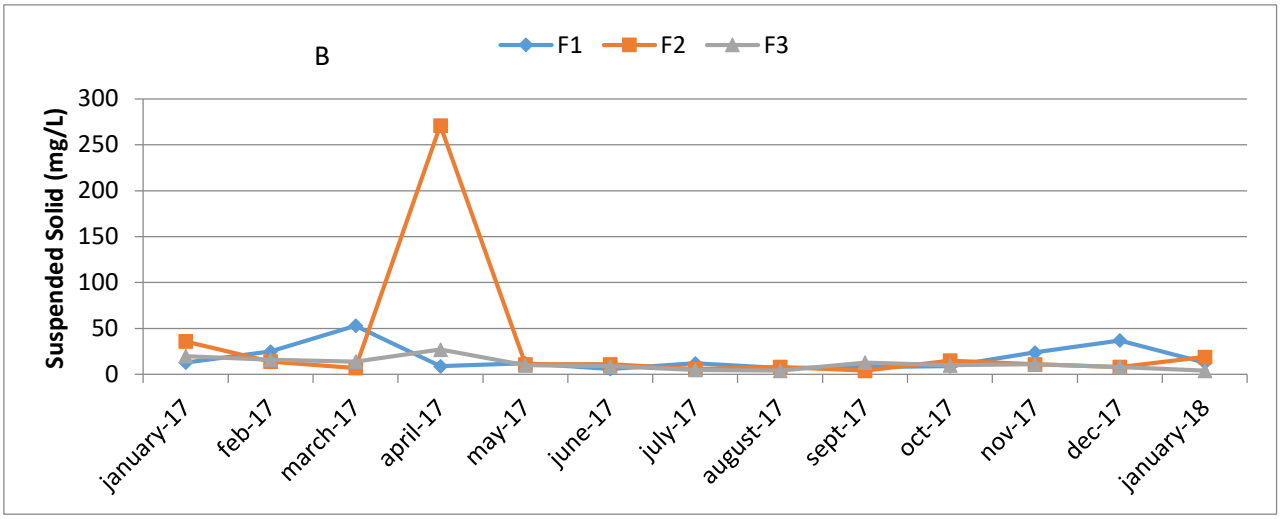
The levels of SS in the Mufueh stream did not vary significantly from one station to another during the study period. The mean levels of SS in the different stations were 11.69±7.95 mg/L, 17.15 ±21.25 mg/L and 12.54±9.47 mg/L obtained in the stations Mf1, Mf2

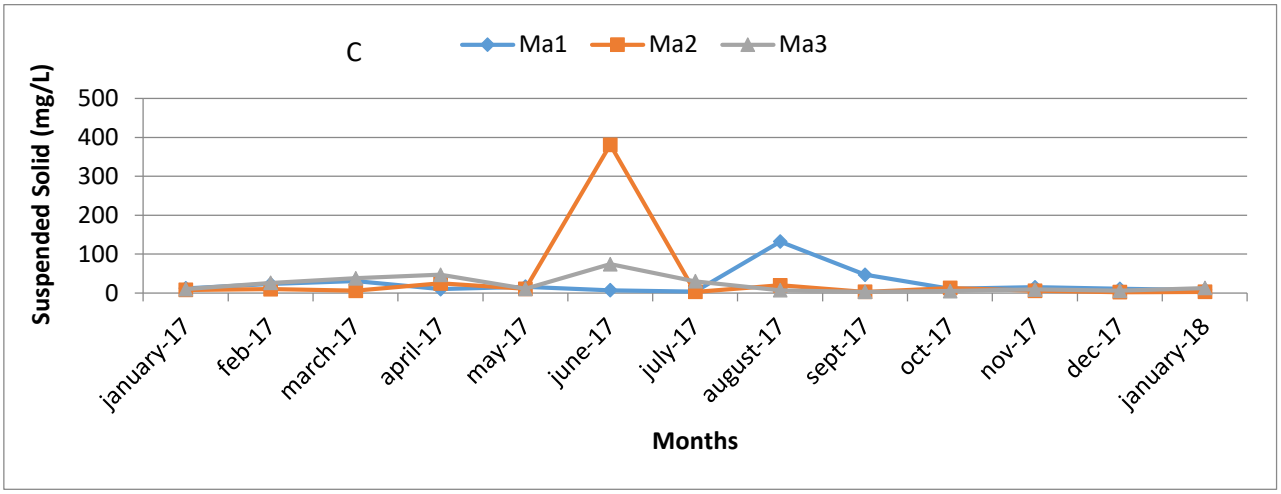
and Mf3 respectively. The lowest value in this stream was 2 mg/L at Mf2 in July 2017 and the maximum value was 80 mg/L in March 2017 at Mf2 (figure 10A)

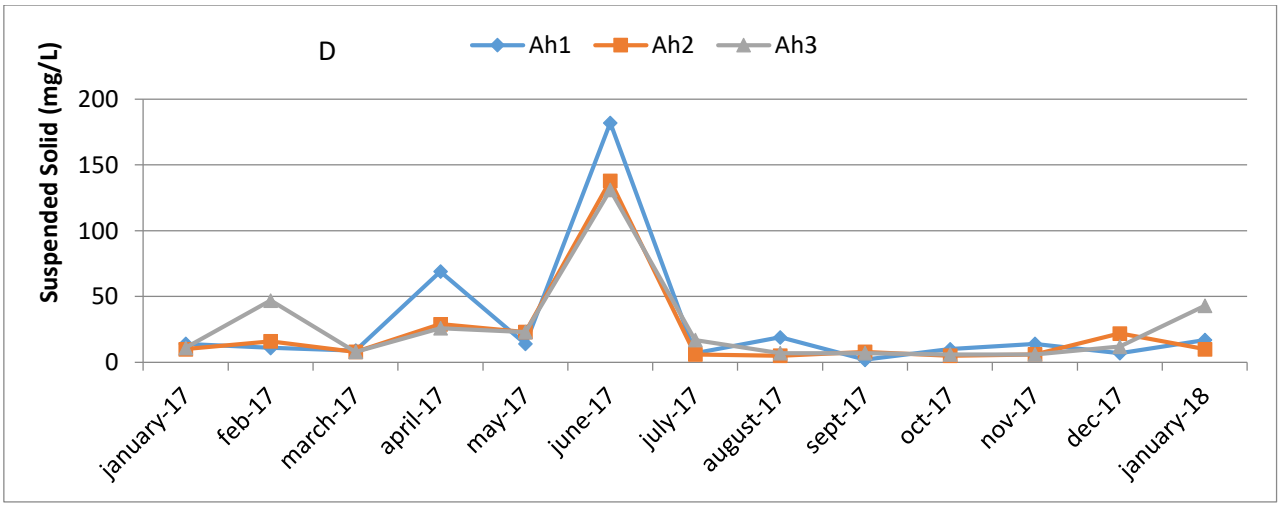
In the Furmuki stream, a maximum value of 271 mg/L was obtained in the month of April 2017 at the station f2 (figure 10B). The concentration of SS increase from upstream to downstream and no significant difference was noted between the stations. The concentration of SS in the Mankon stream fluctuate around 2 mg/L in the month of December 2017 at mk2 and 381 mg/L still at mk2 in the month of june 2017 (figure 10C). The different sampling stations of the stream showed no significant different. Contrarily to Furmuki, the concentration of SS in Ayabah and mezam, generally decrease from upstream to downstream with a lowest value of 2 mg/L in September 2017 at A1 and a highest value of 138 mg/L still at A1 in the June 2017. But a sharp and steady increase was noted at mz from November 2017 to January 2018 (figure 10D).

Generally the concentration of SS varied from one season to another with significant differences noted among the different seasons and sampling stations as on table III. This differences between the two seasons were significant at mf3 (P=0.02, α= 0.05) and at F1 (P= 0.0001, α= 0.001). The lowest value of 5.83±2.99 and a highest value of 65.1±139.5 was noted in mk2 respectively in the dry and rainy seasons. These values varied more in the rainy season than in the dry season with a variation coefficient of 214.




B
F1
F2
F3
Suspended Solid (mg/L)
300
250
200
150
100
50
0
january-17
feb-17
march-17
april-17
may-17
june-17
july-17
august-17
sept-17
oct-17
nov-17
dec-17
january-18


C
Ma1
Ma2
Ma3
Suspended Solid (mg/L)
500
400
300
200
100
0
january-17
feb-17
march-17
april-17
may-17
june-17
july-17
august-17
sept-17
oct-17
nov-17
dec-17
january-18
Months


D
Ah1
Ah2
Ah3
Suspended Solid (mg/L)
200
150
100
50
0
january-17
feb-17
march-17
april-17
may-17
june-17
july-17
august-17
sept-17
oct-17
nov-17
dec-17
january-18

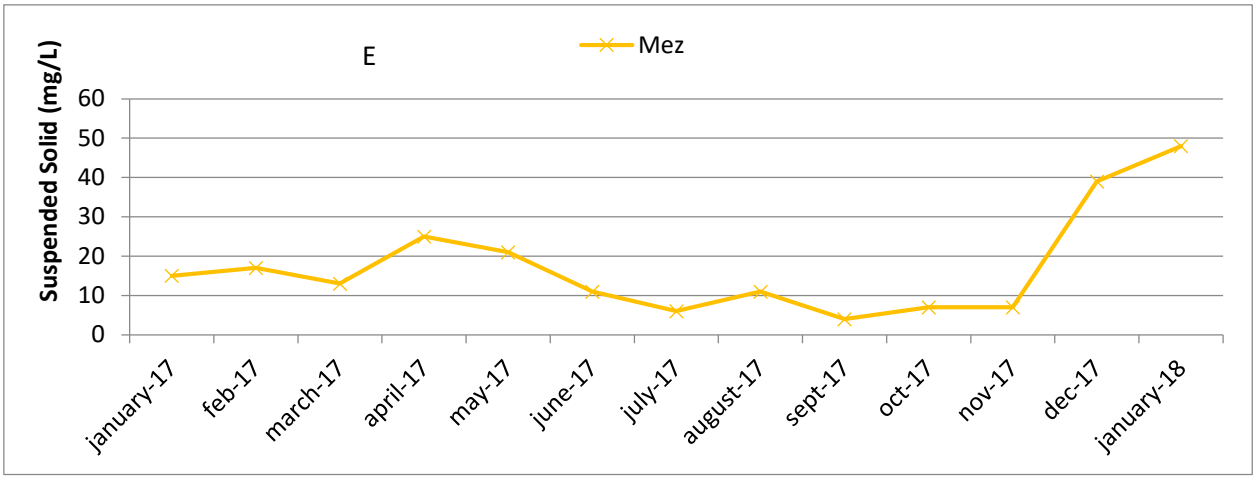
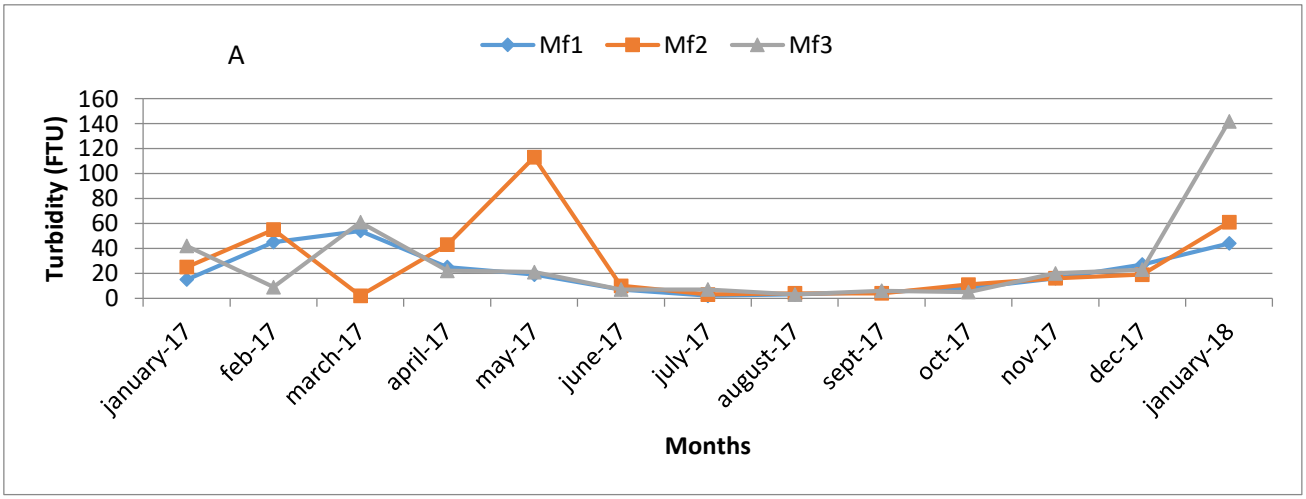


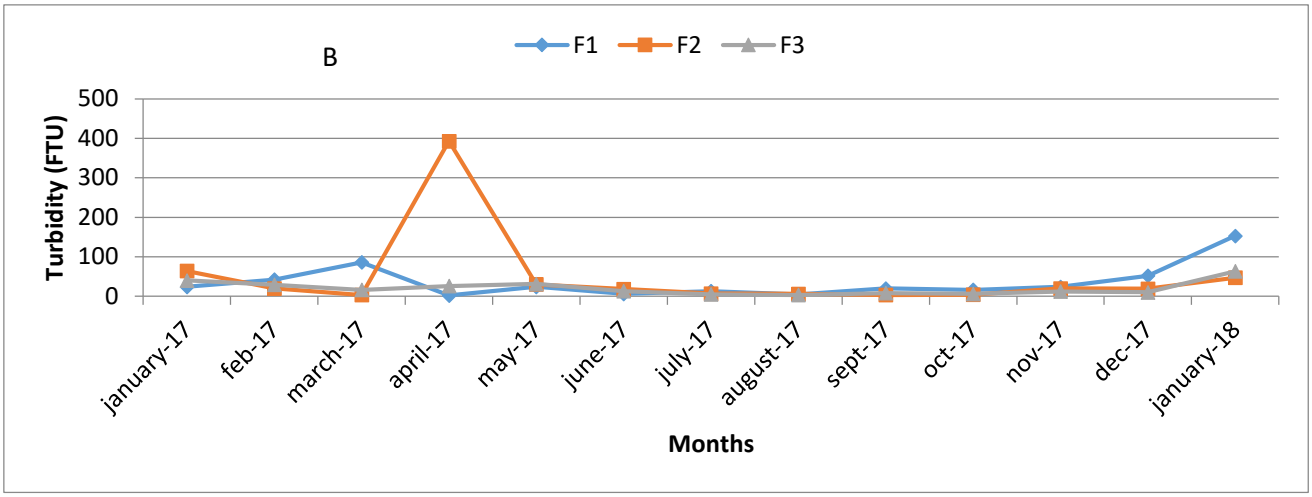
Figure 10: Spatiotemporal variation of suspended solids in the different streams studied (A = Mufurh, B = Furmuki, C = Mankon, D = Ayabah and E = Mezam).

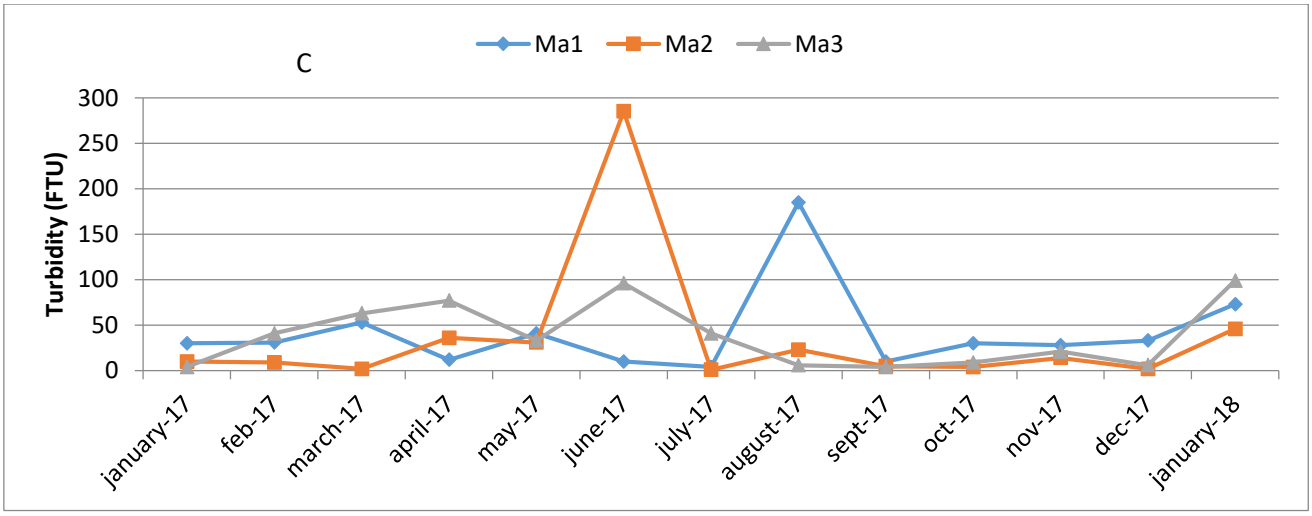
III-1-1-1-3. Turbidity

The mean values of turbidity were generally below 50 NTU in all the streams (figure 11). Though turbidity values higher then 100NTU were registered in particular stations like mf2 in May 2017, Mf3 in January 2018, F1, Mk1 and A2 in January 2018, August 2017 and June 2017 respectively. Generally, there was an increaseed from September 2017 to January 2018 especially in mz. Other streams of the study area show turbidity values higher than 250 NTU such as the mk2 (285NTU) in the month of June 2017 and the station f2 (393NTU) in the month of April 2017. This turbidity values show no significant different between the different sampling stations and the different stream.

Seasonally some significant differences were noted in turbidity values between the dry season and the rainy season in some stations based on the test of Mann Whitney. These include mz (P= 0.01, α = 0.05) but, it was very significant in the mf1 (P= 0.008, α= 0.01), mf3 (P= 0.01, α= 0.01) and at F1 (P= 0.0005, α= 0.001) respectively as on table III.




B
F1
F2
F3
Turbidity (FTU)
500
400
300
200
100
0
january-17
feb-17
march-17
april-17
may-17
june-17
july-17
august-17
sept-17
oct-17
nov-17
dec-17
january-18
Months


C
Ma1
Ma2
Ma3
Turbidity (FTU)
300
250
200
150
100
50
0
january-17
feb-17
march-17
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may-17
june-17
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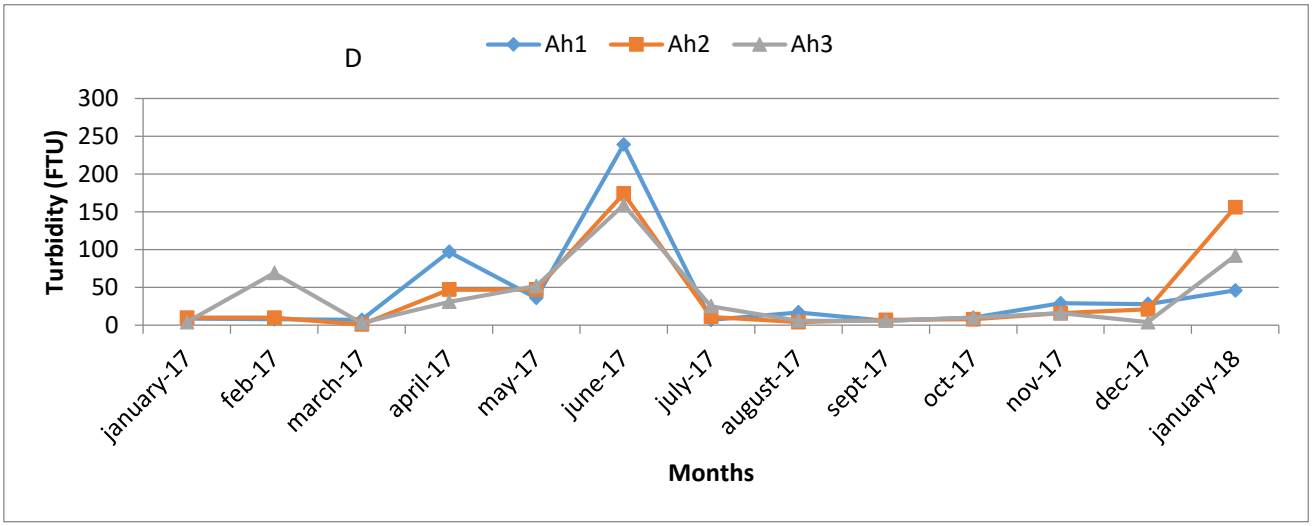
august-17
sept-17
oct-17
nov-17
dec-17
january-18


D
Ah1
Ah2
Ah3
Turbidity (FTU)
300
250
200
150
100
50
0
january-17
feb-17
march-17
april-17
may-17
june-17
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august-17
sept-17
oct-17
nov-17
dec-17
january-18
Months

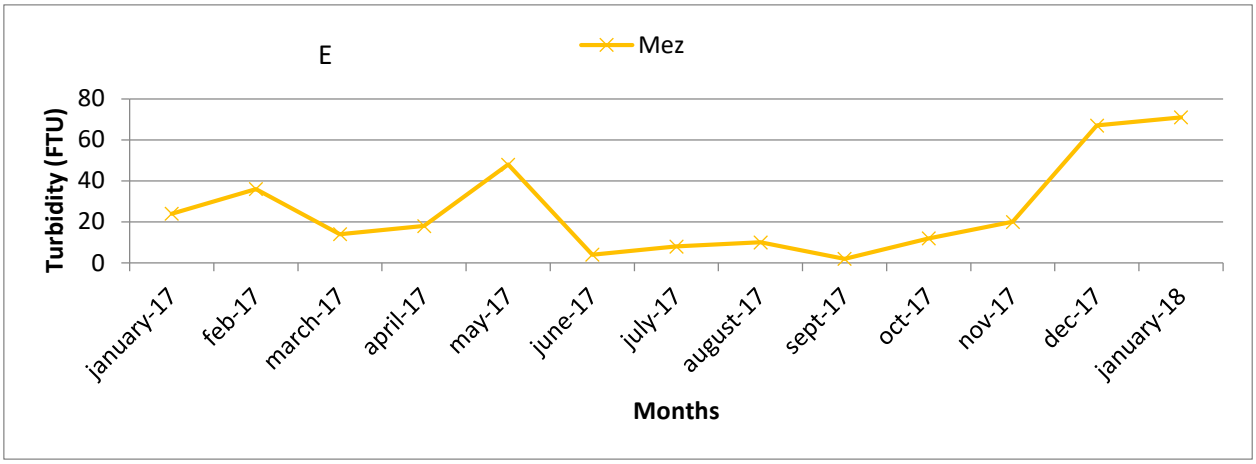


Figure 11: Spatiotemporal variation of turbidity in the different streams studied (A = Mufurh, B = Furmuki, C = Mankon, D = Ayabah and E = mezam).

III-1-1-1-4. Colour

In the Mufurh stream, the value of colour remained below 200 Pt.Co meanwhile higher values were observed in the month of May 2017 at mf2 (754 Pt.co) and mf3 (495 Pt.Co) (figure 12A). These values do not show a significant difference between the different sampling stations. Hence, the mean values of colour in this stream are 59.5±44.3, 128.8±193.3, 106.6±127.1 Pt.Co respectively for mf1, mf2 and mf3.

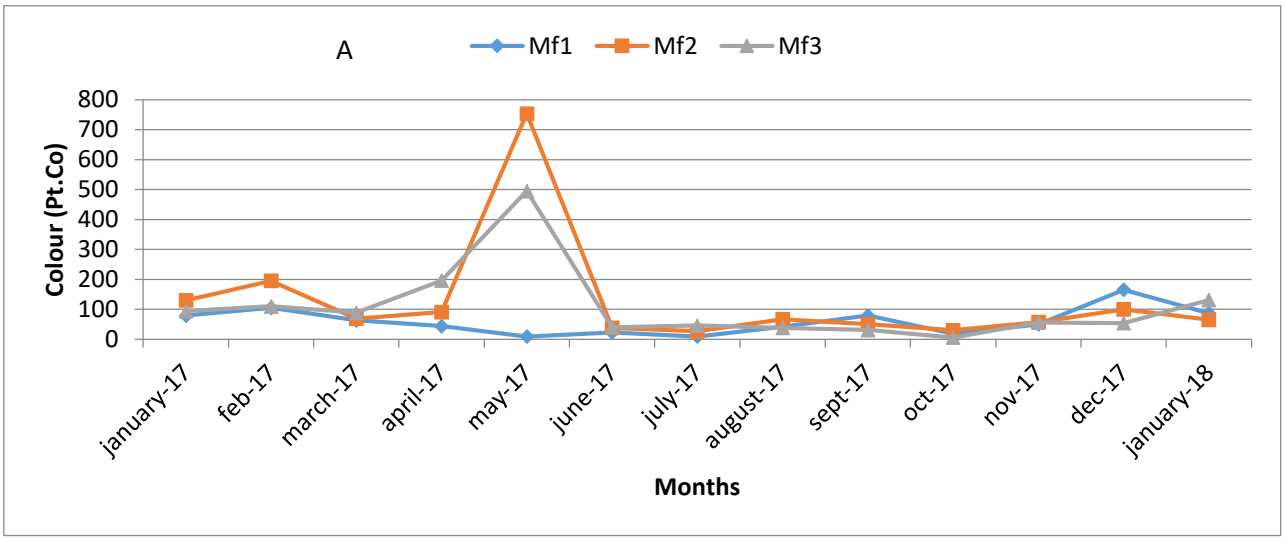
The values of colour in the Furmuki stream are relatively low compared to those of the mufurh stream. The maximum value (317 Pt.Co) at F1 in March 2017 and the minimum value was at the F2 (19 Pt.Co) in August 2017 (figure 12B). In all, no significant difference was noticed between the sampling stations.

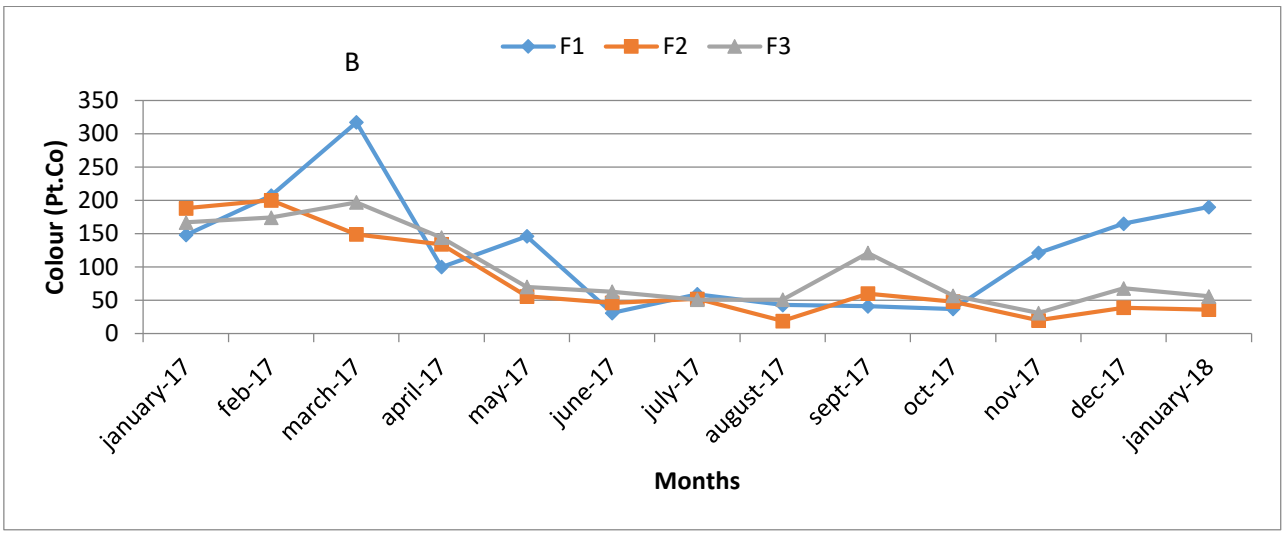
In the Mankon stream, the values of colour vary between 4 and 626 Pt.Co at mk2 in November 2017 and June 2017. The mean values of the difference stations are 114.7±114.7, 115.1±167.1 and 154.5±161 respectively at the station Mk1, Mk2 and Mk3 (figure 12C).

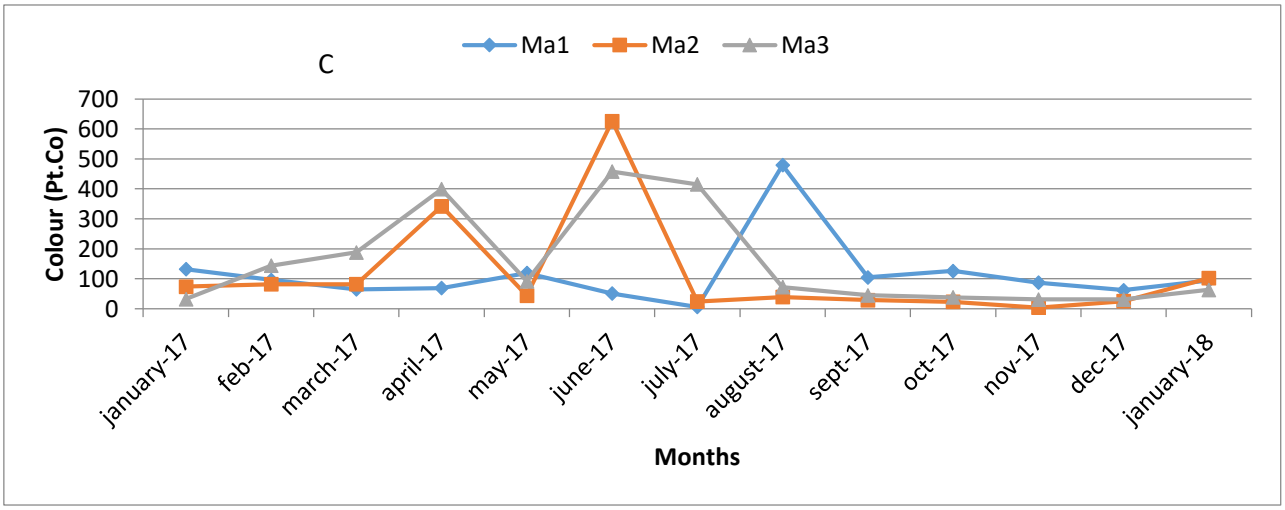
As for the Ayabah stream, it registered the highest values of colour compared to the other streams with a minimum of 2 Pt.Co at A3 in November 2017 and a maximum value of 1248 Pt.Co at A1 in June 2017 figure 12. Still, no significant difference was noticed between this sampling stations. Hence, the mean values of colour in this stream are 205±371, 175.5±304.1, 159.5±225.3 and respectively at A1, A2 and A3

In the Mz, the variation was different in that, from January 2017 to march 2017 it was conctant but increased in April 2017 which again drop till November 2017 for a mean of 95.0±78.7 and a minimum and maximum value of 29 and 285 Pt.Co respectively.

Generally, on the seasonal plan, the highest (337±48.6) and the lowest (32.0±25.13) values were all obtain in the rainy season as seen on table III. The test U of Mann Whitney showed a few significant differences between the two seasons at mf1 (P= 0.002, α= 0.01) and F1 (P= 0.0005, α= 0.001).







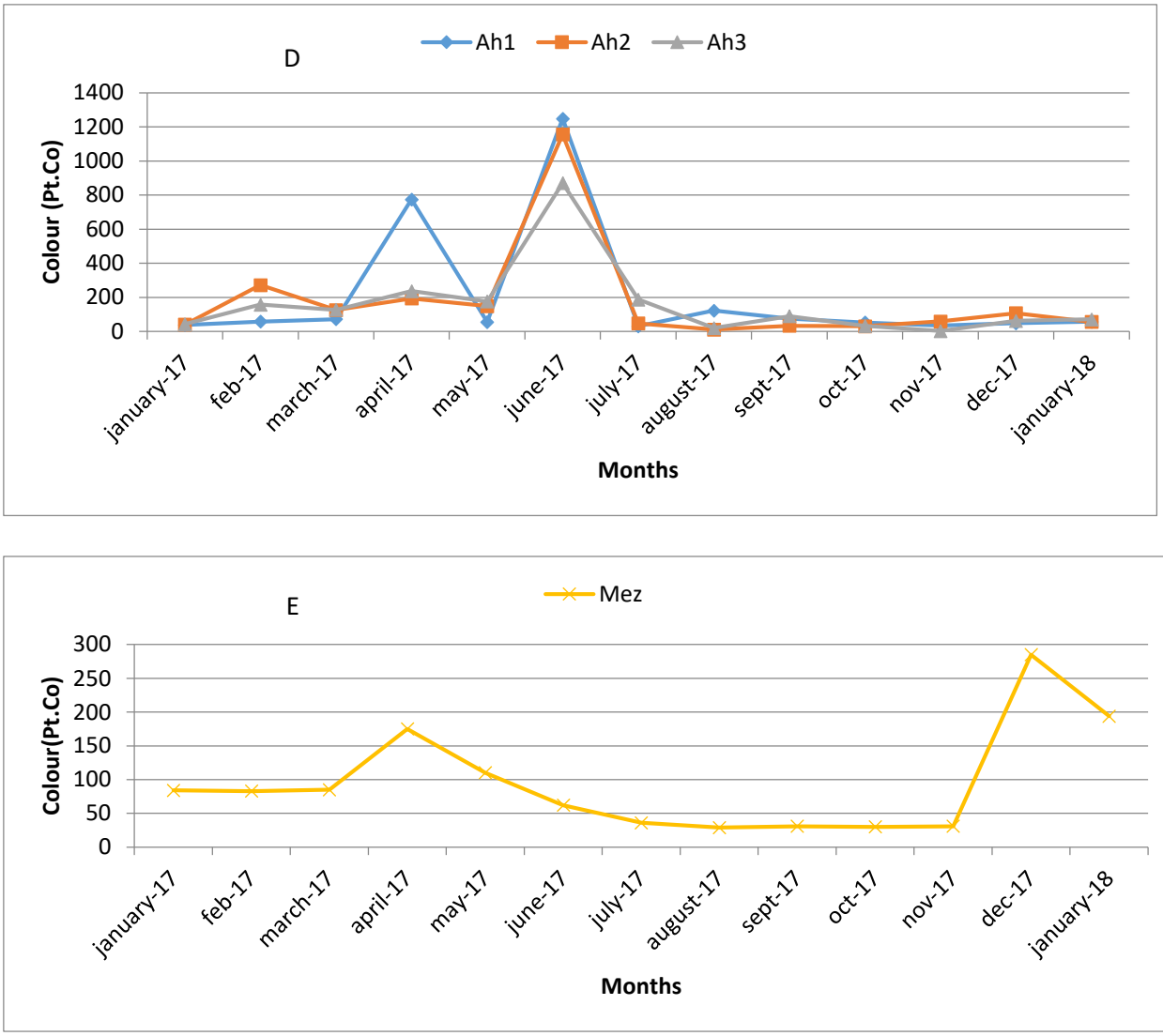


Figure 12: Spatiotemporal variation of colour in the different streams studied (A = Mufurh, B = Furmuki, C = Mankon, D = Ayabah and E = Mezam).

Table III: Mean seasonal values and standard deviations of temperature, turbidity, SS, colour measured in the different sampling stations.

River	Stations	Seasons	Temperature (°C)	Turbidity (NTU)	S.S (mg/L)	Colour (Pt.Co)
Mufueh	Mf1	DS	18.17±2.32	33.5±16.45	15.67±9.87	91.5±40.7
		RS	19.50±1.26	9.86±8.73	8.29±3.999	32.0±25.13
		U	-2.63	5.26	3.87	5.73
		p	0.24	**0.008****	0.07	**0.002****
	Mf2	DS	19.08±2.01	29.67±23.29	14.0±11.52	102.7±52.8
		RS	19.57±1.27	26.9±40.9	19.9±28.2	151±267
		U	-0.46	1.86	1.08	3.1
		p	0.83	0.41	0.64	0.16
	Mf3	DS	19.50±1.67	49.5±48.9	17.17±11.72	89.0±30.1
		RS	20.0±1.13	10.14±7.88	8.57±5.03	121.7±176.0
		U	-0.77	5.26	4.64	2.79
		p	0.73	**0.01****	**0.02***	0.21
Furmuki	F1	DS	19.08±2.29	63.5±49.5	27.50±15.36	191.3±68.6
		RS	19.56±1.55	12.29±8.26	9.0±2.31	65.3±42.5
		U	-1.39	6.19	6.5	6.19
		p	0.54	**0.0005*****	**0.0001*****	**0.0005*****
	F2	DS	20.83±1.75	28.83±22.30	15.83±10.80	105.3±82.7
		RS	20.57±1.69	65.9±144.6	46.6±99	59.3±35.5
		U	0.62	2.01	1.39	0.93
		p	0.79	0.37	0.54	0.69
	F3	DS	22.17±169	28.33±20.46	12.17±5.74	115.5±71.6
		RS	21.29±1.58	13.14±11.04	11.14±765	79.6±37.4
		U	2.01	3.71	1.39	1.86
		p	0.37	0.09	0.54	0.41
Mankon	Mk1	DS	21.38±0.59	41.33±18.01	16.67±8.69	89.3±25.4
		RS	20.29±0.39	41.7±64.5	32.4±46.2	136.4±156.9
		U	5.73	2.94	0.77	-0.62
		p	**0.002****	0.18	0.74	0.79
	Mk2	DS	24.5±1.52	13.83±16.45	5.83±2.99	61.5±38.1

Continuetion of Table III

		RS	20.57±1.37	55.0±102.4	65.1±139.5	161.0±235.5
		U	6.19	-1.34	-3.71	0.31
		p	**0.0005*** **	0.59	0.08	0.89
	Mk3	DS	23.58±1.56	39.0±36.9	17.0±12.43	81.5±68.0
		RS	22.71±1.47	38.0±36.4	25.3±26.8	217.0±195.2
		U	1.86	0.15	0	-3.4
		p	0.41	0.95	1	0.12
Ayabah	A1	DS	22.0±1.87	21.17±15.79	12.0±3.69	51.17±14.09
		RS	20.36±0.80	58.9±85.7	43.3±65.2	337±481
		U	3.87	-0.77	-1.08	-2.79
		p	0.7	0.74	0.64	0.21
	A2	DS	25.28±1.43	35.7±59.3	12.0±5.93	110.0±85.9
		RS	21.57±1.80	42.6±60.9	30.6±48.3	232±413
		U	6.04	-0.31	0.31	1.24
		p	**0.0008*** **	0.89	0.89	0.59
	A3	DS	24.67±1.21	31.3±39.1	21.17±18.63	77.0±56.5
		RS	22.14±1.68	41.3±54.5	31.0±44.8	230±294
		U	5.11	-1.86	0.15	-2.79
		p	**0.008** **	0.41	0.95	0.21
Mezam	Mz	DS	20.98±1.63	38.7±24.6	23.17±16.35	127.0±94.0
		RS	21.43±1.10	14.57±15.65	12.14±7.93	67.6±55.7
		U	-0.93	4.95	3.25	3.25
		p	0.68	**0.01***	0.14	0.14

DR = dry season, SP = rainy season; U = Mann-Whitney test; p = p-value; (*) = significant difference ; the code Mf_1, Mf_2, Mf_3, f_1, f_1, f_1 Mk_1, Mk_2, Mk_3, A_1, A_2, A_3 and Mz represent sampling stations.

III-1-1-2- Spatial and seasonal variation of the chemical parameters

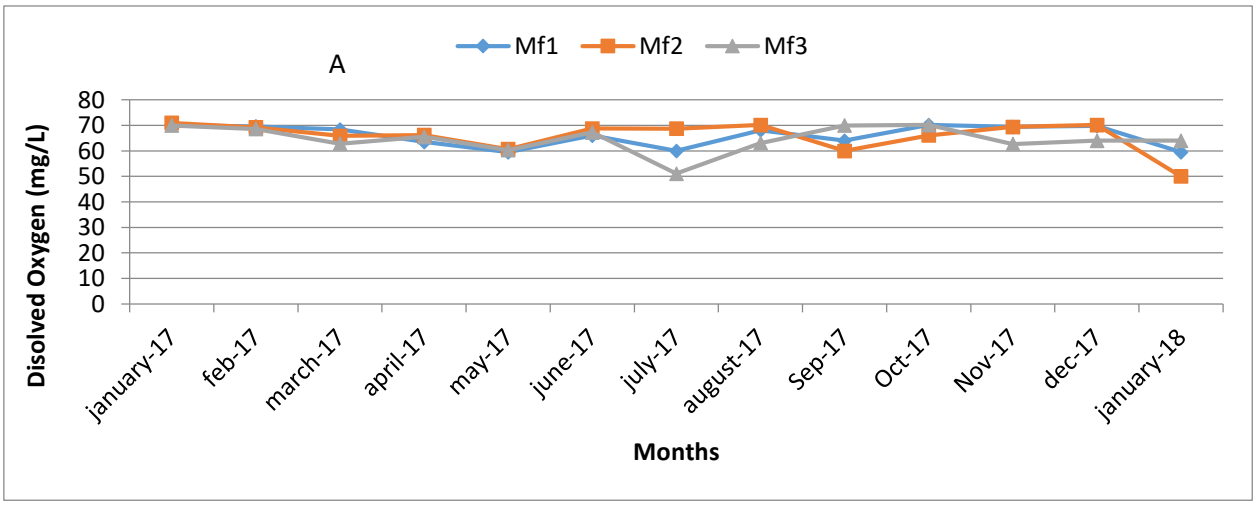
III-1-1-2-1. Dissolved Oxygen

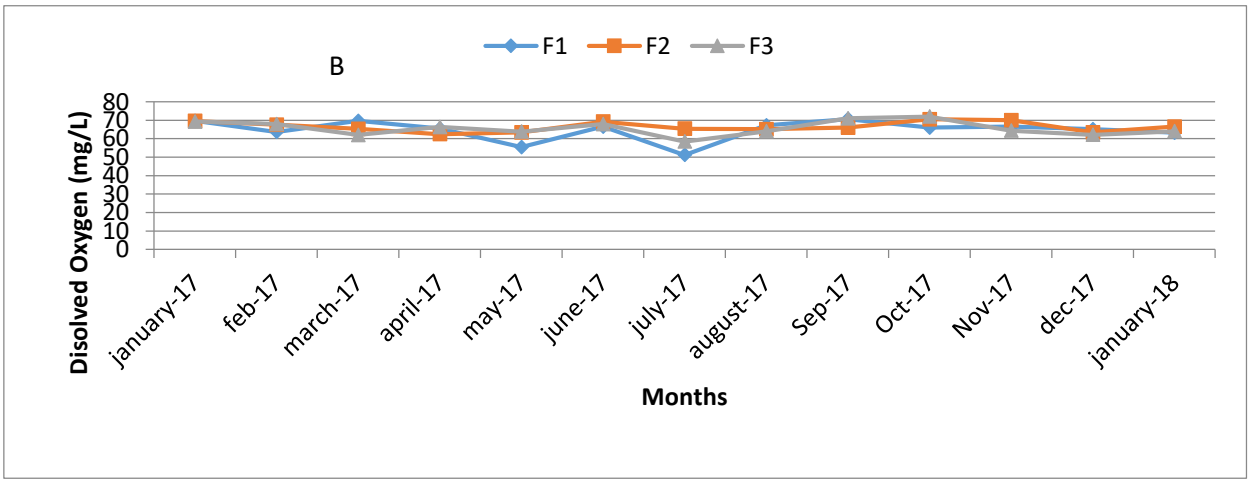
With a saturation level of 2.65±1.03 mg/L, the waters upstream of the Mufueh (Mf1) were more oxygenated than those midstream **(**Mf2), which were in turn more oxygenated then those downstream (Mf3) whose mean oxygen saturation is 1.60±0.66 mg/L (figure 13A). This saturation levels shows no significant difference between the sampling stations.

In the Furmuki, most of the stations showed an oxygen saturation above 60% except for the month of May and July 2017 at F1 which shows saturation levels slightly above 50%. Here, a low levels of dissolved oxygen was noted in the waters though the months of September and October 2017 in F1 and F2 respectively showed saturation levels above 70% which is said to be satisfactory (figure 13B).

As for Mankon and Ayabah streams, a constant variation in dissolved oxygen level was observed which range between 60% and 70 % in both streams and their sampling stations. But, a saturation level of 72% was noted at mk1 in August 2017. Contrary to the other stations, a dissolved Oxygen saturation level of closed to 75% was observed in June and October 2017 at Mezam (figure 13C). In the both streams, no significant difference was noted between the stations.

On a seasonal plan generally, no major difference was noticed between the dry and rainy seasons in the streams of Bamenda except for the second station of Ayabah (A2) which showed a difference in the two seasons ($P = 0.02$, $\alpha = 0.05$) table IV.





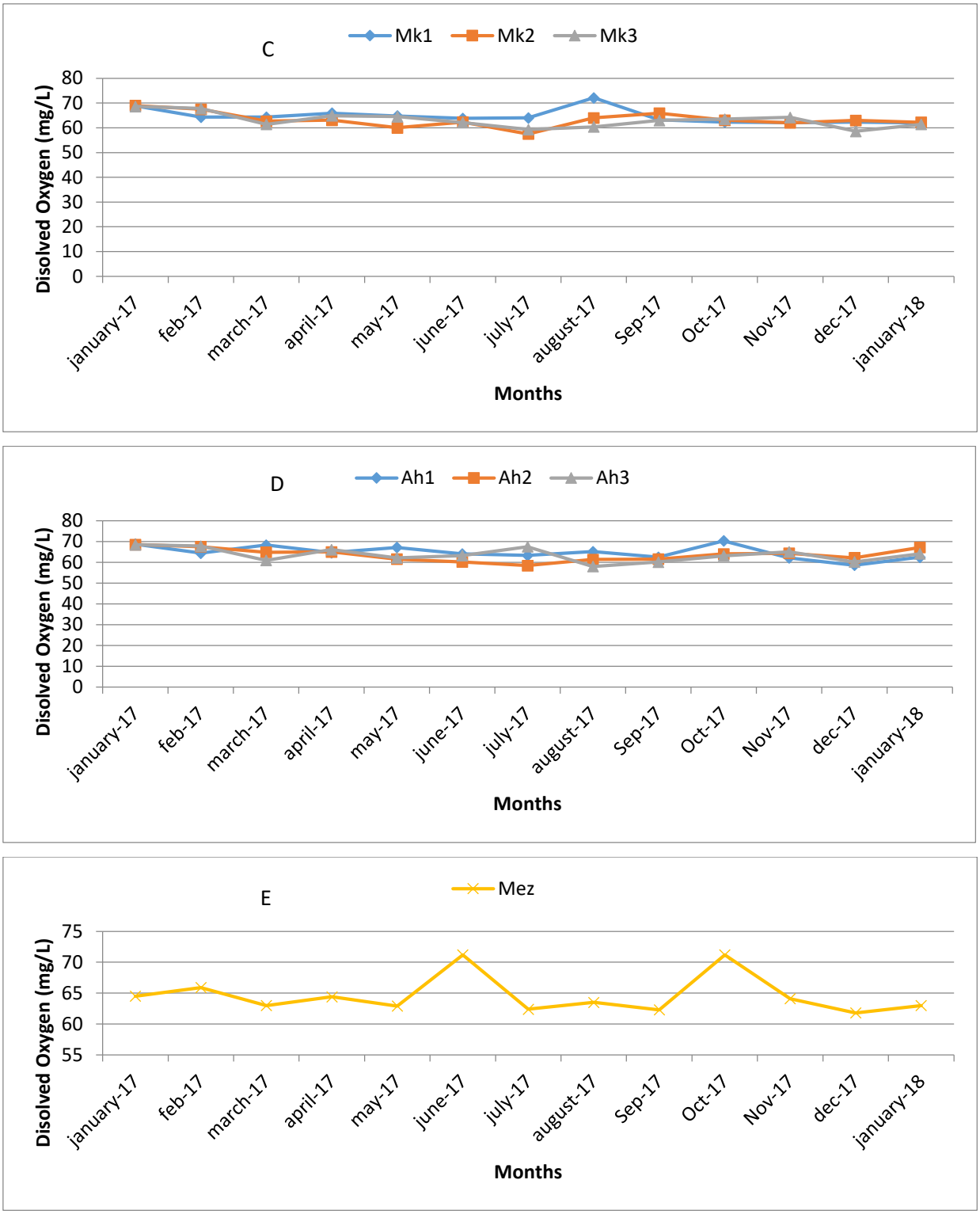


Figure 13: Spatiotemporal variation of Dissolved Oxygen in the different streams studied (A = Mufurh, B = Furmuki, C = Mankon, D = Ayabah and E = Mezam).

III-1-1-2-2. Oxydability

In the Mufueh stream, oxydability values lie between 0.36 and 6.32 mg/L at the station mf1. As for Mf2 and Mf3, the values ranges between 0.39 and 5.33mg/L and between 0.19 and 5.13 mg/L of oxygen respectively (figure 14A). The highest value was registered in the month of May 2017 at the station Mf1. Oxydability values along this stream shows no significant difference between the different sampling stations.

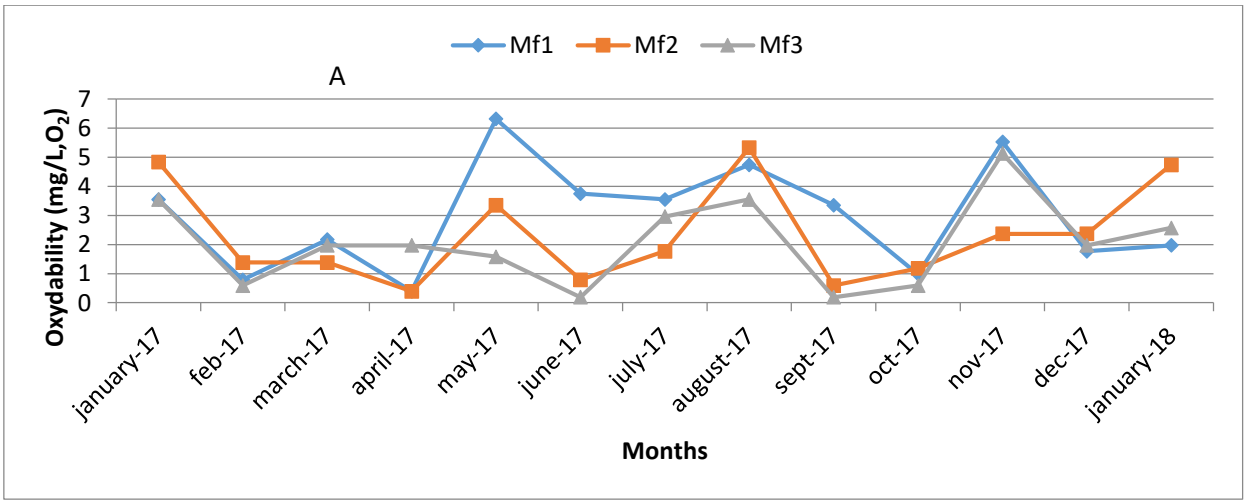
Oxydability values in the Furmuki stream generally ranges between 0.19 and 7.70 mg/L O_2 of oxygen (figure 14B). The mean values at the level of the stations F1, F2 and F3 are 3.08±2.35 mg/L, 2.07±2.31 mg/L and 3.16±2.31 mg/L of oxygen respectively.

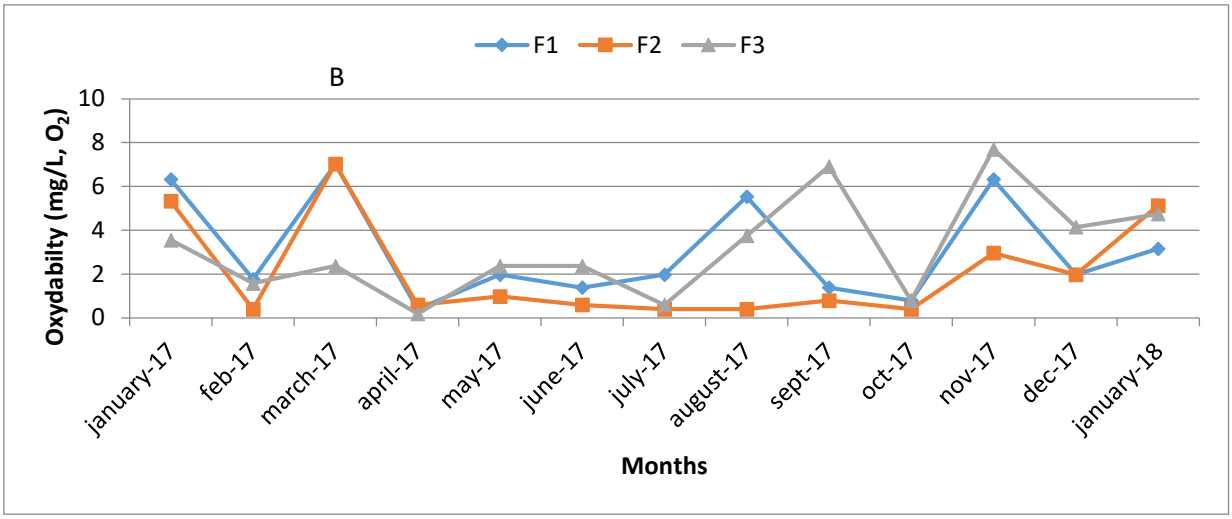
In the Mankon stream, a maximum value of 9.48 mg/L of oxygen was recorded at mk3 in December 2017, while the minimum value of 0.19 mg/L of oxygen was gotten at mk1 in April 2017 (figure 14C). No significant difference was noted between the stations.

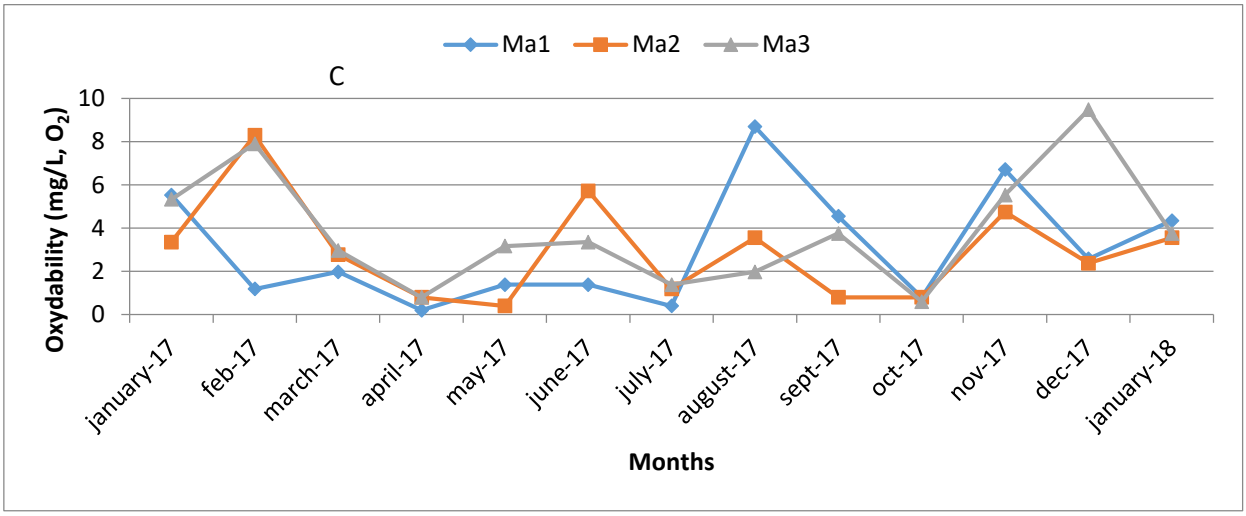
As for Ayabah stream, oxydability values varied between 0.19 and 15.60 mg/L of oxygen (figure 14D). This stream registered the highest value (15.60 mg/L) of oxydability of all the streams studied in Bamenda.

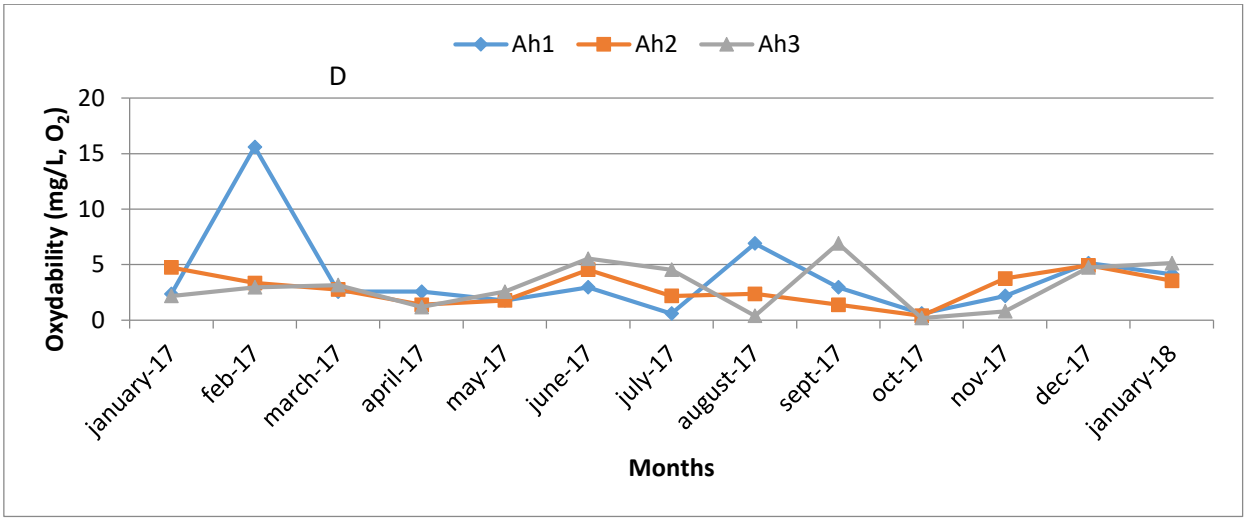
At the Mezam River, the values range between 0.19 – 11.25 mg/L for an over all mean of 3.54±3.7. This values fluctuated much across the year and the high value was recorded in February with is marked by high wasted accumulation in the waters.

This parameter varied from one season to and another. The test of Mann Whitney showed significant difference between the two seasons and from one station to another. This include, F1 and F2 (P= 0.02, α= 0.05), In Mk3 (P= 0.005, α= 0.01), A2 (P= 0.008, α= 0.01) and Mz (P= 0.04, α= 0.05) as on table IV. This difference could be due to the accumulation of organic substances in the streams during the dry season.




F1
F2
F3
B
Oxydabilty (mg/L, O2)
10
8
6
4
2
0
january-17
feb-17
march-17
april-17
may-17
june-17
july-17
august-17
sept-17
oct-17
nov-17
dec-17
january-18
Months


Ma1
Ma2
Ma3
C
Oxydability (mg/L, O2)
10
8
6
4
2
0
january-17
feb-17
march-17
april-17
may-17
june-17
july-17
august-17
sept-17
oct-17
nov-17
dec-17
january-18
Months


Ah1
Ah2
Ah3
D
Oxydability (mg/L, O2)
20
15
10
5
0
january-17
feb-17
march-17
april-17
may-17
june-17
july-17
august-17
sept-17
oct-17
nov-17
dec-17
january-18
Months

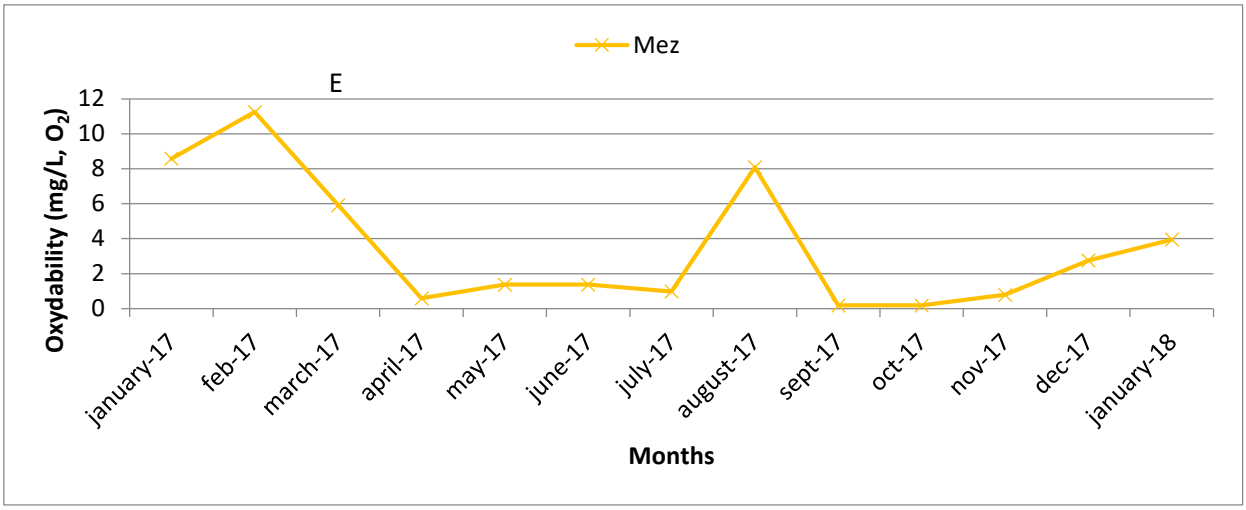


Figure 14: Spatiotemporal variation of Oxydability in the different streams studied (A = Mufurh, B = Furmuki, C = Mankon, D = Ayabah and E = Mezam).

III-1-1-2-3. Salinity

Water salinity varied between 0.01 and 0.05 PSU (figure 15A) in the mufueh stream with a mean values of 0.023±0.012 (PSU). The test of Mann Whitney presents significant differences between the stations, mf1 and mf2 (P= 0.0015, α= 0.01), Mf1 and Mf3 (P= 0.0007, α= 0.001)

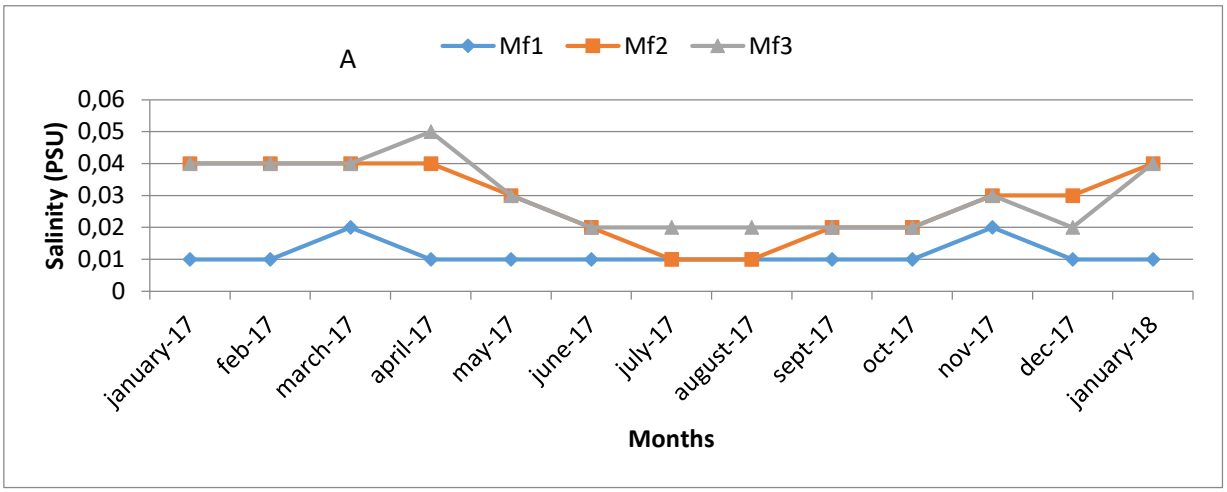
In the Furmuki, the mean values of salinity in the 3 sampling stations are 0.02±0.01, 0.04±0.02 and 0.07±0.03 for F1, F2 and F3 respectively (figure 15B). Just like in the mufueh, Mann Whitney showed significant differences between the stations, F1 and F2 (P= 0.0051, α= 0.01), F1 and F3 (P= 0.0000, α= 0.001) and F2 and F3 (P= 0.025, α= 0.05).

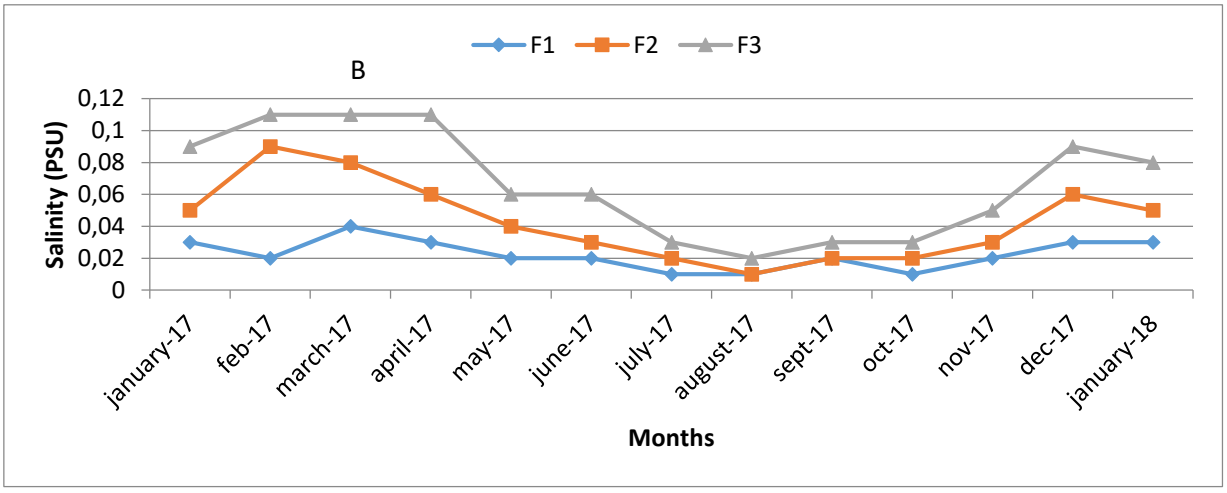
Unlike in the Mufueh, water salinity in Mankan varied between 0.01 and 0.18 $^{0}/_{00}$ (figure 15C). The mean sality value in this stream is 0.087±0.023. The only significant difference was noted between Mk1 and Mk3 (P= 0.006, α= 0.01).

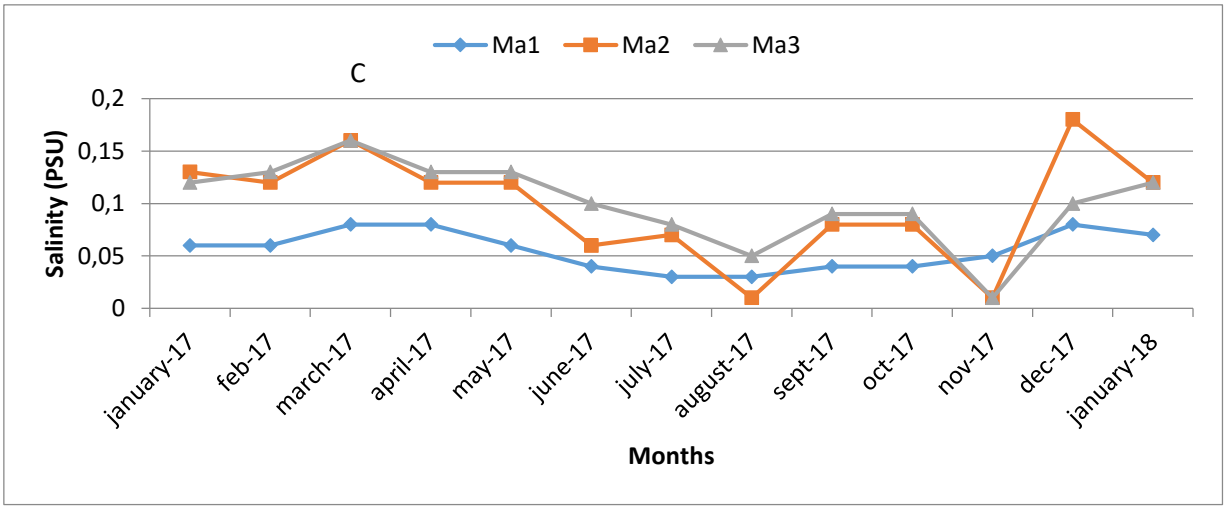
Contrarilly to the other streams the values of water salinity are highest in the Ayabah stream and vary from 0.01 to 0.22 $^{0}/_{00}$ (figure 15D). There are relatively higher at the station A2 (0.20 $^{0}/_{00}$) and A3 (0.22 $^{0}/_{00}$) situated downstream of the food market of Bamenda. It should be noted that this is one of the biggest markets in the town and all its wasted drain into this stream. The variation of salinity in this two stations are significantly different (H test of Kruskal- Wallis; $p < 0.05$) from those of the other stations.

This parameter did not vary much at mz, a high value of $0.01^{0}/_{00}$ in March 2017 and $0.01^{0}/_{00}$ in August 2017 for a mean of 0.05±0.01. The test of Mann Whitney showed no significant differences in the months.

Seasonally some significant differences are noted in water salinity values between the dry season and the rainy season in some stations based on the test of Mann Whitney. These include mf2 (P= 0.01, α = 0.01) but, it was less significant in the F1 (P= 0.02, α= 0.05), F2 (P= 0.01, α= 0.05) and at F3 (P= 0.4, α= 0.05) and mk1 (P= 0.03, α= 0.05) as on table IV.







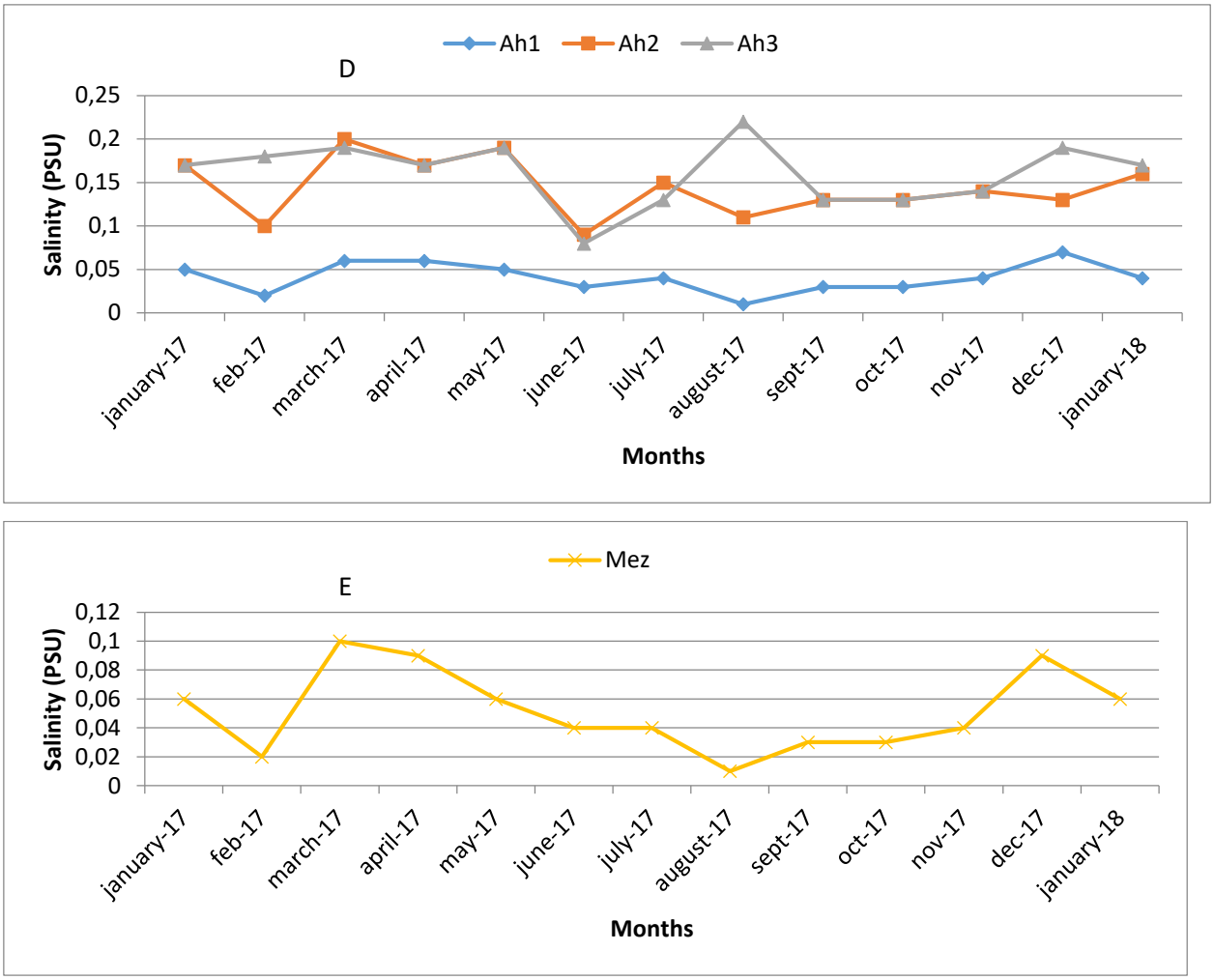


Figure 15: Spatiotemporal variation of water salinity in the different streams studied (A = Mufurh, B = Furmuki, C = mankon, D = Ayabah and E = Mezam).

Table IV: mean seasonal values and standard deviations oxygen, carbondioxid, oxydability and salinity measured in the different sampling stations.

River	Stations	Seasons	Oxygene (mg/L)	Carbondioxid (mg/L)	Oxydability (mg/L)	Salinity (0/00
Mufueh	Mf1	DS	3.00±1.02	20.24±18.68	2.63±1.68	0.01±0.01
		RS	2.34±1.01	15.72±8.95	3.30±2.05	0.01±0
		U	1.86	0.31	-1.39	2.17
		p	0.042	0.89	0.54	0.12
	Mf2	DS	1.98±1.15	19.07±10.04	2.85±1.57	0.04±0.01
		RS	1.63±1.0	16.09±4.24	1.91±1.81	0.02±0.01
		U	0.77	1.55	2.79	4.95
		p	0.73	0.49	0.21	**0.01****

Continuetion of Table IV

	Mf3	DS	1.60±0.32	24.62±24.36	2.63±1.56	0.04±0.01
		RS	1.60±0.88	16.85±4.64	1.58±8.83	0.03±0.01
		U	1.85	-1.24	2.79	3.41
		p	0.41	0.59	0.21	0.09
Furmuki	F1	DS	2.15±0.64	16.43±18.04	4.43±2.39	0.03±0.01
		RS	2.15±0.80	21.84±14.37	1.91±1.70	0.02±0.01
		U	0.31	-2.17	4.64	0.49
		p	0.89	0.33	**0.02***	**0.02***
	F2	DS	2.55±1.05	15.55±10.53	3.80±2.46	0.06±0.02
		RS	2.44±1.01	15.84±9.20	0.59±0.23	0.03±0.02
		U	0.77	-0.46	4.8	4.95
		p	0.74	0.84	**0.02***	**0.01***
	F3	DS	2.60±1.09	22.29±20.36	4.01±2.14	0.08±0.02
		RS	7.35±0.25	21.12±14.76	2.42±2.34	0.05±0.03
		U	1.39	-1.86	3.1	4.33
		p	0.54	0.4	0.16	**0.4***
Mankon	Mk1	DS	2.53±1.65	24.1±28.4	3.72±2.17	0.067±0.01
		RS	2.81±1.44	14.32±8.10	2.48±3.10	0.046±0.02
		U	-0.93	0.46	2.79	4.33
		p	0.69	0.84	0.21	**0.03***
	Mk2	DS	2.35±0.59	26.7±25.1	4.177±2.17	0.12±0.06
		RS	2.23±1.14	26.8±30.6	1.89±199	0.08±0.04
		U	0.62	1.39	3.87	3.87
		p	0.79	0.54	0.07	0.07
	Mk3	DS	2.18±0.50	20.8±27.3	5.83±2.47	0.11±0.05
		RS	2.41±1.37	19.11±4.81	2.141±12.86	0.10±0.03
		U	0.62	-3.71	5.42	2.01
		p	0.79	0.08	**0.005****	0.37
Ayabah	A1	DS	2.68±0.69	17.3±25.3	5.33±5.16	0.05±0.02
		RS	2.77±1.49	16.09±10.18	2.62±2.15	0.04±0.02
		U	0.93	-1.55	2.32	2.48
		p	0.69	0.5	0.3	0.26
	A2	DS	2.65±0.81	26.4±25.8	3.85±0.84	0.15±0.03

Continuetion of Table IV

		RS	1.80±1.23	24.39±5.12	2.0±1.29	0.14±0.03
		U	4.64	-1.55	5.26	1.35
		p	**0.02***	0.49	**0.008****	0.54
	A3	DS	2.32±0.73	31.7±25.1	3.16±1.61	0.17±0.02
		RS	2.10±0.94	18.10±7.98	3.04±2.65	0.15±0.05
		U	0.77	2.63	0.62	2.47
		p	0.74	0.24	0.79	0.26
Mezam	Mz	DS	2.33±0.59	16.13±22.61	5.54±3.87	0.06±0.03
		RS	2.46±138	14.07±6.59	1.83±2.81	0.04±0.03
		U	1.55	-1.86	4.33	2.63
		p	0.5	0.41	**0.04***	0.23

DR = dry season, SP = rainy season; U = Mann-Whitney test; p = p-value; (*) = significant difference ; the code Mf_1, Mf_2, Mf_3, f_1, $f_{1,}f_1$ Mk_1, Mk_2, Mk_3, A_1, A_2, A_3 and Mz represent sampling stations.

III-1-1-2-4. Ammonium

Although must of the ammonium values registered in the mufueh are inferior to 0.5 mg/L, a concentration of 1.07 mg/L was recorded at mf2 in May 2017 (figure 16A). The mean concentration in the 3 sampling stations mf1 (0.11±0.11), mf2 (0.23±0.30), mf3 (0.16±0.19) shows that, the concentration of ammonium increases from upstream to downstream.

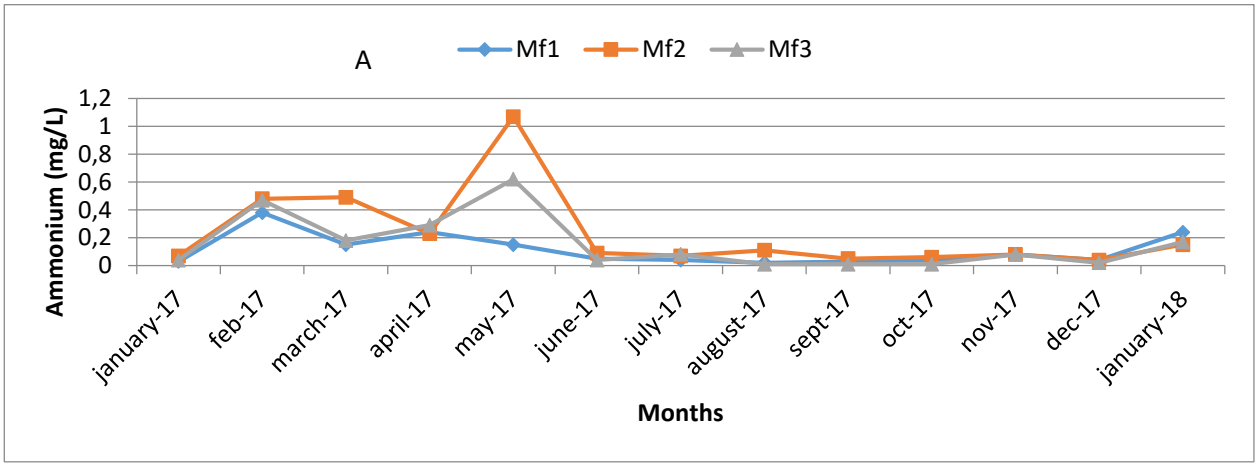
In the furmuki, the stations F1and F2 varies in a similar manner and are different from F3. The concentration of ammonium is higher in the station F3 with a mean of 0.16±0.15 mg/L (figure 16B). No significant difference was observed among these stations ($P < 0.5$).

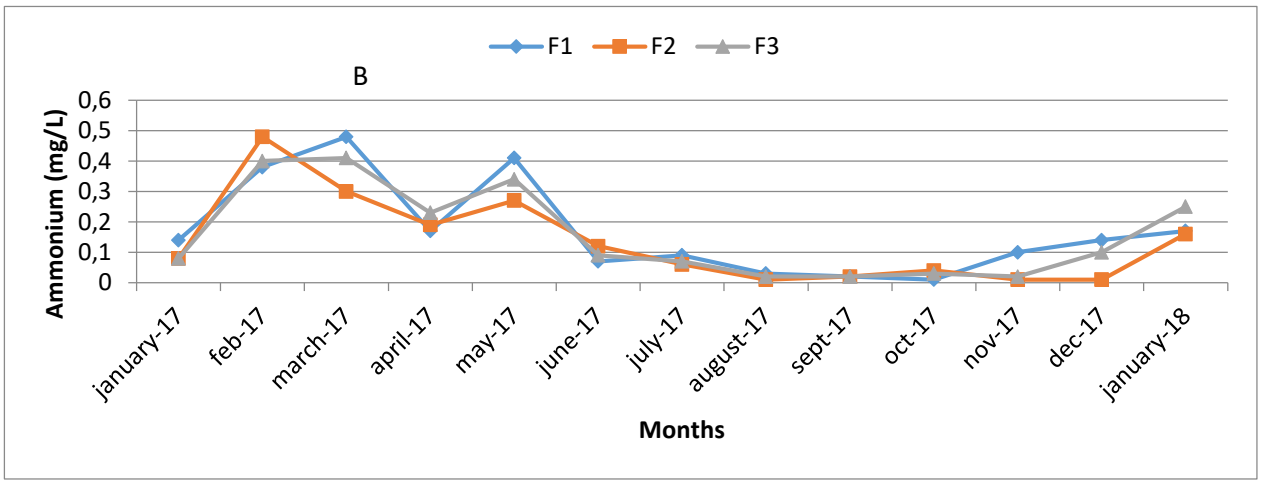
Contrarilly to the Mufeh and Furmuki where most of the values were less than 0.4 mg/L, in the mankon, a majority of the values went between 0.5 and 1mg/L. meanwhile, concentrations as low as 0.01 were obtain in mk1 in December 2017 and mk2 in September 2017 (figure 16C).

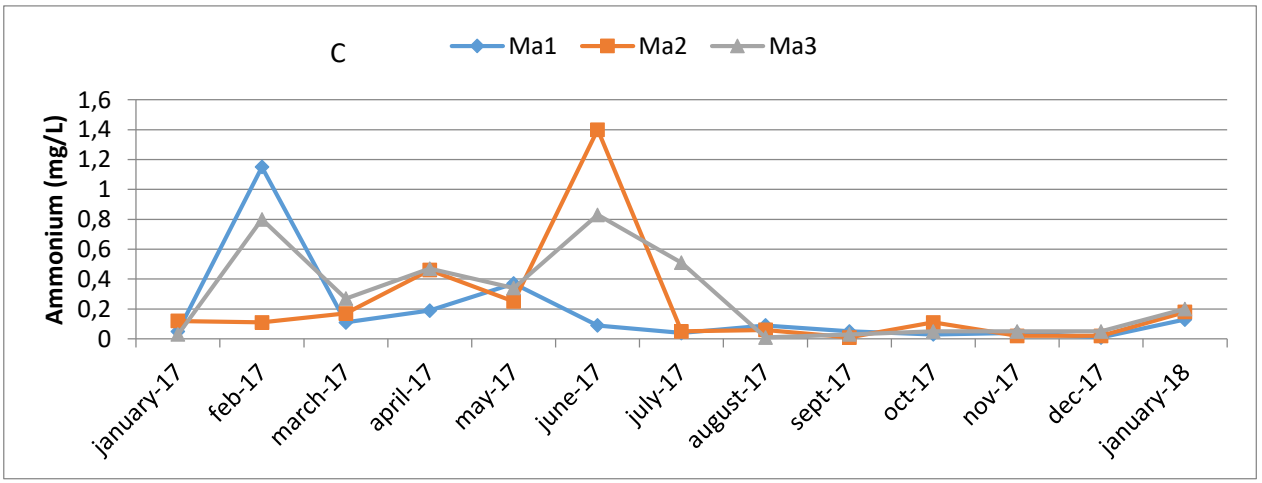
In the Ayabah streans, the concentration of ammonium lies between 0.01 and 2.15 mg/L with the lowest value (0.01 mg/L) was obtained in November 2017 at A3 and a highest in June 2017 at A1 (figure 16D). Contrarily to the other stream above, in the Ayabah the concentration decreases from upstream to downstream.

At the Mezam River, the variation was quite different becaused it went from zero in January to a maximum value of 0.87 mg/L in February 2017 and drop progressively to November 2017 and increases again to January 2018 for a mean of 0.21±0.2. They was no

much variation in concentration from one season to another and no significant difference was observed between the two seasons table V.







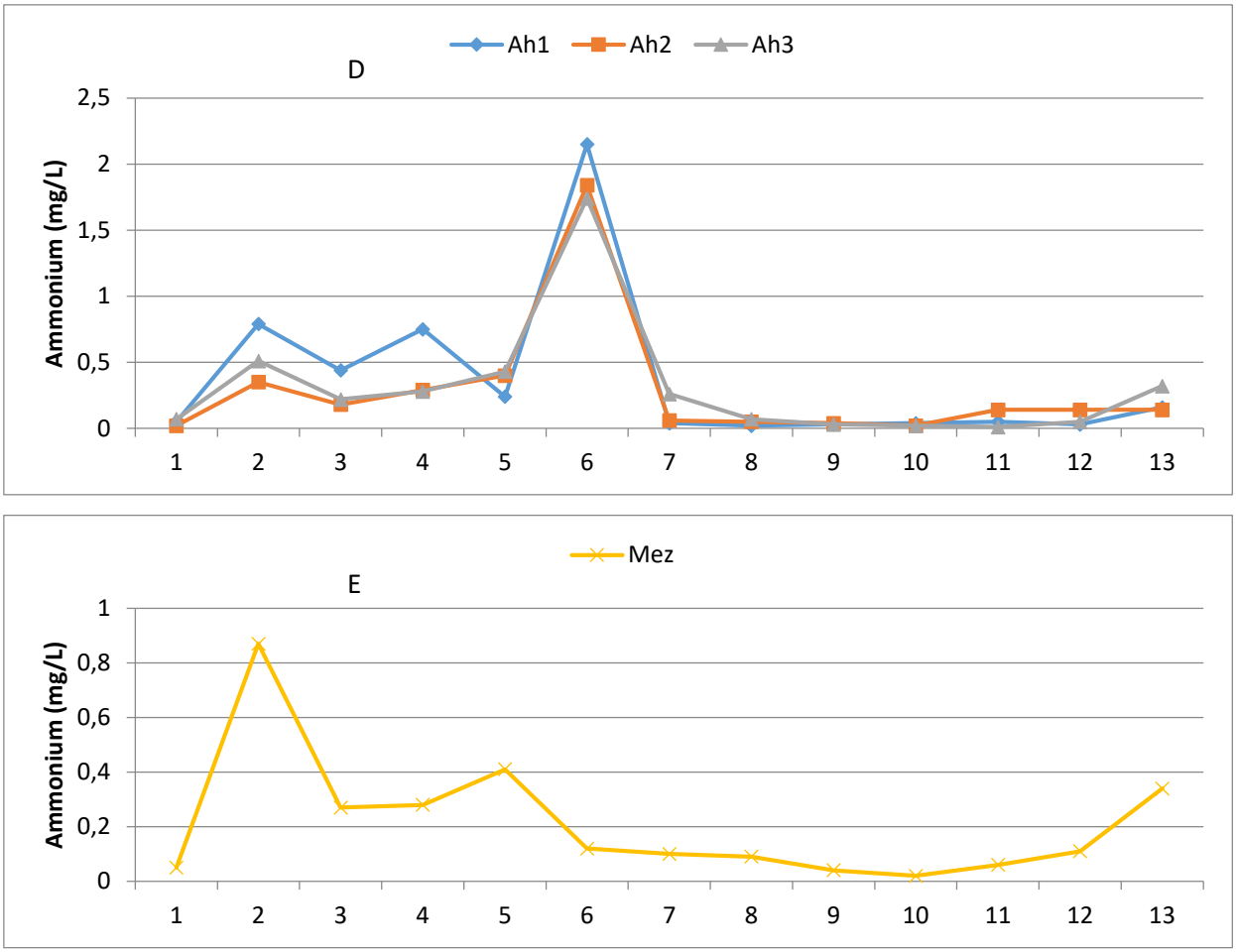


Figure 16: Spatiotemporal variation of water Ammonium in the different streams studied (A = Mufurh, B = Furmuki, C = Mankon, D = Ayabah and E = Mezam)

III-1-1-2-5. Nitrate

The concentration of nitrate in the Mufueh varied between 0.3 to 4.0 mg/L for the station mf1 and from 0.3 to 4.63 mg/L for the station mf3. In the station mf2, the concentration increased to 10.90 mg/L (figure 17A). Throughout the study period, the concentration of nitrate showed no significant different between the stations of mufueh stream.

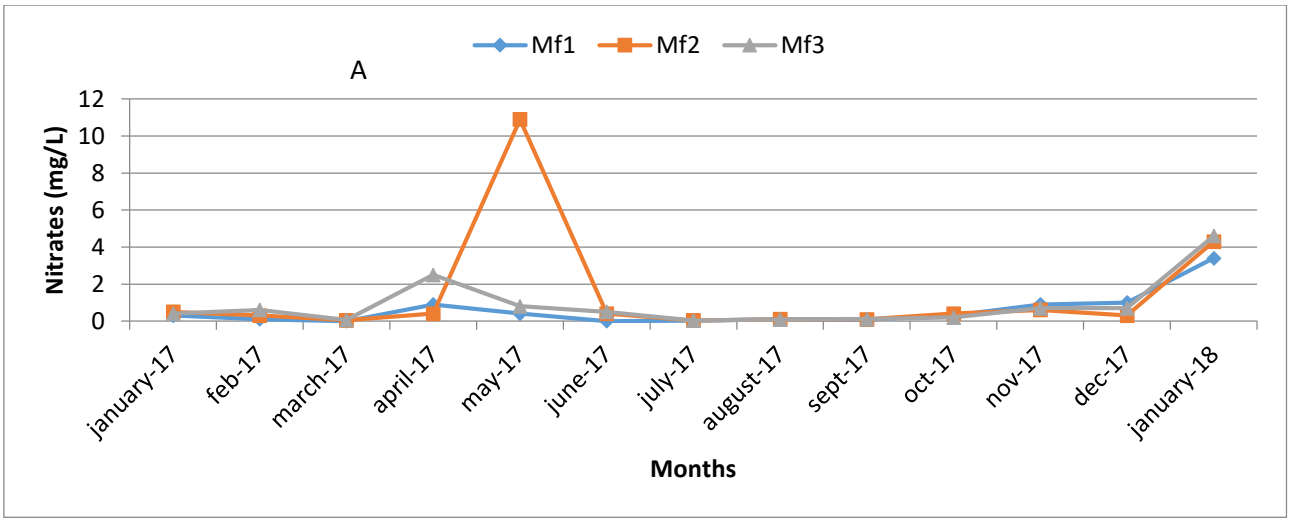
With mean values of 0.73±0.71, 1.07±0.80 and 0.98±0.88 respectively obtained for F1, F2 and F3, nitrate concentration are generally low in the Furmuki than in the Mufueh stream. This concentrations increased from F1 to F2 and reduces in the station F3 (figure 17B). No significant difference was noted between the different stations.

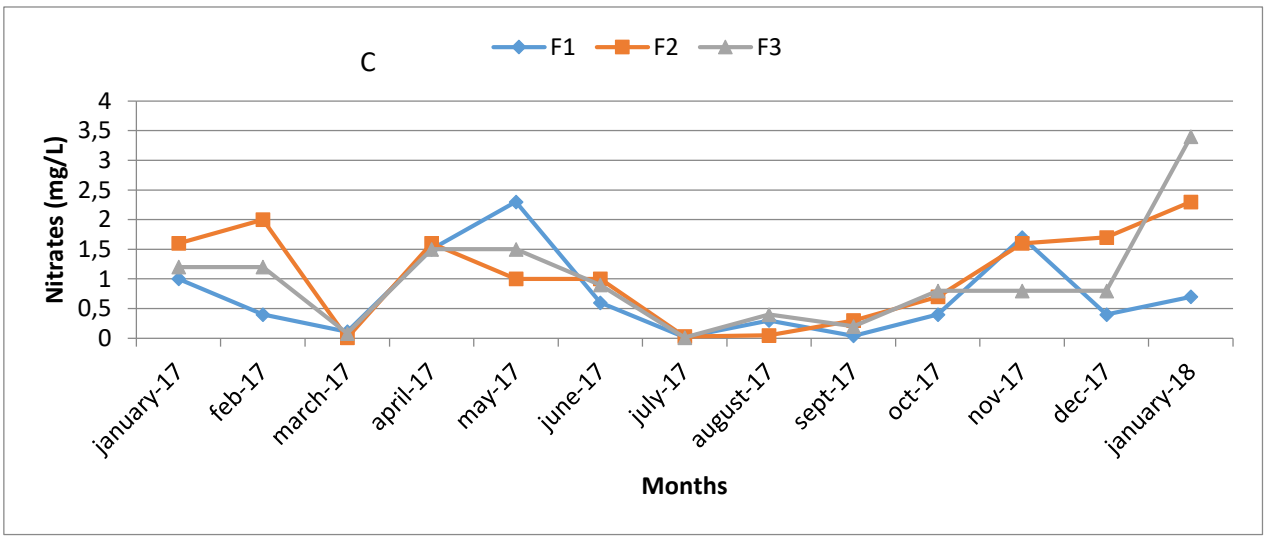
In the Mankon stream, the concentration of nitrate fluctuate between 0.01 mg/L in July and August 2017 at mk2 and mk3 respectively and 19.3 mg/L in June at the station Mk2 (figure 17C). Statistically, no significant difference was observed between the different

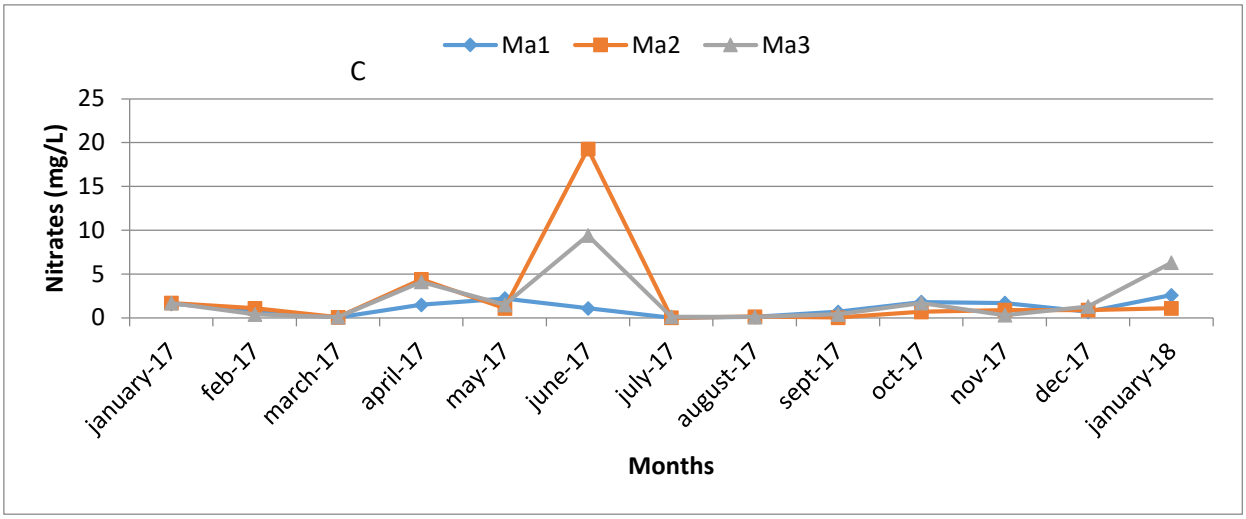
sampling points of the stream studied. The mean value of nitrate concentration in the stream oscillate around 1.89±0.67.

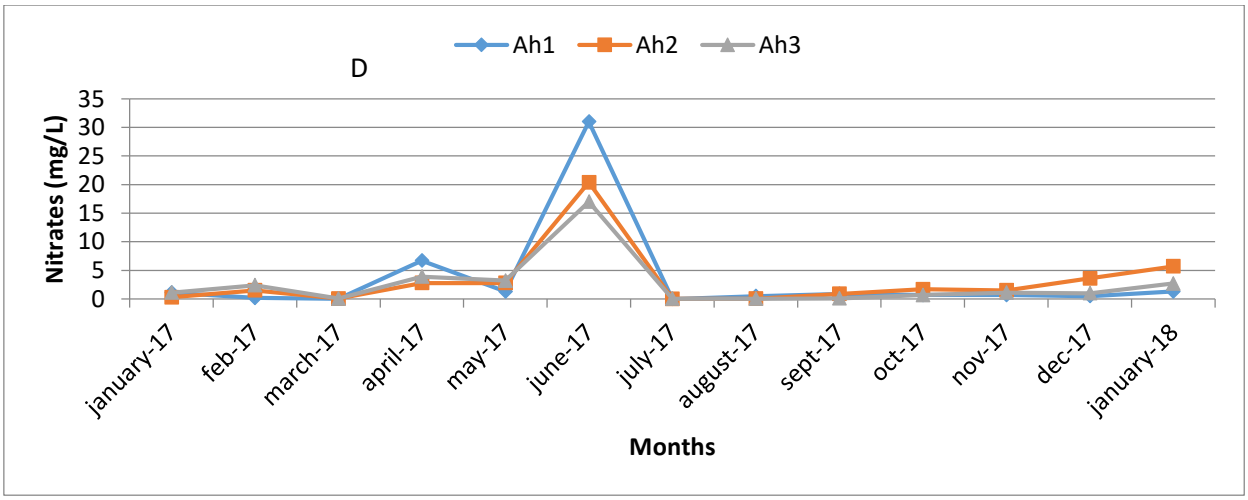
In the Ayabah and Mezam streams, the mean nitrate concentrations are 3.46±8.45 mg/L, 3.18±5.43 mg/L and 2.57±5.43 mg/L for the stations A1, A2 and A3 respectively. A minimum value of 0 mg/L was registered at A1 in the July 2017 and a maximum value of 20 mg/L was recorded in June 2017 at A2 (figure 17D).

Over at the Mezam, nitrates varied between 0.01 and 6.20 mg/L for a mean of 1027±1.65 mg/L. this values where fairly constant through out the study except at January 2018 which register the high value. The test of Mann Whitney shows no difference between the stations and between the seasons throughout the study period confer table V.









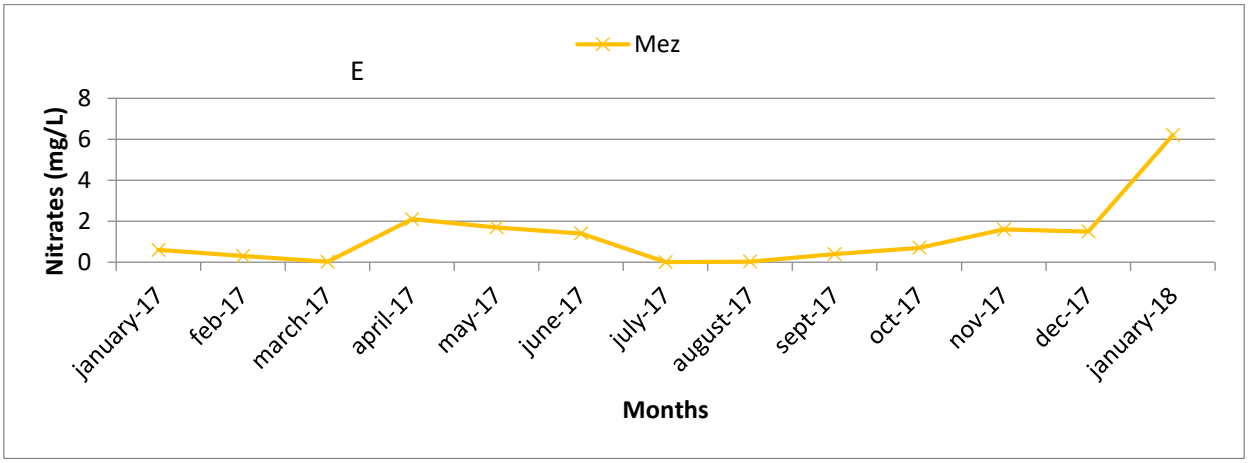


Figure 17: Spatiotemporal variation of water nitrates in the different streams assessed (A = mufurh, B = Furmuki, C = mankon, D = Ayabah and E = mezam)

III-1-1-2-5. Orthophosphates

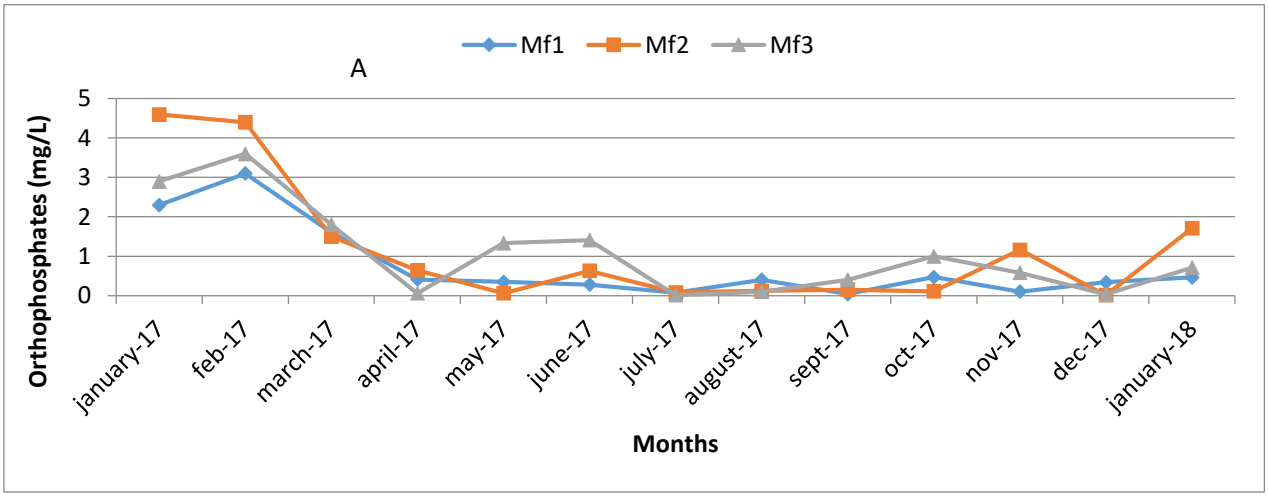
The levels of orthophosphates in the Mufueh stream did not vary significantly from one station to another during the study period. The mean levels of orthophosphates in the different stations are 0.76±0.96 mg/L, 1.17 ±1.59 mg/L and 1.07±1.14 mg/L obtain in the stations mf1, mf2 and mf3 respectively. The lowest value in this stream was 0.01 mg/L at Mf1, Mf2 and Mf3 in November, December and July 2017 respectively and the maximum value was 4.60 mg/L in January 2017 at Mf2 (figure 18A)

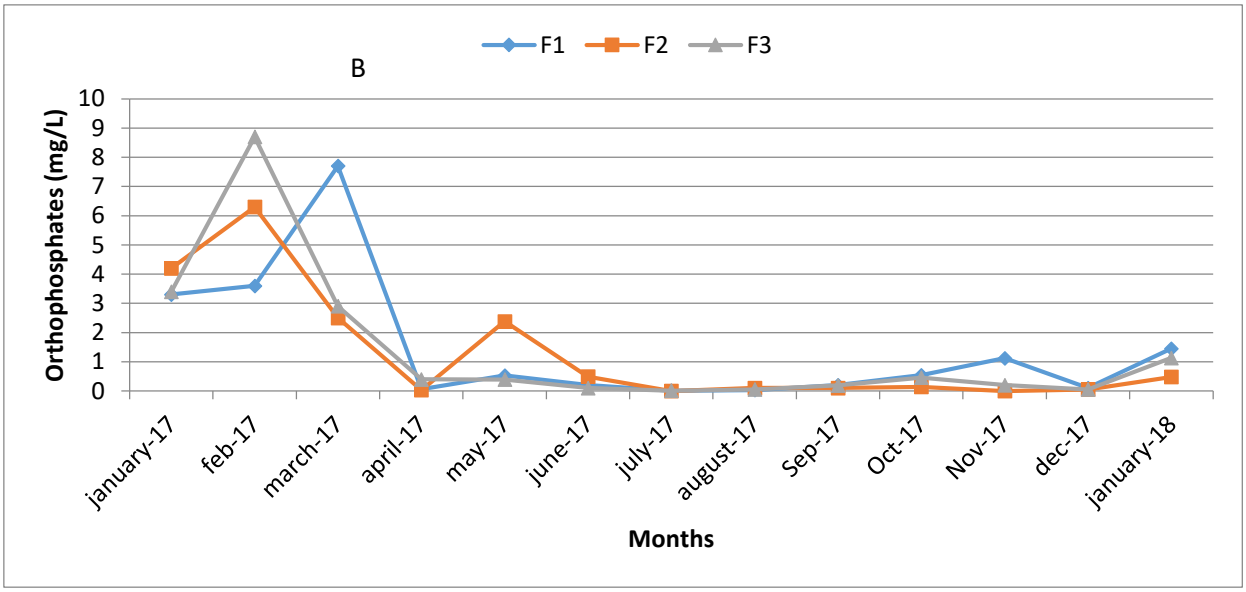
In the Furmuki stream, a maximum value of 8.70 mg/L was attain in the month of February 2017 at the station f3 (figure 18B). The concentration of orthophosphates decrease from F1 to F2 and increases at F3 and no significant difference was noted between the stations.

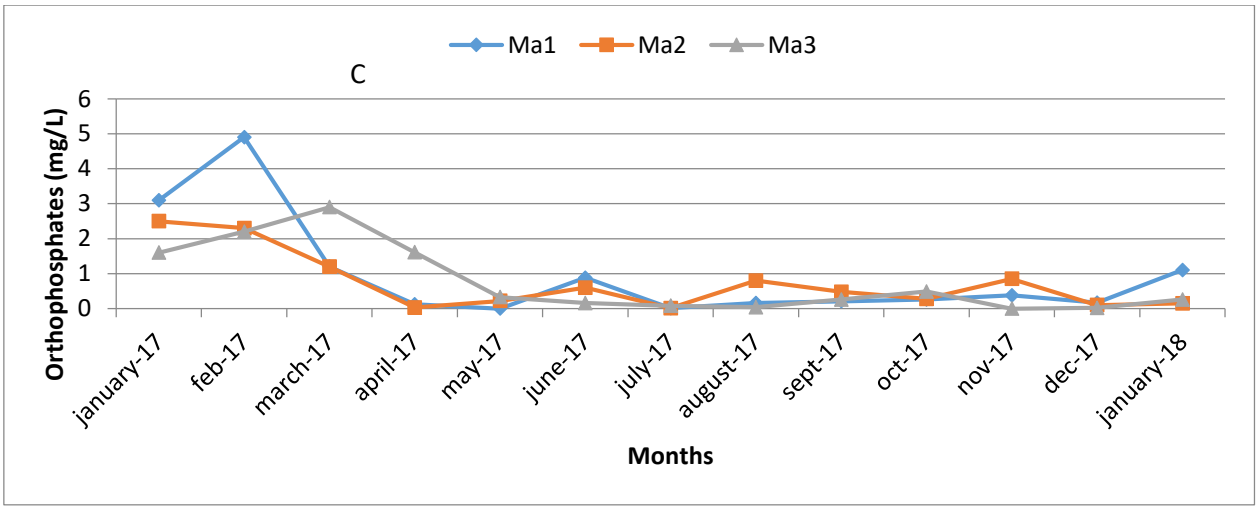
The concentration of orthophosphates in the Mankon stream fluctuate between 0 mg/L in the month of May 2017 at Mk1 and 4.90 mg/L still at Mk1 in the month of February 2017 (figure 18C). The different sampling stations of the stream showed no significant different.

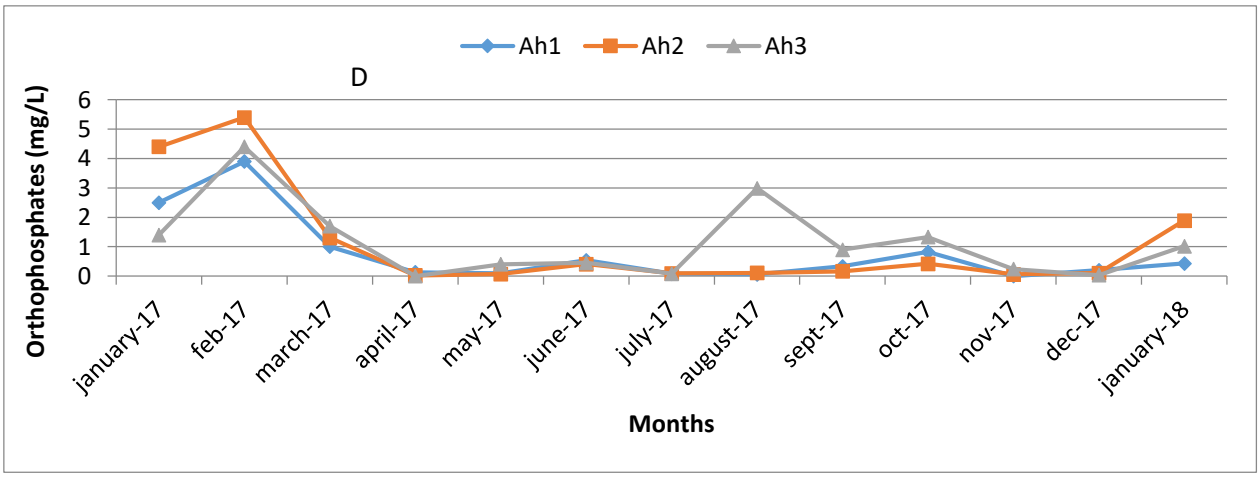
Contrarily to Furmuki, the concentration of orthophosphates in Ayabah and Mezam, generally increase from upstream to downstream with a lowest value of 0 mg/L in November 2017 at A1 and in April 2017 at A3. A highest value of 5.40 mg/L still at A2 in the February 2017 (figure 18D).

Generally the concentration of orthophosphates varied from one season to another with significant differences noted among the different seasons and sampling stations as on table V. This differences between the two seasons were significant at mf2 (P=0.04, α= 0.05), F1 (P= 0.008, α= 0.01) and at mk1 (P=0.008, α= 0.01).




F1
F2
F3
B
Orthophosphates (mg/L)
10
9
8
7
6
5
4
3
2
1
0
january-17
feb-17
march-17
april-17
may-17
june-17
july-17
august-17
Sep-17
Oct-17
Nov-17
dec-17
january-18
Months


Ma1
Ma2
Ma3
C
Orthophosphates (mg/L)
6
5
4
3
2
1
0
january-17
feb-17
march-17
april-17
may-17
june-17
july-17
august-17
sept-17
oct-17
nov-17
dec-17
january-18
Months


Ah1
Ah2
Ah3
D
Orthophosphates (mg/L)
6
5
4
3
2
1
0
january-17
feb-17
march-17
april-17
may-17
june-17
july-17
august-17
sept-17
oct-17
nov-17
dec-17
january-18
Months

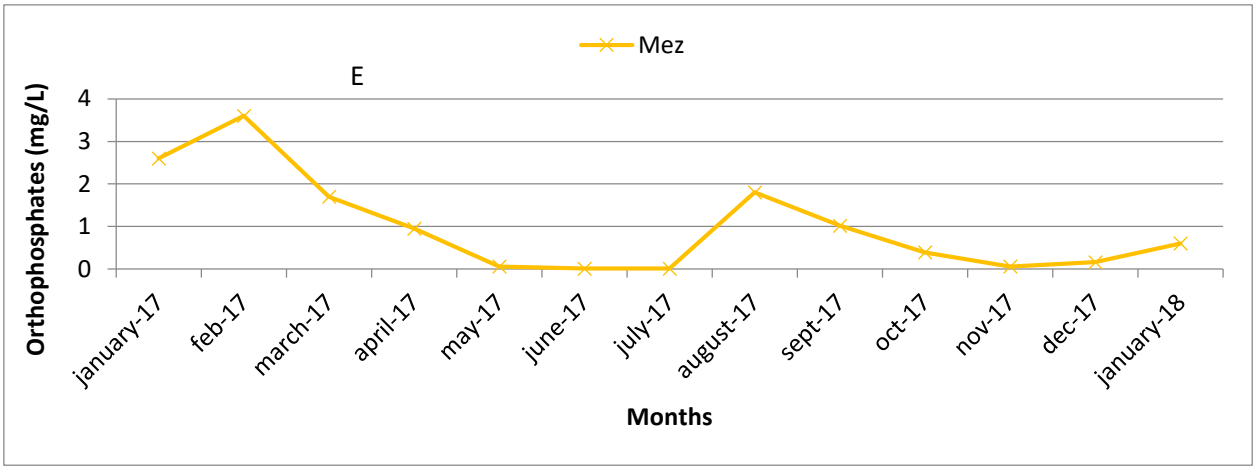


Figure 18: Spatiotemporal variation of water Orthophosphates in the different streams studied (A = Mufurh, B = Furmuki, C = Mankon, D = Ayabah and E = Mezam.

Table V: mean seasonal values and standard deviations of ammonium, nitrates and orthophusphates measured in the different sampling stations.

River	Stations	Seasons	Ammonium (mg/L NH4+)	Nitrates (mg/L NO3-)	Orthophosphates (mg/L PO43-)
Mufueh	Mf1	DS	0.15±0.14	0.95±1.27	1.32±1.22
		RS	0.08±0.08	0.26±0.32	0.29±0.17
		U	2.32	2.48	3.41
		p	0.3	0.27	0.12
	Mf2	DS	0.29±0.21	1.01±1.63	2.23±1.86
		RS	0.24±0.37	1.76±4.03	0.26±0.26
		U	0.46	1.24	4.33
		p	0.81	0.59	**0.04***
	Mf3	DS	0.16±0.17	1.18±1.69	1.60±1.42
		RS	0.15±0.23	0.60±0.88	0.62±0.62
		U	1.86	1.86	2.79
		p	0.41	0.41	0.21
Furmuki	F1	DS	0.24±0.16	0.72±0.57	2.88±2.71
		RS	0.11±0.14	0.73±0.85	0.22±0.23
		U	3.87	1.34	5.26
		p	0.07	0.59	**0.008****
	F2	DS	0.17±0.19	1.54±0.80	2.26±2.58
		RS	0.10±0.10	0.67±0.58	0.46±0.86
		U	0.93	4.02	2.32
		p	0.69	0.06	0.3

Continuetion of Table V

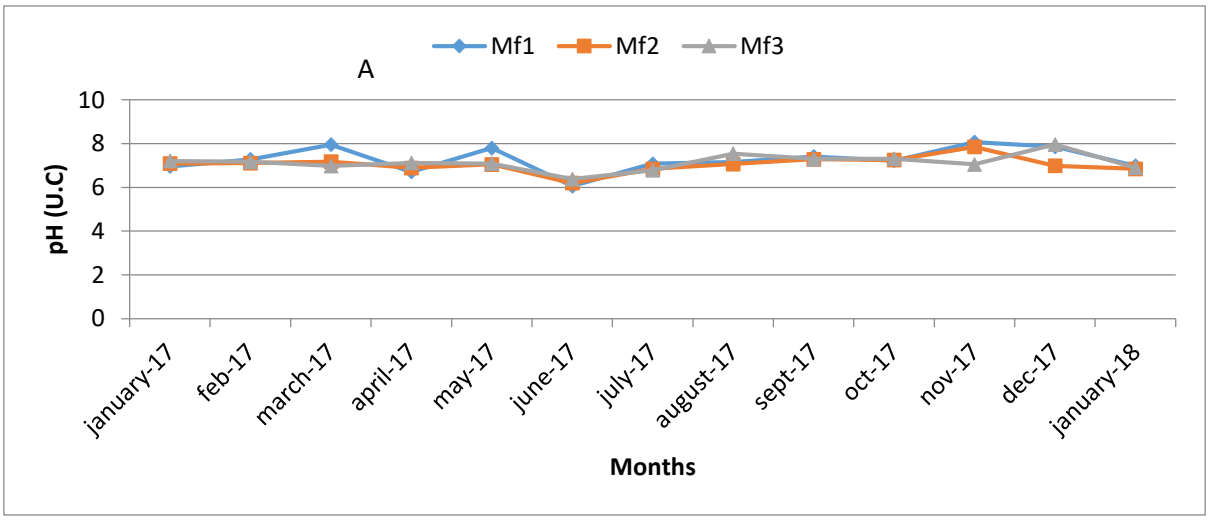
	F3	DS	0.21±0.16	1.25±1.13	2.73±3.23
		RS	0.11±0.12	0.76±0.60	0.23±0.19
		U	2.79	1.24	3.87
		p	0.29	0.59	0.07
Mankon	Mk1	DS	0.25±0.44	1.24±0.91	1.81±1.83
		RS	0.12±0.12	1.06±0.84	0.23±0.30
		U	0	0.77	5.26
		p	1	0.74	**0.008****
	Mk2	DS	0.10±0.07	0.96±053	1.18±1.03
		RS	0.33±0.50	3.67±7.06	0.35±0.30
		U	-1.08	0.93	3.4
		p	0.64	0.69	0.12
	Mk3	DS	0.23±0.29	1.68±235	1.16±1.25
		RS	0.32±031	2.48±3.36	0.42±0.55
		U	-0.77	-0.93	0.77
		p	0.74	0.67	0.74
Ayabah	A1	DS	0.25±0.30	0.64±0.50	1.34±1.56
		RS	0.47±0.79	5.87±11.31	0.29±0.29
		U	1.08	-2.01	2.79
		p	0.64	0.37	0.21
	A2	DS	0.16±0.11	2.11±2.16	2.19±2.24
		RS	0.39±0.66	4.10±7.28	0.18±0.16
		U	0.15	0.31	3.4
		p	0.95	0.89	0.12
	A3	DS	0.20±0.19	1.40±0.98	1.47±1.58
		RS	0.40±0.61	3.57±6.13	0.88±1.04
		U	-0.77	0.31	1.86
		p	0.74	0.89	0.42
Mezam	Mz	DS	0.28±0.31	1.70±2.29	1.45±1.44
		RS	0.15±0.15	0.91±0.83	0.06±0.68
		U	1.55	0.62	2.63
		p	0.5	0.79	0.24

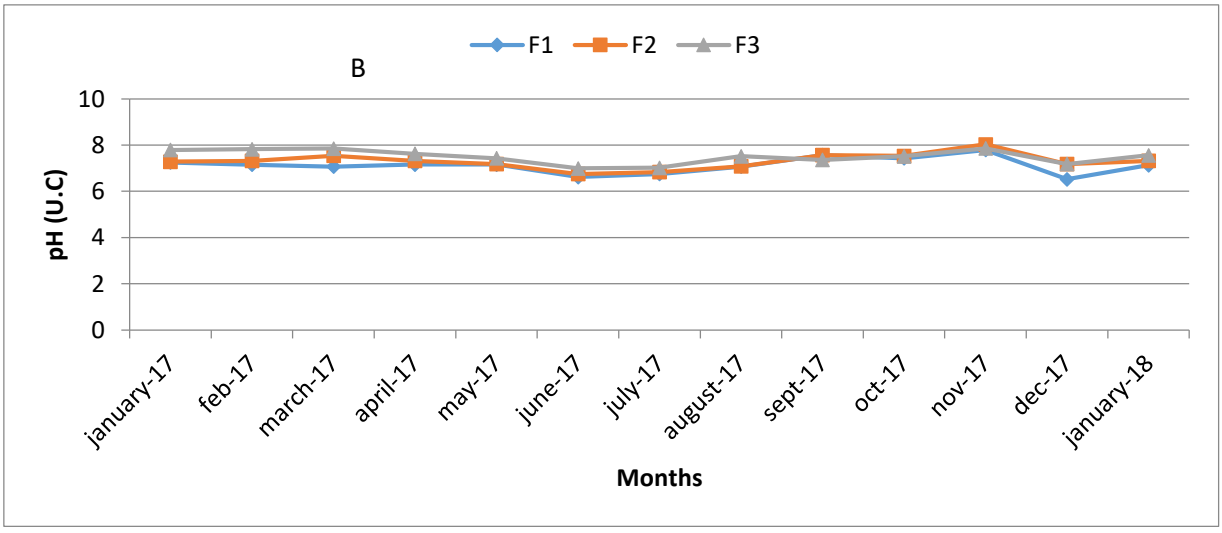
DR = dry season, SP = rainy season; U = Mann-Whitney test; p = p-value; (*) = significant difference ; the code Mf_1, Mf_2, Mf_3, f_1, $f_{1,}f_1$ Mk_1, Mk_2, Mk_3, A_1, A_2, A_3 and Mz represent sampling stations.

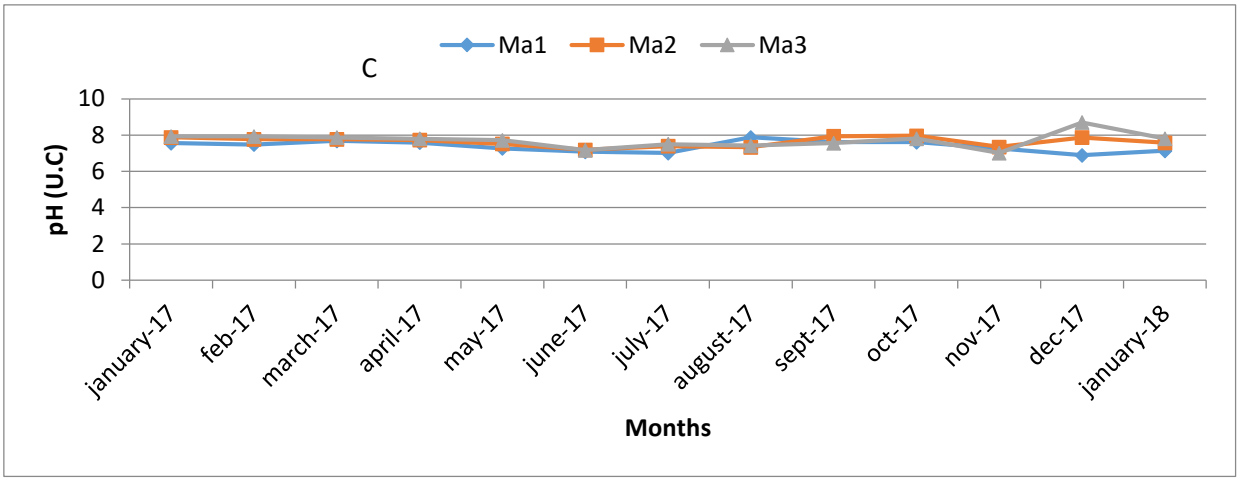
III-1-1-2-6. pH

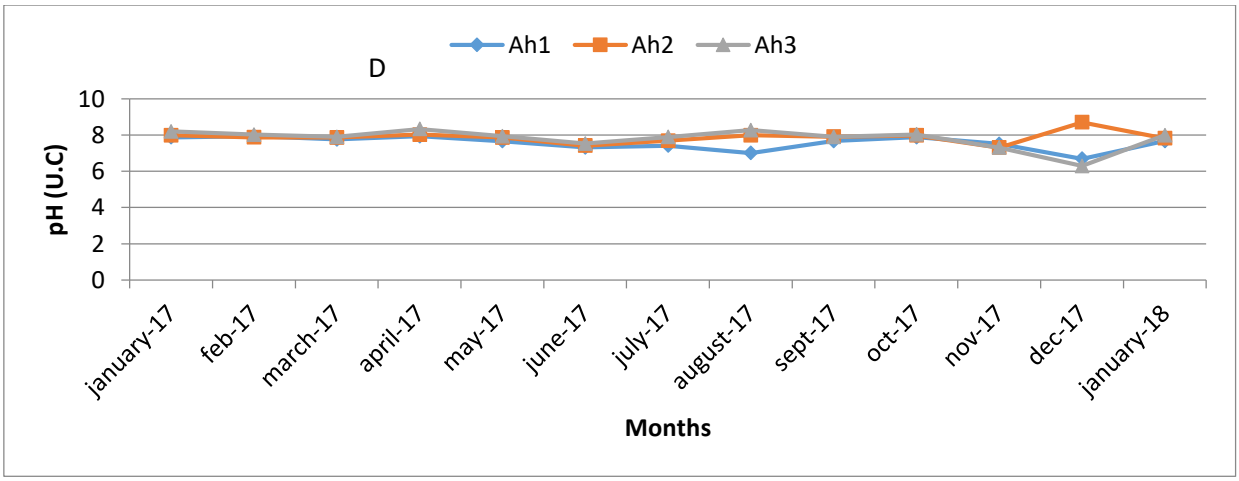
The values of pH in the Mufueh, Furmuki and Mankon generally vary between 6 and 8 CU (figure 19A). Despite the fact that a few values superior to 8CU were noted in the months of November and December 2017 at the stations mf1, F2 and mk3 respectively. The mean values of pH 7.15±0.11 (mufueh), 7.27±0.13 (Furmuki) and 7.58±0.17 (Mankon) shows that this waters are neutral. The values of p H show a significant different between the different sampling stations F1 and F3 ($P = 0.11$, $\alpha = 0.05$), Mk1 and Mk2 ($P = 0.04$, $\alpha = 0.05$), Mk1 and Mk3 ($P = 0.028$, $\alpha = 0.05$).

In Ayabah stream, the variations of pH depends on the sampling station. In A1 pH varied between 7.01 and 7.93 CU while in A2 and A3, the variation is between 7 and 8.96 CU showing that the waters of this stream are slightly basic. While at Mezam River, pH values 7.11 and 8.24 CU for a mean of 7.63±0.3 CU (figure 19D). The test of Mann Whitney shows significant differences between A1 and A2 ($P = 0.027$, $\alpha = 0.05$) and between A1and A3 ($P = 0.031$, $\alpha = 0.05$) see table VI.









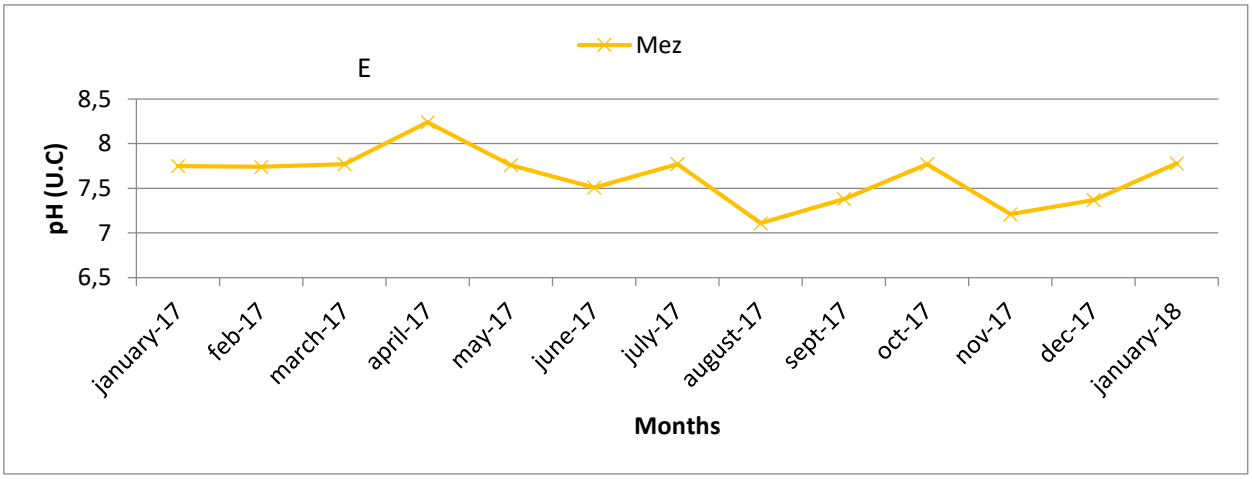


Figure 19: Spatiotemporal variation of water pH in the different streams studied (A = Mufurh, B = Furmuki, C = Mankon, D = Ayabah and C = Mezam.

III-1-1-2-7. Electrical conductivity

Electrical conductivity in the waters of Mufueh varied between 21µS/cm at the station mf1 in June 2017 and 233 µS/cm at the station Mf3 in December 2017 (figure 20A). The

sampling station Mf1 shows the least values of electrical conductivity with a mean value of 28.46±5.58 µS/cm. The sampling station Mf3 shows the highest value of electrical conductivity with a mean value of 82.1±49.3 µS/cm. At the level of Mf2, electrical conductivity values are less than 200 µS/cm for a mean value of 75.6±42.8 µS/cm. The variation of electrical conductivity are significant along the Mufueh stream, mostly between Mf1 and Mf2 ($P = 0.0004$, $\alpha = 0.001$) and Mf1 and Mf3 ($P = 0.0001$, $\alpha = 0.001$).

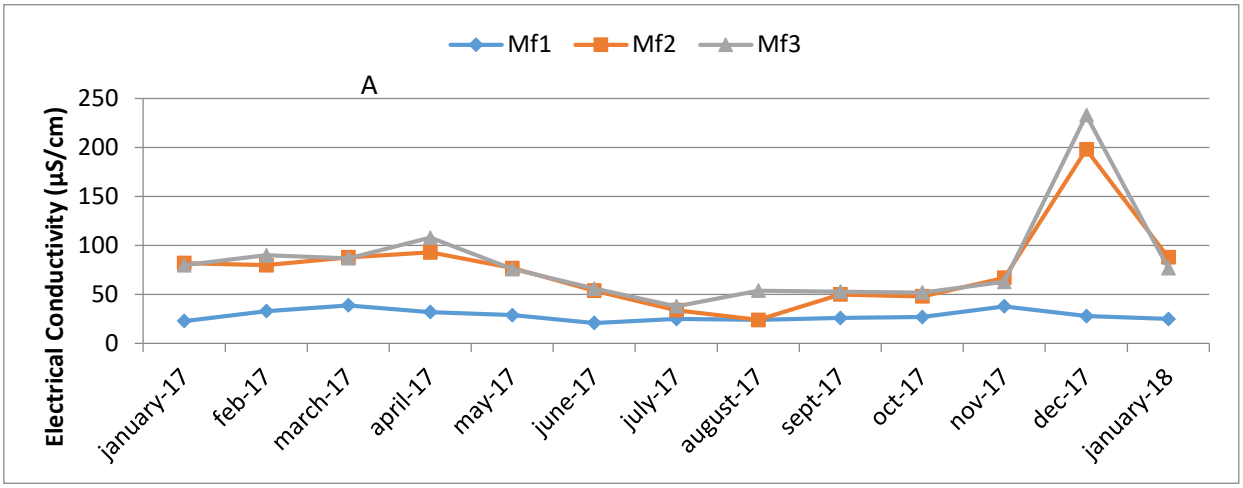
The values of electrical conductivity in the Furmuki are generally lower the 500µS/cm in almost all the sampling stations and throughout the study period with an exception of F1 in the month of December which went as high as 602µS/cm (figure 20B). The values at the level of the different sampling points shows that electrical conductivity increases from upstream to downstream of the Furmuki stream. The test U of Mann Whitney shows significant differences between the sampling points along the streav, F1 and F2 ($P = 0.372$, $\alpha = 0.05$), F1 and F3 ($P = 0.0000$, $\alpha = 0.001$), F2 and F3 ($P = 0.0307$, $\alpha = 0.05$).

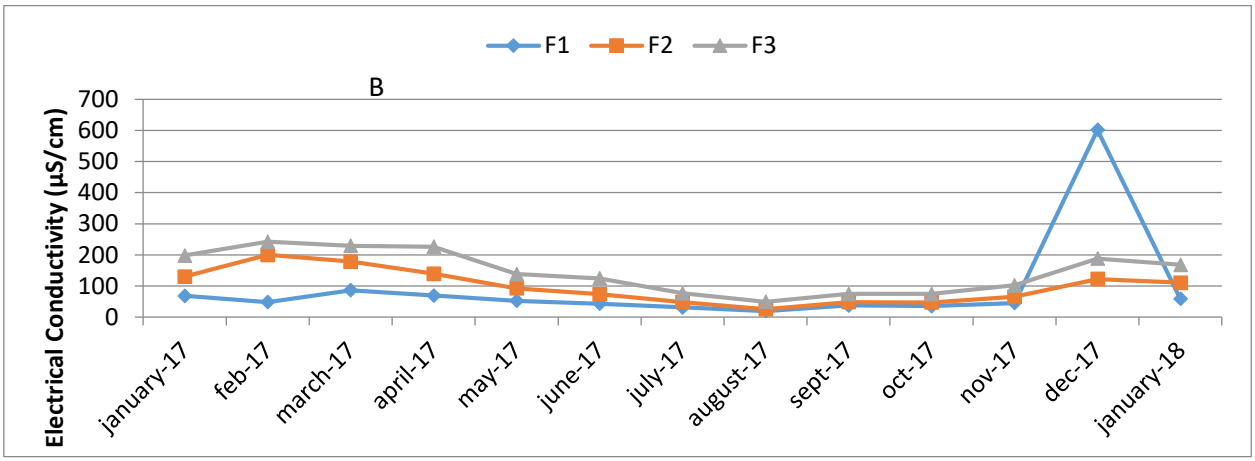
In the Mankon stream, electrical conductivity vary between 23 µS/cm in August 2017 and 399µS/cm all at the station Mk2. The mean values of each station 130.5±66.1 µS/cm, 223.2±97.3 µS/cm and 231.5±59.4 µS/cm for Mk1, Mk2 and Mk3 respectively shows that the concentration of the ions increases from upstream to downstream (figure 20C). Following the test of Mann Whitney, the variation of electrical conductivity are significant along the mankon stream, mostly between mk1 and mk2 ($P = 0.0086$, $\alpha = 0.01$) and Mf1 and Mf3 ($P = 0.0010$, $\alpha = 0.001$).

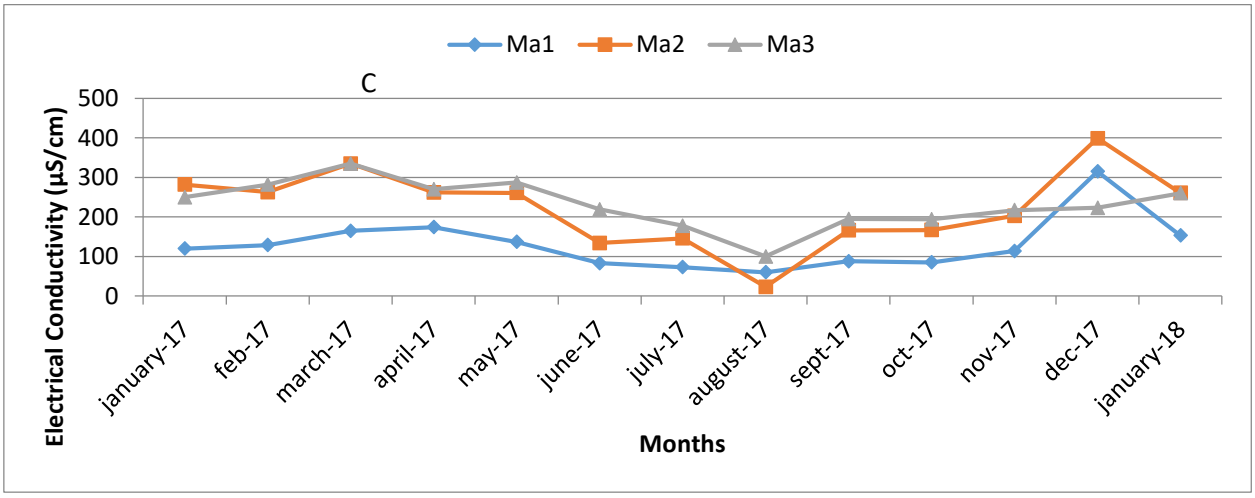
The values of electrical conductivity obtain in the Ayabah stream are highest at the point A1 (466µS/cm) situated below a huge car maintenance station. All the waste from car battery and other parts are directly washed into this point of the stream. The other two sampling points also shows values slightly higher than 400 µS/cm (figure 20D) for this, this stream is considered to be the most miniralized stream among all the others considered in this research work. Just like the other streams above, the Ayabah also showed significant differences from one sampling point to another, A1 and A2, A1 and A3 both at ($P = 0.0000$, $\alpha = 0.001$). This parameter did not vary much at the Mezam River but it registerd a minimum value of 34 µS/cm in August 2017 and a maximum of 203 µS/cm in March, April and December 2017.

Seasonally, electrical conductivity varied from one sampling station to another and from one stream to another. The lowest electrical conductivity value was recorded in the rainy season at mf1 (26.69±3.55) and the highest value was obtain in the dry season at the station A3 (365.7±43.8) as shown on table VI below. From this table, electrical conductivity varied

much in the dry season then in the rainy season variance coefficient (11.95). Significant differences where noted between the different seasons at mk2, mk3, F1, F2 and F3 all at (P= 0.002, $\alpha = 0.05$) and mk2 (P = 0.005, $\alpha = 0.01$).







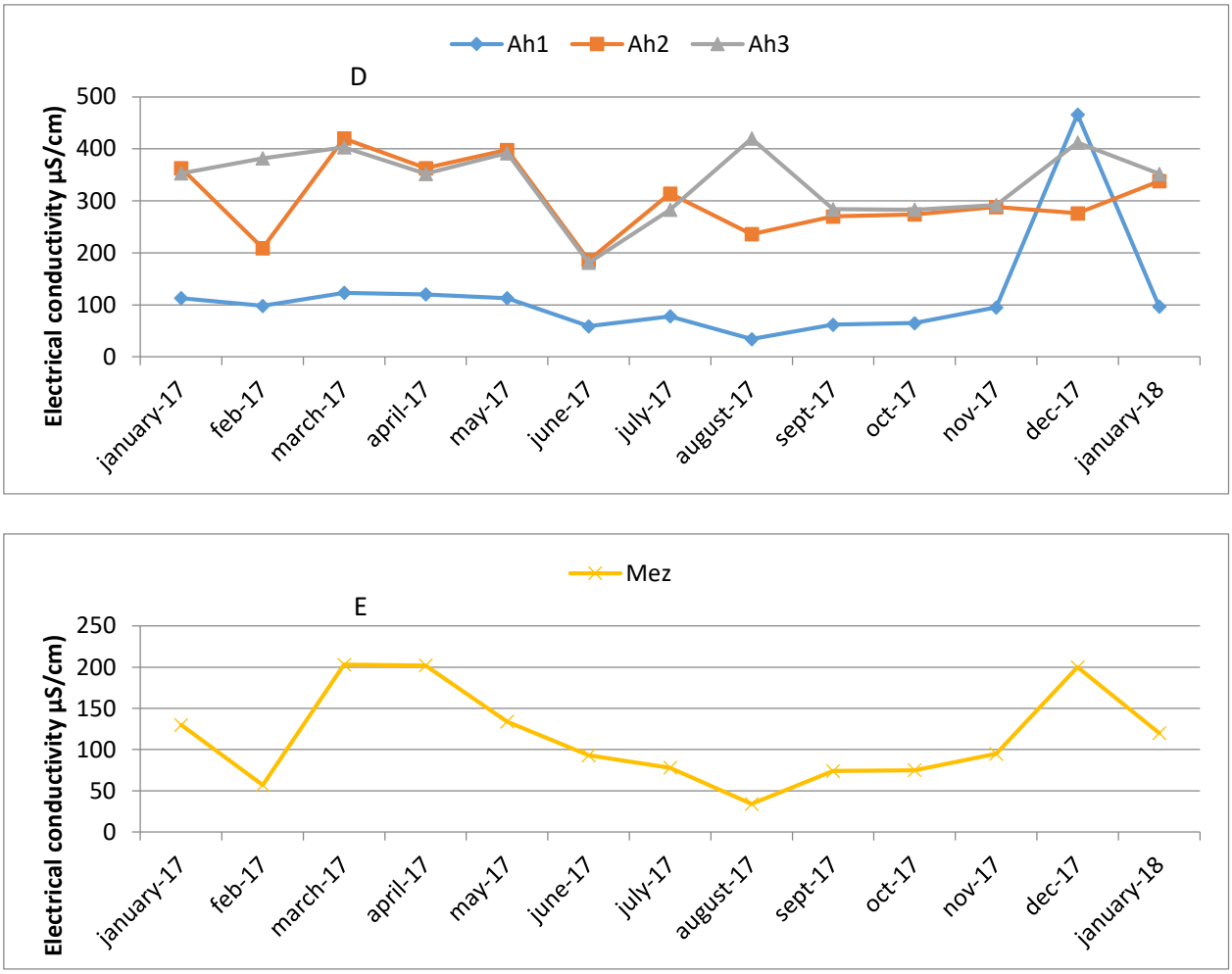


Figure 20: Spatiotemporal variation of water Electrical Conductivity in the different streams studied (A = Mufurh, B = Furmuki, C = Mankon, D = Ayabah and E = Mezam.

Table IIII: mean seasonal values and standard deviations of pH, electrical conductivity, alkalinity and TDS measured in the different sampling stations.

River	Stations	Seasons	pH (UC)	Alcalinity (mg/L CaCO3)	Conductivity (µS/cm)	TDS (mg/L)
Mufueh	Mf1	DS	7.51±0.50	16.33±22.36	31.0±6.72	15.67±3.98
		RS	7.06±0.55	12.57±11.0	26.29±3.55	12.86±1.87
		U	2.79	0	2.63	2.63
		p	0.21	1	0.24	0.24
	Mf2	DS	7.19±0.35	8.33±4.63	100.5±48.4	49.83±23.46
		RS	6.94±0.37	10.86±5.98	54.29±23.81	27.0±12.11
		U	1.7	-1.7	4.64	4.64
		p	0.46	0.45	**0.02***	**0.02***

Continuetion of Table VI

	Mf3	DS	7.21±0.38	6.33±3.20	105.0±63.4	52.8±31.8
		RS	7.07±0.39	12.29±8.83	62.43±22.98	31.14±11.51
		U	0	-2.48	4.64	4.64
		p	1	0.26	**0.02***	**0.02***
Furmuki	F1	DS	7.15±0.41	6.33±3.44	151.2±221.4	72.7±103.3
		RS	7.12±0.34	9.43±7.89	40.86±16.05	20.43±8.30
		U	-0.15	-0.77	4.64	4.64
		p	0.95	0.73	**0.02***	**0.02***
	F2	DS	7.45±0.31	9.0±5.18	134.2±48.6	66.67±24.20
		RS	7.18±0.32	10.0±7.12	67.4±38.1	33.71±18.98
		U	2.63	0	4.64	4.64
		p	0.24	1	**0.02***	**0.02***
	F3	DS	7.68±0.28	9.0±1.67	187.8±50.0	93.50±24.11
		RS	7.35±0.25	14.86±8.93	108.7±60.4	54.4±30.1
		U	4.64	-1.55	4.64	4.64
		p	**0.02***	0.49	**0.02***	**0.02***
Mankon	Mk1	DS	7.34±0.29	8.67±4.13	166.0±75.6	82.2±36.1
		RS	7.44±0.32	19.71±13.54	100.0±40.5	49.86
		U	-1.39	-2.63	4.02	4.02
		p	0.54	0.24	0.06	0.06
	Mk2	DS	7.70±0.20	11.0±5.76	290.5±68.0	143.3±30.2
		RS	7.58±0.31	14.29±6.47	165.6	82.6±40.4
		U	1.55	-2.17	5.42	5.88
		p	0.5	0.33	**0.005****	**0.001****
	Mk3	DS	7.86±0.54	13.67±6.62	261.2±43.4	130.67±21.86
		RS	7.57±0.23	16.0±9.80	206.1±62.1	103.0±31.1
		U	4.18	0	3.4	3.56
		p	**0.05***	1	0.12	0.1
Ayabah	A1	DS	7.57±0.46	10.33±6.38	165.3±147.7	80.5±68.6
		RS	7.55±0.33	14.86±7.38	75.9±30.8	38.14±15.41
		U	0.93	-2.79	4.18	4.18
		p	0.69	0.21	**0.05***	**0.05***
	A2	DS	7.93±0.45	11.33±6.28	315.7±73.9	157.8±37.2

Continuetion of Table VI

		RS	7.84±0.22	25.71±24.70	291.6±73.0	145.4±36.0
		U	-0.31	-2.79	1.7	1.86
		p	0.89	0.2	0.46	0.42
	A3	DS	7.62±0.72	16.33±7.63	365.7±43.8	182.83±21.78
		RS	7.98±0.27	15.71±6.87	313.6±80.9	156.9±40.3
		U	-1.7	0.31	2.94	2.94
		p	0.46	0.89	0.18	0.18
Mezam	Mz	DS	7.60±0.25	8.0±2.83	134.2±57.9	67.2±28.6
		RS	7.65±036	12.0±6.0	98.6±54.4	49.3±27.2
		U	-0.62	-2.63	2.48	2.32
		p	0.79	0.23	0.27	0.3

DR = dry season, SP = rainy season; U = Mann-Whitney test; p = p-value; (*) = significant difference ; the code Mf_1, Mf_2, Mf_3, f_1, $f_{1,}f_1$ Mk_1, Mk_2, Mk_3, A_1, A_2, A_3 and Mz represent sampling stations.

III-1-1-3. Concentration of metallic elements in the water and sediments

The concentration of this elements in water and sediments in the different streams and sampling points are shown. Generally, the lowest mean value for all the water elements was obtain in the Ayabah, contrarily to the mufueh and Furmuki were high values of the mean concentration was observed mostly at the sampling station F3. The minimum value of Iron (Fe) 0 mgL was recorded at the station F2, Mk2, A1 and A2 while the maximum value 0.988 mg/L was recorded at F3. As for Nickel (Ni), it varied between 0.03 and 0.054 mg/L at the sampling point's Mk2 and F3 respectively. Looking at Chromium, its lowest value (0.08 mg/L) was gotton at F2 and its highest value (0.136 mg/L) was at Mf1 and Cobalt varied between 0.002 and 0.017 mg/L. Elements such as Lead (Pb), Cadmium (Cd), Zinc (Zn) and Copper (Cu) all registered 0 mg/L throughout the study period.

Analysis of the water sediments, it was realized that some elements which were totally absent in the water colonn were actually stock up at the level of the sediments. Lead (Pb), Cadmium (Cd), Zinc (Zn) and Copper (Cu) registered maximum values of 35 µg/Kg, 4.6 mg/Kg, 138.4 µg/Kg and 74.6 µg/Kg respectively. Iron (Fe) was highly concentrated at all the sampling stations with a maximum value of 56899.6 µg/Kg and a minimum of 10969.7 µg/Kg respectively at mf3 and mz.

III-1-1-4. Organic Pollution Indice (OPI)

In the Mufueh stream, OPI oscillate between 3.33 obtain in March and May 2017 at the station Mf1 and 5.0. The stations showed high values of OPI indicating low organic pollution, with an over all OPI mean of values 4.22±0.46. The test of Kruscal Wallis shows no significant difference between the sampling stations.

There was a large variation in OPI in the Furmuki stream from. At F1 the lowest value was 2.66 recorded in January, March and November 2017 and 4.33 seen in the months April and September 2017 which shows a strong to low organic pollution range. In the second and third sampling points, a strong to null organic pollution with a minimum value of 2.66 in the march at mf2 and a maximum of 5 seen in July 2017 both at mf2 and mf3 (figure 21).

Looking at the mankon stream, an overall moderate organic pollution with mean values of 3.77±0.63, 3.64±0.67 and 3.61±0.57 for the sampling points Mk1, Mk2 and Mk3 respectively (figure 21). Observing at the individual variation of the different stations, a large variation from strong to nul organic pollution was noted (Mk1 3-5, Mk2 2.66-5 and Mk3 2.66-4.66),

Down in the stream Ayabah, the organic pollution concentration varied between strong and low with a minimum value of 2 at A1 in Ferbruary 2017 and a maximum of 4.66 both at A3 and mz in April and may respectively (figure 21).

At the Mezam, OPI showed a general moderate pollution level for a range of 2.33 to 4.66 and a mean of 3.66±0.7. The low OPIat this point could be due to the mixing and dilution effect of all the streams.

Seasonally, OPI varied from one sampling station to another and from one stream to another. The lowest organic pollution concentration was obtain in the dry season at A1 (2) and the highest value was also obtain in the rainy season at the stations F2, F3, mk1 and Mk2 (5) as. From this stations, OPI varied much in the dry season then in the rainy season variance coefficient (12.75). Significant differences where noted between the different seasons at mk1 ($P= 0.002$) and A3 ($P = 0.008$) respectively at $\alpha = 0.01$. The difference in temperature between the two seasons was very significant at mk2 ($P= 0.0005$) and A2 ($P= 0.0008$) respectively at $\alpha = 0.001$. Despite this monthly differences, all the stream in bamenda have a moderate organic pollution concentration. This pollution id still low because of the high rain during the rainy season which wash away all the substances along the stream.

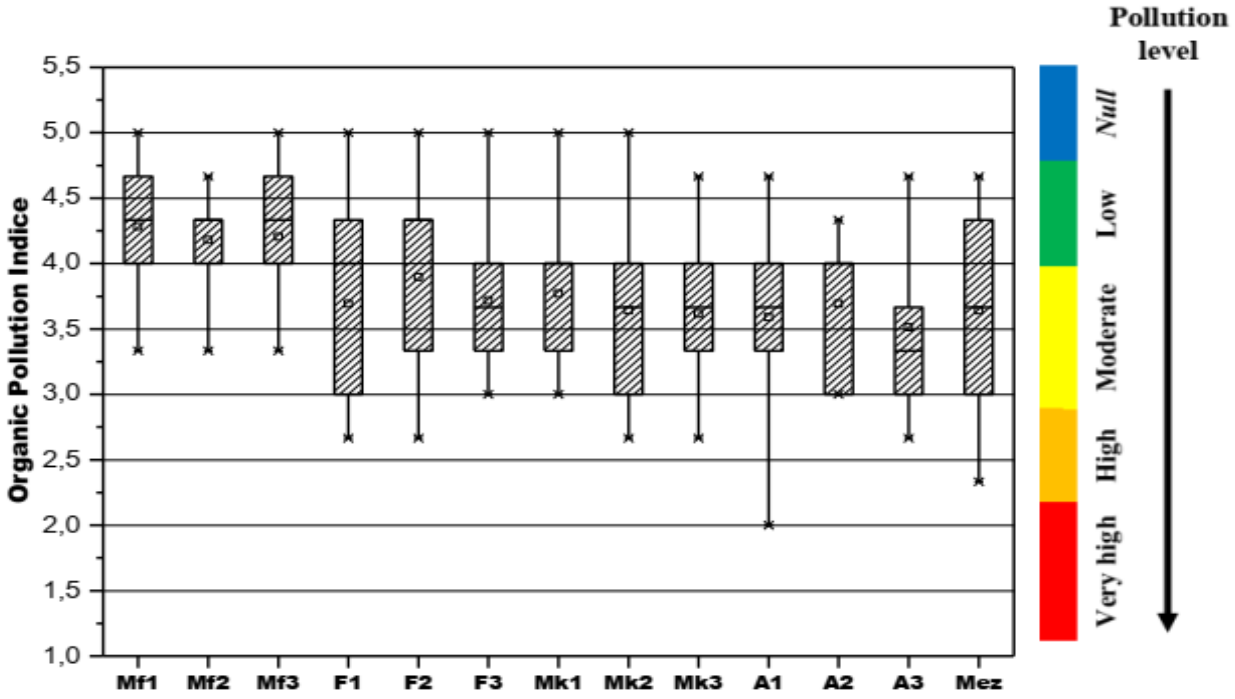


Figure 21: Spatial variation of organic pollution in the different streams studied

III-1-1-5. Principal Component Analysis (PCA)

A Principal Component analysis (PCA) was realized to determine the characteristic of physico-chemical parameters in relation to the various groups. The matrix is a table of 16 columns corresponding to the environmental parameters taken into account during the study and 169 lines representing the 13 sampling stations during the 13 month of study of our investigation. The essentials of the original variance is provided on the first two factorial axes F1 (55.2%) and F2 (14.3%) which gives a sum 69.5% of total inertia (Figure 22A).

On the circle correlation, (Figure 22B) the 1st axis which explains 55.2 % of the distribution shows on the positive side resistivity and on the negative side Turbidity, Suspended solids, Colour, Alkalinity, TDS, Electrical Conductivity, Temperature, pH, Nitrates, Ammonia, Salinity and dissolved CO_2.

On the 2nd axis which explains 14.3 % of the distribution, on the positive coordinates Dissolved Oxygen and Oxydability while on the negative side, it's Orthophosphate. This axis F2 shows an organic gradient of pollution as observed during the study (Figure 22B).

The factorial chart (Figure 22C) presents the distribution of the 13 sampling stations in relation to their physico-chemical characteristics. Lookin at this, three sub groups of sampling stations from this factorial design can be distinguish. On the F1 axis are most stations on the

negative co-ordinates this stations are; Ayaba 2, Ayaba 3, Mankong 2, Mankong 3 which all represent group I and characterized by slight acidic water, Alkaline, Colored, Turbides, mineralized and of low resistivity. This first Axis also incorporate on the positive part, the stations Mufeh 1, Mufeh 2, Mufeh 3, Formuki 1, Formuki 2 forming group II which are less acidic, lowly mineralized with high resistivity values. The 2 axis harbors on the positive co-ordinates, the stations Ayaba 1, Mezam, Mankong 1 making up the last group 3 representing water of moderate oxygenation rich in oxydable organic matter with low orthophosphate as seen on Figure 22C.

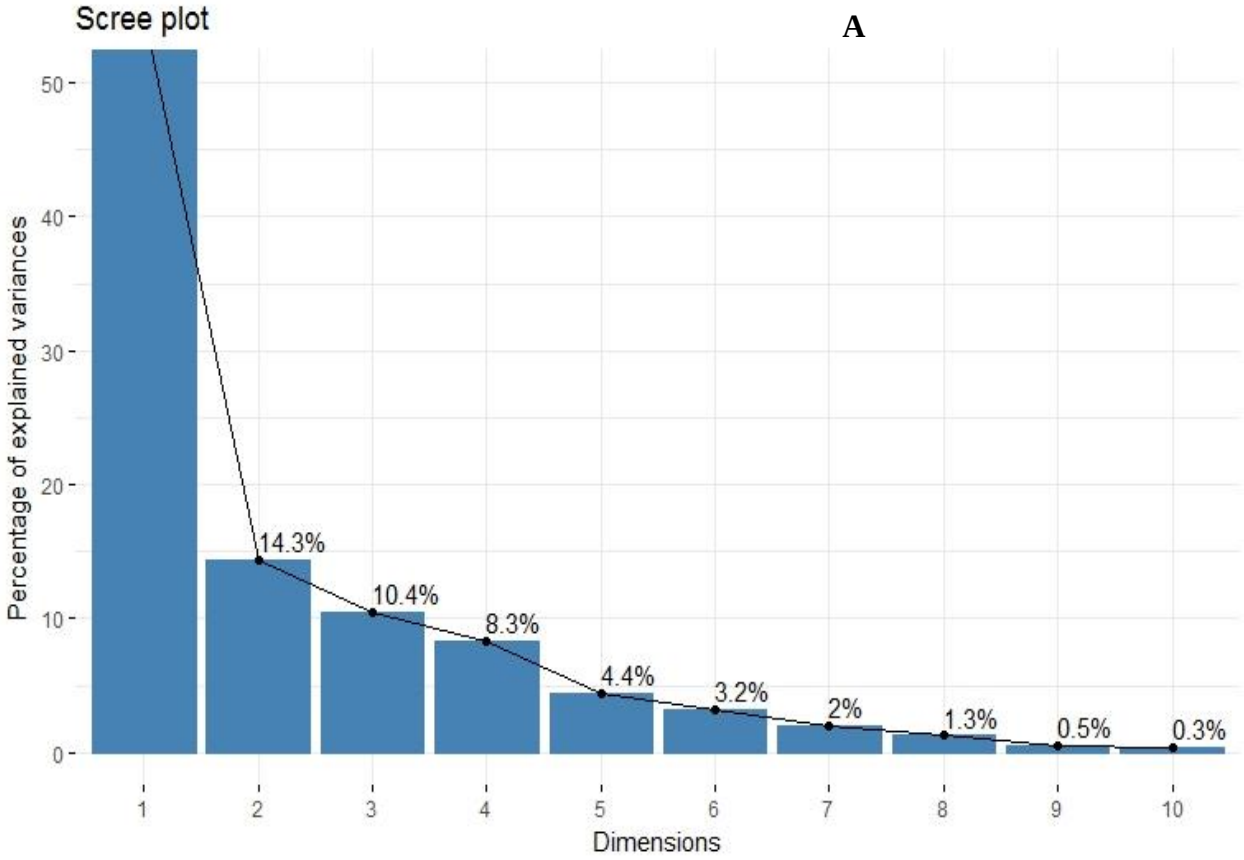
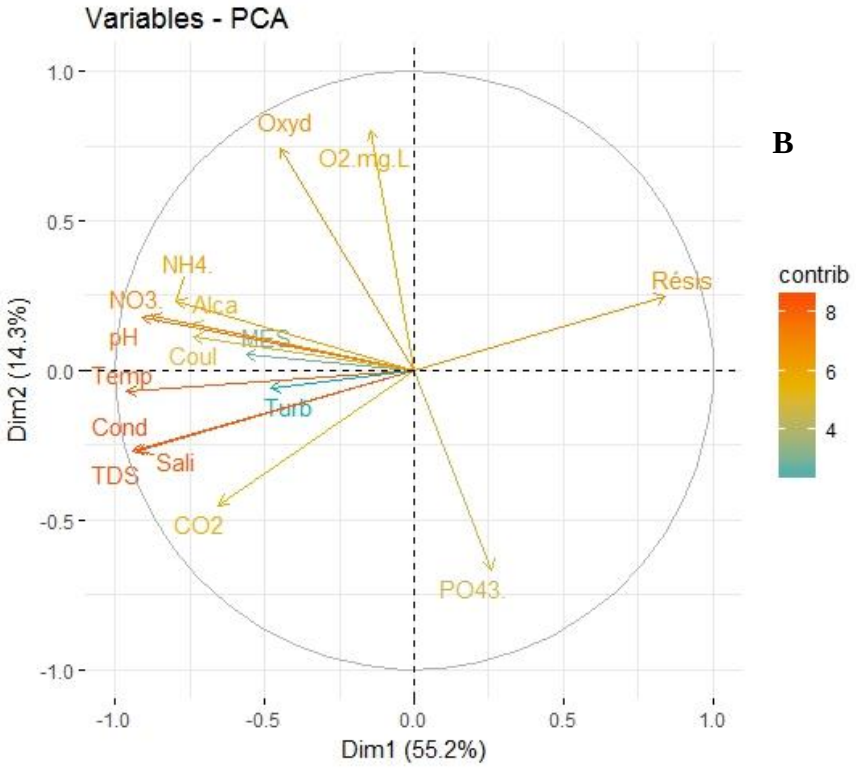
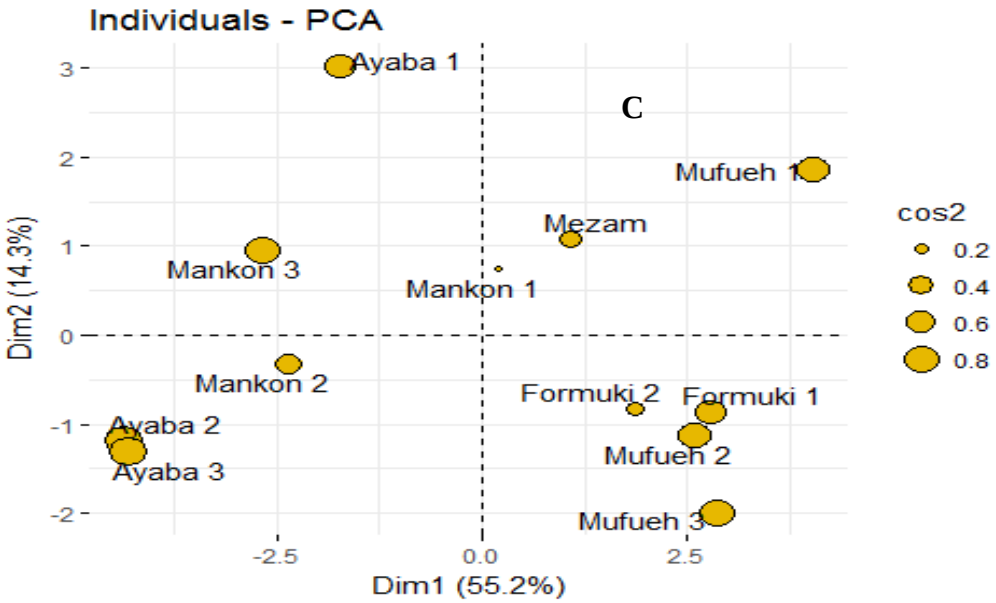


Figure 22: Results of the Principal component Analysis on the different environmental variables measured in the various sampling stations during the study period: (A) Histogram of the different values; (B) Cycle of correlation between variables and the factorial

Continuetion of figure 22





III-1-2- Community structure of benthic macroinvertebrates

III-1-2-1 Diversity and taxa distribution

III-1-2-1-1 Taxa richness

Generally, for the 13 sampling stations, a total of 115 macroinvertebrate taxa were sampled and 113 were identified to the genus and / or species level while the other two were identified to the family level as on Appendix 4. This taxa are divided into 3 phyla (Arthropoda, Mollusca and Annelida), 4 classes (Crustaceans, Insecta, Gastropoda and Achetea), 10 orders and 56 families. Arthropods are the most diversified with 2 classes, 8 orders, 51 families and 111 morphotypes. There are closely followed by Mollusca with 1 class of Gastropods with a single order, 2 families and 3 species. Annelids where the least diversified with 1 class of Acheata, a single order with 1 family of Gossiphoniidae counting 2 species.

The class of insect was the most represented with 100 morphotypes belonging to 7 orders, and 51 families. The class of Gastropods counted 3 species divided into a single order and and 2 families while the class Acheata has 2 species all belonging to 1 order and 1 family. Of the 7 orders representing the class insecta, that of Coleoptera and Hemiptera are the most represented with 10 families each. This is followed by Trichoptera, Diptera, Ephemeroptera, Odonata and Plecoptera which count 9, 8, 7, 5, and 1 family respectively. The Order Diptera is the most diversified with 31 taxa. This order is followed by Hemiptera (27 taxa), Coleoptera (20 taxa) Odonata (12 taxa), Trichoptera (11 taxa), Ephemeroptera (8 taxa) and finally Plecoptera with a single taxon.

The families Chironomidae (20 taxa), Gerridae (11 taxa) Dytiscidae (6 taxa) and Hydrophilidae, Libellulidae, Nepidae, Sciomyzidae all represented by 4 taxa each has the highest taxonomic richness. For all the taxa identified in this study, the groups EPT (Ephemeroptera - Plecoptera - Trichoptera), Dictyoptera, Chrysomelidae, Dytiscidae, Gyrinidae, Haliplidae, Helodidae, Hydrochidae, Tanypodinae, Orthocladiinae, Hydrometridae, Mesoveliidae, Veliidae, Calopterygidae, Chlorocyphidae, Corduliidae, Gomphidae and Gerridae were present in all the sampling stations and rivers while other groups like the Mollusca and Annelides were totally absent in the Mufueh river and the cruteceans were only seen in the Ayabah and Mezam rivers.

III-1-2-2- Distribution of taxa in the different sampling stations

III-1-2-2-1- Mufueh stream

The Mufueh stream have an average taxonomic richness with a total of 94 morphotypes divided into 42 families, 2 classes (Insects and Gastropods) and 2 phyla (Arthropodes and Mollusca) as on Table VII. The class of insects dominated the community with 7 orders, 40 families and 92 species while the class of Gastropods counts just a single order, 2 families and 2 species. The Order of Dipterans registered the highest number of species belonging to 6 families which was closely followed by Hemiptera 23 morphotypes in 9 families, Coleoptera 19 species in 9 families, Odonata 11 species in 5 families, Trichoptera with 8 species in 6 families, Ephemeroptera having 5 species in 4 families and the least was the order of Plecoptera with a single species and a single family.

The sampling station Mf1 showed the highest taxonomic richness compared to the other two sampling stations of the same river. This sampling point though dominated by the class of insect, had 7 orders, 33 families and 66 taxa. The order Diptera was the most diversified with 21 species followed by Hemiptera with 18 species, Coleoptera (13 species), Trichoptera and Odonata with 6 species each, Ephemeroptera having just 3 species and the least was the Plecoptera with a single species. This is the only point on the Mufueh River in which Plecopteras were sampled and was represented by the species *Clioperla llio*.

At the second sampling station of the Mufueh River (Mf2), 36 species divided into 23 families and 7 orders were identified. Insects were the most represented with 6 orders, 22 families and 37 taxxons and Gastropods were the least with a single order and family represented by *Vorticfex* sp. The Diptera were the most diversified with 11, Hemiptera (9 species), coleoptere (6 taxons) while the other orders followed with 5 or less species as on Table VII.

Looking at the last sampling point of this river, 52 morphotypes recorded in 21 families and 7 orders. Just like the other two stations above, Diptera was still the most diversified with 14 species, followed by Coleoptera 12 species, Odonata (11 species), Hemiptera (10 species) while Ephemeroptera and Trichoptera both registered 2 species each

Overall mean values and standard deviations of metrics for macroinvertebrates sampled at the three sampling sites of the Mufueh River are presented in figure 23 A, B and C below. Among metrics in the abundance category, the abundances of Ephemeroptera-

Plecoptera-Trichoptera (EPT), Ephemeroptera-Trichoptera-Odonata-Coleoptera (ETOC), Chironomidae + Basommatophora abundance

Comparing the combine abundance of the different taxa as per sampling station, it was observed that, the group of Ephemeroptera, Plecoptera and Trichoptera (EPT) are most abundant at the mf1 than the other two sampling points figure 23 A. At this station (mf1), the EPT groups represent 9 families and 10 species. These abundance followed in mf2 which show 5 families with 6 species and Mf3 was the least in terms of EPT abundance having just 3 families and 4 species. The Ephemeroptera-Trichoptera-Odonata-Coleoptera (ETOC) were in equal abundance at mf1 and mf3 while Chironomidae + Basommatophora were highest at site Mf2 (figure 23 C). The dominance of Chironomidae + Basommatophora abundance at mf2 could be as a result of the disappearance of sensitive taxa due to pollution.

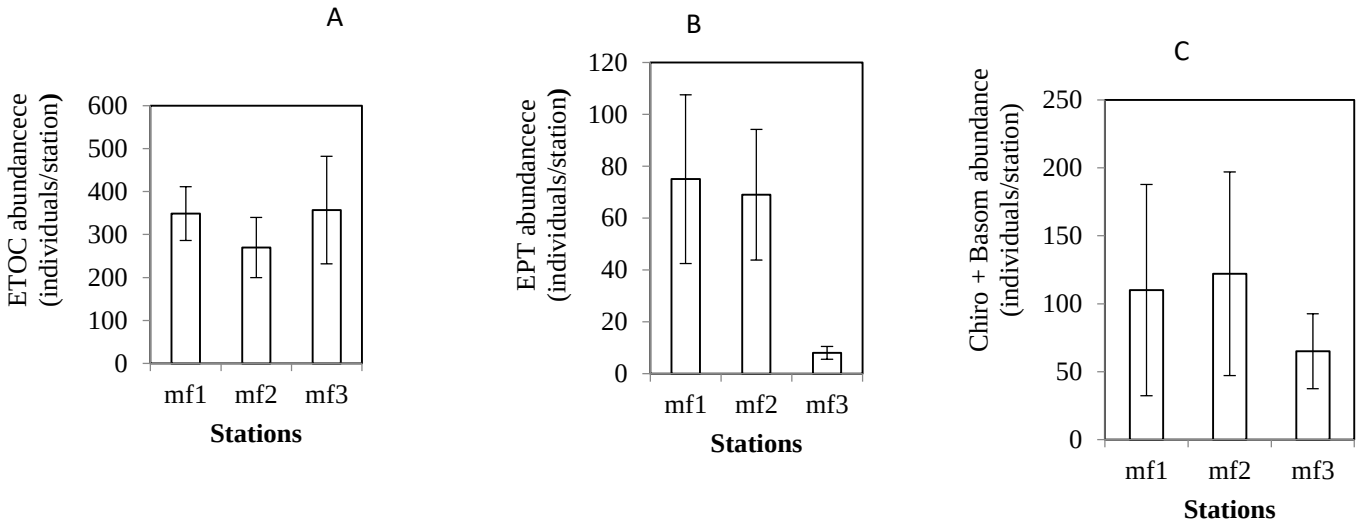


Figure 23: Overall mean values and standard deviations for each of the metrics in the abundance category at three sampling sites on the Mufueh River, A) EPT = Ephemeroptera PlecopteraTrichoptera, B) ETOC = Ephemeroptera-Trichoptera-Odonata-Coleoptera, C) Chirono+ Basom = Chironomidae + Basommatophora

Table VII: List of occurrence of benthic macroinvertebrates taxa sampled on the mufueh river (mf1, mf2 and mf3 sampling points) during the study period.

Phylum	**Class**	**Order**	**Family**	**Genus**	**Species**	mufueh		
						mf1	mf2	mf3
	Insecta	Coleoptera	Chrysomelidae	Donacia	*Donacia* sp.	1	1	2
			Gyrinidae	Gyretes	*Gyretes* sp.	63	4	0
				Dineutus	*Dineutus* sp.	3	4	0

Continuetion of Table VII

				Gyrinus	*Gyrinus* sp.	56	16	0
			Hydrophilidae	Helobata	*Helobata* sp.	3	0	2
				Derallus	*Derallus* sp.	2	0	5
				Sperchopsis	*Sperchopsis* sp.	0	0	1
				Berosus	*Berosus* sp.	0	0	13
			Dytiscidae	Cybista	*Cybista* sp.	0	0	11
				Agabetes	*Agabetes* sp.	0	0	2
				copelatus	*Copelatus* sp.	2	0	10
				Desmopachria	*Desmopachria* sp.	5	0	6
				Hydroptrapes	*Hydroptrapes* sp.	0	0	1
				Ilybius	*Ilybius* sp.	12	0	1
			Dryopidae	Dryops	*Dryops* sp.	1	0	0
			Georissidae	Georissue	*Georissue* sp.	2	0	0
			Salpingidae	Aegilites	*Aegilites* sp.	2	4	0
			Haliplidae	Peltodytes	*Peltodytes* sp.	1	0	25
			Psephenidae	psephenus	*psephenus* sp.	0	1	0
		Odonata	Libellulidae	Pantala	*Pantala falvesceus*	38	19	85
				Tramea	*Tramea* sp.	51	36	107
				Miathyria	*Miathyria* sp.	0	0	2
			Gomphidae	Hagenius	*Hagenius* sp.	0	0	4
			Coenagrionidae	Hagen	*Hagen* sp.	0	9	2
				Enallagma	*Enallagma cyathijerum*	0	0	12
				Nehalennia	*Nehalennia spaciosa*	1	0	16
			Calopterygidae	Calopteryx	*Calopteryx maculata*	13	63	21
				Hetaerina	*Hetaerina titia*	16	39	15
			Aeshnidae	Gynacantha	*Gynacantha nervosa Rambus*	0	5	3
				Aeshna	*Aeshna* sp.	3	0	3
		Hemiptera	Gerridae	Limnogonus	*Limnogonus metrobates*	4	0	0
					Limnogonus sp.	2	0	0
				Ventidius	*Ventidius pulai*	3	0	0
					Ventidius	10	0	0

Continuetion of Table VII

					modulatus			
					Ventidius malayensis	13	0	0
				Limnometra	*Limnometra ciliata*	8	0	0
					Limnometra sp.	10	0	0
					Limnometra matsudai	4	0	0
			Corixidae	Palmacorix	*Palmacorix* sp.	0	4	2
			Macroveliidae	Macrovelia	*Macrovelia hornii Uhler*	0	1	10
			Veliidae	Steinovelia	*Steinovelia* sp.	18	0	0
				Microvelia	*Microvelia* sp.	1	2	8
				Rhagovelia	*Rhagovelia mayr*	3	13	0
			Nepidae	Nepa	*Nepa* sp.	1	0	4
				Curictini	*Curictini* sp.	21	2	10
				Laccotrephes	*Laccotrephes* sp.	1	0	0
				Ranatra	*Ranatra fabricius*	2	5	12
			Belostomatidae	Lethocerus	*Lethocerus* sp.	42	0	2
				Abedus	*Abedus sp.*	0	7	0
				Belostoma	*Belostoma latreille*	0	26	16
			Notonectidae	Notonecta	*Notonect Linnaeus*	4	0	0
			Hydrometridae	Hydrometra	*Hydrometra australisay*	5	0	0
			Naucoridae	Pelocoris	*Pelocoris shoshone*	0	7	13
		Ephimeroptera	Caenidae	Caenis	*Caenis femina*	0	19	4
				Brachycerus	*Brachycerus* sp	4	11	1
			Polymitalyiidae	Ephoron	*Ephoron* sp.	4	2	0
			Potamanthidae	Potamanthus	*Potamanthus* sp.	4	0	0
			Baetidae	Procloeon	*Procloeon pennulatum*	0	18	0
		Trichoptera	Hydroptilidae	Orthotrichia	*Orthotrichia* sp.	0	0	1
				Palaeagapetus	*Palaeagapetus* sp.	9	0	0

Continuetion of Table VII

			Lepidostomatidae	Theliopsche	*Theliopsche* sp.	17	0	0
			Goeridae	Goeracea	*Goeracea* sp.	5	0	0
			Sericostomatidae	Agarodes	*Agarodes* sp.	9	0	0
			Philopotamidae	Dolophilodes	*Dolophilodes* sp	20	0	0
				Chimarra	*Chimarra* sp.	2	1	0
			Hydropsychidae	Hydropsyche	*Hydropsyche* sp.	0	18	2
		Plecoptera	Perlolidae	Clioperla	*Clioperla llio*	1	0	0
		Diptera	Dolichopodidae	Rhaphium	*Rhaphium campestres*	2	0	0
			Sciomyzidae	NI	*NI*	8	0	0
				Tetanocera	*Tetanocera vicinan*	2	0	0
			Syrphidae	Eristalis	*Eristalis tenax*	5	4	0
			Tipulidae	Tipula	*Tipula eluta loew*	3	0	0
				Hexatoma	*Hexatoma sp.*	8	0	0
			Simullidae	Simulium	*Simulium sp.*	2	0	0
			Chironomidae	Chironomous	*Chironomous riparious*	15	36	4
					Chironomous staegeri	18	14	3
					Chironomous stigmaterus	14	10	4
					Chironomous crassicaudatus	1	9	6
					Chironomous plumosus	0	7	3
				PseudoChironomous	*PseudoChironomous* sp.	2	0	0
				Dicrotendipes	*Dicrotendipes neonodestus*	0	0	2
				Eukiefferiella	*Eukiefferiella* sp.	1	0	1
				Zalutschia	*Zalutschia* sp.	0	0	1
				Micropsectra	*micropsectra* sp.	6	0	0
				Denopelopia	*Denopelopia atria*	15	0	0
				Polypedilum	*Polypedilum*	9	0	3

					beckae			
					Polypedilum illinoense	0	8	4
					Polypedilum laetum	2	3	4
				Procladus	*Procladus bellus*	2	6	4
				Catopilopia	*Catopilopia gesta*	25	0	0
				Brundiniella	*Brundiniella eumorpha*	0	2	1
				Radotanypus	*Radotanypus florens*	0	19	12
Mollusca	Gastropoda	Basommatophora	Physidae	Archephysa	*Archephysa lordi*	0	0	5
			Planorbidae	Vorticfex	*Vorticfex* sp.	0	8	8
Total	2	8	42	83	94	642	463	499

III-1-2-2-2- Furmuki stream

In the Furmuki stream, a total of 60 morphotypes were counted and identified belonging to 54 general, 30 families, 8 orders, 3 classes (Insects, Achaeta and Gastropods), and 3 phyla as on Table VIII. The class of Insects dominated with 6 orders, 27 families and 55 taxa. This class is followed by that of Gastropods counting a single order, 2 families and 3 species. It should be noted that this three species of gastropods were highly abundance especially at the second and third sampling points of the Furmuki stream. The least of the classes was the class of Achaeta with a single order, family and 2 species. The most diversified Order was that of Diptera with 27 taxa, followed by Hemiptera 7 taxa, Coleoptera and Odonata with 6 taxa each then by Ephimeroptera and Trichoptera with 5 and 4 taxa respectively. A good number of species that were identified in this stream were absent in the mufueh stream above.

At the first sampling point of the Furmuki stream (F1) upstream, 48 species were identified and was divided into 24 families, 6 orders, 2 classes and 2 phyla. The class of insects was the most represented with 6 orders, 23 families and 46 taxa and the class of Achaeta was second with a single order and a family counting 2 taxa. The Diptera order was the most diversified with 5 families and 24 taxa followed by odonata and Ephimeroptera with

5 taxa each then was the orders Coleoptera, Hemiptera and Trichoptera counting each 4 taxa. The Chironomidae species *Brundiniella eumorpha* and *Catopilopia gesta* were totally absent at the sampling station of the Furmuki stream and present in the other two stations while species like *Eukiefferiella* sp. and *Tanypus* sp. were only present at F1 and absent at the other two sampling points of the Furmuki stream during the study period.

The second sampling point of the Furmuki stream (F2), midd stream, registered 43 taxa divided into 20 families, 8 orders, 3 classes and 3 phyla. Here, the complete absent of the order Coleoptera noted at the sampling station throughout the research period. The class of insect was highly represented 5 orders, 17 families and 38 taxa. This class was next by that of Gastropods with 2 orders 2 families and 3 taxa while the class of Achaets had just 1 order with 1 family and 2 species. The order of Diptera was the most diversified with 5 families and 22 taxa followed by Odonata with 3 families and 5 taxa, the Hemiptere and Ephimeroptera had respective 3 families and 4 taxa each while the least was the Trichoptera with 3 families and 3 taxa. The order of Basommatophores had 2 families and 3 taxa. This sampling point was dominated by members of the species *Archephysa lordi* and *Petrophysa zionis* of the family Physidae. This two species of the family were excessively abundant at this second sampling station of the Furmuki stream especially during the dry seasons when the water velocity drops.

Looking at the third station of the Furmuki (F3), 40 taxa belong to 20 families, 8 orders, 3 classes and 3 phyla were collected. The class of Insects was the most represented with 6 orders and 17 families and 36 taxa. The class of Gastropods registered 1 order, 1 family and 2 taxa while the Achaeta were the least with a single order, family and 2 taxa. The order of Diptera was the most diversified with 3 families and 16 species, it was next by Hemiptera (3 families and 6 taxa), Odonata (3 families and 5 taxa), Coleoptera (4 families and 4 species), Ephemeroptera (3 families and 4 taxa) and Trichoptera coming with 1 family and 1 species.

Looking at the abundances of the different taxa as per sampling station, it was noticed that the group of Ephemeroptera, Plecoptera and Trichoptera (EPT) are most abundant at the f2 than the other two sampling points figure 24A. At this station (f2), the EPT groups represent 6 families and 7 species. These station was followed by f1 having 8 families with 9 species and f3 was the least in terms of EPT abundance having just 4 families and 5 species. As for the Ephemeroptera-Trichoptera-Odonata-Coleoptera (ETOC), there were in equal

abundance at all the sampling points of furmuki stream while Chironomidae + Basommatophora were highest at site f2 (figure 24C). The dominance of Chironomidae + Basommatophora abundance at f2 could be as a result of favorable breeding conditions and the disappearance of pollution sensitive taxa.

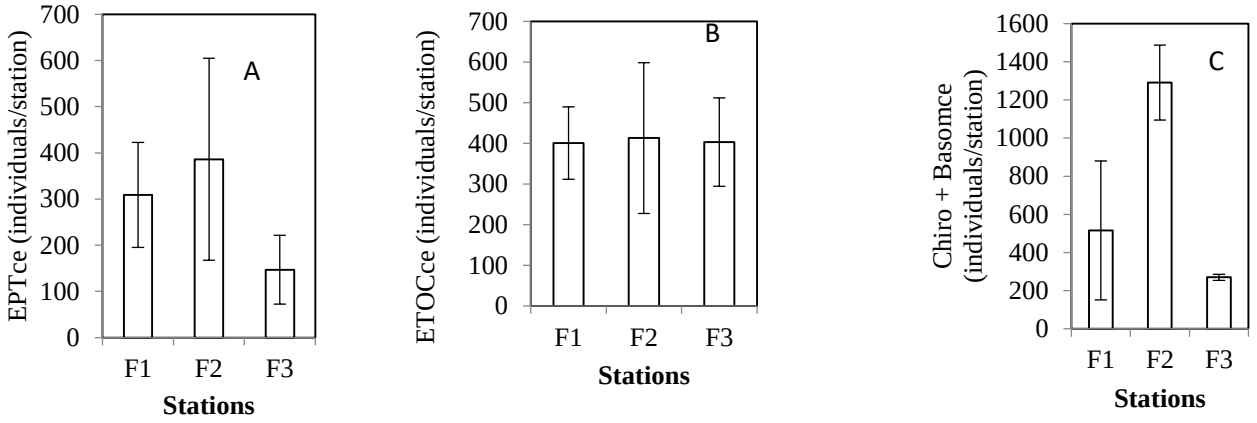


Figure 24: Overall mean values and standard deviations for each of the metrics in the abundance category at three sampling sites on the Furmuki River, A) EPT = Ephemeroptera **PlecopteraTrichoptera, B) ETOC = Ephemeroptera-Trichoptera-Odonata-Coleoptera, C) Chirono+ Basom = Chironomidae + Basommatophora**

Table VIII: List of occurrence of benthic macroinvertebrates taxa sampled on the furmuki river (f1, f2 and f3 sampling points) during the study period.

Phylum	Class	Order	Family	Genus	Species	Furmuki		
						F1	F2	F3
		Coleoptera	Gyrinidae	Gyretes	*Gyretes* sp.	0	0	2
				Gyrinus	*Gyrinus* sp.	1	0	0
			Dytiscidae	copelatus	*copelatus* sp.	0	0	5
			Dryopidae	Dryops	*Dryops* sp.	1	0	2
			Salpingidae	Aegilites	*Aegilites* sp.	7	0	7
			Elmidae	Lara	*Lara* sp.	5	0	0
		Odonata	Libellulidae	Pantala	*Pantala falvesceus*	17	1	18
				Tramea	*Tramea sp*	11	9	49
			Coenagrionidae	Nehalennia	*Nehalennia spaciosa*	0	3	7
			Calopterygidae	Calopteryx	*Calopteryx maculata*	27	10	106
				Hetaerina	*Hetaerina titia*	20	4	60
			Aeshnidae	Gynacantha	*Gynacantha*	3	0	0

Continuetion of Table VIII

Continuetion of Table VIII

					nervosa Rambus			
		Hemiptera	Veliidae	Rhagovelia	*Rhagovelia mayr*	0	16	0
			Nepidae	Nepa	*Nepa* sp.	3	3	1
				Curictini	*Curictini* sp.	0	0	2
				Ranatra	*Ranatra fabricius*	0	0	2
			Belostomatidae	Abedus	*Abedus* sp.	6	11	15
				Belostoma	*Belostoma latreille*	30	12	64
			Naucoridae	Pelocoris	*Pelocoris shoshone*	11	0	9
		Ephimeroptera	Caenidae	Caenis	*Caenis femina*	63	101	66
				Brachycerus	*Brachycerus* sp	41	52	13
			Siphlonuridae	Siphlonurus	*Siphlonurus* sp.	2	0	0
			Polymitalyiidae	Ephoron	*Ephoron* sp.	7	5	13
			Baetidae	Procloeon	*Procloeon pennulatum*	112	223	43
		Trichoptera	Limnephilidae	Anabolia	*Anabolia* sp.	4	1	0
			Brachycentridae	Brachycentrus	*Brachycentrus* sp.	7	2	0
			Philopotamidae	Chimarra	*Chimarra* sp.	5	0	0
			Hydropsychidae	Hydropsyche	*Hydropsyche* sp.	68	2	12
		Diptera	Dolichopodidae	Rhaphium	*Rhaphium campestres*	0	3	0
			Sciomyzidae	Dictya	*Dictya pictipes*	3	1	0
				Ilybius	*Ilybius* sp.	2	0	0
				Sepedon	*Sepedon* sp.	1	8	0
				Tetanocera	*Tetanocera vicinan*	8	2	0
			Syrphidae	Eristalis	*Eristalis tenax*	3	10	4
			Tipulidae	Tipula	*Tipula eluta*	3	2	0
			Simullidae	Simulium	*Simulium* sp.	36	25	12
			Chironomidae	Chironomous	*Chironomous riparious*	61	61	14
					Chironomous staegeri	46	22	2
					Chironomous stigmaterus	97	64	10
					Chironomous	45	70	12

Continuetion of Table VIII

					crassicaudatus			
					Chironomous plumosus	13	6	3
				PseudoChironomous	*PseudoChironomous* sp.	3	0	0
				Dicrotendipes	*Dicrotendipes neonodestus*	2	0	0
				Ablabesmyia	*Ablabesmyia peleensis*	2	1	1
				Eukiefferiella	*Eukiefferiella* sp.	0	0	1
				Zalutschia	*Zalutschia* sp.	6	1	1
				micropsectra	*micropsectra* sp.	1	2	0
				Polypedilum	*Polypedilum beckae*	23	29	8
					Polypedilum illinoense	63	69	19
					Polypedilum laetum	29	36	8
				Tanypus	*Tanypus* sp.	3	0	0
				Procladus	*Procladus bellus*	31	58	16
				Catopilopia	*Catopilopia gesta*	0	1	0
				Brundiniella	*Brundiniella eumorpha*	0	1	2
				Radotanypus	*Radotanypus florens*	90	86	27
Annelida	Achaeta	Rhynchobdellida	Glossiphoniidae	Haementeria	*Haementeria Costata*	9	4	30
				Helobdella	*Helobdella stagnalis*	18	77	63
Mollusca	Gastropoda	Basommatophora	Physidae	Petrophysa	*Petrophysa zionis*	0	172	37
				Archephysa	*Archephysa lordi*	0	608	109
			Planorbidae	Vorticfex	*Vorticfex* sp.	0	4	0
Total	3	8	30	54	60	1049	1878	875

III-1-2-2-3- Mankon stream

The Mankon stream registered the least taxonomic richness with 57 morphotypes belonging to 3 phyla, 3 classes (Insecta, Achaeta and Gastropoda), 8 orders and 27 families (Table IX). The most diversify class was that of insect and count 6 orders, 26 families and 52 taxa. This class was followed by the classes of Annelids and Gastropods both having 1 order, family and 2 taxa each. The order of Diptera dominated with 21 species, it was followed by that of Hemiptera with 16 species next was that of coleopteran, Odonata, Ephemeroptera and Trichoptera respectively having 6, 5, 4 and 1 family.

A total of 38 taxa belonging to 14 families, 7, orders, 3 classes and 3 phyla were sampled

Orders, 12 families and 34 species. Gastropods and Annelids both had a single order, family and 2 species each. A high taxanomic diversity was noted in the Hemiptera order with 4 families and 13 taxa. It was followed by the Diptera with just 1 family and 11 species the Coleoptera (4 families 5 taxa), Odonata (2 families and 4 species) and Ephemeroptera coming with a single family and species. The absent of the Trichoptera order throughout the study period at this sampling point and it is also wealth noting that this was the only station in which Gerridae was collected which counted as much as 8 species.

At the second sampling point of the Mankon stream (Mk2), the sampled specimens belong to 3 phyla, 3 classes, 7 orders, 19 families and 38 species. Insects are the most represented with 5 orders, 17 families and 34 taxa while the classes of Achaeta and Gastropods did not really vary from the 1 family and 2 taxa each. Diptera are the most diversified with 6 families and 16 species with the absent of trichoptera also noted at the station.

As for the third station on the Mankon stream (Mk3), 37 taxa were harvested representing 19 families, 8 orders, 3 classes and 3 phyla. The class of insects dominated with 6 orders, 17 families and 33 taxa. Gastropods and Annelids were represented by just 1 order, 1 family and 2 taxa. This sampling point was dominated by Diptera with 4 families and 15 species, Hemiptera (4 families and 6 taxa), Odonata (3 families and 5 taxa), Ephimeroptera (3 families and 4 taxa), Coleoptera with 2 families and 2 species and the reappearance of Trichoptera with a single family and species.

Examining the abundances of the various orders sampled from the mankon stream, it was noticed that the group of Ephemeroptera, Plecoptera and Trichoptera (EPT) are most abundant at the Mk2, followed by Mk3 and these abundance was least at the first sampling point (Mk1) as seen on figure 25 A. the low abundance of EPT at mk1 could be due to the

stagnant nature of water at this point couple with the detergents from car washing activities. This EPT groups represent 4, 3 and 1 family for the stations Mk3, Mk2 Mk1 respectively. Looking at the abundance of Ephemeroptera-Trichoptera-Odonata-Coleoptera (ETOC), an abundance was observed at Mk2, followed by Mk3 and least by Mk1. The Chironomidae + Basommatophora abundance followed same distribution as the Ephemeroptera-Trichoptera-Odonata-Coleoptera (ETOC) from mk2, mk3 and least abundance at mk1 (figure 25C). The dominance of Chironomidae + Basommatophora abundance at mk2 could be as a result of favorable breeding conditions and the disappearance of sensitive taxa due to pollution.

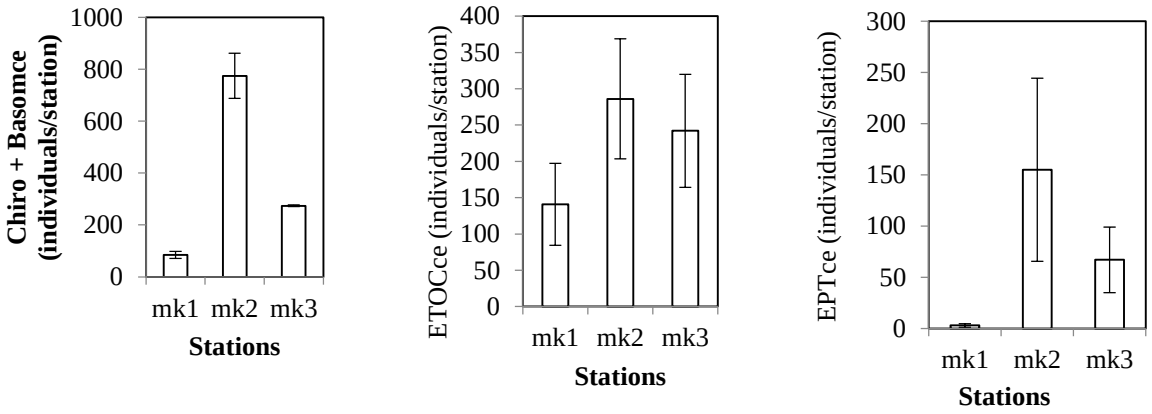


Figure 25: Overall mean values and standard deviations for each of the metrics in the abundance category at three sampling sites on the Mankon River, A) EPT = Ephemeroptera PlecopteraTrichoptera, B) ETOC = Ephemeroptera-Trichoptera-Odonata-Coleoptera, C) Chirono+ Basom = Chironomidae + Basommatophora

Table IX: List of occurrence of benthic macroinvertebrates taxa sampled on the Mankon river (mk1, mk2 and mk3 sampling points) during the study period.

Phylum	Class	Order	Family	Genus	Species	mankon		
						mk1	mk2	mk3
	Insecta	Coleoptera	Gyrinidae	Gyretes	*Gyretes* sp.	3	0	0
			Dytiscidae	Cybista	*Cybista* sp.	6	0	0
				copelatus	*copelatus* sp.	3	0	0
			Salpingidae	Aegilites	*Aegilites* sp.	4	1	2
			Haliplidae	Peltodytes	*Peltodytes* sp.	3	0	0
			Elmidae	Lara	*Lara* sp.	0	0	2
		Odonata	Libellulidae	Pantala	*Pantala falvesceus*	27	22	38
				Tramea	*Tramea* sp.	40	31	43
			Coenagrionidae	Nehalennia	*Nehalennia spaciosa*	0	1	1
			Calopterygidae	Calopteryx	*Calopteryx*	30	47	51

					maculata			
				Hetaerina	*Hetaerina titia*	22	29	38
		Hemiptera	Gerridae	Ventidius	*Ventidius pulai*	3	0	0
					Ventidius modulatus	4	0	0
					Ventidius malayensis	8	0	0
				Metrocoris	*Metrocoris nigrofasciutus*	2	0	0
				Limnometra	*Limnometra ciliata*	1	0	0
					Limnometra sp.	3	0	0
				Aselepios	*Aselepios* sp.	2	0	0
				Tenagogonus	*Tenagogonus* sp.	2	0	0
			Macroveliidae	Macrovelia	*Macrovelia. hornii*	0	13	14
			Veliidae	Rhagovelia	*Rhagovelia mayr*	0	6	0
			Nepidae	Nepa	*Nepa* sp.	11	3	1
				Ranatra	*Ranatra fabricius*	1	0	3
			Belostomatidae	Abedus	*Abedus* sp.	3	4	7
				Belostoma	*Belostoma latreille*	18	18	30
			Notonectidae	Notonecta	*Notonecta. Linnaeus*	3	0	0
			Naucoridae	Pelocoris	*Pelocoris shoshone*	0	0	2
		Ephimeroptera	Caenidae	Caenis	*Caenis femina*	0	64	29
				Brachycerus	*Brachycerus* sp.	0	33	14
			Polymitalyiidae	Ephoron	*Ephoron* sp.	3	12	11
			Baetidae	Procloeon	*Procloeon pennulatum*	0	46	5
		Trichoptera	Hydropsychidae	Hydropsyche	*Hydropsyche* sp.	0	0	8
		Diptera	Dolichopodidae	Rhaphium	*Rhaphium campestres*	0	3	2
			Sciomyzidae	Tetanocera	*Tetanocera vicinan*	0	3	0
			Syrphidae	Eristalis	*Eristalis tenax*	0	2	9

Continuetion of Table IX

Continuetion of Table IX

			Tipulidae	Tipula	*Tipula eluta*	0	1	0
				Hexatoma	*Hexatoma* sp.	0	1	0
			Simullidae	Simulium	*Simulium* sp.	0	67	6
			Chironomidae	Chironomous	*Chironomous riparious*	3	76	18
					Chironomous staegeri	1	31	8
					Chironomous stigmaterus	5	42	14
					Chironomous crassicaudatus	2	59	19
					Chironomous plumosus	1	31	4
				Ablabesmyia	*Ablabesmyia peleensis*	0	2	0
				Eukiefferiella	*Eukiefferiella* sp.	0	2	0
				Polypedilum	*Polypedilum beckae*	2	32	7
					Polypedilum illinoense	4	48	14
					Polypedilum laetum	3	21	10
				Tanypus	*Tanypus* sp.	4	0	0
				Procladus	*Procladus bellus*	3	24	11
				Catopilopia	*Catopilopia gesta*	0	0	1
				Brundiniella	*Brundiniella eumorpha*	0	3	2
				Radotanypus	*Radotanypus florens*	5	78	27
Annelida	Achaeta	Rhynchobdellida	Glossiphoniidae	Haementeria	*Haementeria Costata*	30	19	12
				Helobdella	*Helobdella stagnalis*	11	26	50
Mollusca	Gastropoda	Basommatophora	Physidae	Petrophysa	*Petrophysa zionis*	15	63	33
				Archephysa	*Archephysa lordi*	37	263	106
Total	3	8	27	48	57	328	1227	652

III-1-2-2-4- Ayabah stream

The Ayabah stream recorded the least number of morphotypes. Here, a total of 55 morphotypes sampled partition into 3 phyla, 4 classes (insects, crustaceans, Gastropoda and

Annelids), 10 orders, and 28 families as seen on Table X. Insects dominated with 7 orders, 25 families and 52 taxa. This class is followed by that of Gastropods and Annelids with 1 order, 1 family and and 2 taxa each and the least of the classes was that of crustaceans with just a single family and taxon. The order of Diptera was the most diversified with 25 taxa followed by that of Hemiptera, coleopteran, Odonata, Ephimeroptera, Plecoptera and Trichoptera with 9, 6, 4,4, 1 and 1 taxon respectively.

At A1, the first sampling pint of the Ayabah stream, 45 taxa were recorded belonging to 24 families, 9 orders, 4 classes and 3 phyla. The class of insects was the most represented with 7 orders, 22 families and 42 taxa. Gastropods and Annelids both had a single order, family and 2 taxa while the crustaceans was just a taxon. At this stations, Diptera were the most dominates with 7 families and 20 species, Hemiptera (6 families and 9 species, Odonata and Coleoptera both had 2 families with 2 and 4 species respectively while the Trichoptera and Plecoptera both had 1 family and species.

For the second station (A2), 37 taxa were identified into 17 families, 7 orders, 3 classes and 3 phyla. Still, insects dominated with 5 orders, 15 families and 35 taxa. This was followed by the Annelids and Gastropods with single order, family and 2 species. Here, Diptera were the most diversified with 19 taxa and 6 families followed by Odonata and Hemiptera with 3 families and 4 species and lastly by Coleopteran and Ephimeroptera with 2 families, 2 species each.

At the last sampling station of the Ayabah stream (A3), a total of 35 morphotypes were registered in 16 families, 7 orders, 3 classes and 3 phyla. The insect community dominated with 5 classes, 14 families and 33 taxa. In this samples, a high diversity of Diptera was noted with 16 species in 4 classes and the least was the Ephimeroptera with just 3 species in 2 families. The Trichoptera order was noted absent from the station throughout the study period.

Looking at the Mezam River, which is the control point for the other stream. This sampling point receive water from all the other rivers above, it recorded 36 taxa into 22 families, 10 orders, 4 classes and 3 phyla. The insects dominated with 7 orders, 19 families and 32 taxa. Hemiptera were the most diversified here with 8 taxa in 4 favilies, coloeptera with 7 species in 5 families Odonata (3 favilies and 6 species), Ephemeroptera (3 families, 4 taxa), Diptera (1 family and 5 species), Trichoptera with 3 families and 3 species and finally the plecoptera with just a single family and species. It is wealth noting that this is the only sampling point which had high plecoptera and crustacean. It is also only at this station that

Talking of the abundances of the various orders sampled from the Ayabah and mezam stream, it was noticed that, the group of Ephemeroptera, Plecoptera and Trichoptera (EPT) are most abundant at the A1, followed by Mz, then at A2 ansd least abundance at A3 as seen on figure 26 A. the low abundance of EPT at Mk1 could be due to the sand mining activities at this point. Looking at the abundance of Ephemeroptera-Trichoptera-Odonata-Coleoptera (ETOC), an abundance was noted at Mz, followed by A1 while A2 and A3 has equal abundance of this groups of organisms. Conversely to what was observe with the ETOC groups above, the Chironomidae + Basommatophora are at equal abundance at A2 and A3 then followed by A1 and mz has the least abundance (figure 26C). The dominance of Chironomidae + Basommatophora abundance at A2 and A3 could be as a result of closeness to the food comecial markets which and collect all remains of food stuff.

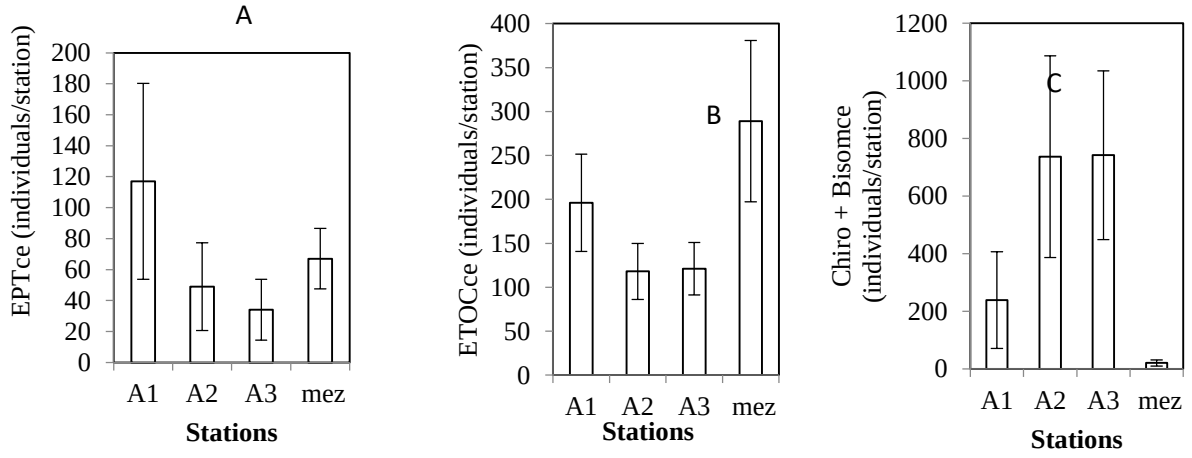


Figure 26: Overall mean values and standard deviations for each of the metrics in the abundance category at three sampling sites on the Ayabah and Mezam River, A) EPT = Ephemeroptera PlecopteraTrichoptera, B) ETOC = Ephemeroptera-Trichoptera-Odonata-Coleoptera, C) Chirono+ Basom = Chironomidae + Basommatophora

Table X: List of occurrence of benthic macroinvertebrates taxa sampled on the Ayabah and Mezam River (A1, A2, A3 and mz sampling points) during the study period.

Phylum	**Class**	**Order**	**Family**	**Genus**	**Species**	Ayabah			Mezam
						A1	A2	A3	mez
Anthropoda	Crustacea	Decapoda	Potamolidae	NI	NI	2	0	0	2
	Insecta	Coleoptera	Chrysomelidae	Donacia	*Donacia* sp.	0	0	0	0
			Gyrinidae	Gyretes	*Gyretes* sp.	1	2	3	4
				Gyrinus	*Gyrinus* sp.	0	1	2	0
			Hydrophilidae	Helobata	*Helobata* sp.	0	0	0	2

Continuetion of Table X

				Cybista	*Cybista* sp.	0	0	9	0
			Dytiscidae	Desmopachria	*Desmopachria* sp.	0	0	0	2
				Hydroptrapes	*Hydroptrapes* sp.	0	0	0	2
				Ilybius	*Ilybius* sp.	2	0	0	0
			Dryopidae	Dryops	*Dryops* sp.	0	0	0	2
			Salpingidae	Aegilites	*Aegilites* sp.	0	0	3	4
			Elmidae	Lara	*Lara* sp.	0	2	0	0
		Odonata	Libellulidae	Pantala	*Pantala falvesceus*	9	14	15	29
				Tramea	*Tramea* sp.	19	21	25	43
			Coenagrionidae	Hagen	*Hagen* sp.	0	0	0	13
				Nehalennia	*Nehalennia spaciosa*	0	0	0	7
			Calopterygidae	Calopteryx	*Calopteryx maculata*	37	16	22	73
				Hetaerina	*Hetaerina titia*	14	13	8	44
		Hemiptera	Gerridae	Ventidius	*Ventidius pulai*	0	0	0	2
					Ventidiusmodulatus	0	0	0	1
					Ventidius malayensis	0	0	0	2
			Corixidae	Palmacorix	*Palmacorix* sp.	2	0	0	0
			Macroveliidae	Macrovelia	*Macrovelia hornii Uhler*	10	0	2	1
				Microvelia	*Microvelia* sp.	4	0	0	3
				Rhagovelia	*Rhagovelia mayr*	3	0	0	3
			Nepidae	Nepa	*Nepa* sp.	3	6	0	0
				Ranatra	*Ranatra fabricius*	2	0	0	0
			Belostomatidae	Abedus	*Abedus* sp.	3	1	2	15
				Belostoma	*Belostoma latreille*	11	20	20	14
			Naucoridae	Pelocoris	*Pelocoris shoshone*	2	8	3	0
		Ephimeroptera	Caenidae	Caenis	*Caenis femina*	44	24	23	8
				Brachycerus	*Brachycerus*	12	12	9	2

Continuetion of Table X

					sp.				
			Polymitalyiidae	Ephoron	*Ephoron* sp.	8	0	0	12
			Baetidae	Procloeon	*Procloeon pennulatum*	48	13	2	20
		Trichoptera	Phryganeidae	Phryganus	*Phryganus* sp.	0	0	0	3
			Brachycentridae	Brachycentrus	*Brachycentrus* sp.	0	0	0	2
			Hydropsychidae	Hydropsyche	*Hydropsyche* sp.	2	0	0	17
		Plecoptera	Perlolidae	Clioperla	*Clioperla llio*	3	0	0	3
		Diptera	Ephydridae	Allotrichoma	*Allotrichoma* sp.	1	4	0	0
			Dolichopodidae	Rhaphium	*Rhaphium campestres*	0	1	2	0
			Empididae	Hemerodrominae	*Hemerodrominae* sp.	2	0	0	0
			Sciomyzidae	Dictya	*Dictya pictipes*	2	0	0	0
				Tetanocera	*Tetanocera vicinan*	43	2	0	0
			Syrphidae	Eristalis	*Eristalis tenax*	4	8	12	0
			Tipulidae	Tipula	*Tipula eluta loew*	3	0	0	0
			Simullidae	Simulium	*Simulium* sp.	14	6	8	0
			Chironomidae	Chironomous	*Chironomous riparious*	19	129	98	0
					Chironomous staegeri	14	65	68	0
					Chironomous stigmaterus	20	48	52	0
					Chironomous crassicaudatus	31	117	132	0
					Chironomous plumosus	9	53	30	0
				PseudoChironomous	*PseudoChironomous* sp.	1	0	0	0
				Ablabesmyia	*Ablabesmyia peleensis*	0	1	0	0
				Eukiefferiella	*Eukiefferiella* sp.	5	0	0	4
				Zalutschia	*Zalutschia sp.*	0	1	0	4
				Denopelopia	*Denopelopia*	0	1	3	0

Continuetion of Table X

					atria				
				Polypedilum	*Polypedilum beckae*	18	24	21	1
					Polypedilum illinoense	33	41	45	6
					Polypedilum laetum	17	22	19	0
				Procladus	*Procladus bellus*	23	24	26	0
				Catopilopia	*Catopilopia gesta*	0	0	3	0
				Brundiniella	*Brundiniella eumorpha*	2	13	6	3
				Radotanypus	*Radotanypus florens*	46	77	75	0
Annelida	Achaeta	Rhynchobdellida	Glossiphoniidae	Haementeria	*Haementeria Costata*	6	13	20	0
				Helobdella	*Helobdella stagnalis*	17	34	23	2
Mollusca	Gastropoda	Basommatophora	Physidae	Petrophysa	*Petrophysa zionis*	0	35	44	0
				Archephysa	*Archephysa lordi*	1	86	120	3
Total	**4**	**10**	**55**	**104**	**113**	**572**	**958**	**955**	**358**

III-1-2-3- Numerical structure of benthic macro invertebrates community in bamenda

III-1-2-3-1- Abundance dynamics

A total of 10457 benthic macroinvertebrates individuals were sampled from all the 13 sampling stations throughout the 13 months of the study period. The highest relative abundance of this macroinvertebrates was recorded at the Furmuki stream where 3802 idividauals where identified which represent 36% of the total abundance. This was followed by the Ayabah stream with 2485 individuals representing 24% of the total abundance. As for the Mankon stream, it had 2207 individuals and 21% of the abundance while Mufueh stream had 1605 idividuals giving 15% of the total abundance and Mezam stream was the least with just 358 individuals and 4% of the abundance. The small abundance of organisms at Mezam stream could be explain by the huge water volume and high speed of the stream (figure 27)

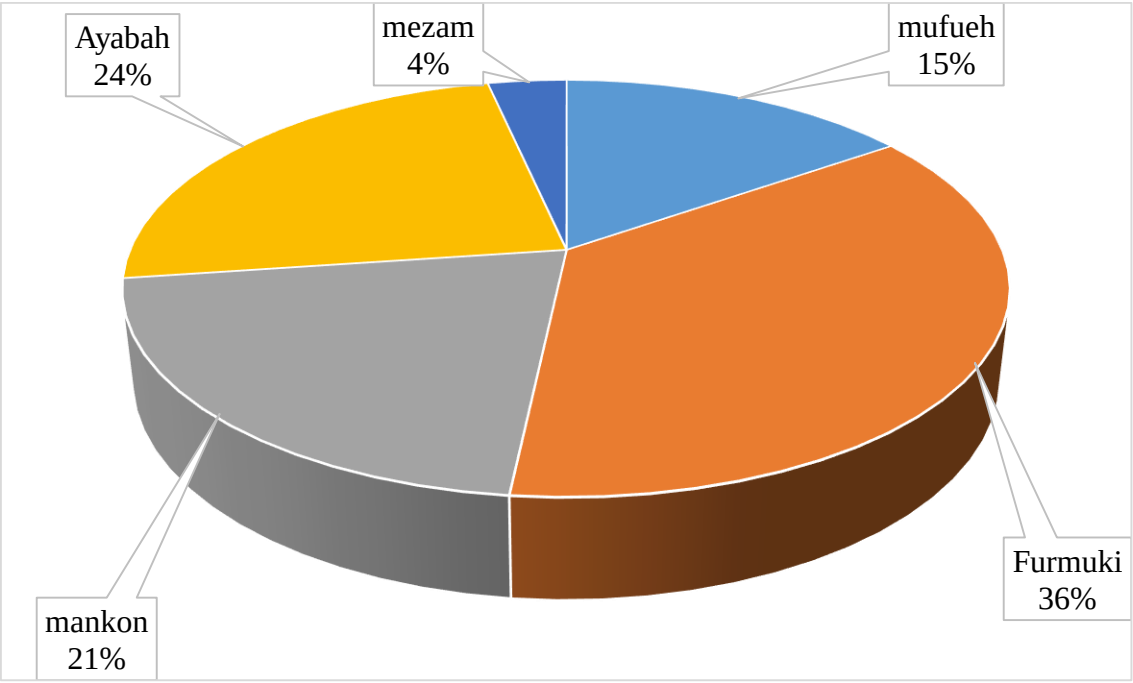


Figure 27: Relative abundance of benthic macroinvertebrtaes sampled in the streams studied in Bamenda.

Looking at the difference abundances in the sampling stations as on figure 28 below, it was noticed that, the station F2 registered the highest abundance. It was followed by Mk2, F1. The A1 and A2 stations have the same relative abundance and the smallest abundance was resisted at the station Mk1. The rest of the sampling stations were not too different from each other as concern their abundances.

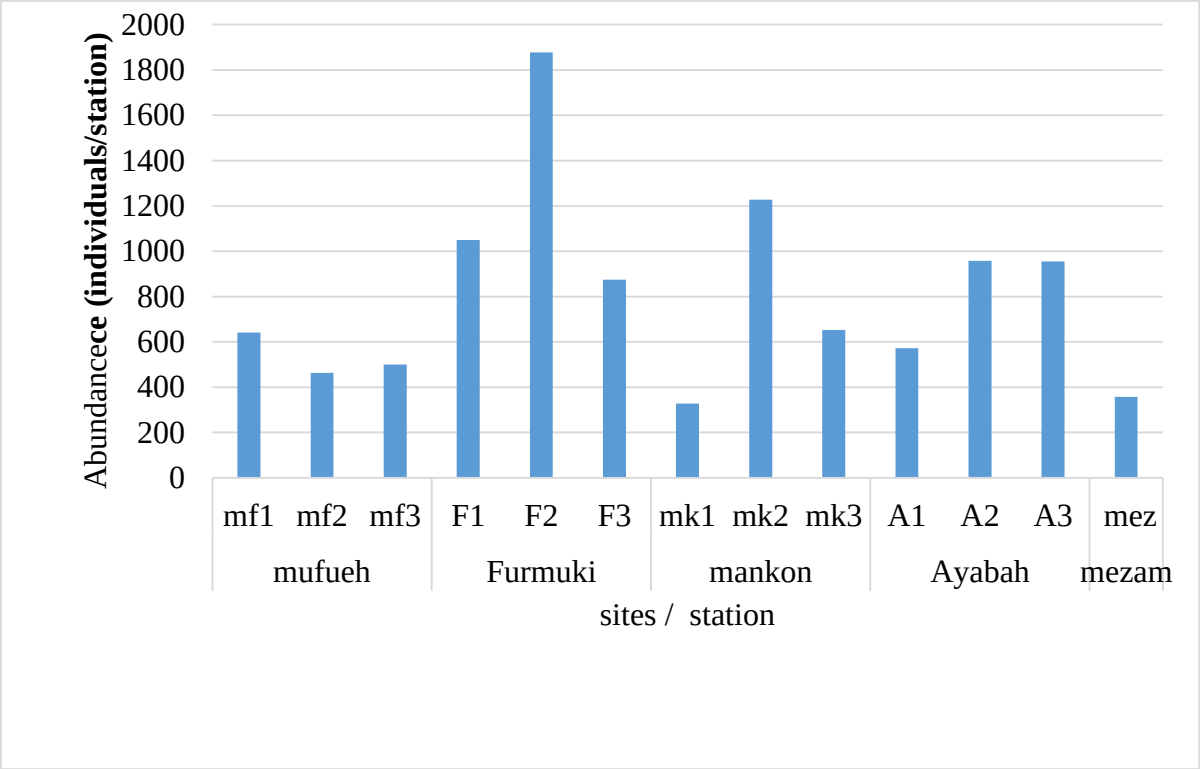


Figure 28: Abundance of benthic macroinvertebrtaes recorded in the different sampling stations studied in Bamenda.

III-1-2-3-2- Seasonal and spatial variation of the main benthic macroinvertebrate classes

Figure 29 below shows the spatial variation of relative abundance for the four classes of benthic macroinvertebrates identified in all the sampling points throughout the research period. The class of insects dominate the macro fauna at the stations mf1 (100%), Mf2, Mf3, F1 (98%), A1 (78%), A2 (82%), Mz (99%) and F3, Mk1, Mk2, Mk3 all had 75% of domnation over the other classes. Gastropods only co-dominated together with insects at the station F2 (48%). The Gastropods where present in 10 stations out of the 13 stations under consideration. At the ststions Mk2 and Mk3 the registered closed to 30% relative abundance. The class of Achaeta were present in 9 ststions and their highest relative abundance was registered at mk1 (15%), Mk3 and F3 (12%). As for the class of crustaceans, there were only present at A2 and Mz and had a relative abundance of less than 0.1%.

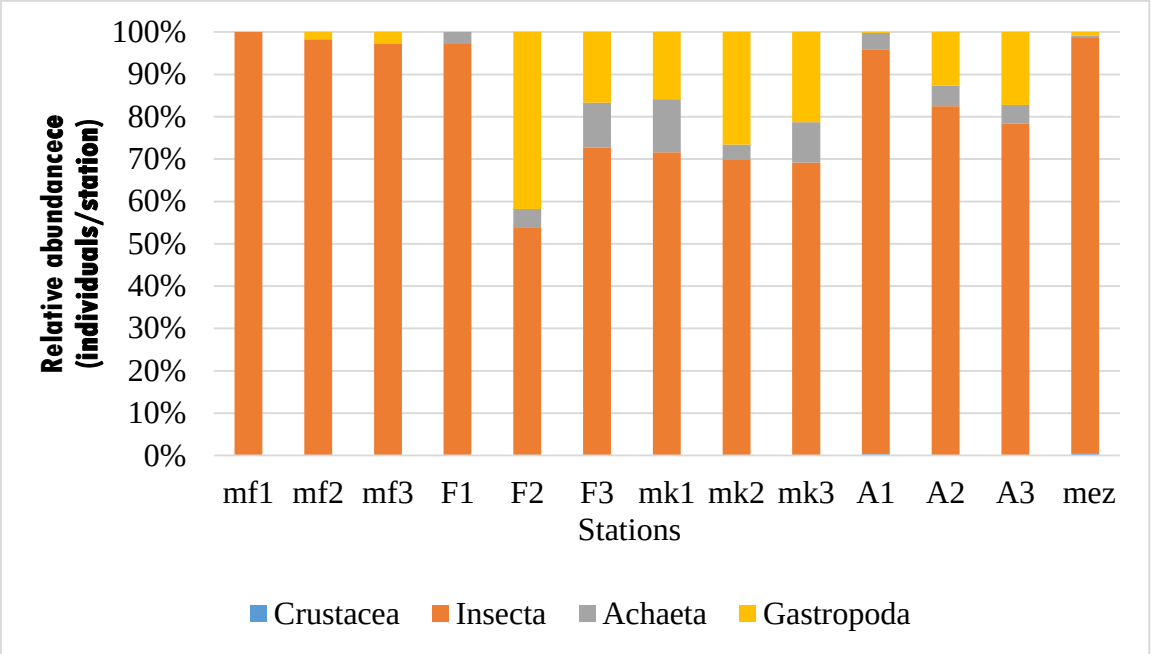
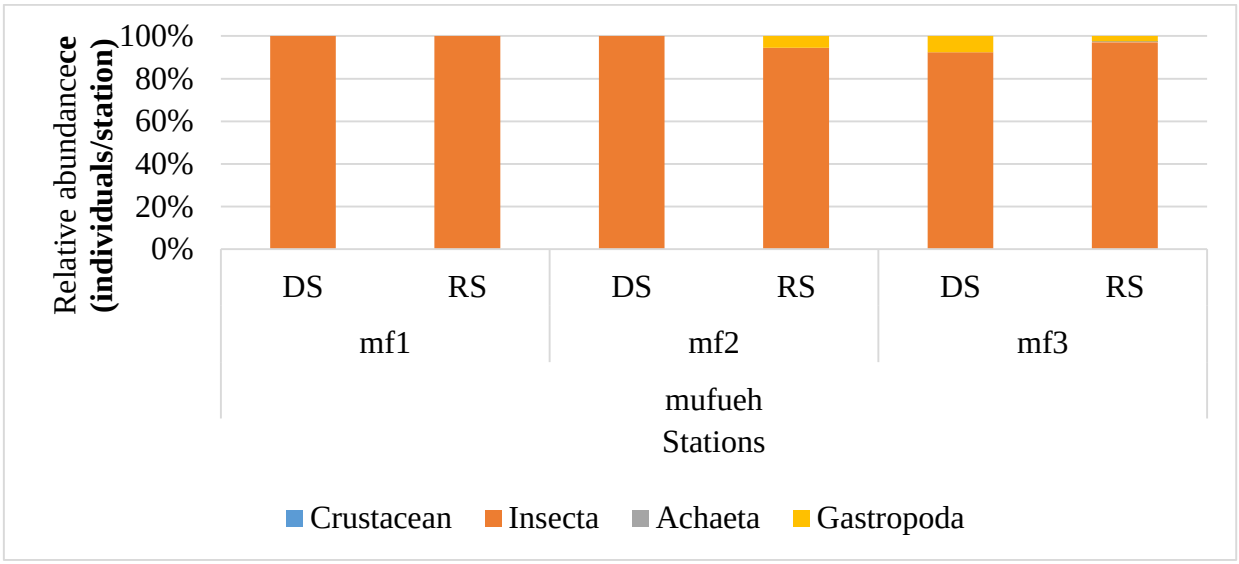
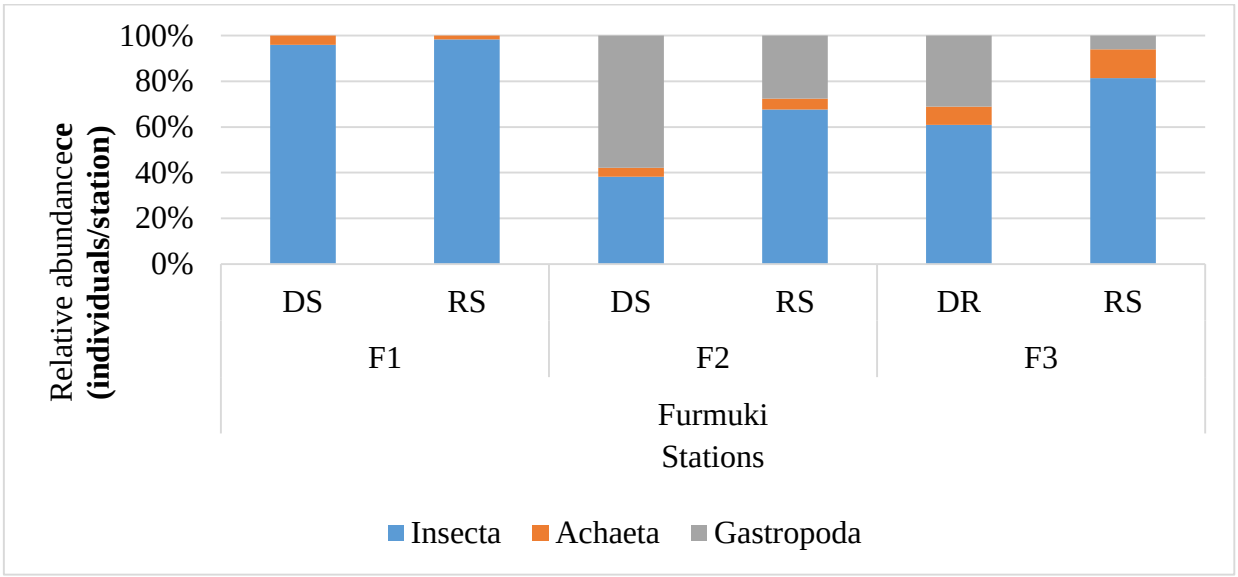
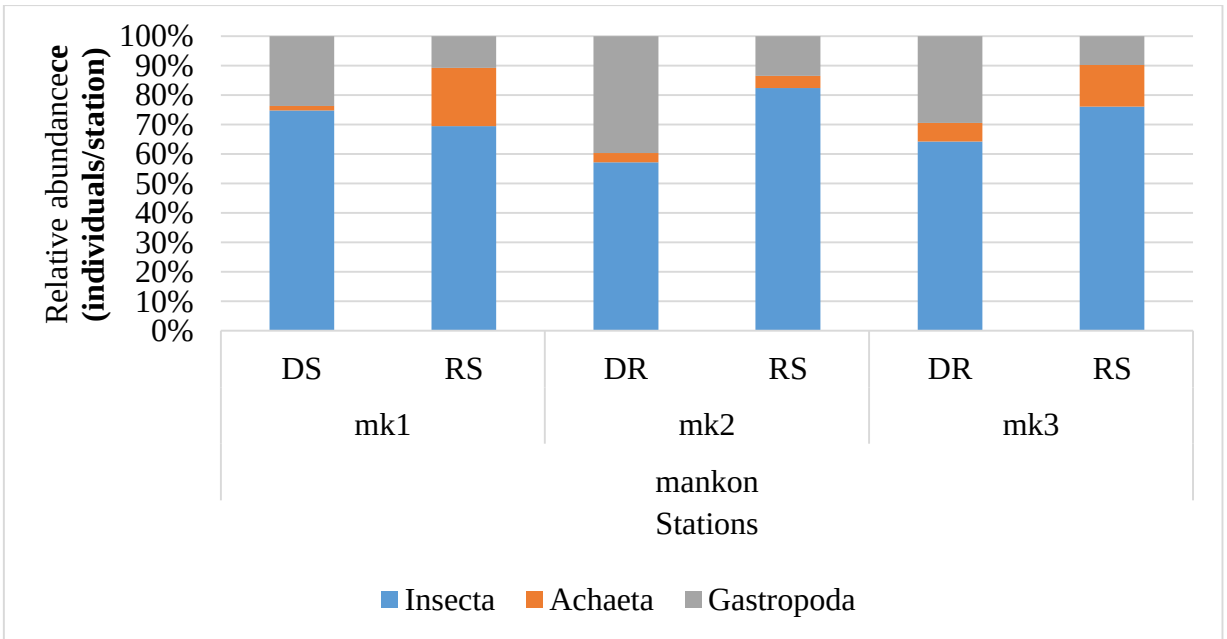


Figure 29: Spatial variation of the relative abundance of macroinvertebrate classes identified.

The seasonal distribution of the relative abundance for the 4 classes of macroinvertebrates sampled in the different streams and their stations are shown on figure 30. At the mufueh stream, insects dominated with a relative abundance of above 95% in all the stations and in all the two seasons of the year. Looking the Furmuki stream, insecst had a high relative abundance at F1 in both the rainy and dry seasons. At f2, gastropods dominated in the dry season with a relative abundance of 65% while insects dominated this same in the rainy season with a relative abundance of 60%. Further downstream at F3, though insects dominated the two seasons, Achaeta registered a relative abundance of over 15% in the rainy season. Similarly, at the mankon stream, insects were the highest with a relative abundance of 60% and above in all the stations and seasons. Gastropods registered 40, 25 and 21% respectively at the stations Mk2, Mk3 and Mk1 all in the dry season while Achaetae had just 20% at mk1 as its maximum relative abundance in the mankon stream. At the Ayabah and Mezam streams, insects recorded a relative abundance of above 98% in all most all the stations and seasons except in the dry season at the station A2 and A3 were it had 62 and 58% respectively. At this stations (A2 and A3), Gastropods had an abundance of 30 and 30% respectively.


Relative abundance (individuals/station)
100%
80%
60%
40%
20%
0%
DS
RS
DS
RS
DS
RS
mf1
mf2
mf3
mufueh
Stations
Crustacean
Insecta
Achaeta
Gastropoda


Relative abundance (individuals/station)
100%
80%
60%
40%
20%
0%
DS
RS
DS
RS
DR
RS
F1
F2
F3
Furmuki
Stations
Insecta
Achaeta
Gastropoda


Relative abundance (individuals/station)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
DS
RS
DR
RS
DR
RS
mk1
mk2
mk3
mankon
Stations
Insecta
Achaeta
Gastropoda

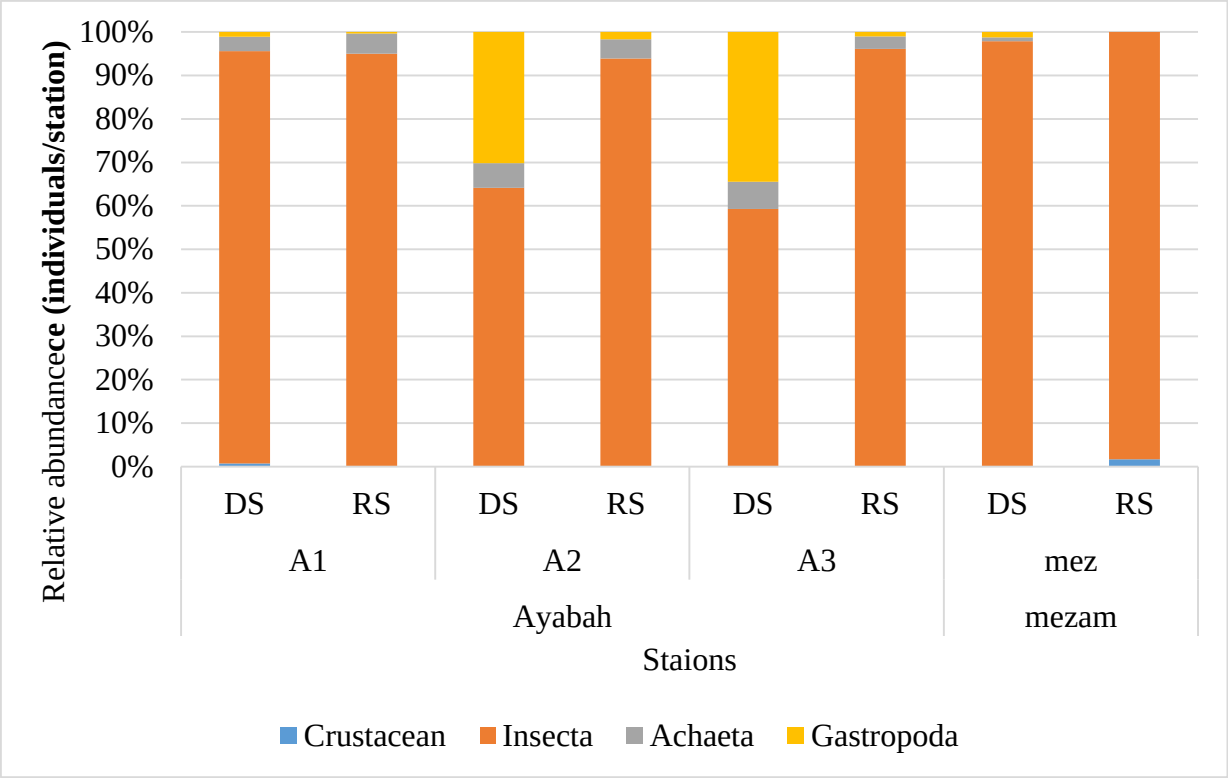


Figure 30: Seasonal variations of relative abundance for the classes of macro invertebrates identified in each sampling station. DR = Dry season and RS = Rainy season.

III-1-2-3-3- Seasonal and spatial variation of the main benthic macro invertebrate orders

The main macroinvertebrates fauna talking of here, are those which in each station represent at least 5% of the entire population of organisms at this station (figure 31)

Generally at the Mf1, hemeptera the highest relative abundant of 25% it was followed by the diptera and coleopteran with 22% abundant. At Mf2 and Mf3, odonata were the most represented with a relative abundant of 42 and 51 % respectively. Looking at the other station, it was notice that each order dominated at a particular time. The stations F1, Mk2, A1 and A2 were dominated by the dipteran, showing a relative abundant of 60, 41, 55 and 64% respectively. At the stations F3, Mk1, Mk3 and Mz it was odonata that were the most represented respectively with an abundant of 29, 35, 27 and 60%. The order of bassomatophora dominated at F2, showing an abundant of 41%.

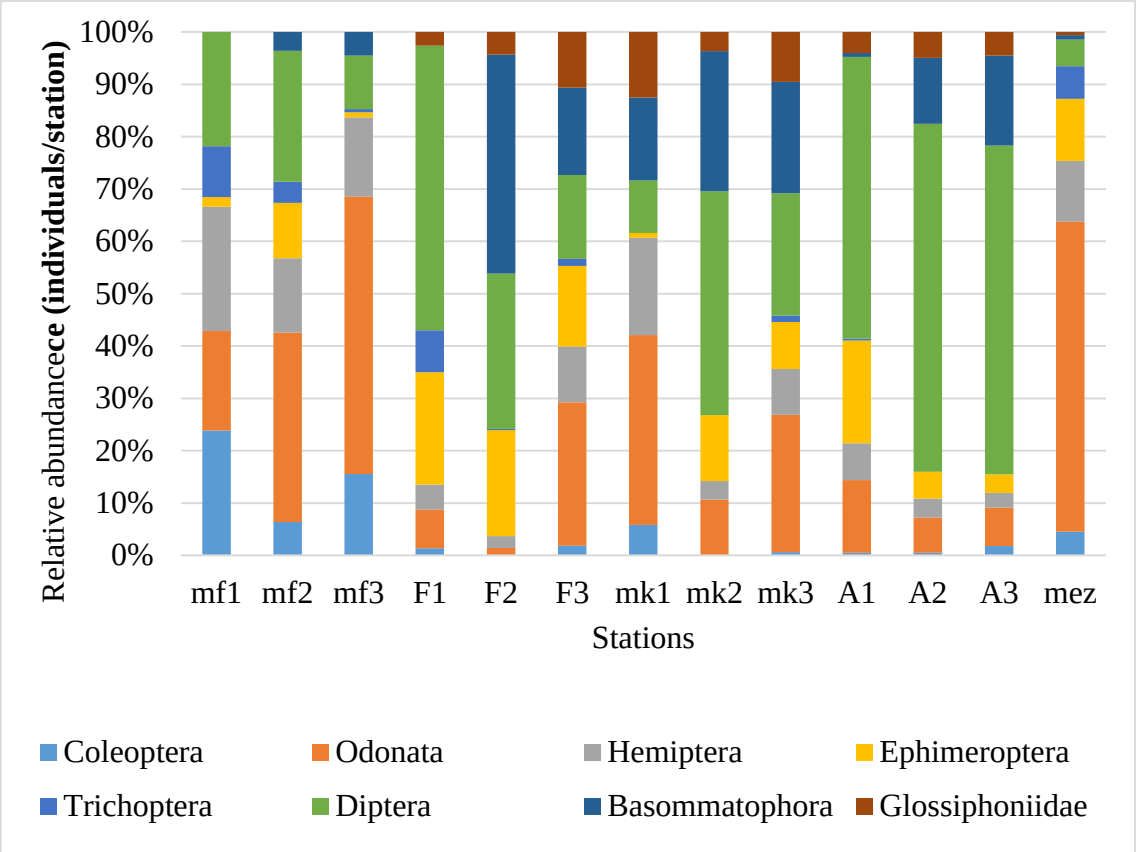


Figure 31: Spatial variation of relative abundance of the main benthic macroinvertebrate orders identified in each station.

Using a cluster heat diagram (figure 32) to visualize the distribution of this main orders in the different streams of Bamenda, it is seen that, Diptera were excessively abundant and over shadow the others in the Ayabah stream. This same group was fairly abundant in mankon and furmuki streams and its abundance decreased in the mufurh and mezam streams. The order Basomatophora had a high relative abundance in the Furmuki, mankon and Ayabah streams and this abundant in the mezam and mufueh streams while Odonata dominated in the mufueh and mankon streams and had a low relative abundant in the ayabah, Mankon and Mezam, as for the Ephimeroptera, Trichoptera, Hemiptera and Coleoptera orders, where only high in relative abundance at mufueh and Furmuki streams. This groups were fairly constantin the other streams of the town.

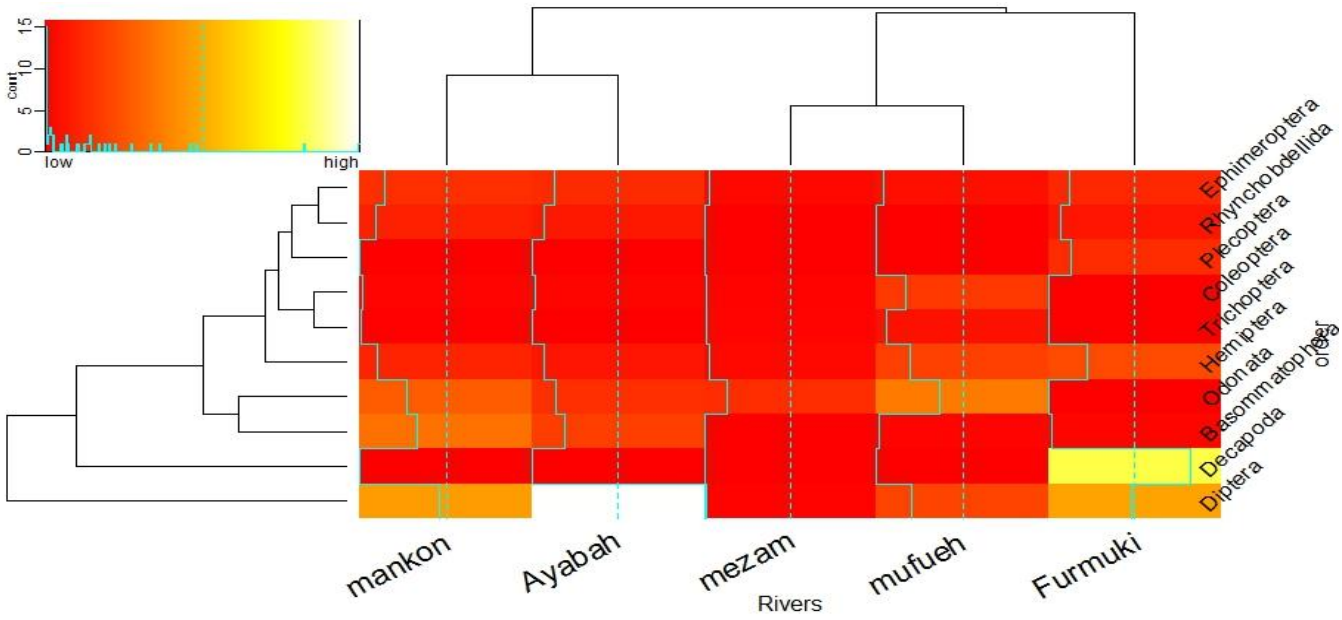


Figure 32: Heat diagram showing the distribution of the various orders in the different streams in Bamenda.

The seasonal distribution of the relative abundance of the main orders (those that represent at least 5% of total abundance in each sampling station) of benthic macroinvertebrates sampled from the 13 points of the streams under consideration and presented on figure 33 below.

The mf1 station was dominated by dipterans (30%) which was followed by coleopteran in the dry season. In the rainy season, hemiptera was the most represented (24%) and coleopteran was still came second. At Mf2 and Mf2, the population was dominated by odonata (over 50%) in all the two seasons of the year.

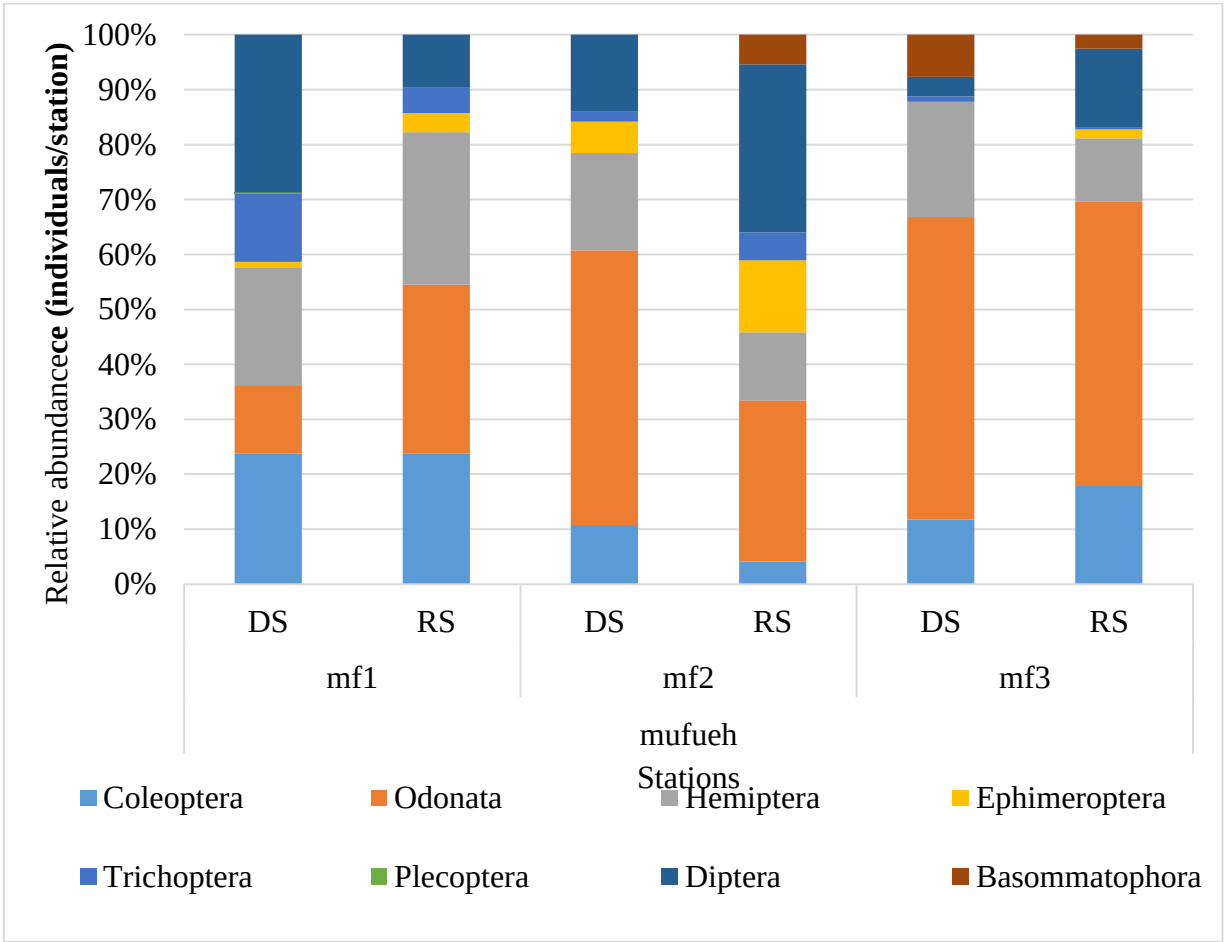
Down at the Furmuki stream, the F1 was dominated in the dry and rainy season by diptera (65 and 45% respectively) and was followed by ephimeroptera with 31% relative abundance. In the second station of this stream, a clear domination of bassomatophora and diptera at 55 and 30% respectively was observed in the dry season while there was an equal representation of diptera, bassomatophora and ephimeroptera (27%). At the third station F3, bassomatophora still had a high relative abundance in the dry season (30%) and was followed by odonata (20%). In the rainy season a co-dominance of 3 groups (Odonata, Ephimeroptera and Diptera) was witness at a 20 % relative abundance.

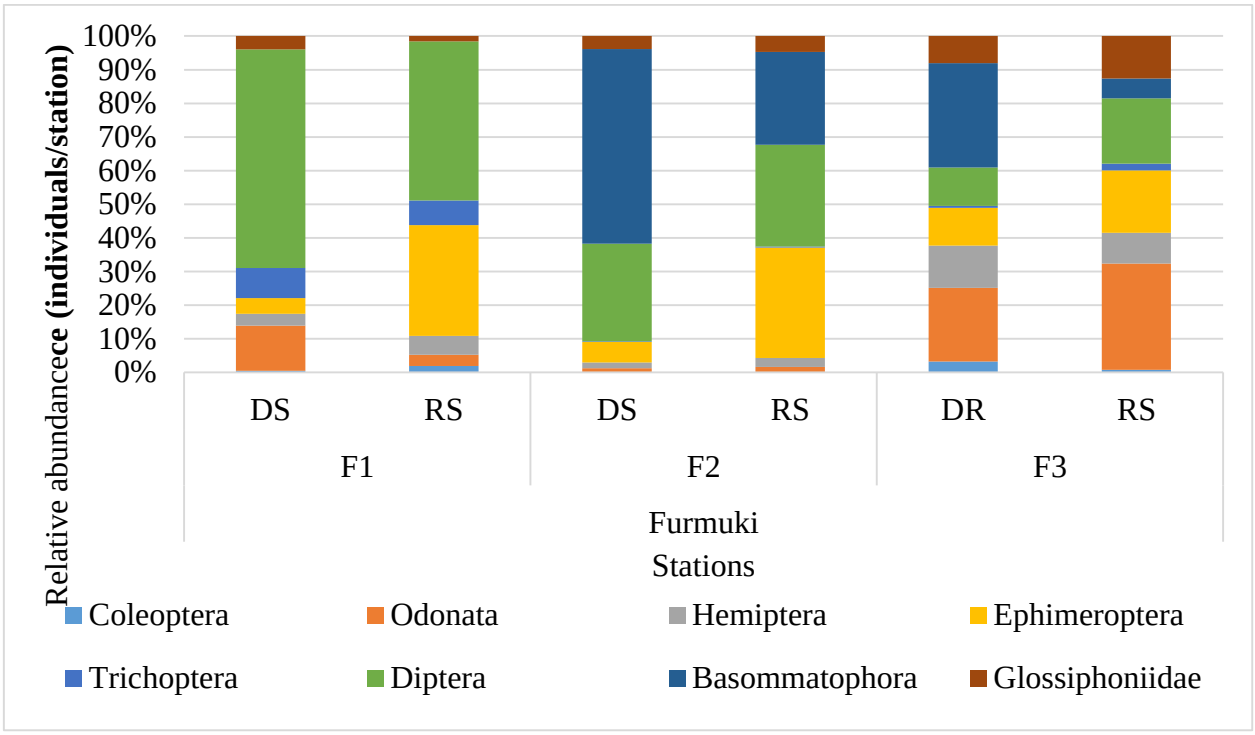
In the Mankon stream Mk1, odonata had a high relative abundance in both the dry and rainy seasons (35 and 27% respectively) this was followed by Bassomatophora (20%) in the dry season and Glossihponiidae (20%) in the rainy season. At Mk2, Bassomatophora (38%)

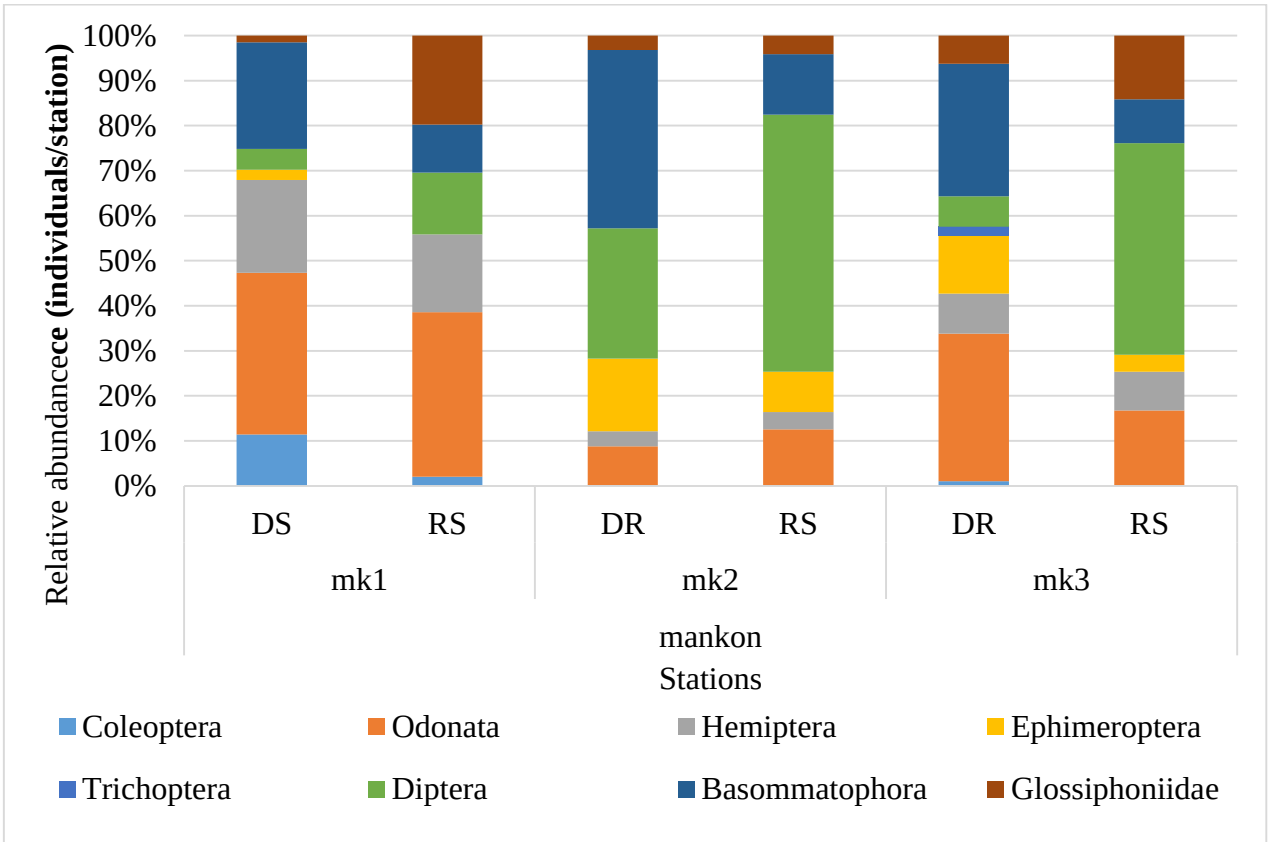
and Diptera (27%) dominated in the dry season while Diptera (54%) and Bassomatophora had a high relative abundance in the rainy season. The relative abundance at Mk3 was dominated in the dry season by odonata (30%) and Bassomatophora (27%) while diptera had a high relative abundance in the rainy season.

At the Ayabah stream, the diptera had high relative abundance in all the three stations (A1, A2 and A3) of above 50%, especially in the rainy season which went up to 90%. This was followed by bassomatophora with 30% relative abundance in A2 and A3 while A1, odanata and ephimeroptera had 21 and 19% relative abundance in the dry and rainy seasons respectively.

Further down at the Mezam River, the population was dominated by odonata (52%) in all the seasons and was followed by hemeptera 11% relative abundance and Ephemeroptera then followed with 14% abundance in the dry season.




100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Relative abundancece (individuals/station)
DS
RS
DS
RS
DR
RS
F1
F2
F3
Furmuki
Stations
Coleoptera
Odonata
Hemiptera
Ephimeroptera
Trichoptera
Diptera
Basommatophora
Glossiphoniidae


100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Relative abundancece (individuals/station)
DS
RS
DR
RS
DR
RS
mk1
mk2
mk3
mankon
Stations
Coleoptera
Odonata
Hemiptera
Ephimeroptera
Trichoptera
Diptera
Basommatophora
Glossiphoniidae

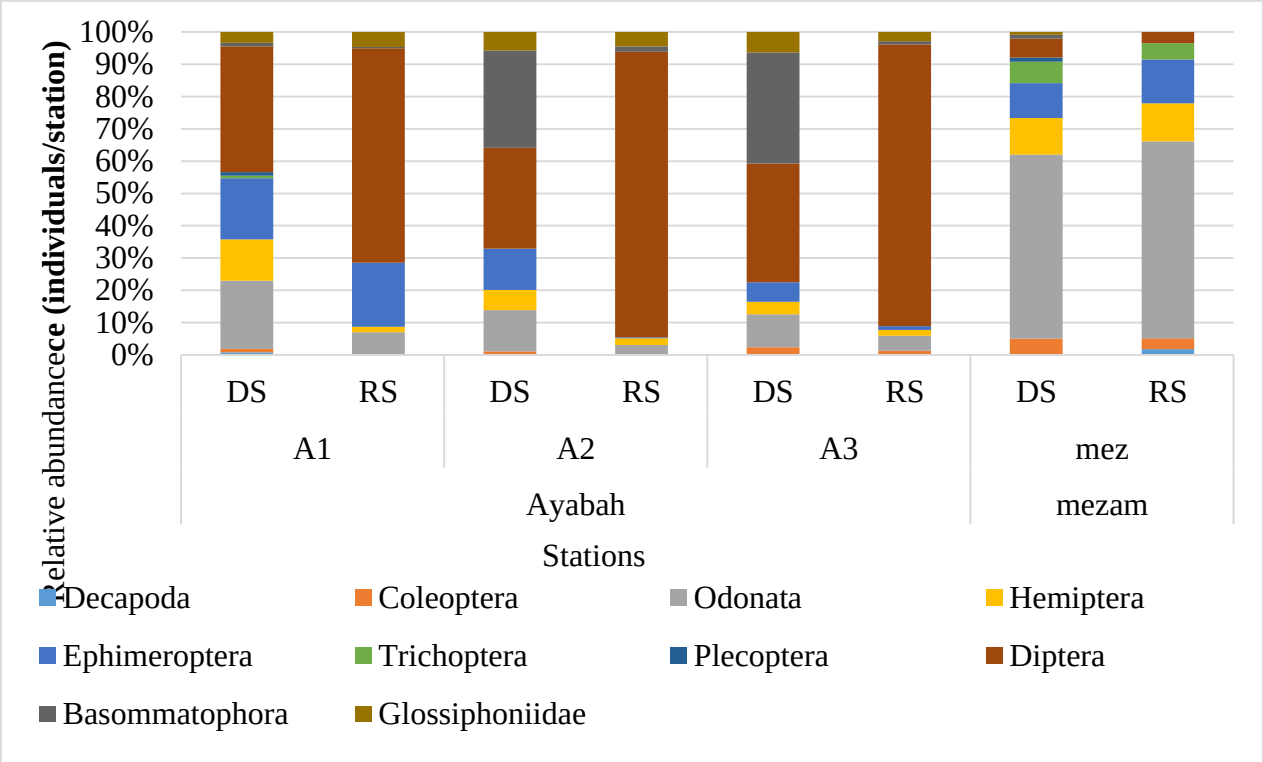


Figure 33: Seasonal variation of relative abundance for the main orders of macro invertebrates identified in each sampling station: DR = dry season and RS = rainy season

III-1-2-3-4- Seasonal and spatial variation of the main benthic macro invertebrate Families

Figure 34 below shows the special variation of relative abundance of the main macro invertebrates families (those representing at least 5% of the total abundance in each sampling station) recorded in all the sampling points. A total of 11 families in which are 9 insects (Gyrinidae, Dytiscidae, Libellulidae, Calopterygidae, Gerridae, Belostomatidae Caenidae, Baetidae and Chironomidae), 1 Achaeta (Glosssiphoniidae) and 1 Gastropoda (Physidae) were analyzed. The families Gyrinidae, Libellulidae and chironomidae were more represented with a relative abundance of 21%. The gyrinidae were only significant at this station and were almost absent in the other 12 sampling stations. The Mf2 was dominated by Chironomidae (30%) and Calopterygidae (21%) while in the Mf3 it was Libellulidae that had the highest relative abundance (60%). At the F1, F2 and F3 stations were respectively dominated by chironomidae (51%), physidae (48%), calopterygidae, chironomidae and physidae (20%). Moving over to the Mankon stream, Mk1, Mk2 and Mk3 had a high relative abundance of libelludae (23%), chironomidae (40%) and physidae (27%) respectively. Chironomidae recorded a relative abundance of above 50% in all the tree sampling stations of the Ayabah

stream while the Mezam was largely Calopterygidae (40%) and Libellulidae (21%) all of the Odonata.

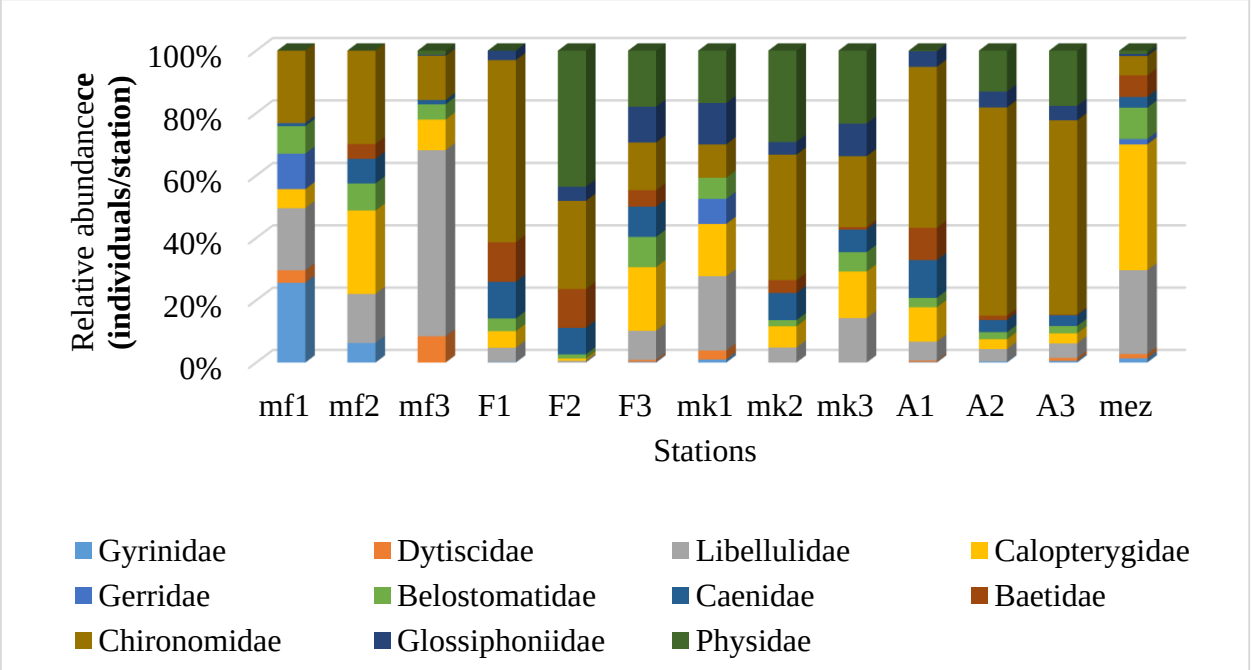


Figure 34: Spatial variation of the relative abundance for the main benthic macro invertebrate's families recorded in this study

The seasonal variations of the main macro invertebrate's families (those representing at least 5% of the total abundance in each sampling station) are illustrated on figure 35 below. The distribution of the different families in the stations is influence by the seasons, at the station mf1, chironomidae and gyrinidae had a high relative abundance (31%) in the dry season while libelludae dominated in the rainy season (24%). At Mf2 and Mf3, all the seasond were dominated by libelludae (over 40%). Down at the Furmuki stream, the first station F1 was dorminated by chironomidae (50%) in all the seasons while physidae had the highest relative abundance at F2 and F3 in all the seasons. In the Mk1, Libellulidae were the most repreasened (33%) in the two seasons and physidae (47%) and chironomidae (51%) dominated in Mk2 and Mk3 in the dry and rainy seasons respectively. The Ayabah stream showed no change in all the seasons as chironomidae were the most abundant in all the 3 stations across all the seasons while Odonata dominated in all seasons at Mezam River. Here, Libellulidae (32%) and Calopterygidae (50%) were the most represented at the Mz station in the dry and rainy seasons respectively

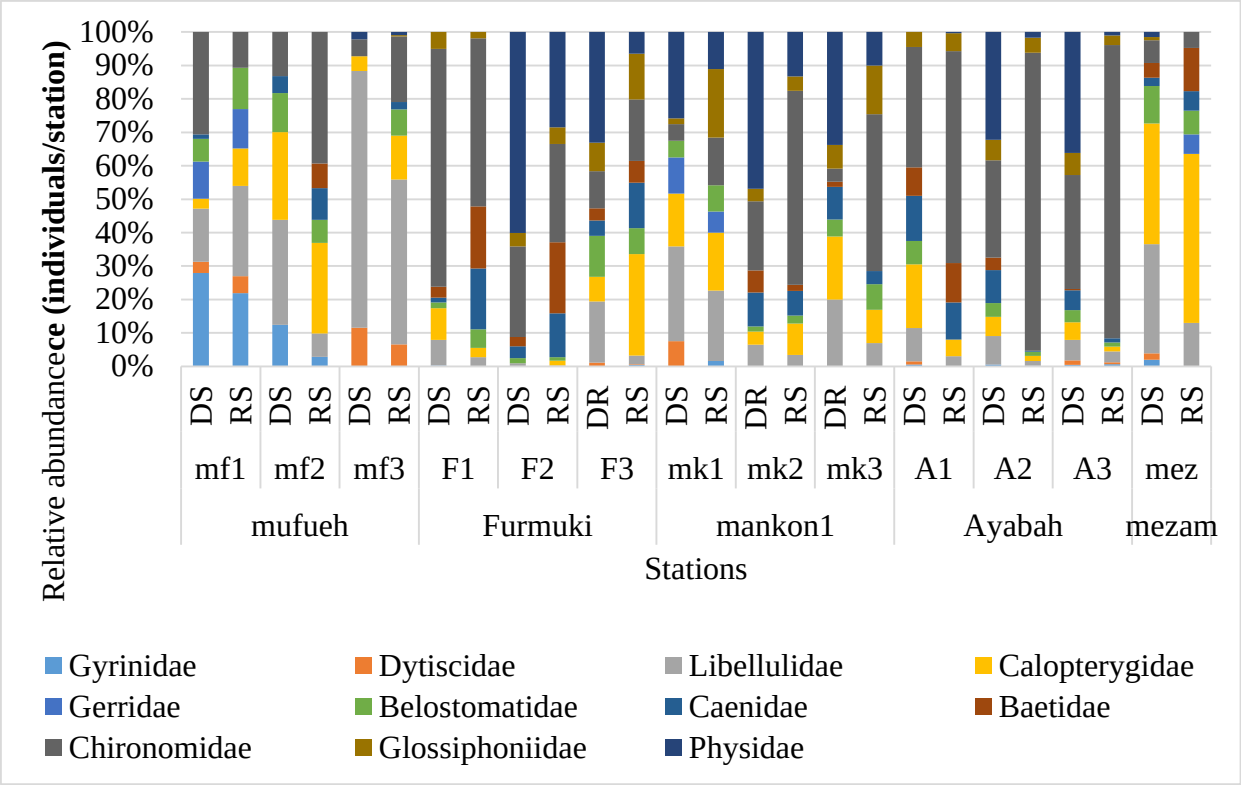


Figure 35: Seasonal variations of relative abundance for the main macro invertebrates families recorded in all the sampling stations during the study period; DS = dry season and RS = rainy season.

III-1-2-3-4 Correlations between biotic metrics and environmental variables

The Spearman correlation values between the biotic and abiotic variables were caculated. The total abundance of the benthic macrofauna is positively and significantly correlated with the substrates and negatively correlated with the depth. The high values of taxonomic richness, Shannon diversity index (H '), EPT, EPTD, EPTC and EPTH indices are positively and significantly favored by high oxygenation and the low mineralization of the waters, the moderate values of IPO, which translates a zero to moderate organic pollution, the importance of the canopy and the sandy substrate. On the other hand, the high values of the other physicochemical parameters influence these descriptors significantly and negatively. In addition, the relative abundances of Diptera and especially Chironomidae are, on one hand, negatively correlated with dissolved oxygen, IPO, water depth and on the other hand, positively associated with other physicochemical parameters. With respect to trophic and respiratory functional groups, good water oxygenation, high IPO values and sandy substrate are positively correlated with increased taxonomic richness of predator and macroinvertebrates, and then that of taxa breathing through their gills and their plastron.

Overall, the high values of the other physicochemical parameters negatively influence these different functional groups of aquatic macroinvertebrates.

III-1-2-4- DENSITY VARIATIONS OF SOME MACRO-INVERTEBRATES TAXA

The aim of this section is to understand the spatial and seasonal variations in density of the different taxa which dominated the macro invertebrate community during the research period.

III-1-2-4-1 spatial and seasonal variations of chirinimidae community structure

The chironomidae family was most abundant in all the 13 sampling stations and it also had the highest number of species in the different stations during the study period.

III-1-2-4-1-1 Egg density and variation

Egg masses were collected together with other macroinvertebrates on the surface of water or attached to the aquatic vegetation. Egg masses were only collected in 7 stations out of the 13 sampling stations. The egg masses were most abundant in F2 (28%), F2 (19%), F3 and Mk3 both had (13%) relative abundance while the stations A3, A2 and Mk2 showed 11, 10 and 6% relative abundance respectively (Figure 36). On the seasonal bases, the egg masses were most abundant in the dry season in all the stations then the rainy season. This could be due to the high water current in the rainy season which easily wash away the egg masses.

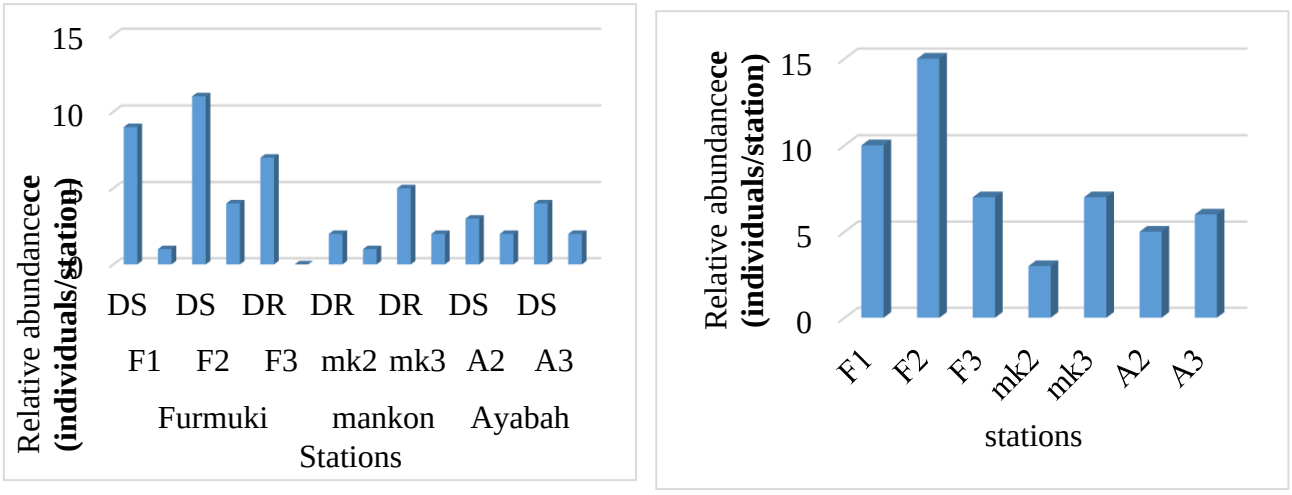


Figure 36: Spatial and seasonal variations of relative abundance for chironomid egg masses in the various stations DS = dry season and RS = rainy season.

The egg masses gelatinous in nature (figure 37A) an oval or ovoid shape with a characteristic brown colour (figure 37B). Each egg mass hatched in to larvulae (figure 37C) few days after collection. The larvulae remains inside the gelatinous egg mass as the mass gradually disintegrate.

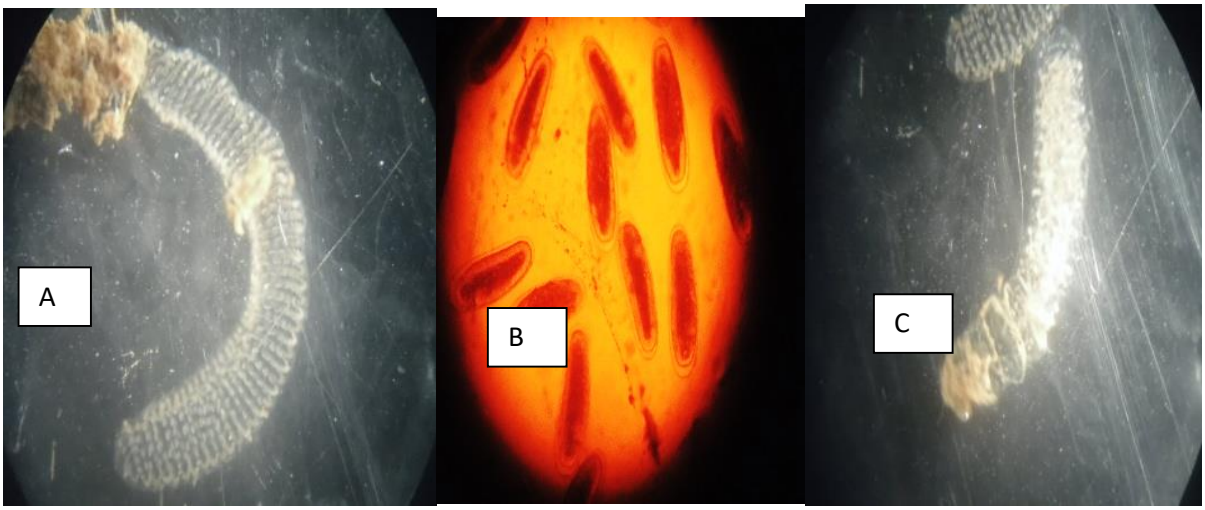


Figure 37: Morphology of: A = Egg mass, B and C = Larvulae.

III-1-2-4-1-2 Relative Abundance of chironomidae general

A total 2443 chironomidae individuals were collected as summarized on Table XI. These organisms were identified to belong to 8 general which was largely dominated by the *Chironomus* (78%), *Radotanypus* (10%), *Polypedilum* (5%), *Brundiniella* (2%), *Procladius* (2%), *Dicrotendipes* (1%), *Micropsectra* (1%), and *Cantopelopia* (1%). The genus *Tanypus*, *Zalutschia* and *Eukiefferiella* represented approximately zero percent since the number of individuals collected (figure 38)

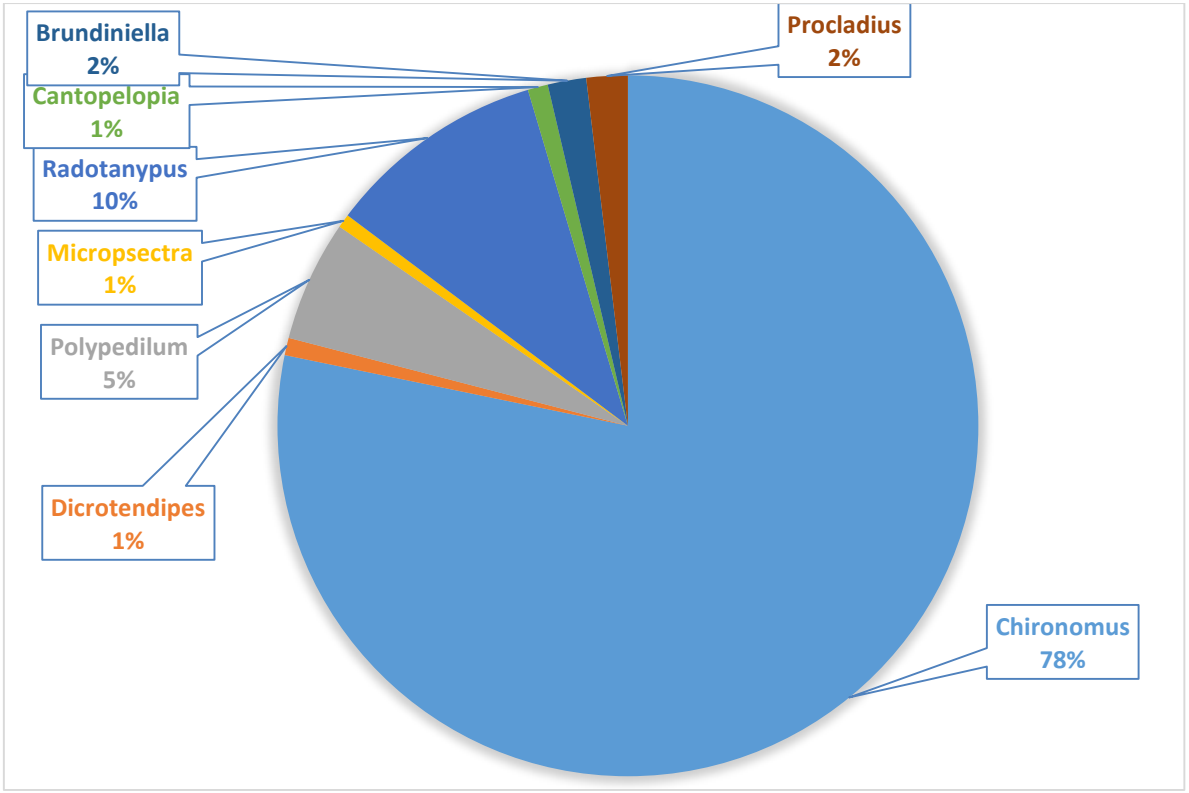


Figure 24: Relative abundance of chironomid general identified

III-1-2-4-1-3 Relative Abundance of chironomidae species per sampling station

A total of 18 chironomid taxa comprised 2443 individuals/m² were found in River mezam and its affluent during the studied period (Table XI). At the mf1, the population was dominated by *Polypedilum laetum* (19%) and *polypedilum illinoeuse* (16%). Most of the chironomus (*C. plumosus* and *C. staegeris*) which dominated the other sampling stations were totally absent here. The station mf3 was so particular in the, it was dorminated by the species *Catopilopia gesta*, this species was only seen in the mufueh stream. All the other stations of the streams Formuki, Mankon and Ayabah except for Mezam, had a high relative abundance of the chironomus (especially *C. riparus, C. crassicaudatus. C. stigmaterus*) which are believed to flourish in organic rich nutrient environments (Freimuth and Bass, 1994). The mezam stream was largely dominated by the *chironomus staegeris* (15%). This station, besides having all the other species seen in other stations, it also had the *Zalutschia* sp. Which was absent in other streams (Figure 39)

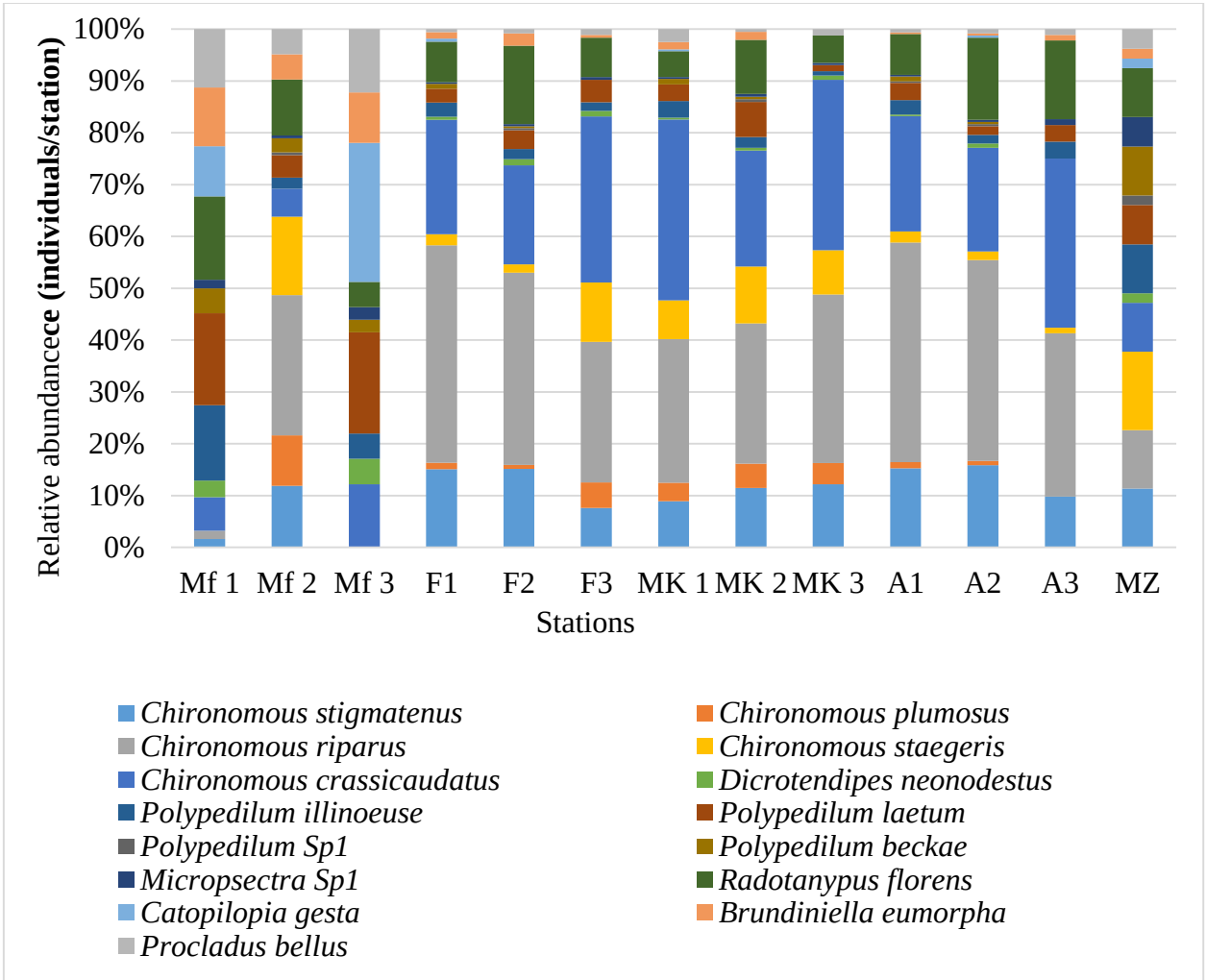


Figure 25: relative abundance of the different chironomids species in the sampling stations

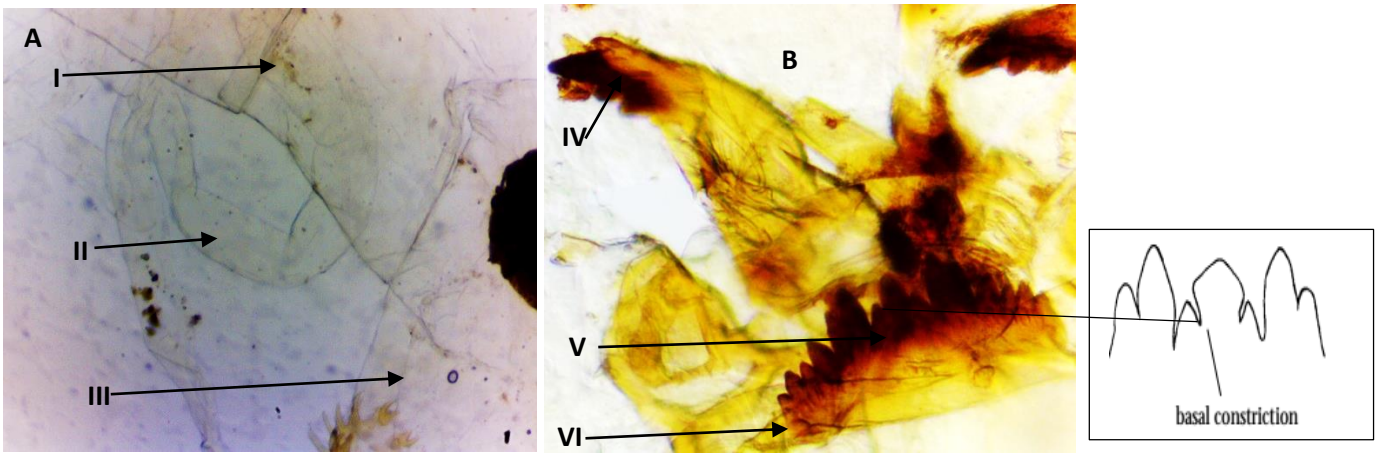
This Larvae belong to 3 sub families of the chironomidae (table XI). The subfamilies Chironominae and Tanypodinae were collected at all sampling occasions while the Orthocladiinae were rare. Among the Chironominae are represented by *Chironomus stigmaterus, Chironomus plumosus, Chironomus riparus, Chironomus staegeris, Chironomus crassicaudatus, Polypedilum illinoeuse, Polypedilum laetum, Polypedilum beckae, Dicrotendipes neonodestus and Micropsectra sp.* While the Tanypodinae were represented by *Radotanypus florens, Cantopelopia gesta, Brundiniella eumorpha, Procladius bellus and Tanypus* sp. And the Orthocladiinae by *Zalutschia* sp. and *Eukiefferiella* sp.

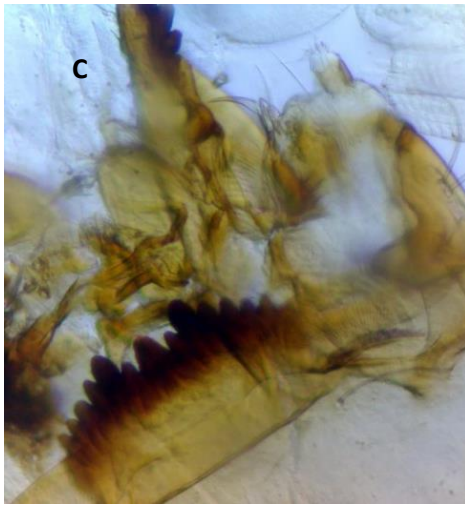
Table XI: Summary of the general and species of Chironomidea collected during the study.

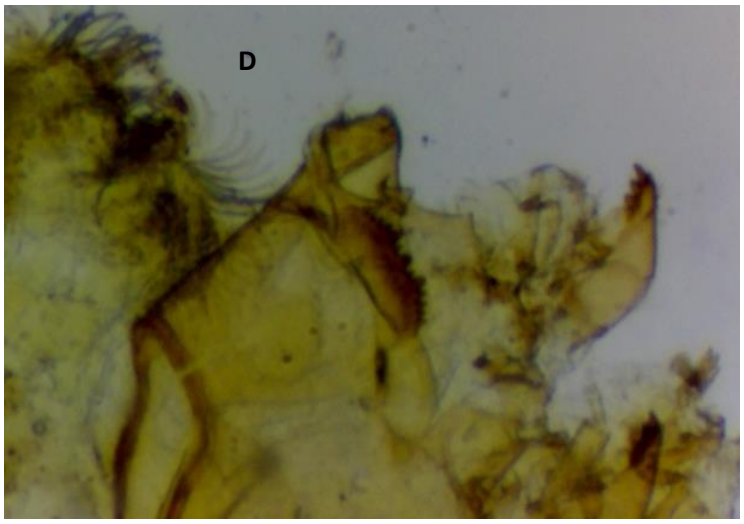
SUBFAMILY	GENUS	SPECIES	Number of individuals identified
Chironominea	Chironomus	*Chironomus stigmatenus*	305
		Chironomus plumosus	16
		Chironomus riparus	810
		Chironomus. staegeris	143
		Chironomus crassicaudatus	577
	Dicrotendipes	*Dicrotendipes neonodestus*	19
	Polypedilum	*Polypedilum illinoeuse*	68
		Polypedilum laetum	100
		Polypedilum sp.	6
		Polypedilum beckae	26
	Micropsectra	*Micropsectra* sp.	15
Tanypodinae	Radotanypus	*Radotanypus florens*	240
	Cantopelopia	*Cantopelopia gesta*	22
	Brundiniella	*Brundiniella eumorpha*	42
	Procladius	*Procladius bellus*	45
	Tanypus	*Tanypus* sp.	2
Orthocladiinae	Eukiefferiella	*Eukiefferiella* sp.	*3*
	Zalutschia	*Zalutschia* sp.	4
Total	11	*18*	2443

III-1-2-4-2-Taxonimic features in mouth parts of identified species.

This section deals with the morphological characteristics of larvae identified based on their mouth parts structure. The nomenclature is done following the recommendations of Epler (2001). The genus Chironomus: Larvae are distinguished by the presence of a frontoclypeal apotome and one medial labral sclerite; a single multi-toothed comb; mandible; 0-1 pairs of caudolateral tubules and 0, 1 or 2 pairs of ventral tubules figure 40A. Larvae are usually found in sediments, and can occur in highly polluted conditions. Larvae of *C. riparius* and *C. stigmaterus* are most often associated with high nutrient/low oxygen conditions. Five species were identified in this genus (figure 40A). *C. stigmatenus*: Anteromedian margin of ventromental plate smooth, margin of plate may be faintly crenulate. Central tooth of mentum usually basally constricted figure 40B. *C. plumosus*: Anteromedial margin of ventromental plate with fineteeth, Mandible with 3 dark inner teeth figure 40C. *C. riparus*: Mandible with 3 dark inner teeth; 2 pairs of ventral tubules present figure 40D. *C. staegeris*: Mandible with 2 dark inner teet, Inner apex of ventromental plate directed medially figure 40E. *C. crassicaudatus*: Inner apex of ventromental plate directed caudad (figure 40F).







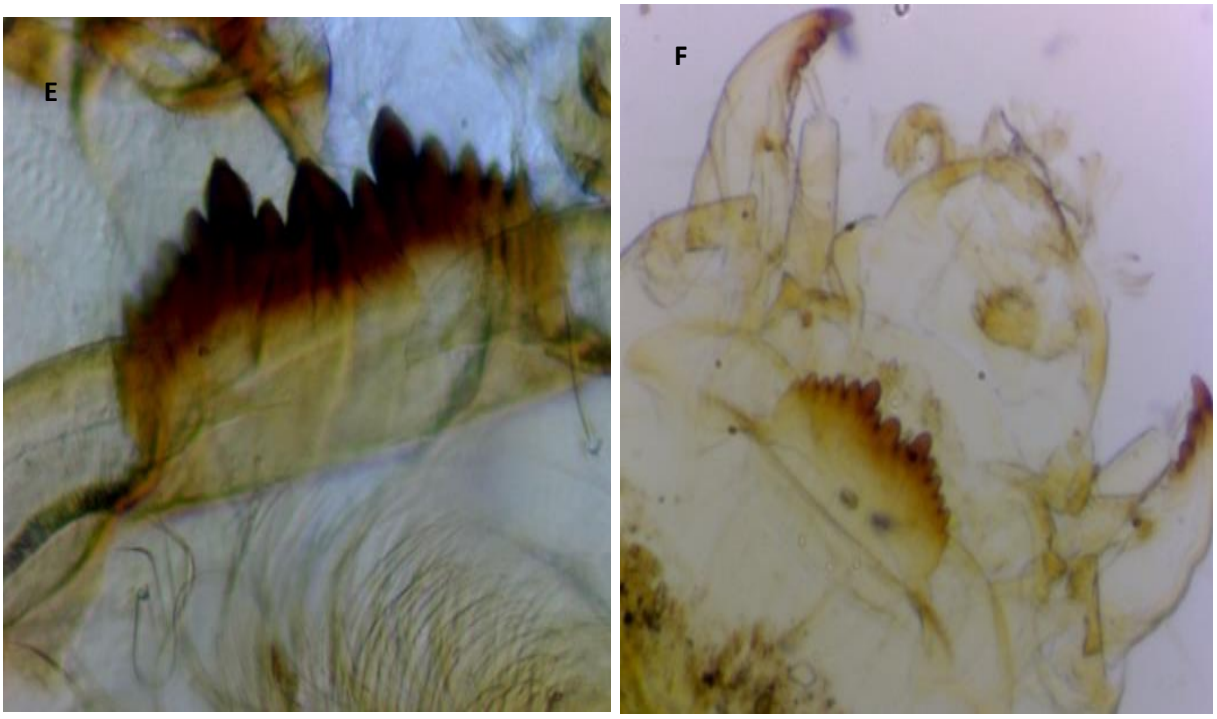


Figure 26: Taxonomic features on the mouth parts and abdoments of chironomus; A; posterior segments of chironomus, AI; 8th and 9th abdominal segments, AII; ventral tubules, AIII; posterior proleg, B; mouth parts of C. stigmatenus, BIV; mandibles with a dorsal tooth

Genus Dicrotendipes: mentum convex with an odd number of teeth; ventromental plate width less than width of mentum; and mentum tooth and first lateral teeth pointed and enlarged. As for *D. neomodestus,* it has a postmentum length < 250 µm; mentum width < 150 µm; pectin mandibularis with 12 or fewer figure 41A.

Genus Polypedilum: The distinctive mentum, with median and second lateral teeth longer than first lateral teeth, will distinguish most members of the genus. Others have 4 median teeth of the mentum not separated from the rest of mentum by a distinct line. *P. illinoeuse*: Width of 1 ventromental plate 2.5X or less the distance between the plates. Figure 41B. *P. laetum:* Mentum with central 4 teeth higher than remaining lateral teeth; mentum with 14 teeth or 16 teeth figure 41C. *P. beckae:* Mentum with 16 teeth, with 6 central teeth slightly higher or all teeth subequa figure 41D.

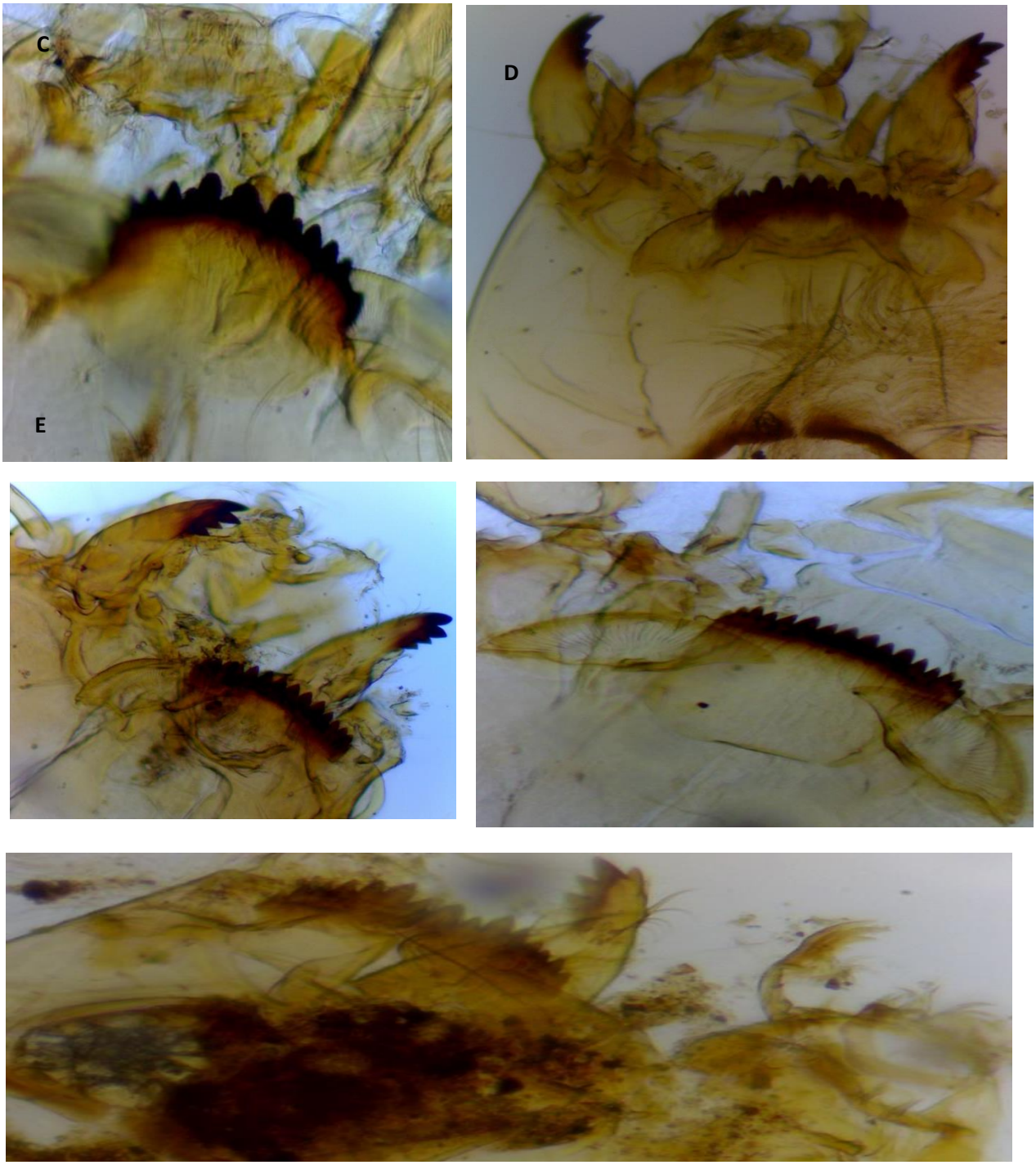


Figure 27: Teeth disposition in some chironomids. A) D. neomodestus, B) P. illinoeuse, C) P. laetum, D) P. beckae and E) P. sp.

Genus Radotanypus: Distinguished by the rotund head capsule; ring organ near middle of maxillary palp; ligula with inner teeth directed forward; dorsomental plates with 5 large teeth, a bifid innermost tooth. *R. florens* with a yellowish-brown head capsule, without dark marking. Ligula short and squat; paraligula with 2 or fewer lateral branches; small claws of posterior parapod with ovoid base figure 42A.

Genus Procladius: *Procladius* larvae are distinguished by the rotund head capsule; well-developed dorsomental tooth plates; mandible with large blunt basal tooth; black/dark brown five toothed ligula figure 42B

Genus Tanypus: *Tanypus* larvae may be distinguished by the stout mandible (the apical tooth appears small in relation to the remainder of the mandible); well developed, transverse dorsomental teeth figure 42C.

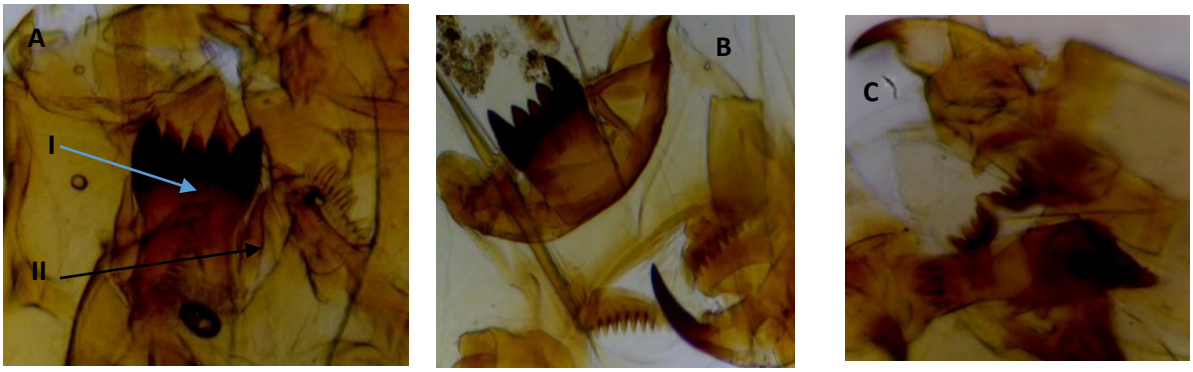


Figure 28: Chironomid mouth parts: A; R. florens, AI; Ligula, AII; Paraligula B; Procladius sp. C; Tanypus sp.

Genus Eukiefferiella: The simple, vestigial ventromental plates; inner margin of mandible with spines/serrations; 4 or 5 segmented antennae and body with simple setae figure 43A. Genus Zalutschia: mentum with first lateral tooth reduced; well-developed ventromental plates with weak beard; and mandible with 3 inner teeth distinguish this genus figure 43B.

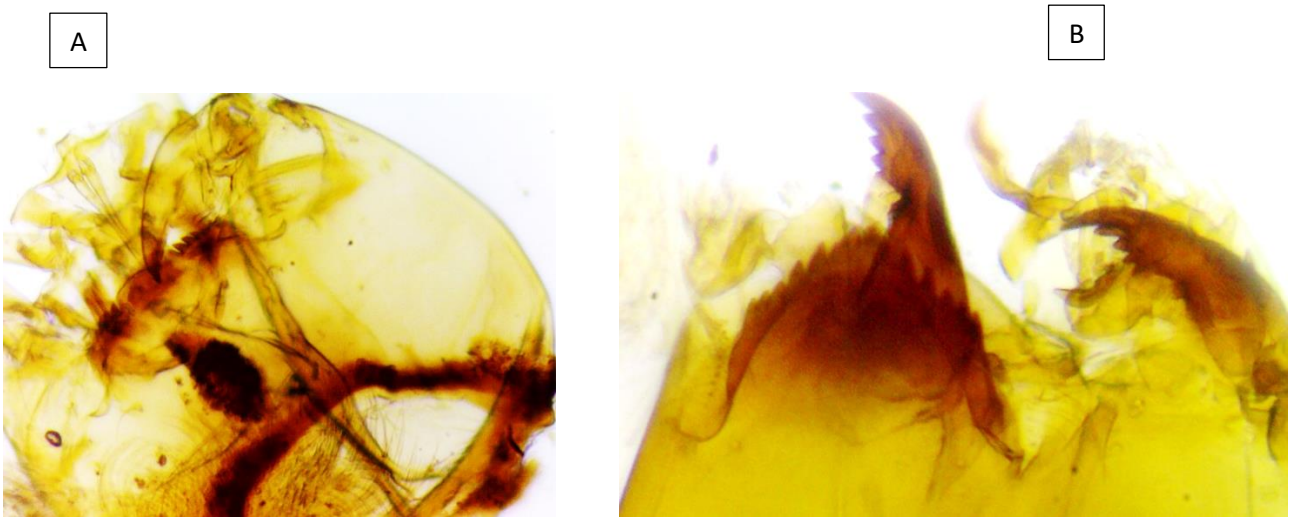


Figure 29: Head capsules, A; Eukiefferiella and B; Zalutschia.

III-1-2-4-3- Morphological deformity in Chironomidae laevae

The term "deformity" refers to morphological features that depart from the normal Chironomidae larval configuration (Warwick, 1985; Nazarova *et al.*, 2004). Since chironomid larvae live in close association with sediments and often feed on organic detritus and associated algae, deformities in chironomids can be used to show the effects of pollution on macroinvertebrates. All the larvae collected from the 13 sampling sites were screened for deformities in the mentum, mandible, premandible, ligula and paraligula. Among the structures examined, the premandible and paraligula did not displayed deformities throughout the study perid and are thus not presented.

III-1-2-4-3-1- Mentum and ligula deformities in Chironomidae larvae

All species exhibited relatively low levels of mentum deformities (Table XII). The most common deformity for *Chironomus*, *Polypedilum* and *Radotanypus* was either the absence, split, worn and /or fussion of a lateral tooth of the mentum and ligula as summaried on table XIII.

Table XII: Number and description of mentum and ligula deformities recorded among chironomid taxa at the 13 sampling sites

species	Type of deformity	Description of deformity	Number of individuals showing deformity
Polypedilum illinoeuse (Figure 44)	Split teeth	split median tooth	3
	missing tooth	missing 1st and 2nd left and right lateral teeth	2
	worn teeth	worn median tooth	4
	fused tooth	all right and left lateral teeth fused	1
Polypedilum beckae Figure 44	missing tooth	missing 4th and 5th right lateral teeth	2
	fused tooth	fused 4th, 5th and 6th right lateral teeth	1
Radotanypus florens Figure 45	fused and missing teeth	fused and missing median tooth with the 1st right and left lateral teeth	1
	broken teeth	broken median and 1st right lateral teeth	1
Chironomous plumosus Figure 45	missing tooth	missing 1st left lateral tooth	4
	missing tooth	missing 4th, 5th and 6th lateral teeth	1

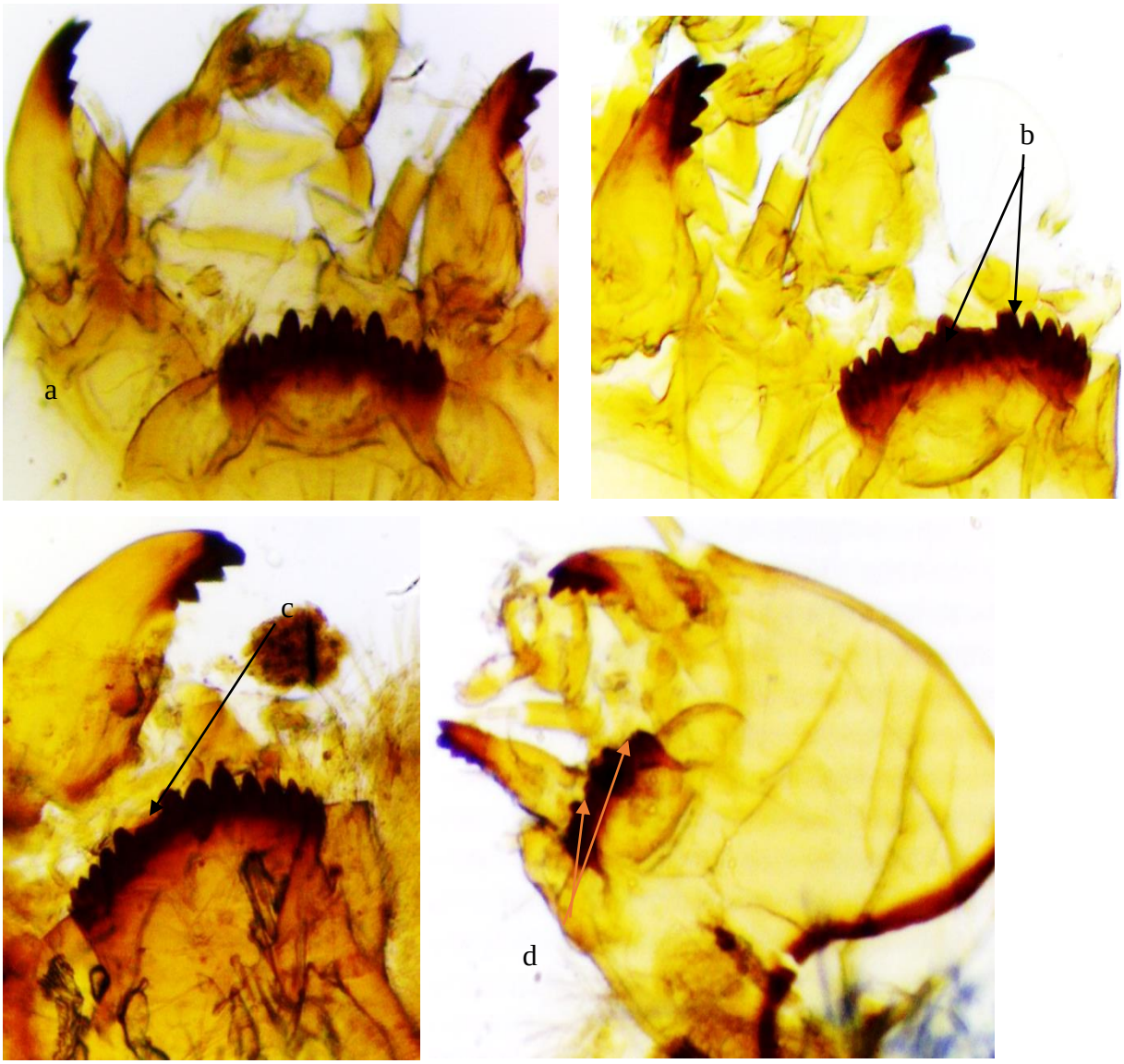


Figure 30: Normal and deformed menta of Chironomidae. (a) Normal mentum of Polypedilum illinoeuse (b) missing 1st and 2nd left and right lateral teeth (c) worn median teeth (d) fused right and left lateral teeth.

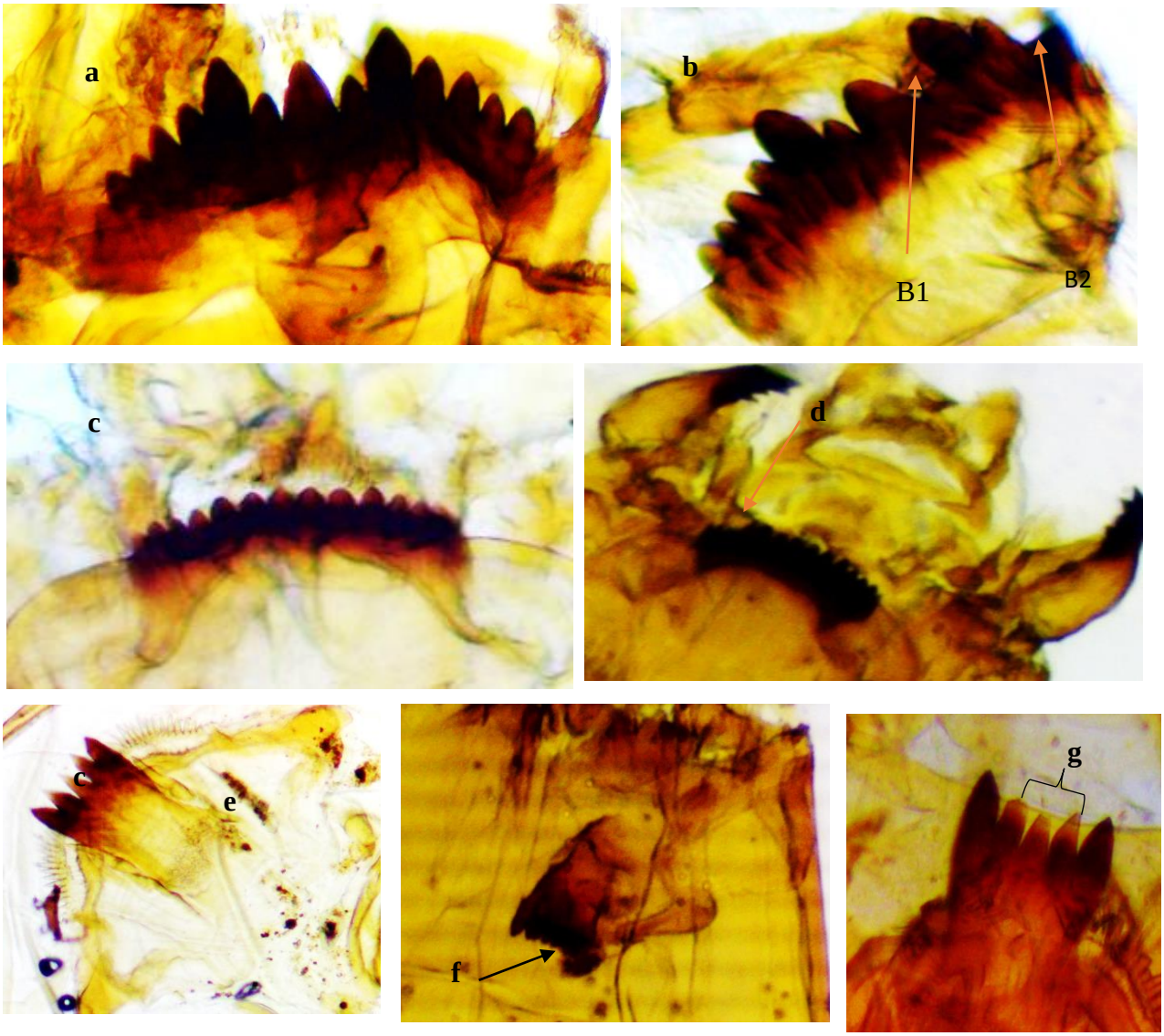


Figure 31: Normal and deformed menta of Chironomidae. (a) normal mentum of Chironomous plumosus (B1) missing 1st left lateral tooth (B2) missing 4th, 5th and 6th lateral teeth (c) normal mentum of Polypedilum beckae (d) missing 4th and 5th right lateral teeth (e)

III-1-2-4-3-2- Mandible Deformities in Chironomidae larvae

The frequency of deformity in the mandibles was lower than that observed in the mentum. Similar to the mentum, the most common mandibular deformity involved the loss of a tooth (Table XIII) and (Figure 46).

Table XIII: Number and description of mandible deformities recorded among chironomid taxa at the 13 sampling sites

Species	Type of deformity	Description of deformity	Number of individuals showing deformity
Chironomous plumosus	missing tooth	missing basal teeth on the right mandible	3
	missing tooth	missing of all teeth on the left mandible	2
Chironomous stigmatenus	missing tooth	missing right basal teeth on the mandible	2
Dicrotendipes neonodestus	missing tooth	missing of all teeth on the right mandible	2
	missing tooth	both the right and left teeth all missing on the mandible	1
	missing tooth	Right and left teeth on mandible are in a degradation process.	1

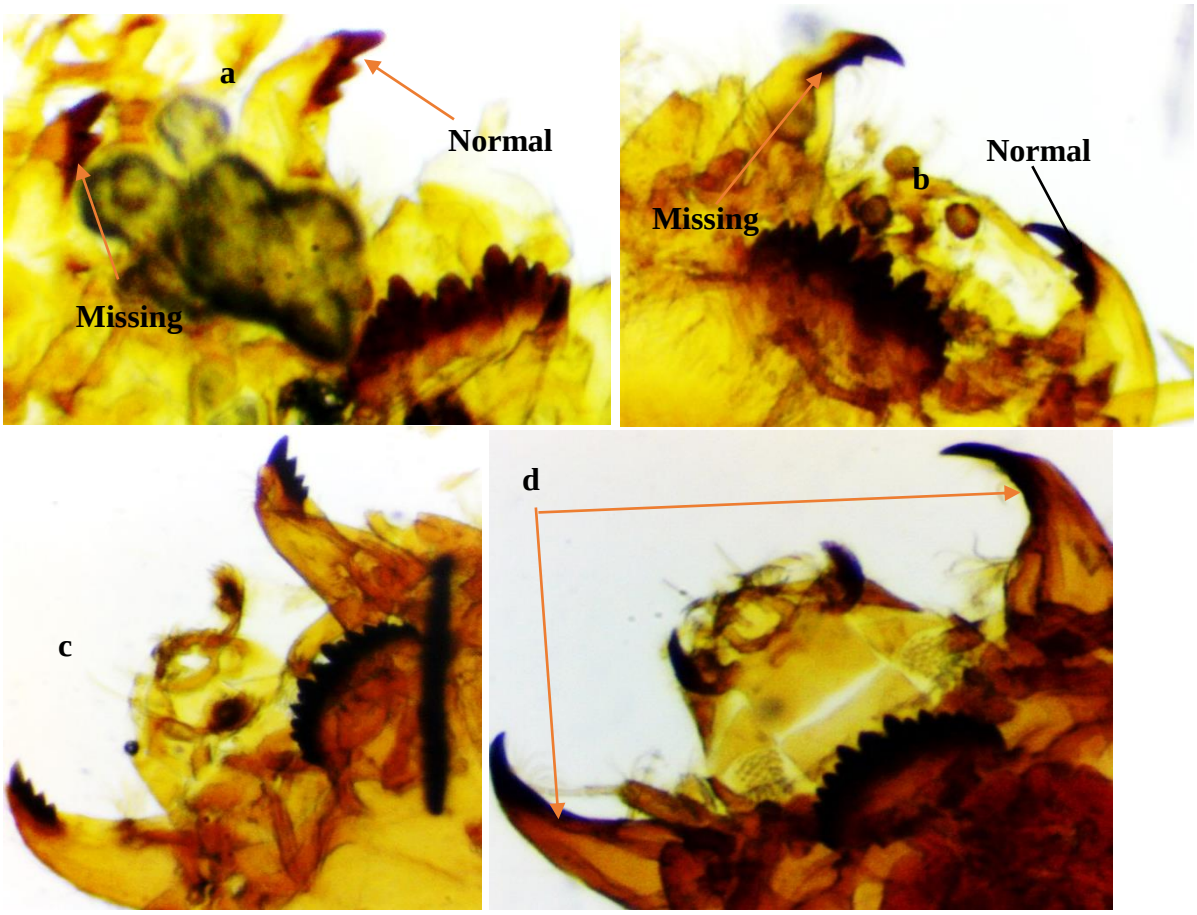


Figure 32: Normal and deformed mandibles of Chironomidae (a) normal Mandible and missing basal teeth on the right mandible of Chironomous plumosus (b) normal mandibles and missing right basal teeth on the mandible Chironomous stigmatenus (c) normal Mandible of *Dicrotendipes neonodestus*

III-1-2-4-4- Examining the chironomid pupal exuviae

The study on chironomid pupal exuviae was on the stations F1, F2, F3, Mk2, mk3, A2 and A3. This are the stations which had a high abundance of the chironomid larvae and provided favorable conditions for the sampling of the pupal exuviae. All the exuvia were collected in the dry season. A total of 350 individuals were mounted between slid plat and slid plat cover (50 individuals per sampling site) and identified to the generic level.

The general structure of the pupal exuviae has three main body divisions: head, thorax, and abdomen. In many cases, the head and thorax are referred to collectively as the cephalothorax (Figure 47).

Head: The head region of the chironomid pupal exuviae consists of the frontal area, eyes, and antennal and mouthpart sheaths (Figure 47). The frontal apotome is the area of integument covering the dorsal side of the pharate adult head. Some other important characters in this body region can include cephalic tubercles, frontal warts, and frontal setae

Thorax: The thorax of the chironomid pupal exuviae includes the legs, wings, and halter sheaths. It bears structures of potential taxonomic significance such as several groups of setae and especially the thoracic horn, which can vary greatly among taxa in presence, size, and shape

Abdomen: The abdomen of the chironomid pupa includes eight segments plus a terminal segment modified into anal lobes and genital sheaths. The dorsal tergites and ventral sternites often bear distinctive groups of spines, hookrows, shagreen, setae, and spurs (Figs. 47).

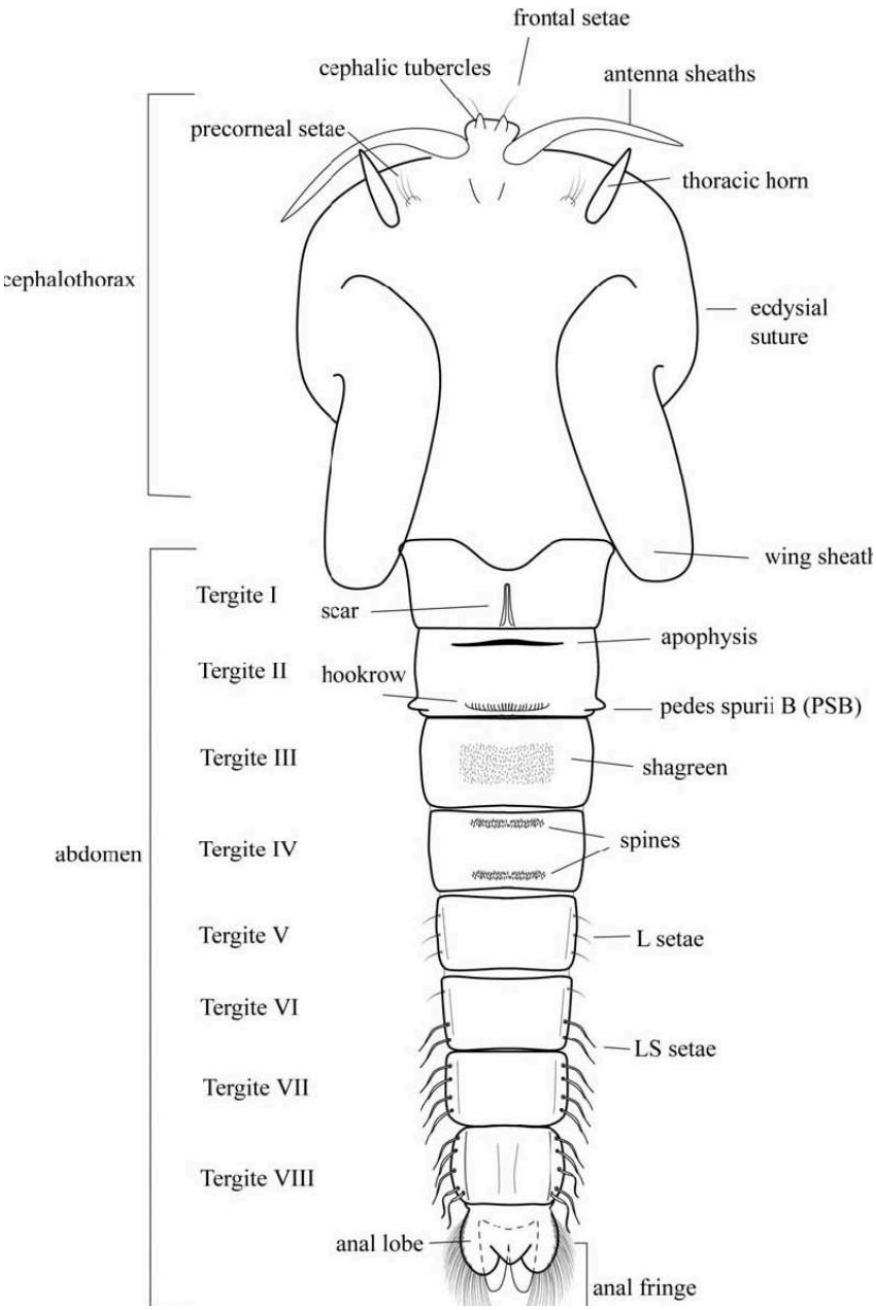


Figure 33: Morphology and terminology of Chironomidae pupal cephalothorax and abdomen (Rufer 2007)

III-1-2-4-4-1- Diversity and distribution of the taxa

The microscopic examination of the mounted slides of pupal exuviae perminated us identify 4 species which all belong to the family chironomidae, sub-family Chironominea and the genus chironomus (Table XIV). This species are, chironomus sp1, chironomus sp2, chironomus sp3 and chironomus sp4 (figure 48). The species chironomus sp1 had a high relative abundance in all the sampling sites especially at A2 (64%) this was followed by

chironomus sp2 with the most high abundance at A3 (45%), then came chironomus sp3 while chironomus sp4 was the least represented in all the sites and streams (figure 48)

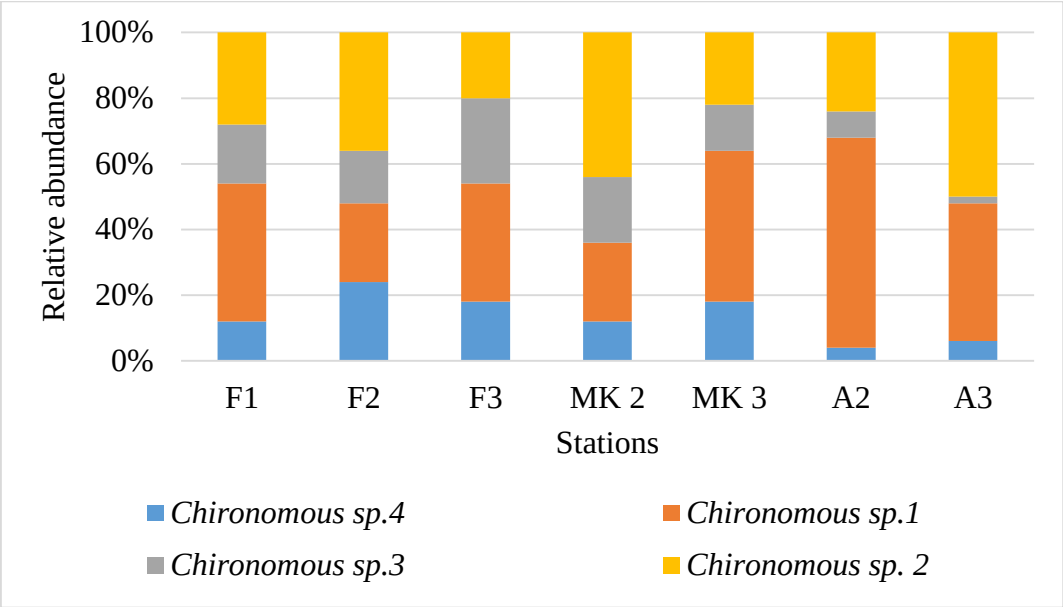


Figure 34: Special variation of relative abundance of the different chironomid species identified in this study.

Table XIV: Distribution of chironomus species in the different sampling sites of the streams

SUBFAMILY	GENUS	SPECIES	F1	F2	F3	MK 2	MK 3	A2	A3
Chironominea	Chironomus	*Chironomous* sp.4	6	12	9	6	9	2	3
		Chironomous sp.1	21	12	18	12	23	32	21
		Chironomous sp.3	9	8	13	10	7	4	1
		Chironomous sp.2	14	18	10	22	11	12	25

III-1-2-4-4-2- Description and characteristics of the different chironomus morphotypes identified

***Chironomus* sp.1**

This species dominated in all the stations. The head region bears cephalic tubercles with bulbous base with an arched apex. The abdomen counts 09 tergites with the last modified into an anal lobe and filaments used for swimming. Tergite I is bare, while II-VIII bears shagreen with either an anterior, posterior, median or lateral patches. Tergite II possesses median shagreen with a continuous hook row (1/2). Tergites III-V possesses median shagreens with a slightly darker posterior. The conjunctives III/IV and IV/V are short setae.

Tergites VI bear a heavier anterior and posterior patch of shagreen meanwhile, Tergites VII and VII bear a light anterior and lateral patches of shagreens respectively. Anal spurs are slightly shorter with a characteristic light brown colour counting 40 anal lobe filaments or fringe (figure 49)

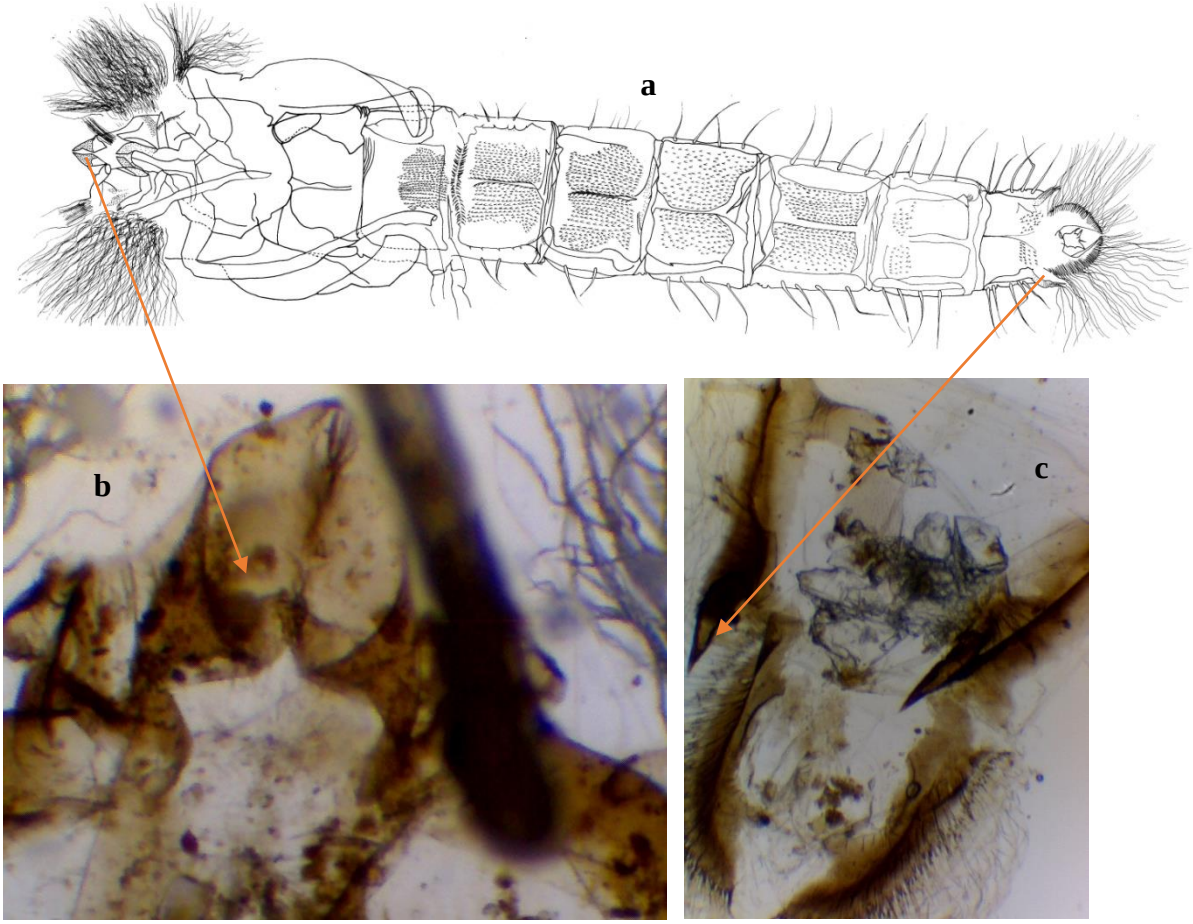


Figure 35: Morphology of *Chironomus* sp.1. (a) General structure of the pupal exvuvia, (b) cephalic tubercles with bulbous base and an arched apex, (c) slightly short light brown anal spurs with anal lobe filaments.

Chironomus sp.2

This species differ from the chironomus sp1 in just few points, chironomus sp1 is light brown while the chironomus sp2 is dark brown in colour. The base of the bulbous cephalic tubercles has a tubular apex which is different form sp1. Their anal spurs are slightly longer and darker than that of *Chironomus* sp. 1, counting around 45 anal lobe filaments (figure 50).

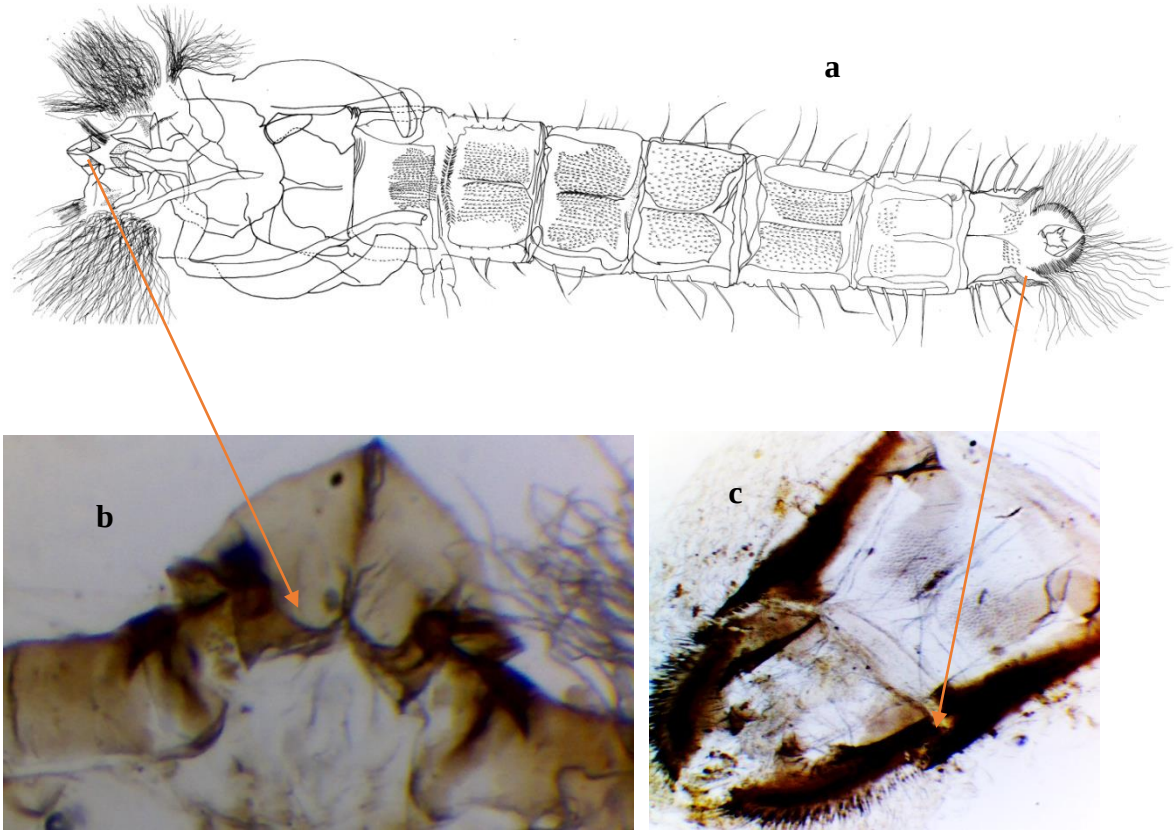


Figure 36: Morphological structure of *Chironomus* sp.2. (a) General structure of the pupal exvuvia, (b) cephalic tubercles with tubula apex, (c) Dark brown anal spurs with anal lobe filaments.

Chironomus sp.3

The head region bears cephalic tubercles which are small and pointed with frontal setae. In the thorax region, the basal ring is medially restricted their tergite II has an anterior band and a medial shagreen, while Tergites III-V bears a dense hour- glass shape of shagreen. Tergite VI possesses an anterior triangular patch of shagreen while tergite VII possess two small patches of anterior shagreen.Tergite VIII possess two medial bands of shagreen, a 5 slender L setae of which two are situated around the anal spur. Anal spur is singular with a characteristic yellow colour and no spine. The abdomen counts 09 tergites with the last modified into an anal lobe. The first tergite is bare and the remaining 07 possessing shagreens which can either be anterior, posterior or medial. Tergite II bears shagreen with continuous hook-row (¾ width). Tergites V-VII bears 4 slender L setae, while Tergite VIII bear 4 or 5 setae that occupy varying position around the anal spur. Anal spur may be single or clawed forming a comb with a characteristic yellow or dark-brown colour depending on the species; possessing spines or not and a complete single row of anal fringe (figure 51)

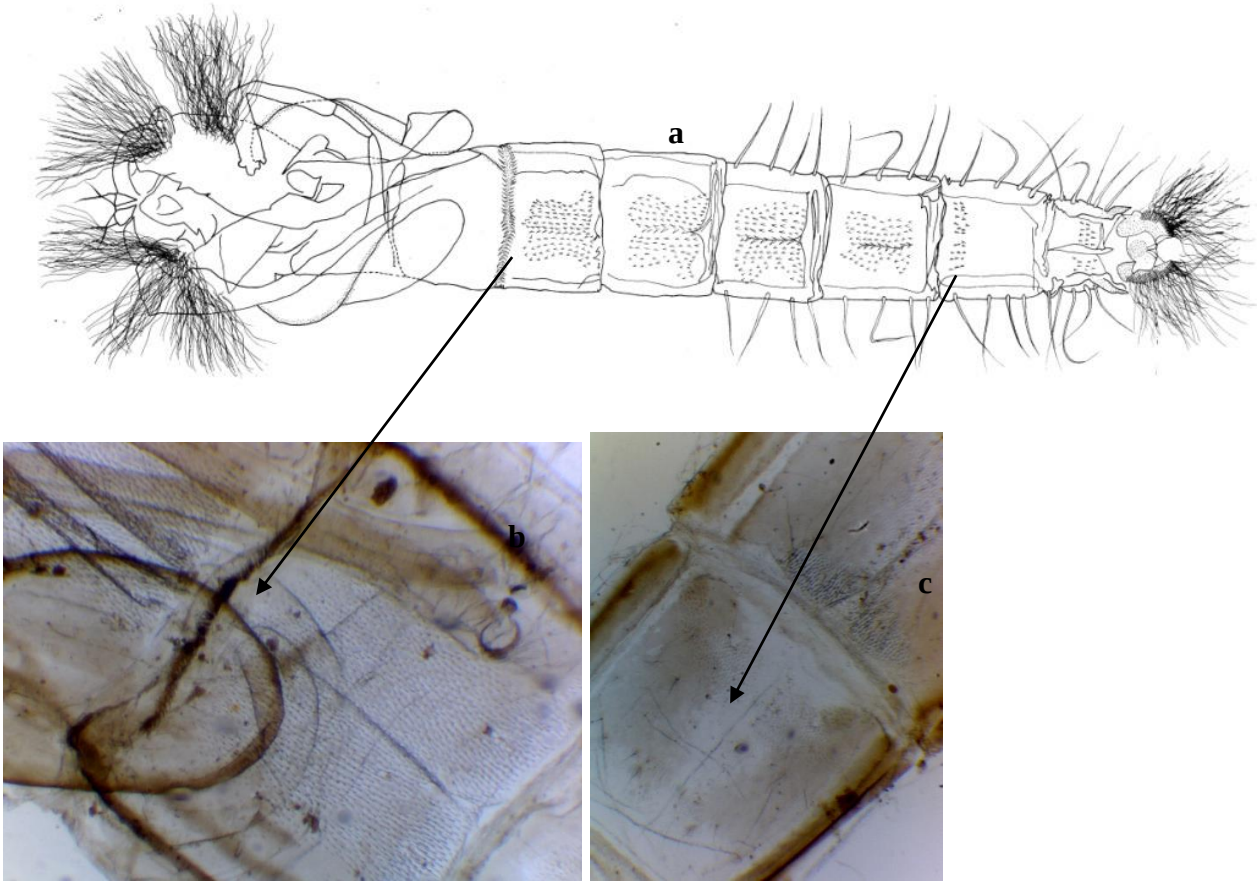


Figure 37: Morphological structure of *Chironomus* sp.3. (a) General structure of the pupal exvuvia, (b) Continuous hook-row on tergite II, (c) Two medial bands of shagreen on Tergite VIII.

Chironomus sp.4

Cephalic tubercles are dark with short frontal setae, while the thorax bears a basal ring which is medially constricted. The pleural area of the abdoment has a brown pigmentation. Tergites II-VI bears continuous shagreens which are anterior with posterior long spines, while Tergites VII-VIII possesses two circular anterior patches of shagreen. Also, tergite VIII bears 5 slender L setae with a gap between the first two and last three and a dark brown globular three point anal claw with minor spines (figure 52).

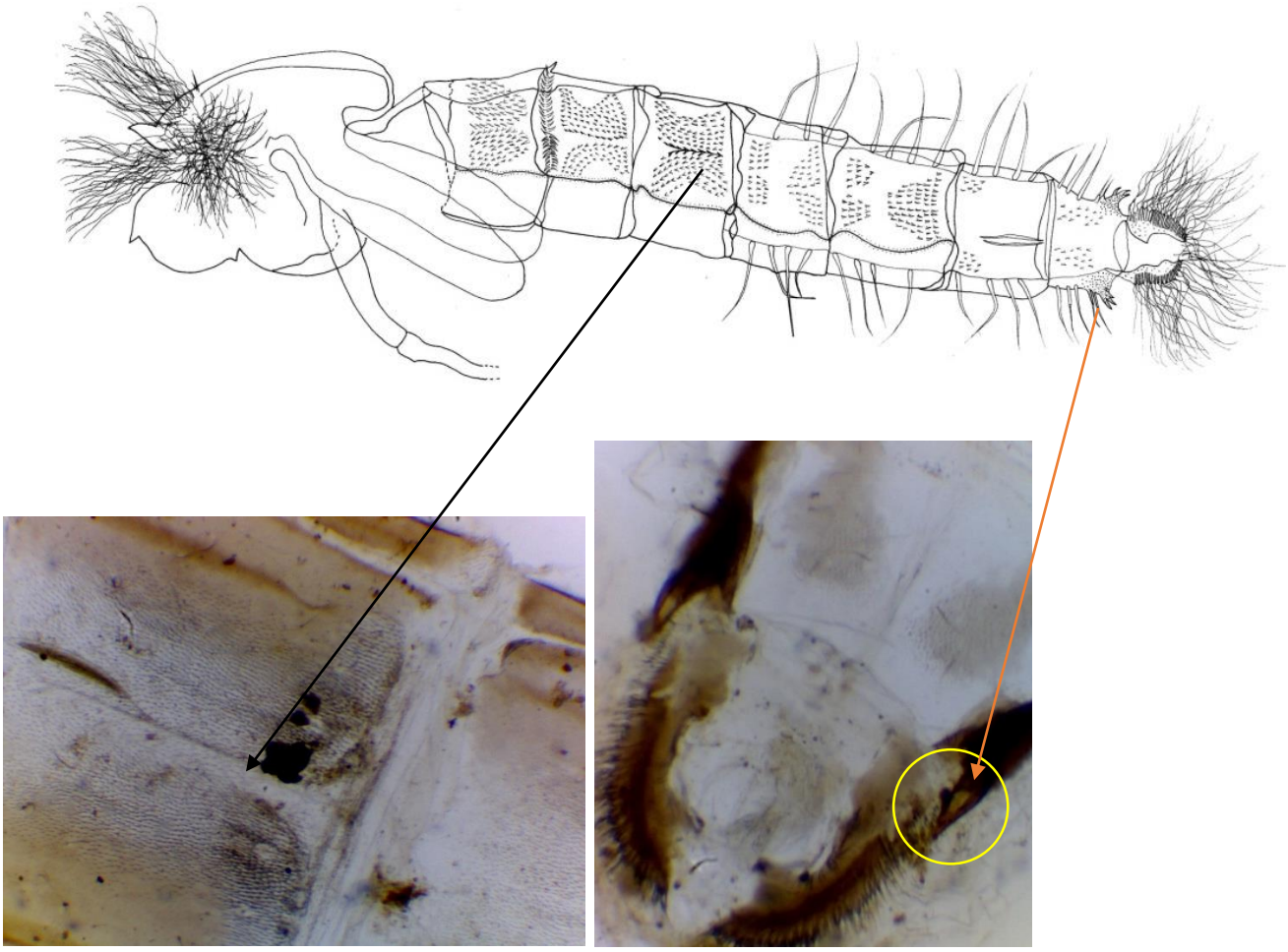


Figure 38: Morphological structure of *Chironomus* sp.4. (a) General structure of the pupal exvuvia, (b) continuous shagreens which are posterior on tergit VI, (c) dark brown globular two point anal claw

III-1-2-5- Thoracic horn structure Chironomid pupal

The pupal thoracic horn in Chironomidae is a respiratory organ specialized for oxygen adsorption. The pupa neither feeds nor reproduces and for most species its movements are limited to respiratory undulations. The chironomid pupae are characterized by a great morphological diversity. This structure help chironomid subfamilies to occupy different ecological niches. The morphology of the thoracic horn provides an example of correspondence between morphological characters and physiological adaptation. The low oxygen tolerant Chironominae have a developed and very high branched thoracic horn (figure 53a). Differences observed among the thoracic horns, permited us to differentiat two subfamilies, the Chironominae and Tanypodinae. Unlike the chironominae, the tanypodinae has a simple thoracic horn which is more or less branched (figure 53b). These two types of thoracic horns suggest different ecological adaptations between the tribes, a high branching of the thoracic horn probably indicating the ability to tolerate low oxygen concentrations.

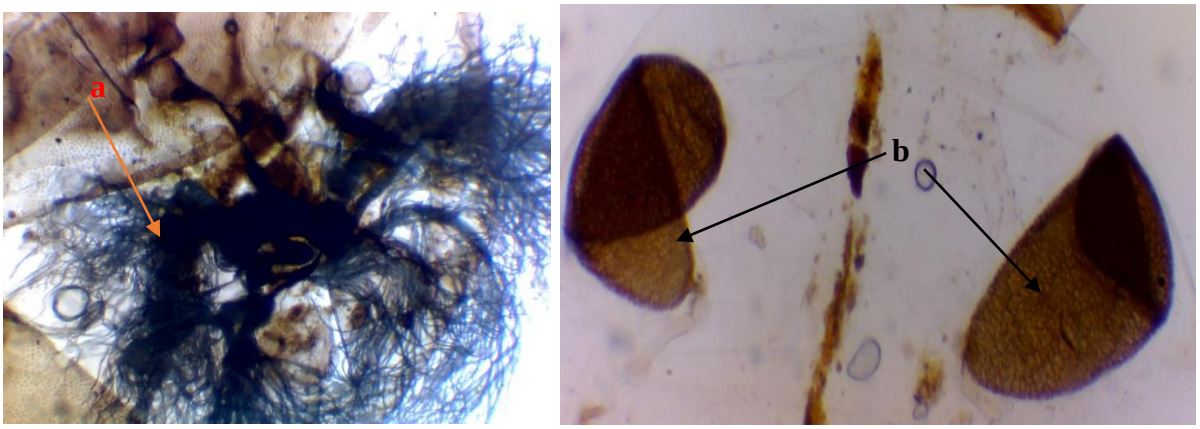


Figure 39: Pupal thoracic horn observed in Chironomids (a) Developed and very high branched thoracic horn in Chironominae (b) simple, less branched thoracic horn in Tanypodinae

III-1-2-6-Feeding habits of chironomid larvae

Chironomids have an important role in the food webs of aquatic communities, representing a major link between producers and secondary consumers. Chironomid larvae are opportunistic omnivorous, ingesting a wide variety of food items. Generally, these larvae ingest five kinds of food: algae, detritus and associated microorganisms, macrophytes, wood debris, and invertebrates (Dias et al., 2008). Based on the feeding mode, chironomid larvae are group in three categories: shredders, detritus, and predators. Therefore, shredders ingest particles larger than 1 mm (figure 55), feeding (vascular plants and macroalgae. Predators (engulfers) were commonly represented by individuals from the Tanypodinae subfamily (figure 54) and feed on living animal (especially other chironomids, there ingest the whole organism) (figure 54). The common food stuff that was found in the alimentary canal of these organism were, algae, fibers and animal remains (Figure 54).

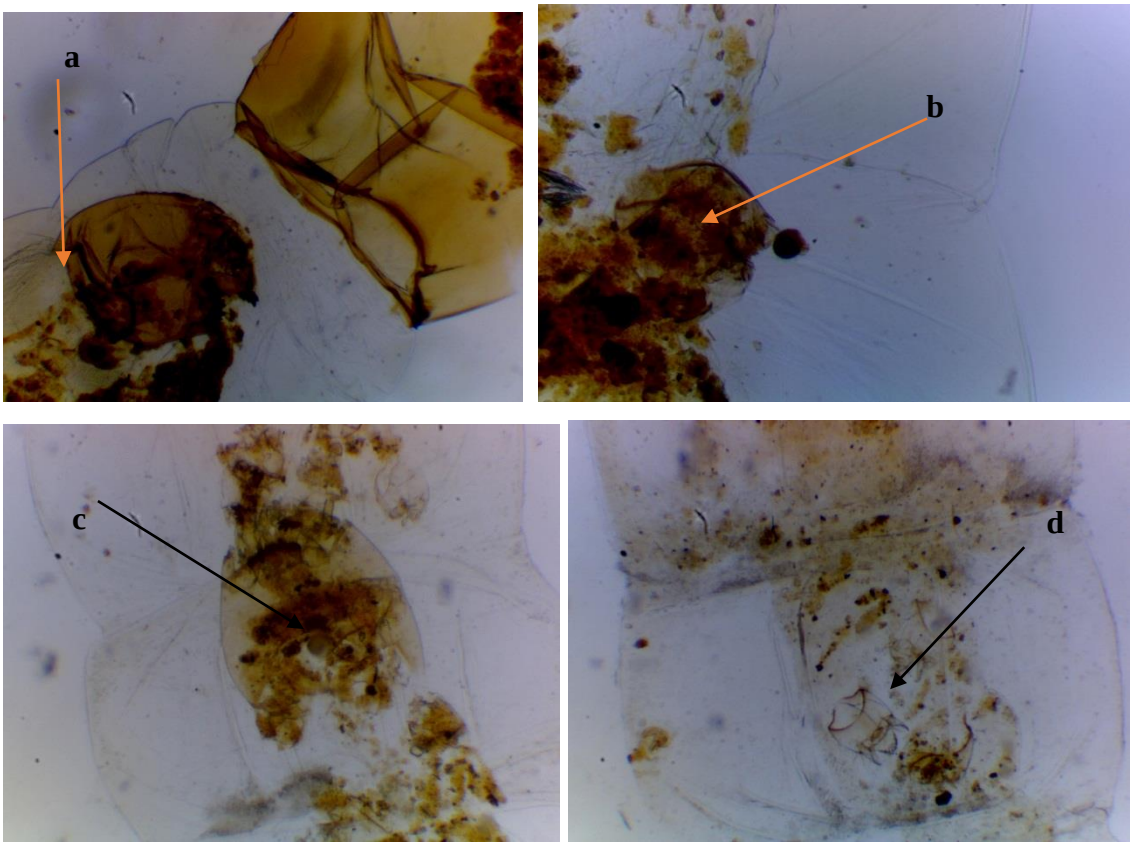


Figure 40: Predators (engulfers) feeding in the Tanypodinae subfamily, (a) freshly ingested pray, (b) and (c) pray in the digestion process, (d) remains of pray after digestion.

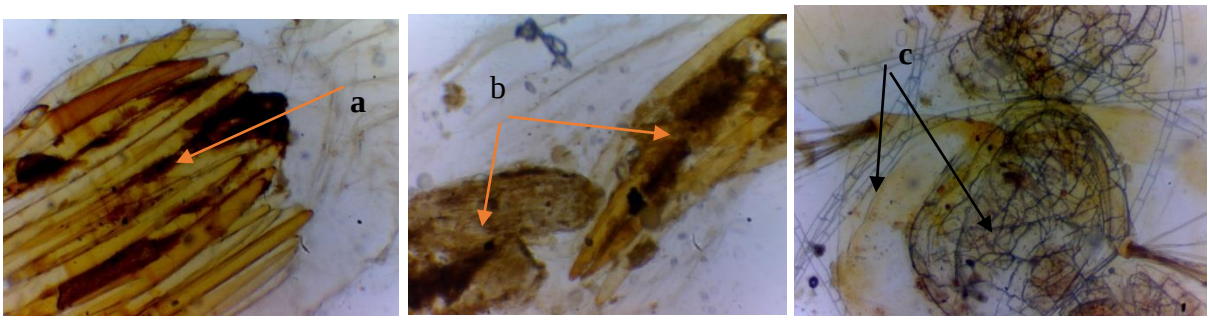


Figure 41: Fibers and algae feeding in Chironomid larvae, (a) freshly ingested fibers, (b) fibers in the process of digestion, (c) algae filaments and unidentified particles in the alimentary canal.

III-1-2-6-Influence of environmental variables on chironomid larvae assemblages

The Pearson correlation test was performed to assess the relation between the environmental variables and the taxa and diversity indices. Several significant correlations ($p<0.05$) were observed, but most of them were low ($r<0.5$). As such, only those that were higher ($r>0.5$) are highlight. There were significant positive correlations between temperature and a number of chironomus species ($r=0.270$) and for the taxa a significant negative correlation was noted between electrical conductivity, Total dissolved solids and *Procladius*

bellus (r=-0.267), (r=-0.267) respectively and a significant positive correlation between nitrate concentration and *Chironomus stigmaterus* (r=0.230).

III-1-2-7- Diversity of chironomids based on Pielou, Shannon and Weaver

The Shannon and weaver mean indice varied from 2.40 bit/ind in mankon 3 to 3.54 bit/ind in mezam with a mean of 2.75 ± 0.36. As for the indice of Pielou, which shows a minimium of 0.63 in mankon 2 to 0.92 in mezam with a mean of 0.76± 0.10 as seen on figure 56.

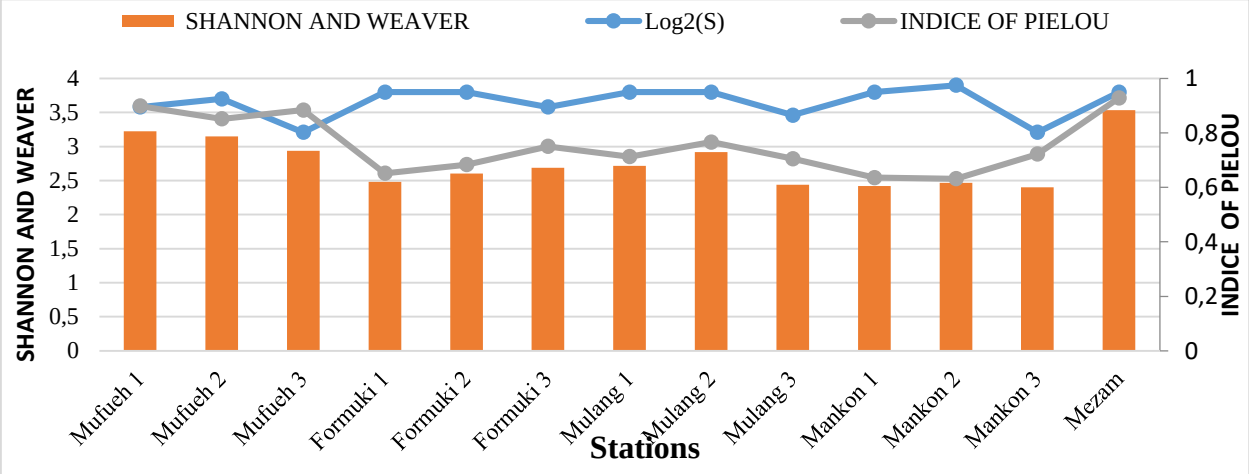


Figure 42: variation indices of Pielou and Shannon and Weaver

III-1-3- Abundance and diversity of the order Odonata

The order of odonata (dragonflies) are hemimetabolous insects (having no pupal stage in the transition from larva to adult) with predominantly aquatic nymphal stage and terrestrial adult. Odonata can be found in a wide array of fresh water systems dependent on biotic and abiotic constraints**.** Each type of water body has a characteristic species assemblage of odonata that can typically be found. It was realized that, the species *Aeshna* sp. and *Hagenius* sp. were only found in the mufueh stream, *Gynacantha nervosa Rambus* in Furmuki stream and *Hagen* sp. was seen just in mezam and mufueh streams throughout the study period (Appendix 4).

III-1-3-1- Species composition and abundance

A total of 1750 individuals of Odonates were recorded during the entire study period. This individuals belong to 11 species and 5 families (Appendix 4). On the basis of total number of species Libellulidae and Coenagrionidae were the most dominant family with 3 species each followed by Calopterygidae and Ashnidae (2 species each) and Gomphidae was the least with 1

species. On the basis of total number of individuals recorded, Calopterygidae was the most dominant family constituting 48% of the total number of recorded Odonates (figure 57). *Calopteryx maculate* (30%) was the most abundant species of this family (figure 58) followed by *Hetaerina titia* (18%). Family Libellulidae was the second most dominant family and constituted 47% of the total individuals of Odonates recorded during the study period. *Tramea* sp. was the most abundant species and accounted for 28% of the total individuals of this family, it was followed by *Pantala falvesceus* and *Miathyria* sp with 19 and 0% abundance respectively. Family Coenagrionidae with 3 species constituting 4% and Ashnidae with 2 species had 1% of the total number of individuals of the Odonates, respectively. *Ashna* sp., *Hagenius* sp. and *Hagen* sp. Where the least abundant species during the entire study period with 0% each since there were found just in particular stations and months (figure 58).

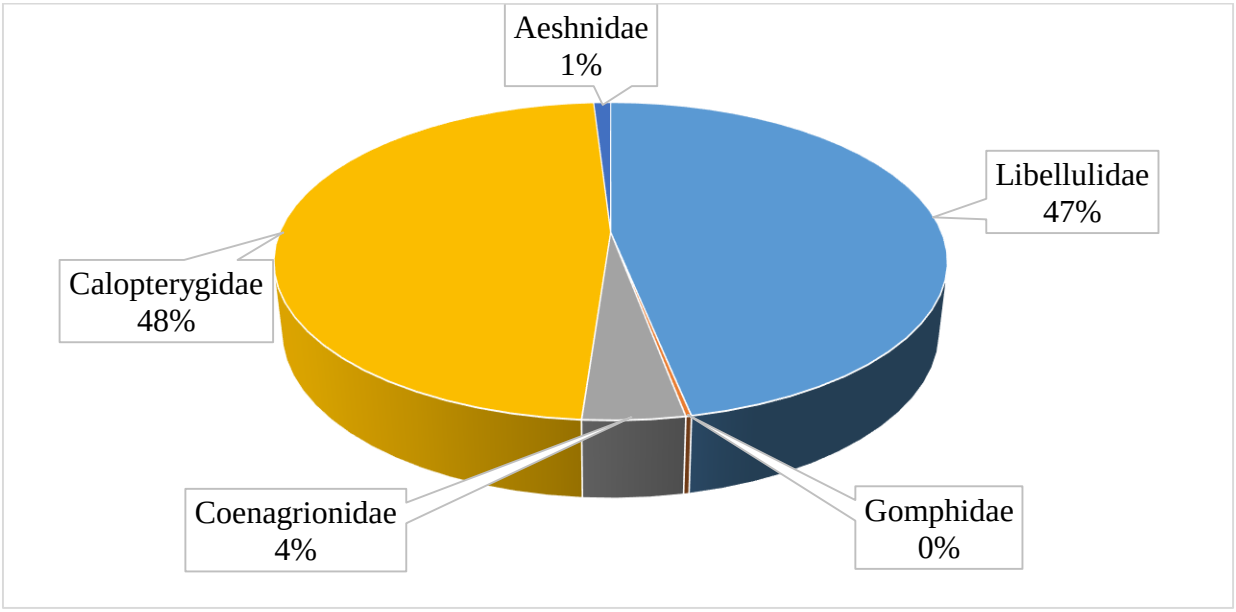


Figure 43: Relative abundance of Odonata families recorded during the study period

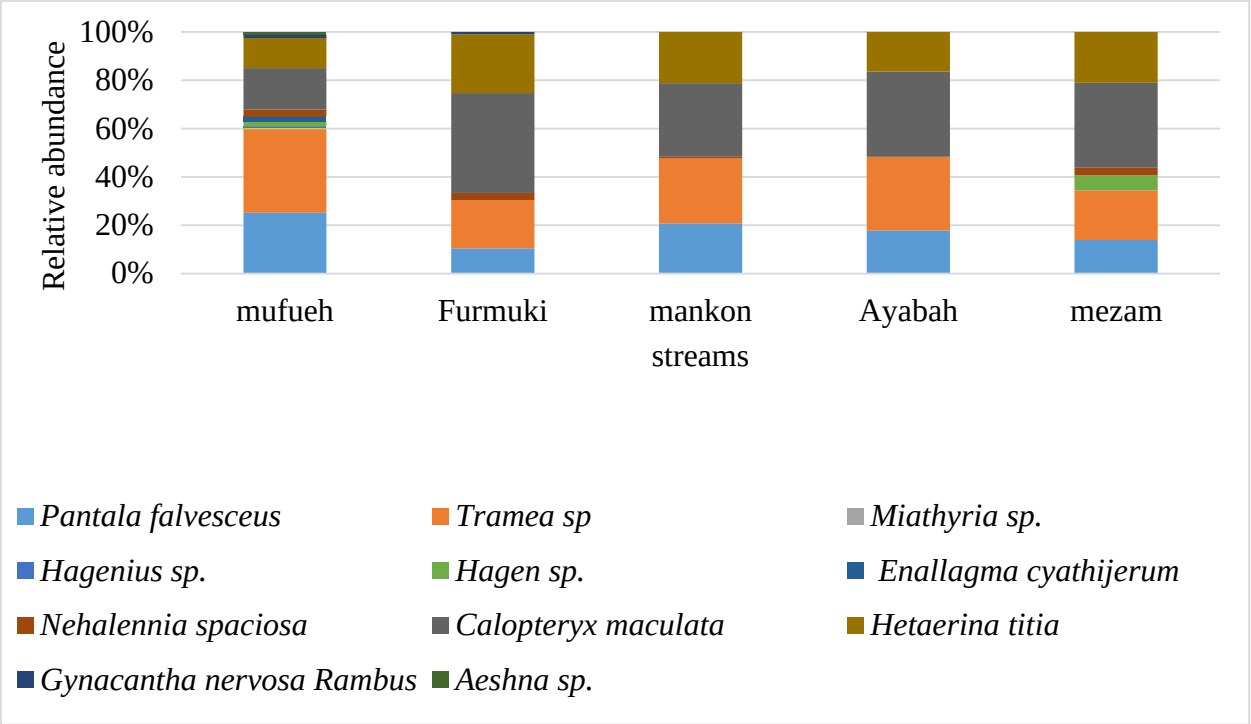


Figure 44: Relative abundance of different Odonata species recorded in the diferent streams

III-1-3-2- Morphological description of *Aeshnidae* sp. larvae

III-1-3-2-1- Larval habitat and Distribution

larva instars of *Aeshna* sp. were sampled only from Mufueh stream and precisely from the third sampling site of the stream (mf3). This is sampling point was characterized by deep, calm and dark waters (4.5 m wide, 13 m deep). The substrate at this station is composed mainly of fine sand, mud, and decayed leaves. This species *Aeshna* sp. was recorded just within 3 moths (June, July and August) out of the 13 months of the research period. This 3 month period is characterized by heavy rains and floods in Bamenda. During the month of June, mostly the early stage larvae were recorded (early stage), in July, the fully grown larvae were seen (final stage) and in August, just the laevae exuviae (Table XV). The Exuviae are dark brown while the last larva instar is light brown with roughly granulated and hairless skin (Figure 60). This observation could suggest a short and fast life cycle for this species. Morphologically, this species *Aeshna* sp. is different from many other known species of the same family and general at the lavel of the head and abdoment.

Head (Figure 59)

The head is wider (10.5mm) than long (9.5mm) (figure 59A) (Table XV) with rounded cephalic lobes and minute setae. It has a pair of large compound eyes large which almost

touch each other at the back of the head and its antennae has 7 segments with the third segment been the longest. The mouth is ventral with different mouthpart, Mandibles with four teeth and setae along the border. The Labium measures 13mm in its total leght and is composed of a prementum (12.5mm) and postmentum (1.5mm) articulation reaching anterior margin of metacoxae. The Prementum (Fig. 59b) bears an anterior extension called the ligula with a pair of extendable labial palps (4mm), each with a movable hook (2.5mm). The ligula is truncate, rounded on external angle, with a stout, blunt end-spine at the internal angle forming some sort of a sphere on the anterior end.

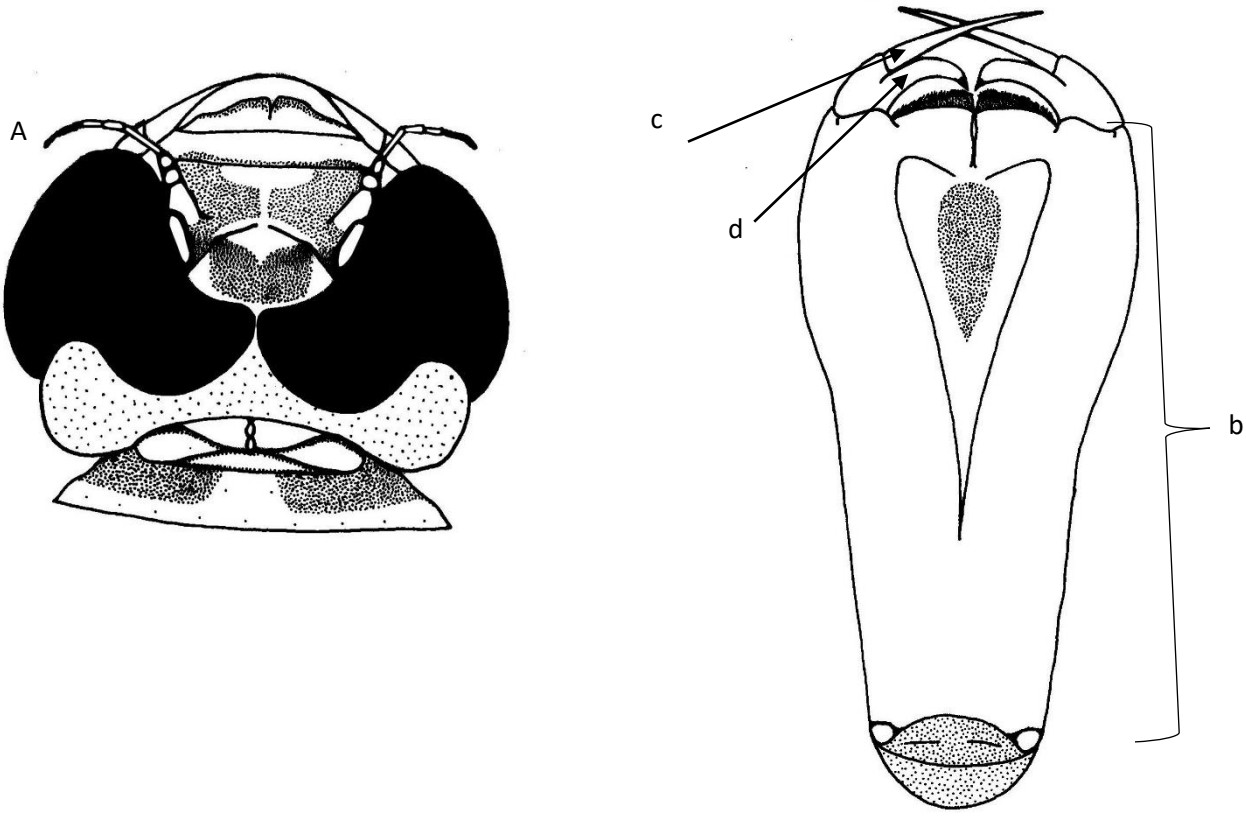


Figure 45: *Aeshna* sp. exuviae details of head morphology. (a) Head dorsal view showing position of the eye, (b) Prementum, (c) Movable hook and (d) labial palps.

The abdomen measures 31.5mm in length and is granulose on its dorsal surfaces and uniformly light brown on its ventral surface figure 60. The abdomen is widest on segments V-VIII. Lateral spines are present on segments VII-IX, which are absent on segment VI. Segment VIII is the longest segment (4.5mm). The Male gonapophyses is indiscernible while the female gonapophyses is well developed and covers ¾ length and not reaching the posterior margin of segment IX (figure 60B). The abdominal terminalia, dorsal view present five short stiff pointed appendages which include two Cerci (3mm), two paraprocts (6.5mm)

with a centrally located epiproct (5.5mm) as seen on figure 60C. The cerci is half the length of the paraprocts, epiproct with middorsal ridge and two apical short spines.

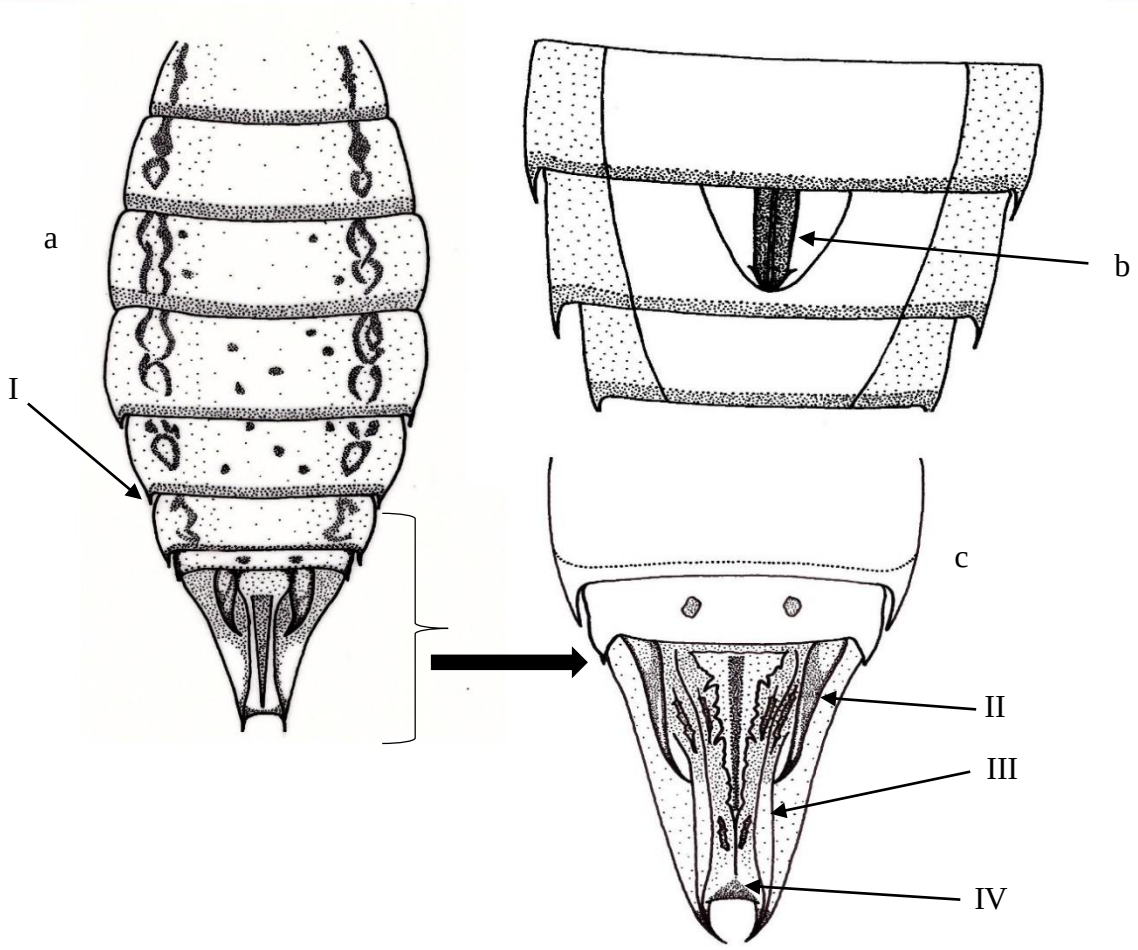


Figure 46: *Aeshna* sp. exuviae details on abdominal morphology. (a) Granulose dorsal abdominal segments, (b) Female gonapophyses, (c) Abdominal terminalia, (I) Lateral spines on segments VIII, (II) Cerci, (III) paraprocts and (IV) epiproct.

Table XV: Measurements (mm) of Aeshna sp. body parts

	BODY LENGTH	**HEAD**	**THORAX**	**ABDOMEN**	**FEMUR**	**TIBIA**	**TARSUS**
early female stages	11	3	1	7	2	1.5	0.5
	15	4	2	9	4	3	2
	33	6	3	24	9	7	5
final female exuviae	50	10	9.5	31.5	14	9.5	6
early male stage	25	5	2	18	6.5	5	2.5
final male exuviae	49	9.5	9	31	14	9.5	6

Measurements *(mm) cont*

Continuetion of Table XV

	TARSUSNUMBER CLAWS	PREMENTUM	POSTMENTUM	LABIA PALP + HOOK	CERCI	PARAPROCT	EPIPROCT
early female stages	2	3.5	0.5	2	-		
	2	4	1	2			
	2	8	1	3			
final female exuviae	2	13	1.5	4	3	6	5.5
early male stage	2	6	1	2			
final male exuviae	2	12	1.5	4	3	6	5

III-1-4- Description of species for the genus Limnometra (Hemiptera: Gerridae)

III-1-4-1- General characteristics

The family Gerridae includes water striders belonging to the superfamily Gerroidea, which dwells on surface of water. These group of organisms usually have narrow elongated bodied and are long-legged. The head is horizontally shorter than pro- and mesonota put together. Their antennae are filiform with 4 segments. The rostrum also bear 4-segment with segments I and II being very short. Their fore legs are shorter than the Middle and hind legs which look slender, hind femora much surpassing apex of abdomen. The second tarsi is segmented while the terminal segment is bifid at its apex. The Gerridae may be distinguished from the Veliidae, the other member of the superfamily, by the fact that, their hind femora extend much beyond apex of abdomen. Middle and hind pairs of legs much closer together at base than fore and middle legs.

III-1-4-2- Distinctive characters of *Limnometra* sp.

Dimensions: Body length, from the tip of the head until apex of last abdominal segment which bear the connexival spines 7.32±0.88 mm. Maximum body width at mesoacetabula 2.68±0.26 mm. The head measures 1±0.08 mm in length and 1.15±0.06 mm in width. The first antennomere (measured straight from base to apex) is as long as 1.65±0.13 mm. The mesofemur which is usually longer than that of the pro and metafemur, measured 6.38±0.39 mm while the connexival length was 0.53±0.05 mm (Table XVI)

Table IVVI: minimum, maximum, mean and standard deviation of different body parts measurements

Body part (mm x 1000)	*Limnometra* sp.		
	Min	Max	Mean
body length	6	7.9	7.32±0.88
body width	2.3	2.9	2.68±0.26
head length	0.9	1.1	1±0.08
head width	1.1	1.2	1.15±0.06
profemur	2.1	2.9	2.45±0.34
mesofemur	5.9	6.7	6.38±0.39
metafemur	5.8	6.5	6.13±0.3
first antennal segment	1.5	1.8	1.65±0.13
abdominal spine	0.5	0.6	0.53±0.05

Body colour: Dorsum of head brownish yellow with distinct black markings: narrow medially and long dark marks on the head. Side of head in front of eye with broad black sport (Figure 61a). Antenna light brown with the first antenna segment being relatively longer (Figure 61b). Pronotum light brown with a black median line from the base of the head to the base of the pronotum. Black sublateral stripes were also noticed on the pronotum. Sides of thorax are yellowish. Legs mainly light yellow, except at the articulations which are brownish yellow. The connexival spines light yellow at it base and brownish yellow at its elongated curved tips (Figure 61c).

Structural characteristics: the maximum length of antennomeres is 1.8 mm and maximum lengths of leg segments is profemur 2.9 mm, mesofemur 6.9 mm and metafemur 6.5 mm. Mesofemur distinctly longer than metafemur. Abdominal sternites with median carina. Connexival spines narrow and relatively slender, slightly convergent and up curved, do not reach apex of proctiger on Segment 8 and genitalia relatively large.

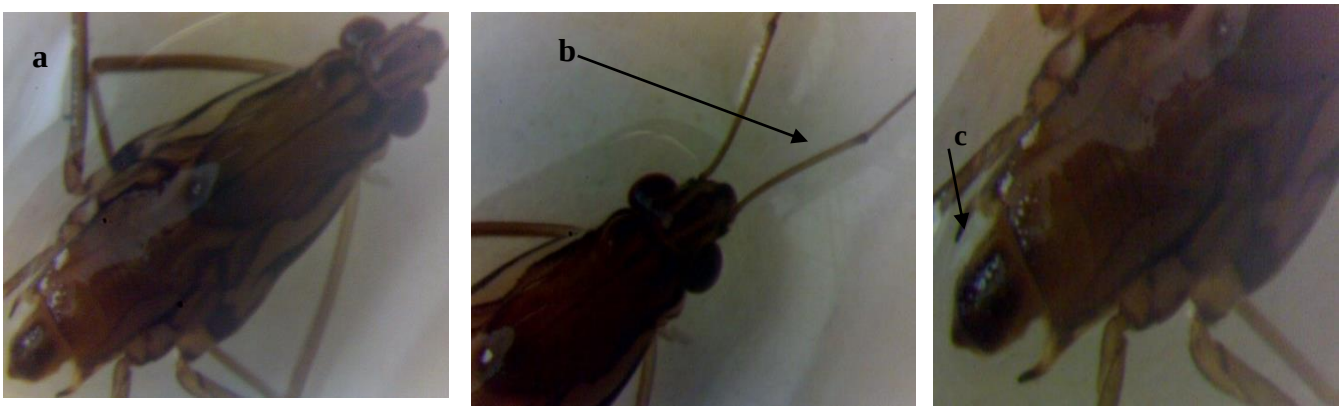


Figure 47: *Limnometra* sp. details of the overall morphology. (a) Body colour, (b) first antenna segment, (c) connexival spines elongated curved and dark brawn tips.

III-2- DISCUSSION

III-2-1- Physicochemical characterization of the stream studied

In the course of this study, the physicochemical quality of water varied significantly from one sampling point to another and from one season to another. The low values of temperatures (16 – 24 ^{o}C) registered at Mufueh (mf1, mf2, mf3), Furmuki (F1, F2, F3), mk1 and the Mezam stations could be due to low solar radiation reaching the water colon. This is because of the important tall grasses and tress cover line along the stream banks which constitute a barrier that reduces the impact of sun rays on the temperature variation along the streams. This riparian vegetation affects water temperature by adsorbing some of the incoming radiation (Dallas, 2008). Qiu (2013) suggested that, streams located at the upper part of the drainage basin in forest zone, temperatures are low and do not vary much. This temperature range is similar and close to that obtain by Tita e*t al.* (2012) in the mezam river systems in Bamenda, North West Region (18.5-25) and Tchakonté *et al*. (2015) in the sub-urban zones of Douala, littoral (23-26). Conversely, the relatively high temperature values (21 – 27 ^{o} C) obtain in the sampling sites mk3, A1, A2 and A3 could be partly explain by the high level of human activities. Hence, exposing the water to increased direct solar radiation, causing higher water temperatures. It could also be due to the high activity of river side inhabitants who dump all sort of waste in the streams as they flow through the Central Business District (CBD) and the food market of the municipality. So, all the hot substances from the different restaurants and animal cleaning points are empt\ied in the stream. According to Ajeagah *et al.*, 2016, water temperature increases with increase discharges of organic matter. Seasonaly, temperatures fluctuated much in the rainy season since rainfall usually influence temperature variations. In the present study, the temperature increased slightly during the rainy season but decreased in the dry season in most of the sampling sites. This difference may be due to the influx of warm water from tributaries with a resulting decrease in water transparency. Mansor *et al.* (2012) also observed an increase in temperature during heavy rains and the reverse effect during the dry season.

with inferences to the research works of Camacho (1992) and AE (2003), the low levels of Suspended Solids (SS) (2 – 74 Mg/L) in mf1, mf2, mf3, F1, F3, mk3 and mz which are globally inferior to 75 mg/L indicates low levels of physical pollution of water. The high Suspended solids recorded at the stations F2, mk1 and mk2 (2-381 mg/L) could be related to the fact that this points are situated below pig farms and car washing areas. While the high values of SS in A1, A2 and A3 is due to the fact that, this stream is located in a zone of high

anthropic activities of the main market and food market of Bamenda. This streams are the main receptacles of all sort of waste from the population. This results are similar to those obtained by Ajeagah *et al*. (2016) on the Olezoa in Yaounde where one of the stations received waste from the popular student residential quarter Yaounde (Banamosadi).

The low Turbidity values (2 – 99 NTU) and colour (9 – 197 Pt.Co) at the sites mf1, F3, mk3 and mz across the study period present a low load in organic matter of water and a low input of allochtonic matter in this hydrosystems. It was noticed that this sampling points are located at the periphery of the town. So, the water at this point is less turbid which gives much time for particles to settle to the bottom of the stream. This results are in concurent with those of Foto Menbohan *et al*. 2012, 2013 in sub urban streams of Yaounde. But the observed results are higher than those obtain by Tchakonté *et al*, (2015) in the sub urban towns of Douala (2 – 66 NTU) and (0 – 138 Pt.Co) for Turbidity and Colour respectively. Conversely, high values of Turbidity (3 – 393 NTU) and Coulor (11 – 1156 Pt.Co) were recorded in those point located in and around the contral town (mf2, F1, F2, Mk2, A1, A2 and A3) which are indicative of anthropogenic pollution. Dhirendra *et al*., 2009 underlines that, rivers which received diverse urban effluent are rich in fibers and other suspended solids and shows high Colour and Turbidity values.

The high values in the percentage saturation of dissolved Oxygen (70 %) observed in the stations mf1, mf2, mf3, F1, mk3 and mz shows the clean nature of water at this points which is largely characterized by photosynthesis. These sampling points has large stones and rocks which create turbulence in the waters and favours re-oxygenation at the water / are interphase (Fernanades *et al*., 2014). This results are in accordance with those of Ajeagah *et al*., 2018 (72%) in the forest zone of the central region. The sampling points situated along the central business district (CBD) showed low dissolved oxygen saturation which attest for a high influx of organic matter into the different points as a result of urbanization activities. To this effect, Elias *et al.* (2009) and Cabral-Oliveira *et al*. (2014) suggested that, the high levels of biodegradable organic matter in a river increases the biological, biochemical and chemical demand in oxygen. Hence, a high oxygen consumption in processes such as organic matter degradation by decomposing microorganisms. This hypoxic nature of urban streams was already highlighted by Foto Menbohan (2012), Tchakonté *et al*. (2015) and Ajeagah *et al*. (2016, 2017). Seasonally, Higher dissolved oxygen saturation was recorded during the rainy season in almost all the sampling points. This may be due to the combined effects of higher

wind energy and heavy rainfall which causes mixing of freshwater. A previous study by Damotharan *et al.* (2010) observed similar results.

The low values of Oxydability observed in the sampling points mf1, mf2, mf3 and A3 is an indicator of a low organic and inorganic oxydable matter content of this waters. Hence shows low metabolic activities of decomposers in this medium. This observations concurs with that of Williams *et al*. (2012). Kaniz *et al*. (2014) also noted low levels of Oxydable matter in the Merbok Estuary in Kedah, Malaysia

The high oxydability values observed at the stations F1, F2, F3, Mk1, mk2 and A1 could be explain by an excessive influx of organic and inorganic matter of anthropogenic origin into the different points of the hydrosytems. This streams (Furmuki, mankon and Ayabah) flows across the heart of the town, suggesting a synergy of domestic and urban pollution. To this effect, Verneaux (1970) and Davinder *et al*. (2013) underscores that, an Oxydability value above 6 mg/L is an indicator of high organic pollution and poor water quality. Higher oxydability values were observed during the dry season compared to the rainy season (figure 14). This value accounts for the high decomposition of organic material over this period which is directly correlated with burdens of organic materials in streams (Grafny *et al.* 2000).

Looking at the mineral nitrogen forms (NH_4^+ and NO_3^-) and orthophosphates (PO_4^{3-}), it was noticed that, their levels were low in the Mufueh and Mezam streams showing a low mineralization process of the streams which is distinguish by a low influx of substances, low organic matter, low nitrogenous and phosphate metabolic waste from human activities. This results are similar to those obtain by Ajeagah *et al*. (2018) and Foto Menbohan *et al*. (2013) in streams situated in sub-urban towns of Yaounde. Low levels of mineral nitrogen and orthophosphates were also noted by Davinder *et al*. (2013) in the Porsuk streams, western Turkey.

The spatio-temporal fluctuations of mineral ions (moderately higher) in the Furmuki, Mankon and Ayabah streams could be related to the input of urban or domestic waste into this streams. The moderately high water content in mineral nitrogen and orthophosphates would reflect the high content of these waters in decomposing organic matter and their low dissolved oxygen. Indeed, average levels of this variable above 1 mg / L in the different stations, highlight critical water pollution (Nisbet and Verneaux, 1970). This predict sources of pollution upstream of the different sampling stations (Rodier *et al*., 2009). However, in this streams, mineral nitrogen contents increases from upstream to downstream and could be

explained by the mineralization of the substances that accumulates gradually and whose residence time is greater downstream. These observations are in line with the concept of river continuum process, which considers that downstream sectors of rivers are sedimentation zones dominated by organic matter Vannote et al. (1980), Benda *et al*. (2004).

The pH observed in all sampling stations, ranges between neutral and alkalinity with no significant variation. This observations differed from that of Tita *et al*. (2012) who showed that the waters of Bamenda were slightly acidic. According to Azinwi *et al*. (2017), the soils in Bamenda are composed of fine sand, fine clayey, silt and clay giving it a slight acidic to neutral. To this effect, Arienzo *et al.* (2001) proposed that, the physicochemical properties of a river are directly link to the soils of it drainage basin. This almost basic nature of the water could be explained by the large influx of urban and domestic residue into the streams. According to Wang *et al.* (2012), pollution contributes to an increase in the pH of streams.

The low alkalinity values obtain in most of the stations (2 – 36 mg/L) could essentially be due to the low acidity and low mineralization of this waters. Rodier *et al*. (2009) state to this effects that, variation of water alkalinity is directly link to it mineralization state and the oxidation of organic component. Mary (1999) thinks that, the soil nature of the drainage system of the river equally influences the concentration of hydrogen carbonates and the bicarbonates. Conversely, the moderately high values of alkalinity observed at A1 and A2 (8 – 78 mg/L) could be due to a discharge of waste water and alkaline waste of anthropogenic origin since this stations are close to car maintenance garage and Bamenda food market respectively. This values are inferior to those obtained by Ajeagah *et al*. (2016) (48 – 196 mg/L) in the urban town of Yaounde and largely inferior to those of Tchakonté *et al*. (2015) in the sub-urban (0 – 38 mg/L) and urban towns (156 – 1050 mg/L) of Douala.

The high values of electrical conductivity (21 – 466 µS/cm) and TDS (12 – 283 mg/L) observe in most of the sampling points especially in stations located downs stream is probably due to the continuous discharge of highly mineralized urban and domestic wastes into this streams. Similar findings were also observed by Manikannan *et al*. (2011). Montgomery (1992) highlight the fact that, such discharges are usually rich in divest mineral pollutant (organic, sulphates, phosphates and metallic). This idea is also supported by Bellos and Sawidis (2005) in their theory that, water bodies rich in electrolytes have high conductivity values between and are characterized as polluted.

Based on the values of Organic Pollution Indice (OPI) obtain, it shows that the overall pollution state of streams in Bamenda are moderate (this varied from null pollution to

moderate pollution from one sampling point to another but was dominated by moderate pollution). This results are similar to those obtained by Kaniz *et al.* (2014) in some stations of the Merbok Estuary, Kedah, Malaysia and Nyamsi Tchatcho *et al.* (2014) in some reference stations of a sub-urban forest stream in Yaounde where the levels of pollution varied between moderate to null. This pollution level in Bamenda, could be explain by the low rate of domestic waste collection by the city council and largely by the absence of a waste collection plan and the absence of a communal waste treatment plant. Here, only 30% of the population has access to thrash cans from the city council and the rest 70% of the population dump their waste in the plots or streams around them as a result of poor mentality of the population and the (Azinwi *et al*., 2017).

As for what concern heavy metals, the concentrations of copper, Nickel, Cadmium, Cobalt, Iron and Zinc remained very low throughout the study period. Rodier *et al*. (2009) pointed out that, these metals are usually found in trace quantities in natural water (ranging from a few µg / L to the order of tens µg / L); this was exactly the case with these metals in the five streams in the town of Bamenda. This results are similar to those obtain by Asongwe and Yerima, (2016) in the Urban and Peri-Urban Wetlands of Bamenda, Kengni *et al*. (2012) find similar copper, nickel and zinc concentrations in streams of the Mgoua watershed in Douala. In addition, the zinc and copper concentrations are consistently lower than WHO standards (2006) for surface water quality. However, this metal concentration were relatively higher in the sediments of this streams and it varied from one sampling point to another. While the concentration for some metals (Cr and Pb) were low in the sediments, some others (Cr and Fe^{2+}), were very high in some sampling sites. Variations of the concentrations of these metals were tandem to specific site activities. This behavior can be attributed to pollution sources existing in the surrounding area. The seemingly high heavy metal contents of some of the sediments could also be associated with their alluvial-colluvial origin and the imperfect drainage in the streams. Bellos and Sawidis (2005), also reported high concentrations of heavy metals in stream sediments (Gleysols) in the Yaounde municipality.

Concerning the concentration of the cations in the water colon, varied as follows $Na^+ > Ca^{2+} > K^+$, this shows that Na^+ is the most abundant cation followed by Ca^{2+} in streams of the study area. This results are completely different from those obtain by Magha *et al*., 2015 ($Ca^{2+} > Mg^{2+} > K^+ > Na^+$) in various springs in Bamenda municipality with Ca^{2+} being the most abundant and Na^+ the least abundant. The main source of Ca^{2+} and Na^+ may be from the weathering of calco-sodico feldspaths and hornblende in the basic rock (McDonald *et al*.,

2008). While the most common source of K^+ is the decomposition of silicate minerals (Marzoli *et al.*, 2000).

III-2-2- Biological characterization of the stream assessed

III-2-2-1- Taxonomic richness of the benthic macro fauna

Regarding the biological data obtained in the course of this research work, 113 taxa of benthic macroinvertebrates were identified in all the five streams and their 13 sampling points. This taxa are low compared to the 178 taxa obtain by Tchakonté *et al*. (2015) in the urban and sub-urban streams of Douala and the 197 taxa gotten by Foto Menbohan *et al*. (2012 and 2013) in the urban and sub-urban streams of Yaoundé. This could be justified by the high urbanization and anthropization of Bamenda town. This data is supported by several authors in that, the number of benthic macro invertebrate species reduces drastically with increase in urbanization (Grimm *et al*., 2000; Xu *et al.,* 2013; Albrecht *et al*., 2013). Furthermore, among the current threats to biodiversity, urbanization is of prime importance (McDonald *et al*., 2008; McKinney, 2002) and is currently the second largest cause of ecosystem destruction in the world (Ellis *et al*., 2010). The differences in diversity observed in the different urban towns could be explained by the fact that, the streams in Yaounde receives essentially organic pollutant while those of Bamenda town, besides receiving the organic pollutants, there also collect larger agricultural waste from the different farms since farming is the main activity of the population. The high abundance of Arthropods (111 taxa) that is largely dominated by Insects (100 taxa), confirm their bio plasticity and their ability to colonise a high variety of ecological niches (Caryou *et al*., 2000; De Meester *et al.*, 2005).

Generally, a high variation in the taxonomic richness of the different streams in the Bamenda drainage basin was noted. This taxonomic richness of taxa reduses as one move from less polluted quarters to highly polluted ones (Central Business District). 94 taxa were collected in the Mufueh stream, 60 taxa in Furmuki, 57 taxa in Mankon, 55 taxa in Ayabah and 37 taxa in the Mezam stream. Willigalla and Fartmann (2012) assumed that the quality of water bodies increased along an urban- sub-urban gradient.

The high taxonomic richness observed in the Mufueh stream and it's 3 sampling stations could be link to the fact that, it originate and flows at the periphery of the main Bamenda urban settlement and this part of the town is less populated. The stream has a relatively stable and heterogeneous microhabitat which accommodate a large number of taxa. This is in line with the observations made by Foto Menbohan (2012) and Tchakonte et al.

(2015) who had 96 taxa in urban areas and 178 in sub urban towns of the Central and Littoral Regions of Cameroon respectively. Similar results were gotten by Jeanmougin *et al*. (2014) in ponds of a megacity (Paris, France), and Camara (2013) in the National Park of Banco (Ivory Coast). The taxonomic richness observed in this stream is greater than that recorded by McKinney (2008) in an urban setting of the United State which presented more sampling points. The presence of some tolerant groups like the EPT (Plecoptera were only seen in this stream), certain families of Odonata (Ashnidae, Gomphidae), Coleptera (Dytiscidae, Gyrinidae, Haliplidae, Hhydrochidae), Hemiptera (Hydrometridae, mesoveliidae, Gerridae) and the rare sub families of Chironomidae (Tanypodinae and Orthocladiinae) shows that, this stream is of good and acceptable physicochemical quality and shows good ecological quality which is appropriate for a large diversity of macro fauna taxa. This is in line with the conclusions of Ajeagah *et al.* (2018); Tachet *et al*. (2010); Alvial *et al*. (2013) who stipulate that, some of this groups has an average sensitivity to an increased in organic pollution. Mora and Csabia (2008); Wilson and Ruse (2005); Yunakov and Germann (2012) noted that, the family Chironomidae is a very diversified group with large number of species, general and sub-families (such as Tanypodinae and Orthocladiinae) which are sensitive to pollution.

In the Mufueh stream, Insects dominated the taxonomic composition with 100 taxa being 98% of the taxonomic richness. In this class of insects, orders such as, Hemiptera, Coleoptera, Trichoptera and Diptera were the most represented. This fauna representation is similar to that observed by Nyamsi Tchatcho *et al*. (2014) in the sub-uban forest streams of Yaounde town whose faun was dominated by Coleoptera, Hemiptera and Odonata. On the same light, Camara (2013) highlighted a high taxonomic richness of Insect of 118 taxa (89%) with a domination of Coleoptera, Trichoptera, Odonata and Diptera in the Banco National Park (Ivory Coast). Song *et al*. (2009) pointed out that, groups like the Ephemeroptera, Plecoptera, Trichoptera and Coleoptera constitute the most abundant and high specific richness of benthic macro invertebrates groups in stream with little or no anthropogenic perturbations. Willigalla and Fartmann (2012) identified factors that determine the species richness of benthic macro invertebrates in 22 central European cities, with a particular focus on the urban-sub urban gradient

On the seasonal plan, there is no significant variation in the taxonomic richness and composition of the macro fauna in the mufueh stream. This could be liken to the low variation in physicochemical parameters in this stream throughout the study period. Edia *et al*. (2007)

and Tchakonte *et al*. (2015) showed the non-seasonal variability in the taxonomic richness in some streams of Ivory Coast and Cameroon respectively.

Conversely the low taxonomic richness registered in the other four streams, Furmuki (60 taxa) Mankon (57 taxa) and Ayabah (55 taxa), could be analised as a result of a poor physicochemical quality of water and the physical modification of the different micro-habitats due to a flashier hydrograph, elevated concentration of nutrients and contaminants, altered channel morphology (symptoms of the urban stream syndrome, Dana, 2012). In fact, in addition to the multiple sources of domestic, municipal and agricultural pollution, the inhabitant along this streams frequently engage in the straightening of river channels, so as to ease the flow of water and avoid flooding. This is done through construction of embankments, raising foundations, widening stream channels and land reclamation along the streams (Fogwe, 2016). This activities destabilizes the benthic communities, destroys riparian vegetation, micro-habitates, homogenizes stream bed and reduces benthic macro invertebrates' diversity (Seger *et al*., 2012; Dana, 2012; Zhang *et al*., 2013).

Since this streams, flows across the dense urbanized town, the macro-fauna is essentially represented by taxa which are said to be resistance to pollution (Chironomidae, Syphidae, Simulidae, Tipulidae, Ephrididae, Sciomyzidae, Physidae and Glossiphoniidae). The absent of pollution sensitive taxa like Plecoptera, Gyrridae, Aeshnidae etc that were present in the Mufueh stream, confirms the deterioration of water and sediment quality of this streams. The works of Foto Menbohan *et al*. (2012, 2013) and Ajeagah *et al.* (2016, 2017) in the hydrographic networks of Mfoundi, in the urban city of Yaounde, showed, an absent of pollution sensitive taxa and the domination of pollution tolerant taxa in urban rivers. Similar results were obtain by Mateusz and Ioannis (2014) in the streams of Greece which are under urban influence and the pollution sensitive macro-fauna were replaced by the pollution tolerant taxa. In this light, Sæther and Spies (2013) and Colas *et al*. (2013) states that, larvae of the Chironominae sub-family (especially Chironomus) and Physidae family are tolerant to organic, chemical and even metallic pollution. This Chironomid taxa were the most diversified in all the three streams due to their several anatomical and morphological adaptations like the procession of hemoglobin which has high affinity for oxygen. There can trap oxygen by undulating their bodies or anal tubes in the water or in their tubes, this helps them resist the hypoxic conditions of the water (Ajeagah *et al*., 2016). Furthermore, their highly branched thoracic horn and the anal tubes on the last abdominal segment plays an

osmoregulatory rule which permits this organisms to survive in highly mineralized waters (Ajeagah *et al*., 2017).

Similarly, other Dipteran groups such as Syrphidae, Psychodidae, Ephydridae, Sciomyzidae are frequently sampled in streams with high organic matter load (Rueda *et al*., 2002) this is because the larvae of Syrphidae and Ephydridae has respiratory siphon situated on their abdomen which extent out of the water and permit them absorb oxygen from the atmosphere which help the survive in very low oxygen ecosystems (Dan and John, 2013). On the other hand, Wang *et al.* (2012) showed that Physidae proliferate in much polluted environments. This pulmonary Gastropods are better adapted in to environmental adverts conditions given that, there have a protective cover and can also inhale atmospheric air directly.

At the Mezam stream, which is considered as a collection station in this study, since it located further downstream of all the other stations and collect water from all the other four streams (Mufueh, Furmuki, Mankon and Ayabah). The lowest taxonomic richness (37 taxa) was obtain at this station. This low diversity could be as a result of it high Electrical conductivity (EC) and pH levels. As for the high EC, Bellos and Sawidis (2005) stated that, water bodies rich in electrolytes have conductivity values between above 250 µS/cm and are therefore characterized by high domestic and urban pollution and for the high pH levels (8.24 CU) downstream. Anila *et al.* (2007) reported that pH values change from acidic to alkaline when colloidal particles mix with seawater and become coagulated. This mixing results in higher pH values downstream. Similar results were recorded by Kaniz *et al*. (2014) in the Merbok Estuary, Kedah, Malaysia where higher pH values were recorded at the stations located further downstream within the estuary. He added that long exposure to high pH negatively affect the macro fauna and leads to the disappearance of some taxa.

Comparing the high taxonomic richness obtained at Mufueh stream, which is considered as a reference stream in this work, we can conveniently say, the rate of macro invertebrate specific diversity lost by total disappearance of sensitive taxa in the other streams in the center of the town is rapidly increasing. In fact, because of their sedentary nature, benthic macro invertebrates cannot escape this growing pollution. These observations concur with those of Davies *et al*. (2010) and Cabral-Oliveira *et al*. (2014) who showed that pollution destabilizes and greatly reduces the diversity of benthic macro-invertebrates and causes on one hand the total disappearance of sensitive species which originally live here and on the other hand, the proliferation of tolerant species which are adapted to such conditions.

III-2-3- Abundance dynamics of the different macroinvertebrates communities

III-2-3-1- Dynamics of the chironomidae

The family Chironomidae was identified to genus and species levels with a view of exploring their bioindication potential (changes in Chironomidae communities in relation to water quality). Among families of aquatic macroinvertebrates, Chironomidae are probably the most abundant, widely distributed and species rich family with an extraordinary ecological range (Harrison, 2002; Porinchu and MacDonald, 2003; Luoto, 2010). Results revealed that chironomid communities of in Bamenda Rivers, at genus and species levels of taxonomic identifications, were sensitive to changes in water quality decreasing in species diversity and richness from Mufueh through Furmuki to Ayabah stream. The Mufueh stream showed more diverse chironomid communities compared to Furmuki, Mankon and Ayabah streams that was consistently dominated by the *Chironomus* spp. and indicating possible slight differences in the water quality status in the streans. Among the three subfamilies of chironomids recorded (Tanypodinae, Orthocladiinae and Chironominae), Chironominae had the highest number of taxa over the study period. This observation corroborate that of Odume *et al*. (2011) who noticed a high diversity of Chironominae compared to Tanypodinae, Orthocladiinae in the Swartkops river, south Africa.

Analysis of Chironomids egg masses shows a low abundance of the egg masses. The low abundance and absence of this egg masses in the Mufueh and Mezam could partly be explained by the low temperatures observed in the streams. Tokeshi (1995) noted that, the duration of the egg stage in chironomids appears to be primarily influenced by temperature which decreases with the length of the egg stage. Bouchard *et al*. (2007) says, the low temperatures delays egg hatching but when temperatures rises to about 20^{o}C, the eggs will hatch in 2 – 3 days. On a similar note, there was a clear difference in the total richness of chironomid taxa between Mufueh and the other four streams with a significantly larger number of taxa present in Furmuki, Mankon and Ayabah streams. The differences in taxa richness between these streams are related to the ability of warm-adapted taxa such as Chironomini and Tanypodinae to utilize such while the relatively low temperature adapted community of Orthocladiinae proliferated in the mufueh several of. This observation is concur with that of Bouchard *et al*. (2007) who observed a high taxonomic richness of Chironomini and Tanypodinae in relatively warm streams compared to Orthocladiinae in cold streams contrasting thermal regimes, By contrast, the water temperatures in Mufueh streams are

apparently not high enough to support these warm-adapted taxa and they are eliminated from the community or they do not colonize these habitats.

Application of living organisms in bio-monitoring of aquatic ecosystems has been a common practice in Cameroon (Tchakonte *et al*., 2015; Ajeagah *et al*., 2017) In this study, chironomid community composition differ between less polluted stream and highly polluted streams. A number of chironomid species collected from these streams such as *Chironomus riparus, Chironomus crassicaudatus, Chironomus staegeris, Chironomus stigmatenus* and *Polypedilum laetum* proved to be good bioindicators for the type of organic and agricultural pollution in the Mezam drainage system. Agricultural activities, through the use of fertilizers and organic manures, often lead to the nutrient enrichment of water and sediment, as does the input of both treated and untreated domestic wastes (Harding *et al*., 1999).

Consequently, the Furmuki, Mankon and Ayabah streams which receives urban waste from the town and agricultural waste draining upstream from the gardens in Santa located on the Bamenda escarpments. The streams were dominated by pollution-tolerant species, such as *Chironomus riparus, Chironomus crassicaudatus, Chironomus staegeris, Chironomus stigmatenus* and *Polypedilum laetum*. This results are similar to those obtain by Ajeagah *et al*. (2017) and Tchakonte *et al*. (2015) in Yaounde and Douala urban towns respectively. According to Steven, 2006; Al-Shami *et al*., 2010b; Wrigh and Burgin, 2009, streams with high nutrient concentration of various sources (agricultural and anthropogenic), are a suitable habitat for *Chironomus* spp. This findings is inline with those of Dermott, 1991; Marziali *et al*., 2010 in which some chironomid genera such as Procladius and Chironomus increasingly dominant in more polluted sites. Similar results where reported from Malaysian rivers such as Langat River (Azrina *et al*., 2006) and Linggi River (Ahmad *et al*., 2002). The group Chironomus dominated in polluted streams because, they have hemoglobin that fulfill physiological roles in transporting and storing oxygen in the larvae that burrow in polluted and hypoxic mud (Osmulski and Leyko, 1986). Moreover, due to special adaptations, *Chironomus* spp. larvae can survive in organically and inorganically polluted rivers with low concentration of dissolved oxygen and high concentrations of pollutants including metals such as Zn (Mousavi *et al*., 2003; Wright and Burgin, 2009; Marziali *et al*., 2010).

On the other hand, a low abundance of some pollution sensitive chironomids (*Eukiefferiella* sp., *Zalutschia* sp. *Brundiniella eumorpha* and *Micropsectra* sp.) were recorded in the Mufueh and Mezam streams. The streams has relatively high Dissolved Oxygen concentration and receives a relatively less polluted. This observation is in line with

the works of Meregalli *et al*. (2000), in River Arrone, Central Italy where he realized the domination of *Eukiefferiella* sp. and *Micropsectra* sp. in less organic polluted stations while chironomus dominated in organic polluted stations. *Micropsectra* sp. will prefer and flourish in less polluted rivers (Harrison, 2002).

III-2-3-2- Morphological larval deformities and feeding mode in Chironomidae communities

Examining the combine effect of urban pollution and high metal concentration in sediment on Chironomidae by recording the different mouth parts deformities in this organisms. By calculating the morphological percentage deformity of the organisms, it was realized 19 % mentum deformity against 8% mandible deformity. This percentages are low compared to the works of Meregalli *et al*. (2000) who reported high levels of morphological deformities reaching 40 and 10% in menta and mandibles respectively, under Zn and Cu concentrations of 212 and 28 ppm, respectively. Nevertheless, high concentration of sediment metals probably induce some morphological deformities in *Chironomid* spp. as observed in this study. The identified deformities are indicative of certain environmental pollution and poor water quality on the studied sites and could serve as an empirical tool for their assessment. According to Morse *et al*. 2007, these freshwater organisms are continuously in contact with water and sediments and respond to all environmental conditions, including synergistic combinations of pollutants.

However, Hamilton and Saether (1971) suggested that a study of the morphological abnormalities in individual organisms might prove particularly useful in determining the biological effects of contaminants in aquatic ecosystems. Petersen and Petersen (1983) stated that, changes at the organismal level might be more useful than changes at the community level for purposes of environmental monitoring. They noticed that, individual response occurs before community responses and thus could provide an earlier warning of pollution. The larval head capsule morphological deformities in *Chironomid* spp. observed in Bamenda hydrosystems are comparable to those reported earlier by Al-Shami *et al.* (2010) in South Africa. This study clearly showed that deformation of the mentum is a widespread developmental anomaly in *Chironomid* spp. Accordint to Vermeulen (1995), *Chironomid* spp. larvae are highly susceptible organisms to morphological deformation. They can be used as important indicators of the effects of water and sediment contaminants. Therefore, incidences of deformities in organisms at particular sites could indicate pollution load at such sites (Jeyasingham and Ling, 2000).

The mouth parts deformities in *Chironomus* spp. larvae differed among the different streams since the sources, nature and concentration of pollution in these streams also differed. For example, the highest incidence of deformities in larval *Chironomus* spp. was observed at Furmuki stream followed by Ayabah stream which shows high concentration of pollution and low water quality. None of the deformities was seen in the Mufueh stream with low urban and metallic pollution. It is difficult to say if this deformities were highly influenced by urban, agricultural pollution or high metallic concentration. However, Dermott (1991) stated that there is no distinct evidence that could determine which of the various urban, agricultural and industrial chemicals induce deformation in the chironomid larvae. Though Nazarova *et al.* (2004) reported the association between deformities in *Chironomus* spp. larvae and contaminated sediments.

Considering the deformities in *Chironomus* spp. larvae are link to the urban runoff, domestic waste and agricultural residues (fertilizers, fungicides, herbicides, and insecticides) that are routinely applied to the surrounding farms and gardens located on the Bamenda escarpment. Meregalli *et al*. (2000) reported that increase in frequency of deformities was correlated with high levels of metal, coal tar, urban or agricultural run-off, and pesticides.

Deformities in Chironomidae larvae are thought to be effects of exposure to particular chemical contaminants (Martinez *et al.,* 2006). However, most of the deformities recorded were associated with the mentum and mandible and the feeding ability of deformed chironomids could be affected. This can contribute to depletion of their population and ultimate reduction in species diversity and richness. The subfamily Chironominae expressed comparatively higher incidences of deformities. These taxa are mostly detrital feeders (Armitage *et al.,* 1995) and their mouth parts are often in close contact with sediment bound contaminant. The occurrence of deformities in other genera such as *Tanypus* sp. and *Radotanypus florens* in this study, highlights the importance of deformities screening in other chironomid genera. This is because different genera shows different sensitivities to pollutants.

Observing the chironomid gut, three main type of food stuff were noticed along their guts which dominated in the different groups; macrophytes and algae in the guts of Chironominae and Orthocladiinae while the Tanypodinae groups largely presented remains animal material (other *chironomid* ssp.) in their gut. This observations is in line with that of Henriques- Oliveira *et al*. (2003) In Rio da Fazenda who noted that, the most important items after detritus, were leaf, wood fragments and fungi in the diet of Chironominae and Orthocladiinae subfamilies. While animal remains were found in Tanypodinae. According to

Pinder (1986), Tanypodinae larvae have a diverse diet among animals and plants items. The occurrence of some genera in the gut contents of these chironomids could partly be due to their availability in the habitat and can also be related to prey size and the predator's developmental stage. Dias *et al*. (2008) says, many factors, such as larval size, food quality and type of sediment might influence the larval feeding behavior. Looking at what was ingested by the larvae, Tanypodinae can be classified as predators since they feed on animal material while Chironominae and Orthocladiinae are particulate organic matter feeders as fine fibre, macrophytes and algae were seen in their gut contents. Henriques- Oliveira *et al*. (2003) talks of the considerable flexibility in the mode of feeding among chironomids

III-2-4- Dynamics of Aeshnidae (*Aeshna* sp.)

Looking at the different Odonata groups, we noticed a low diversity and high taxonomic abundance. However, Odonata species richness decreases with increased urbanization, indicating that urbanization has a negative effect on the species diversity of the organisms (Willigalla and Fartmann, 2012). The low abundance and divisity recorded in Bamenda municipality may be due to the homogeneity of habitats caused by the influx of domestic, urban and agricultural runoffs. This low diversity fails to corroborate the hypothesis that, greater structural complexity increases the availability of niches, leading to a greater species diversity. According to some authors, the species richness of Odonata depends on the availability and heterogeneity of habitat as many species are associated with streams of forested areas (Suhling, 2013; Silva *et al*., 2010). Libellulidae, Calopterygidae and Coenagrionidae dominated in species number and had a wider distribution. This corespond with the findings of Costa *et al*. (2000). According to Dalzochio *et al*. (2011), these families are characterized by largest body size of individuals which increases their dispersal ability. The variability of Odonata fauna across the different sampling sites and different seasons is probably due to the sensitivity of most species of this group. According to Moore (1997), pollution from sewage, fertilizers and pesticides decreases the population of Odonata in streams. Though Hernandez *et al*. (2012) says some species are more tolerant to environmental impacts because thy possess morphological and physiological adaptations associated with the habitat structure and can survive in moderately contaminated waters

The species *Aeshna* sp. was only identified in one station (downstream of the Mufueh) which shows the special characteristics of this sampling site. The high vegetation cover in this station coupled with direct influence of leaf litter, and the very low current flow probably contributed to the presence of *Aeshna* sp. in these streams. This result corroborates

Ferreira-Peruquetti and De Marco-Junior (2002), who claimed that certain pollution sensitive species are solely found in streams with riparian vegetation, organic sediment, and in places with low water current. The importance of vegetation cover on the Odonata species distribution was also addressed by Remsburg and Turner (2009), as it provides structures for thermoregulation, foraging, territory defense, protection for adults, and contribute to the input of branches and leaves that provide places for refuge and larval development. The species *Aeshna* sp. could be consider as an indicator of good water quality since it's abundance increases in the mufueh stream. This period of the year is marked with heavy rains which increase water levels (hence increased availability and heterogeneity of habitat), high Dissolved Oxygen concentration in water and very low nutrient in water (Nitrates and Orthophusphates).

III-2-5- Dynamics of *Limnometra* sp. (Gerridae, Hemiptera)

The order of Hemiptera was the most diverse and relatively abundant in all the streams with a total of 10 families and 27 taxa. This high diversity and density is comparable to that of Takhelmayum *et al*. (2013) in the lower reach of Moirang River in Manipur, N.E. India. Huang *et al.* (2010), in Du river basin in northern Vietnam also found Hemiptera to be the most diverse order. According to Selvakumar *et al.* (2014), changes in community structure is mainly due to changes in the geomorphology and the associated destruction of in-stream physical habitats. The relatively high abundance of Gerridae in the streams could be due to their modified body structure and the fact that there stay water surfaces. They can walk on water surfaces and utilize atmospheric variables without totally depending on water. The dominancy of Gerridae was also recorded by Naranjo *et al.* (2010) in their study of aquatic and semiaquatic Heteroptera (Insecta) in high altitudinal systems of Cuba. The causes of fluctuations in insect abundance, dominance and distribution include macroclimatic and microclimatic changes and variation in the availability of food resources (Zettel *et al*., 2009).

The vast majority of species presented a wide seasonal distribution, whereas, a few were restricted to just one season (*Limnometra* sp., *Limnometra matsudai*, *Graptocorixa* sp. *Limnogonus* sp.) dominated in the rainy season. Saulich & Musolin (2007) stated that in regions where environmental conditions are stable and favorable, some Hemiptera may breed all year round, thus having a homodynamic type of seasonal development.

Contrarily to the other species of the Gerridae, which were seen in almost all stations, the species *Limnometra* sp. and *Limnometra matsudai* of the genus Limnometra were restricted to the first sampling sites (upstream) of Mufueh, Mankon and Ayabah streams. The water at this points

are shallow with low velocity and the organisms are found resting at shaded parts of the water body. This observation corroborate with Zettel *et al*. (2009) who stated that, *Limnometra tiomanensis* was mostly found at lower reaches of small and shallow freshwater streams, where the current is relatively slow and the water is still fully freshwater (0.02 % salinity). Concerning morphological features of the Limnometra, we noticed that, *Limnometra* sp. differ from *Limnometra matsudai* and *Limnometra ciliata*, particularly at the Connexival spines which is narrow, convergent, curved and do not reach apex of proctiger on Segment 8 while in *L. cilita* and *L. matsuda* the Connexival spine is straight up and goes beyoun the proctiger of segment 8. However, these species will still be compared to others occurring in Cameroon and elsewhere, to know whether we are face to just a morphotype or a new species.

CONCLUSION, RECOMMANDATIONS AND PERSPECTIVES

The diversity and community structure of benthic macro invertebrates as indicators of organic pollution (looking at both pollution sensitive and tolerant species) was studied in some urban streams in the Bamenda municipality.

The analysis of physicochemical variables showed that, the Mufueh stream which is situated at the periphery of the town, with a dense riparian vegetation cover along its banks, receives less urban and agricultural perturbations and its water is of good ecological quality. It has low water temperatures, good dissolved oxygen level, low mineralization, neutral pH, with a low organic and metallic pollution with a sandy clay sediment base. Though the Mufueh stream is situated in the town of Bamenda, it shows characteristics of sub-urban streams. Contrarily to the above observations, the Furmuki, Mankon, Ayabah and Mezam streams which flow pass the highly populated Bamenda urban main settlements has very little riparian vegetation cover and sun rays hit the water colon directly. The water is of poor ecological quality especially at the stations, F2, F3, mk2, mk3, A2 and A3 which flow pass the main markets of the town, pig animal farms and poorly constructed toilets that drains into the water. Water colour at this points is relatively high, turbid, highly mineralized, poorly oxygenation, relatively high temperatures with high organic nutrient levels. Comparatively, this streams showed relatively high metallic concentration in the water and especially in their sediments. Based on all this, we can conveniently say, the environmental water quality of Bamenda streams is polluted due to anthropogenic impacts such as municipal and sewage effluent discharges, run-off from informal settlements and agricultural activities such as livestock farming, and has consequently impacted on the benthic macro invertebrate communities. Since there are the main receptors of waste and all sort of effluent from the town.

The present study showed that, the distribution and abundance of aquatic insect at families and genera levels are influenced by physical and chemical condition of the streams. Changes in physical nature altered the stream insect community structure. This change in functional groups and habits of stream insects could fundamentally alter the stream ecosystem function. This could directly affect the diversity and distribution of other fauna such as fishes, which depends upon stream insects for their survival

The study also showed the possible influence of abiotic factors and anthropogenic contaminants on the diversity of macro-fauna. The Mufueh stream was the most diversified. The population here, was dominated by pollution sensitive families (Perlolidae, Pteronarcyridae, Limnometra, Aeshnidae) with high numbers of EPT, EPTC, EPTH and EPTD groups in all three sampling stations of the stream which show a good and better

structure of the different taxa. This is link to the good ecological state of the stream (good riparian vegetation, high oxygen concentration, low temperatures, low mineralization, little or no anthropogenic pollutant).

In the other streams (Furmuki, mankon, Ayabay and mezam), there was relatively low diversity. The population was dominated by pollution tolerant families like the Glossiphoniidae, Physidae, Tipulidae, Sciomyzidae and most especially, the genus Chironomus. On the functional aspects, this groups are mostly saprophytes, filters, detritus and has extra adaptations for respiration. The abundance and diversity further reduces as one goes downstream since the streams collect the different effluents as it flows down town and this effluence increases organic content and turbidity, reduces dissolve oxygen content, increase temperatures, mineralization and also increases water pH. All this factors reduces the benthic macro-invertebrate abundance and diversity. In addition, increased river bed sediments by the influx of organic matter, reduces the habitats (habitats homogeneity) but favours the burrowers hence, shaping the macro invertebrate communities.

Generally, this study provided better understanding of anthropogenic impacts due to urbanization on Bamenda stream macroinvertebrates with regard to water quality. The effects of polluted water quality was examined on different biological organisation as well as taxonomic groups (*Aeshna* sp. and *Limnometra* sp.). The biological water quality at each of the sampled site was determined while Chironomidae species identification provided evidence of marginal water quality differences between the five streams that accounted for differences in species compositions. This also showed how deterioration in environmental water quality affects different aspects of macroinvertebrate communities such as richness, abundance and diversity. The richness and diversity of EPTC groups were the most affected by water quality deterioration. Species identification also revealed that the genus Chironomus was the most tolerant of all the chironomids sampled and could serve as an indicator of organic polluted sites. The deformities in Chironomidae observed in this study provided indication of possible toxic contamination.

The genera and species within the family Chironomidae in the present study displayed varying degrees of sensitivity to water quality deterioration and therefore provided evidence of their bio-indication potential in Bamenda streams. The species level identification revealed evidence of differences in water quality between Mufueh stream and the others (Furmuki, Mankon and Ayabah streams). It indicated that, Furmuki stream was the most polluted, then followed by Ayabah and mankon streams with significantly low species diversity and richness. This results emphasized the importance of species level identification in biological

water quality assessment because within a family, species are differentially sensitive to pollution. This is reflected in the differences between the chironomidae assemblages at the 13 sampling sites of the streams in which some species like (*Cantopelopia gesta, Zalutschia* sp and *Eukiefferiella* sp.) were completely absent at sampled sites where the *Chironomus* spp. Dominated. This suggest differences in water quality at these sites. Without the species level data, it would have been erroneously conclude that, chironomids are all tolerant to municipal, domestic and agricultural pollution in the town of Bamenda.

The examination of mouth part deformities in Chironomidae was particularly useful. It provided evidence of the adverse effects of pollution in the different streams on chironomid communities and may serve as warning indicators of deteriorating water quality. Morphological, deformities also provide indication of species health and fitness of chironomids, which could impact on their ability to feed, and to perform ecological roles such as linking other food chains and utilization of energy and substances in the Bamenda drainage system.

RECOMMANDATIONS

Based on the above observations, we recommend to the general public, Bamenda city council and various researchers to take appropriate measures to protect and rehabilitate the various aquatic ecosystems of the town. It is necessary to put in place, a workable scheme which will help in urban waste management, protection and rehabilitation of the already seemly touch hydrosystems. The Bamenda city council should establish an efficient waste collector and pre-treatment center. Provisions for trash cans should be made in all the quarters and market junctions. The public should be sensitized on the impact of dumping waste into streams and be taught batter waste disposal methods as well. Activities such as land reclamation and river bed reduction and straightening should be strongly prohibited since such activities destroys hydrosystems and causes flooding.

PERSPECTIVES

At the end of this research work, we feel a few aspects which were not well understood at the beginning could be look into in future studies. This aspects are. 1) Establish a clear and potential autecological information on Afro-tropical macroinvertebrates in the whole of North West Region. This will help facilitate basic ecological research focusing on species biology and autecology in order to harness the full potential of our streams. 2) to extend the integrated environmental water quality approach including water chemistry (river and effluent physicochemical quality), macroinvertebrate-based biomonitoring (deformity

screening, taxonomic, and trait based approaches) and ecotoxicology (systematic investigation of effluent effects on stream organisms in model stream ecosystem) to other urban towns of the country. 3) Detect the Bioconcentration and Biomagnification of trace metals in the macroinvertebrates in aquatic system. 4) Carry out genetic mapping of macroinvertebrates with respect to different pollution gradients. 5) Evaluate impact of pollution on other macroinvertebrates groups and their eco-physiology.

REFERENCES

Abbott C. 2003. "Urbanization," Dictionary of American History, the Gale Group Inc., Encyclopedia.com.

Adriaenssens V., Simons F., Nguyen L., Goddeeris B., Goethals, P., DePauw N. 2004. Potential of bio-indication of chironomid communities for assessment of running water quality in Flanders (Belgium). *Belgian Journal of Zoology*, 134 (1): 32-40.

AE, 1999. Système d'évaluation de la qualité de l'eau des cours d'eau : Grilles de seuils par usage et fonction. 1(2): 23.

Ahmad A., Maimon A., Othman M., Mohd Pauzi A. 2002. The potential of local benthic macroinvertbrates as a biological monitoring tool for river quality assessment. *Proceedings of the Regional Symposium on Environment and Natural Resources*. 10–11 (4): 464–471.

Ajeagah Gideon, Enah Dickson, Foto Menbohan S. 2016. Chironomid bio-ecology in an anthropisized aquatic ecosystem in Yaounde (Cameroon): community diversity and relationship with the environmental variables of the water system. *Entomology and Applied Science Letters*, 3 (5): 196-203.

Ajeagah Gideon, Enah Dickson, Foto Menbohan S. 2017. A Study of the Morphological Structure of Chironomidae (Diptera) in a Tropical Urban Polluted Water System. *International Journal of Sciences*, 6 (6): 2305-3925.

Ajeagah Gideon, Gertrude Estelle, Siméon Tchakonté, Paul Alain, Geneviève Bricheux, Télesphore Sime-Ngando, Champlain Djiéto. 2018. Biomorphologie des crustacés d'un cours d'eau peu anthropisé en forêt équatoriale au Cameroun. *Revue des sciences de l'eau*, 31(1) : 29–40

Ajeagah Gideon, Kekeunou S., Njiawouo Pountigni E., Foto Menbohan S. 2014. Morphologie et abondance des stades de développement d'*Ilyocoris cimicoïdes* Linné 1758 (Heteroptera: Naucoridae) dans un lac anthropisé en zone tropicale (Cameroun). *Journal of Applied Biosciences*. 79: 6926 - 6937.

Ajeagah Gideon, Njine T., Bilong Bilong C., Foto Menbohan S., Wouafo Ndayo M., Nola M., Di Giovanni G., Huw S. 2010. Seasonal distribution of enteric opportunistic *Cryptosporidium* spp. (oo) cysts and *Giardia* spp. Cysts in a tropical water basin, Cameroon. *Water*, 2: 44-57.

Albrecht C., Föller K., Clewing C., Hauffe T., Wilke T. 2013. Invaders versus endemics: alien gastropod species in ancient Lake Ohrid. *Hydrobiologia*, 703: 165-175.

Alliaume C., Lasserre G., Louis M. 1990. Organisation spatiale des peuplements ichtyologiques des herbiers à Thalassia du Grand cul-de-Sac Marin en Guadeloupe. *Revue d'Hydrobiologie Tropicale,* 23: 231-250.

Al-Shami S., Salmah M., Hassan A., Azizah M. 2010b. Evaluation of mentum deformities of *Chironomus* spp. (Chironomidae: Diptera) larvae using modified toxic score index (MTSI) to assess the environmental stress in Juru River basin, Penang, Malaysia. *Environmental Monitoring and Assessment,* 10.1007/s10661-010-1630-1

Alvial I., Orth K., Duran B., Alvarez E., Squeo F. 2013. Importance of geochemical factors in determining the distribution patterns of aquatic invertebrates in mountain streams south of the Atacama Desert, Chile. *Hydrobiologia,* 709: 11-25.

Angelier E. 2003. Ecology of streams and rivers. *Science Publisher,* Inc. Enfield, 211-213.

Anila Kumary, Azis P., Natarajan P. 2007. Water quality of the Adimalathura estuary, Southwest coast of India. *Journal of the Marine Biological Association of India,* 49(1): 1–6.

Arienzo M., Adamo P., Bianco M., Violante P. 2001. Impact of land use and urban runoff on the contamination of the Sarno River Basin in Southern Italy. *Water, Air and Soil Pollution,* 131: 349-366.

Armitage P., Cranston P., Pinder L. 1995. The Chironomidae – Biology and ecology of non-biting midges. Chapman and Hall, London. 572 p.

Asongwe Godswill, Bernard Yerima, Aaron Tening. 2016. Spatial variability of selected physico-chemical properties of soils under vegetable cultivation in urban and peri-urban wetland gardens of Bamenda municipality, Cameroon. *African Journal of Agricultural Research*, 11(2): 74-86.

Azinwi Tamfuh1, Tsozué D., Tita M., Boukong A., Ngnipa Tchinda, Ntangmo Tsafack, Mvondo Ze. 2017. Effect of Topographic Position and Seasons on the Micronutrient Levels in Soils and Grown Huckleberry (*Solanum scabrum)* in Bafut (North-West Cameroon), *World Journal of Agricultural Research,* 5 (2): 73-87.

Azrina M., Yap C., Rahim Ismail, Tan S. 2006. Anthropogenic impacts on the distribution and biodiversity of benthic macroinvertebrates and water quality of the Langat River, Peninsular Malaysia. *Ecotoxicology and Environmental Safety*, 64: 337–347.

Balgah R., Kimengsi N. 2016. Building an indigenous agropastoral adaptation framework to climate change in Sub-Saharan Africa: experiences from the North West Region of Cameroon. *Procedia Environmental Sciences* 29: 126 – 127.

Balgah, S., Ndjib G., Ngwa S. 2008. Monitoring land use and land cover dynamics in Buea and Tiko sub divisions in Cameroon: A Natural Resource Management, Published in Annals of the Faculty of Arts, Letters and Social Sciences, University of Yaounde I. 1 (8): 321p.

Barbour M., Gerritsen J., Snyder B., Stribling J. 1999. Rapid bioassessment protocols for use in stream and wadeable rivers: periphyton, benthic macroinvertebrates and fish. 2nd edition, U. S. Environmental Protection Agency, office of water, Washington, D. C., EPA 841 – B – 99-002. 11 chapters, 664p.

Bardos M. 2001. Analyse discriminante: application au risque et scoring financier. Dunod, Paris, 224p.

Basu N., Scheuhammera A., Bursiand S., Elliotte J., Rouvinen-Wattf, Man Chan. 2007. Mink as a sentinel species in environmental health. *Environmental Research*, 103: 130-144.

Beasley G., Kneale P. 2003. Reviewing the impact of metals and PAHs on macroinvertebrates in urban watercourses. *Prog. Phys.Geog*., 26: 236–270.

Beaumont A., Cassier P. 1981. Biologie Animale: des Protozoaires aux Métazoaires épithélioneuriens. 3ème édition, Tome I, 459p.

Bellos D., Sawidis T. 2005. Chemical pollution monitoring of the River Pinios (Thessalia-Greece). *Journal of Environmental Management*, 76(4): 282–292.

Benda L., Poff L., Miller D., Dunne T., Reeves G., Pollack M., Pess G. 2004. Network dynamics hypothesis: spatial and temporal organization of physical heterogeneity in rivers. *BioScience* 54: 413-427.

Benetti C., Garrido J. 2010. The influence of stream habitat and water quality on water beetles assemblages in two rivers in northwest Spain. *Vie et milieu*, 60(1): 53-63.

Berg M. 1992. Freshwater biomonitoring and Chironomidae. Netherlands Journal of Aquatic Ecology 26 : 101–122

Bhat S., Meraj G., Yaseen S., Bhat A., Pandit A., 2013. Assessing the impact of anthropogenic activities on spatio-temporal variation of water quality in Anchar Lake, Kashmir Himalayas. *International Journal of Environmental Sciences,* 3: 1625-1640.

Bhattacharyay G., Sadhu M., Majumdar U., Chaudhuri P., Ali A. 2006. Assessment of impact of heavy metals on the communities and morphological deformities of Chironomidae lavae in the River Damodar (India, West Bengal). *Supplementa ad Acta Hydrobiologica* 8: 21-32.

Bijita Barman, Susmita Gupta. 2015. Aquatic insects as bio-indicator of water quality A study on Bakuamari stream, Chakras hila Wildlife Sanctuary, Assam, North East India, *Journal of Entomology and Zoology Studies*, 3(3): 178-186.

Binder E. (1955). Mollusques nouveaux de Côte d'Ivoire. Prosobranche d'eau douce. *Revue Suisse de Zoologie*, 62: 75-82.

Binder E. (1957). Mollusques aquatiques de Côte d'Ivoire: Gastéropodes. *Bulletin IFAN*, 19: 97-125.

Binder E. (1958). Mollusques aquatiques de Côte d'Ivoire: Lamellibranches. *Bulletin IFAN*, 2: 82-89.

Bird G., 1997. Deformities in cultured Chironomus tentans larvae and the influence of substrates on growth, survival and mentum wear. *Environmental Monitoring and Assessment* 45: 273-283.

Bode R., Novak M., Abele L. 1996. Quality Assurance Work Plan for Biological Stream Monitoring in New York State, Albany (New York). NYS Department of Environmental Conservation, 89p.

Bode R., Novak M., Abele L., Heitzman D., Smith A. 2002. Quality Assurance Work Plan for Biological Stream Monitoring in New York State, Albany (New York). Stream Biomonitoring Unit, Bureau of Water Assessment and Management, Division of Water, NYS Department of Environmental Conservation, 41p.

Bouchard C., Blair S., Haskell W. 2007. Why study physical activity and Physical activity and health Champaign, Ill: *Human Kinetics,* 3: 3-19.

Brookes A., 1988. Channelized Rivers-Perspectives for Environmental Management. John Wiley & Son, Chichester.

Brown D. 1994. Freshwater Snails of Africa and their Medical Importance. CRC Press, Taylor & Francis Ltd. Ed, London, 2nd revised edition, 609p.

Cabral-Oliveira J., Mendes S., Maranhão P., Pardal M. 2014. Effects of sewage pollution on the structure of rocky shore macroinvertebrate assemblages. *Hydrobiologia*, 726: 271-283.

Camacho A. 1992. The natural history of biospeleology. Museo Nacional de Ciencias Naturales, Madrid, Monografias, 7: 680p.

Camara I. 2013. *Composition, structure et déterminisme des macroinvertébrés de la rivière Banco (Parc National du Banco; Côte d'Ivoire)*. Thèse de Doctorat, Université Nangui Abrogoua, 151p.

Caryou J., Compin A., Giani N., Céréghino R. 2000. Associations spécifiques chez les macroinvertébrés benthiques et leur utilisation pour la biotypologie des cours d'eau. Cas du réseau hydrographique d'Adour-Garonne (France). *Annales de Limnologie*, 36: 189-202.

CEAEQ. 2007. Détermination des Orthophosphates dans l'eau: méthode calorimétrique automatisée à l'acide ascorbique. Centre d'Expertise en Analyses Environnementales du Québec, MA. 3030-P1.0, Revue, 3, Ministère du Développement Durable, de l'Environnement et des Parcs du Québec, 12p.

Charvet S., Kosmala A., Statzner B., 1998. Biomonitoring through biological traits of benthic macroinvertebrates: perspectives for a general tool in stream management. *Archiv Fu Hydrobiologia*, 142: 415-432.

Chatzinikolaou Y., Lazaridou M. 2007. Identification of the self-purification stretches of the Pinios River, Central Greece, *Mediterranean Marine Science Volume*. 8 (2): 19-32.

Chessman B. 1995. Rapid assessment of rivers using macroinvertebrates: A procedure based on habitat, specific sampling, family level identification and a biotic index. *Australian Journal of Ecology*, 20: 122-129.

Colas F., Archaimbault V., Férard J., Bouquerel J., Roger M., Devin S. (2013). Benthic indicators of sediment quality associated with run-of-river reservoirs. *Hydrobiologia*, 703: 149-164.

Colas F., Vigneron A., Felten V., Devin S. 2014. The contribution of a niche-based approach to ecological risk assessment: Using macroinvertebrate species under multiple stressors. *Environmental Pollution*, 185: 24-34.

Costa, J., Souza Lo, Oldrini B. 2000. Chave para identificação das famílias e gêneros das larvas conhecidas de Odonata do Brasil: comentários e registros bibliográficos (Insecta, Odonata). *Publicação Avulsa do Museu Nacional*, 99: 1-44

Cranston P. 1996. Identification Guide to the Chironomidae of New South Wales. AWT Identification Guide, Number 1, Australian Water Technologies Pty Ltd, Sydney, 1–376.

Cranston P. 2004. Insecta: Diptera, Chironomidae. *In:* Yule, C.M. & Yong, H.S. (Eds.), *The Freshwater Invertebrates of Malaysia and Singapore*. *Academy of Sciences, Kuala Lumpur*, 710–734.

Cummins K., Wilzbach M. 1985. Field Procedures for Analysis of Functional Feeding Groups of Stream Macroinvertebrates. Contribution 1611, Apalachian Environmental Laboratory, Université de Maryland, Frostburg, 18p.

Dahl J. Wilson G. Nilsson A. 2004. Acceptance and commitment therapy and the treatment of persons at risk for long-term disability resulting from stress and pain symptoms: a preliminary randomized trial. *Behav Ther*. 35:785–801.

Dajoz R. 2000. Précis d'Ecologie. 7ème édition, Dunod, Paris, France, 615p.

Dallas Helen. 2008. Water temperature and riverine ecosystems: An overview of knowledge and approaches for assessing biotic responses, with special reference to South Africa, *Water SA* 34 (3): 393 – 404.

Dalzochio, M.S., Costa, J.M. and Uchôa, M.A., 2011. Diversity of Odonata (Insecta) in lotic systems from Serra da Bodoquena, Mato Grosso do Sul State, Brazil. *Revista Brasileira de Entomologia*, 55 (1): 88-94.

Damotharan P., Perumal N., Arumugam M., Vijayalakshmi S., Balasubramanian T. 2010. Seasonal variation of physico-chemical characteristics in point calimere

coastal waters (South East coast of India). *Middle-East Journal Science Research* 6(4): 333–339.

Dan Polhemus, John Polhemus. 2013. Notes on *Ranatra* (Heteroptera: Nepidae) from Burma and the Andaman Islands, with description of a new species. *Entomologia Americana*, 118: 242–251.

Dana Komínková. 2012. The Urban Stream Syndrome – a Mini-Review, *Environmental & Biological Monitoring Journal*, 5(1): 24-29.

Davies P., Wright I., Findlay S., Jonasson O., Burgin S., 2010. Impact of urban development on aquatic macroinvertebrates in south eastern Australia: degradation of in-stream habitats and comparison with non-urban streams. *Aquatic Ecology*, 44: 685-700.

Davinder S., Vasundara S., Agnihotri A. 2013. Study of textile effluent in and around Ludhiana district in Punjab, India. *International Journal of Environmental Sciences*, 3: 1271-1278.

Day J., Harrison A., De Moor I. 2002. Guides to the Freshwater Invertebrates of Southern Africa, Volume 9: Diptera. Water Research Commission Report, No. TT 201/02, Pretoria-South Africa, 210p.

Day J., Stewart B., De Moor I., Louw A. 2001. Guides to the Freshwater Invertebrates of Southern Africa, Volume 4: Crustacea III. Water Research Commission Report, No. TT 141/101, Pretoria-South Africa, 151p.

De Meester L., Declerck S., Stoks R., Louette G., Van De Meutter F., De Bie T., Michels E., Brendonck L., 2005. Ponds and pools as model systems in conservation biology, ecology and evolutionary biology. *Aquatic Conservation: Marine and Freshwater Ecosystems*, 15 (6): 715-725.

De Moor I., Day J. 2002. Guides to the Freshwater Invertebrates of Southern Africa, Volume 6: Arachnida & Mollusca. Chapter 3: Mollusca. Water Research Commission Report, No. TT 182/02, Pretoria-South Africa, 42-125.

De Moor I., Day J., De Moor F. 2003a. Guides to the Freshwater Invertebrates of Southern Africa, Volume 7: Insecta I. Ephemeroptera, Odonata & Plecoptera. Water Research Commission Report, No. TT 207/03, Pretoria-South Africa, 301p.

Defo C, Yerima B., Noumsi I., Bemmo N. 2015. Assessment of heavy metals in soils and groundwater in an urban watershed of Yaounde (Cameroon-West Africa). Environmental Monitoring Assessment. 187 (3): 77

Dejoux C., Elouard J., Forge P., Maslin J. 1981. Catalogue iconographique des insectes aquatiques de Côte d'Ivoire. ORSTOM 42, 178p.

Dermott R. 1991. Deformities in larval *Procladius* spp. and dominant Chironomini from the St. Clair River. *Hydrobiologia* 219: 171-185.

Derwich E., Benaabidate L., Zian A., Sadki O., Belghity D. 2010. Caractérisation physicochimique des eaux de la nappe alluviale du haut Sebou en aval de sa confluence avec oued Fès. *Larhyss Journal*, 8: 101-112.

Desbois D., 2003. L'analyse discriminante avec SPSS pour Windows. *La Revue Modulad*, 30: 1-49.

Devidal S., Richard-Sirois C., Pouet M., Thomas O. 2007. Solutions curatives pour la restauration des lacs présentant des signes d'eutrophisation, rapport interne, Observatoire de l'Environnement et du Développement Durable, Université de Sherbrooke, Québec, 51p.

Dhirendra Mohan, Alok Kumar, Namita Agrawa. 2009. Studies on physicochemical parameters to assess the water quality of river Ganga for drinking purpose in haridwar district. *Rasayan journal of chemistry*, 2(1): 195-203.

Diggins T., Stewart K., 1993. Deformities of aquatic larval midges (Chironomidae: Diptera) in the sediment of the Buffalo River, New York. *Journal of Great Lake Research* 19: 648-659.

Diomandé D. 2001. *Macrofaune benthique et stratégies alimentaires de Synodontis Bastiani Daget, 1948 et S. Schall (Bloch & Schneider, 1801) en milieu fluvio-lacustre (Bassins Bia et Agnéby; Côte d'Ivoire).* Thèse de Doctorat, Université d'Abobo-Adjamé, Côte d'Ivoire, 260p.

Diomandé D., Gourène G., Sankaré Y. Zabi S. 2000. Synopsis de la classification des larves et des nymphes de Diptères Chironomidae des écosystèmes dulçaquicoles de l'Afrique de l'Ouest. Clés de détermination des sous-familles, des tribus et des genres. *Archives Scientifiques du Centre de Recherches Océanologiques d'Abidjan*, 17: 1-31.

Dolédec S. Statzner B. 2008. Invertebrate traits for the biomonitoring of large European rivers: an assessment of specific types of human impacts. *Freshwater Biology,* 53: 617-634.

Dufrêne M., Legendre P. 1997. Species assemblages and indicator species: the need for a flexible asymmetrical approach. *Ecological Monographs,* 67: 345-366.

Durand J., Lévêque C. 1981. Flore et faune aquatiques de l'Afrique Sahélo-soudanienne. Tome II. Edition de l'ORSTOM, Paris, 517p.

Edet A., Nganje T., Ukpong A., Ekwere A. 2011. Groundwater chemistry and quality of Nigeria: A status review. *Africa Journal of Environmental Science and Technology*. 5 (13): 1152-1169.

Edia O. 2008. *Diversité taxonomique et structure des peuplements de l'entomofaune des rivières côtières Soumié, Eholié, Ehania, Noé (Sud-Est, Côte d'Ivoire)*. Thèse de Doctorat, Université d'Abobo-Adjamé, Côte d'Ivoire, 152p.

Edia O., Brosse S., Ouattara A., Gourène G., Winterton P. Lek-Ang S. 2007. Aquatic insect assemblage patterns in four West-African coastal rivers. *Journal of Biological Sciences,* 7: 1130-1138.

Elias R., Rivero M., Sanchez M., Jaubet L., Vallarino E. 2009. Do treatments of sewage plants really work? The intertidal mussels' community of the southwestern Atlantic shore (388S, 578W) as a case study. *Revista de Biologia Marina y Oceanografia*, 44: 357-368.

Ellis E., Klein Goldewijk, Siebert S., Lightman D., Ramankutty N. 2010. Anthropogenic transformation of the biomes, 1700 to 2000. *Global Ecology and Biogeography, (Global Ecol. Biogeogr.),* 19: 589-606.

Epler J. 2001. Identification manual for the larval Chironomidae (Diptera) of North and South Carolina. A guide to the taxonomy of the midges of the southeastern United States, including Florida. Special Publication SJ2001-SP13. North Carolina Department of Environmental and Natural Resources, Raleigh, NC.

Farhadinejad T., Khakzad A., Jafari M., Shoaee Z. 2014. The study of environmental effects of chemical fertilizers and domestic sewage on water quality of Taft region, central Iran. *Arabian journal of geosciences* 7: 221–229

Feio J., Dolédec S. 2012. Integration of invertebrate traits into predictive models for indirect assessment of stream functional integrity: a case study in Portugal. *Ecological Indicators*, 15: 236-247.

Fernandes J., de Souza A., Tanaka M. 2014. Can the structure of a riparian forest remnant influence stream water quality? A tropical case study. *Hydrobiologia*, 724: 175-185.

Fernández-Díaz M., Benetti C., Garrido J. 2008. Influence of iron and nitrate concentration in water on aquatic Coleoptera community structure: application to the Avia river (Ourense, NW, Spain). *Limnetica*, 27 (2): 285-298.

Ferreira V., Koricheva J., Duarte S., Niyogi D., Guérold F. 2016. Effects of anthropogenic heavy metal contamination on litter decomposition in streams – A meta-analysis. *Environmental Pollution*, 210: 261-270.

Ferreira-Peruquetti P., De Marco-Júnior P. 2002. Efeito da alteração ambiental sobre a comunidade de Odonata em riachos de Mata Atlântica de Minas Gerais, Brasil. *Revista Brasileira de Zoologia*, 19 (2): 317-327.

Feumba R., Ngounou B., Youmbi G., Ekodeck G. 2011. Relationship between Climate and Groundwater Recharge in the Besseke Watershed (Douala Cameroon). *Journal of Water Resource and Protection*, 3: 607-619.

Fodouop K., Mougoué B. 1997. Acteurs locaux et gestion politique de l'environnement à Yaoundé (Cameroun). *Pratiques de gestion de l'environnement dans les pays tropicaux. Bordeaux*, DYMSET-CRET, 529-535.

Fogwe Z. 2006. Cameroon City Counter Flood Strategies. *Journal of Applied Social Sciences*. 7: 129-141.

Fogwe Zephania N. 2016. An Assessment of an Urban Development-Flood-Impact Relationship in a Near Millionaire City of Cameroon (Bamenda), *Journal of Geoscience and Environment Protection*, 4: 136-146

Foto Menbohan S., Koji E., Ajeagah Gideon, Bilong Bilong C., Njiné T. 2012. Impact of dam construction on the diversity of benthic macroinvertebrates community in a periurban stream in Cameroon. *International Journal of Biosciences*. 11: 137 – 145.

Foto Menbohan S., Njiné T. 1991. Influence de la pollution organique sur la diversité des peuplements de ciliés de deux cours d'eau urbains au Cameroun. *Annales de la*

Faculté des Sciences de l'Université de Yaoundé I, Série Sciences Naturelles et Vie, 7: 281-294.

Foto Menbohan S., T. Njiné. 1998. Distribution et dynamique des populations des ciliés dans deux cours d'eaux urbains : l'Abiergue et le Mfoundi à Yaoundé. *Ann. Fac. Sci, Univ. Yaoundé I*, Série Sci. Nat. vie, 34 : 269-279.

Foto Menbohan S., Tchakonte S., Ajeagah G., Zebaze Togouet S. H., Bilong Bilong C., Njine T. 2013. Water quality assessment using benthic macroinvertebrates in a periurban stream (Cameroon). *International Journal of Biotechnology* 2(5): 91- 104.

Friedrich G., Chapman D., Beim A. 1992. The use of biological material. In D. Chapman, water quality assessment: a guide to the use of biota, sediment and water in environmental monitoring, edition Chapman & Hall. pp 171-238.

Gasparini S. 2004. Les Copépodes. Observatoire Océanologique de Villefranche, Fiche Technique, Université Pierre et Marie Curie, 10p.

Gaujous D. 1993. La pollution dans les milieux aquatiques. Aide-mémoire. Editions Technique et Documentation. 212p.

Giller P., Malmqvist. 1999. The biology of rivers and streams. *Oxford University Press, Oxford*. 296p.

Grafny S., Goren M., Gasith A. 2000. Habitat condition and fish assemblage structure in a coastal mediterranean stream (Yarqon, Israel) receiving domestic effluent. *Hydrobiologia 422*: 319–330.

Grimm N., Morgan Grove, Pickett S., Redman C. 2000. Integrated approaches to long-term studies of urban ecological systems. *BioScience* 50 (7): 571- 584.

Hamilton A., Saether O. 1971. The occurrence of characteristic deformities in the chironomid larvae of several Canadian lakes. *Canadian Entomologist* 103: 363-368.

Harding J., Young R., Hayes J., Shearer K., Stark J. 1999. Changes in agricultural intensity and river health along a river continuum. *Freshwater Biology*, 42: 345–357.

Harrison A. 2002. Chironomidae. In: Day J.A, Harrison A.D., de Moore I.J.(eds.). Guides to the Freshwater Invertebrates of Southern Africa: Diptera. WRC report No TT 201/02. DWAF, 9: 110-158.

Hasegawa H., Sasa M. 1987. Taxonomical notes on the chironomid midges of the tribe Chironomini collected from Ryukyu Islands, Japan, with description of their immature stages. *Japan Journal of Sanitary Zoology*, 38(4): 275–295.

Hecky R. 2000. A biogeochemical comparison of Lakes Superior in Malawi, and the limnological consequences of an endless summer. *Aquatic Ecosystem Health and Management,* 3: 23-33.

Henriques-OLiveira, Nessimian J., Dorvil Lé L. 2003. Feeding habits of Chironomid larvae (Insecta: Diptera) from a stream in the floresta da Tijuca, Rio de Janeiro, Brazil. *Brazilian Journal Biology* 63(2): 269-281.

Hernández Y., Manrique R., Cerón A. 2012. Guía de campo de los macroinvertebrados acuáticos de la quebrada Menzuly – Santander – Colombia. Bucaramanga: *Ediciones Universidad Industrial de Santander*. 154 p.

Hilsenhoff W. 1988. "Rapid field assessment of organic pollution with a family-level biotic index". *Journal of North America Benthological Society*, 7: 65-68.

Huang T., Lock K., Chi Dang K., De Pauw N., Goethals P. 2010. Spatial and temporal patterns of macroinvertebrate communities in the Du river Basin in Northern Vietnam. *Journal of Freshwater Ecology*, 25: 637-647.

Ihaka R., Gentleman R. 1996. R: a language for data analysis and graphics. *Journal of Computational and Graphical Statistics,* 5: 299-314.

INRA. 2005. L'émergence d'une ingénierie écologique des milieux aquatiques. Institut National de la Recherche Agronomique: Direction de l'information et de la communication - 147, rue de l'université - 75338. Paris Cedex 07: 144p.

Jacobsen R. 2008. A Key to the Pupal Exuviae of the Midges (Diptera: Chironomidae) of Everglades National Park, Florida. Scientific Investigations Report 2008-5082, U.S. Geological Survey, Reston, Virginia, 119p.

Jain S. 2012. Assessment of water quality at the three Stations of Chambal River. *International Journal of Environmental Sciences,* 3: 881-884.

Janssens de Bisthoven L., Gerhardt A. 2003. Chironomidae (Diptera, Nematocera) fauna in three small streams of Skania, Sweden. *Environmental monitoring and Assessment* 83: 89-102.

Janssens de Bisthoven L., Gerhardt A., Soares A. 2005. Chironomidae larvae as bioindicators of an acid mine drainage in Portugal. *Hydrobiologia* 512:181-191.

Jeanmougin M., Fabien L., Gregoire L., Philippe C. 2014. Fine-scale urbanization affects Odonata species diversity in ponds of a megacity (Paris, France), *Environmental Science and Ecology Journals,* 59: 26 – 34

Jenkins, A. Shaw C. Hornung, M.; Skeffington, R. 1993. Comparison of empirical and dynamic model approaches for surface waters. Critical loads: *concept and applications*. 109-114.

Jeyasingham K., Ling N. 2000. Seasonal influence on head capsule deformities in *Chironomus zealandicus* (Hudson) (Diptera: Chironomidae). *Hydrobiologia* 427**:** 75-82

Jönsson H., Baky A., Jeppsson U., Hellström D., Kärrman E. 2005. Composition of urine, faeces, greywater and biowaste - for utilisation in the URWARE model. Report 2005:6. Chalmers University of Technology: Urban Water.

Jullian E., Hirbe A., Ker B., Liu R., 2005. "Qualité de l'eau du bassin versant de l'Ardèche." Université de Paris 7 - Denis – Diderot, UFR des Sciences Physiques de la Terre (*IUP Génie de l'Environnement*), 149p.

Kaniz F., Wan M., Mansor M. 2014. Spatial and Temporal Variation of Physico-chemical Parameters in the Merbok Estuary, Kedah, Malaysia, *Tropical Life Sciences Research*, 25(2): 1–19.

Karr J. 1999. Defining and measuring river health. *Freshwater Biology,* 41: 221-234.

Kengni L., Tematio P., Filali Rharrassi, Tepoule Ngueke, Tsafack E., Mboumi T., Mounier S. 2012. Pollution des eaux superficielles et des nappes en milieu urbain : cas de la zone industrielle de Douala-Bassa (Cameroun). *International Journal of Biological and Chemical Sciences*, 6(4): 1838 – 1853.

Kikuchi M., Kikuchi T., Okubo S., Sasa M. 1985. Observations on the seasonal prevalence of chironomid midges and mosquitoes by light traps set in a rice paddy area in Tokushima. *Japan Journal of Sanitary Zoology*, 36(4): 333– 342.

Kimengsi J. 2008. *The Contribution of Pamol Plantation and Its Associated Environmental Impacts to the Development of Ekondo-Titi Sub-Division, South West Province of*

Cameroon. Unpublished Master of Science Thesis, FSMS, Department of Geography, University of Buea.

Kimengsi J. 2011. Population Growth, Land Use Change and Forest Degradation in Ndian Division of Cameroon: Drivers and Policy Options. 17th International Interdisciplinary Conference on the Environment, 29th June to 3rd July, 2011, Kona, Hawaii. Retrieved from http://ieaonline.org/wp-content/uploads/2013/06/IEA-Program-And-Abstracts-2011-062411.pdf

Kimengsi, J. 2009. *Pamol Industrial Growth and Land Use Conflicts in Ekondo-Titi Sub-Division, South West Region of Cameroon*. Proceedings of the Second Post Graduate Seminar on Conflict Prevention Management and Resolution, Faculty of Social & Management Sciences, University of Buea, 28th Jan, 2009.

Kometa S., Ndi R. 2012. The Hydro-Geomorphological Implications of Urbanization in Bamenda Cameroon. *Journal of Sustainable Development*, 5(6): 21 p. http://dx.doi.org/10.5539/jsd.v5n6p64

Kourradi R., Benmassaoud F., Benazzou T., Menioui M. 2005. Distribution spatio-temporelle de quelques métaux lourds dans les sédiments de l'estuaire du Bou Regreg. Société Marocaine de Nutrition, Journée d'Etude sur: «Eau: vecteur de Développement Humain». (1er Octobre 2005), pp 22.

Krebs C. 1989. Ecological methodology. Harper Collins Publishers, New York, 654p.

Lambi C., Balgah S. 2010. Reflections on the Changing Landuse Patterns in Some Grassland Rural Environments of the North West Region of Cameroon. *African Journal of Social Sciences (AJOSS)*, 1(1): 33p

Lambi C., Fogwe F. 2001. The February 2000 Floods in Down Town Yaounde. In Lambi, C., & Eze, B. (Eds.), Readings in Geography. *Unique Printers, Bamenda*, Cameroon, p. 26.

Langton P. 1991. *A key to pupal exuviae of West Palaearctic Chironomidae*. Ph.D Thesis, the Natural History Museum, London, England, 400p.

Laycock A. 2007. Irrigation Systems: Design, Planning and Construction, CABI

Lecerf A. 2005. *Perturbations anthropiques et fonctionnement écologique des cours d'eau de tête de bassin: Etude du processus de décomposition des litières*. Thèse de Doctorat, Université Paul Sabatier, Toulouse III, 159p.

Leclercq L. 2001. Intérêt et limites des méthodes d'estimation de la qualité de l'eau. Station scientifique des Hautes-Fagnes, Belgique, Document de travail, 44p.

Lecointre G., Guyader H. 2001. Classification phylogénétique du vivant. Belin Ed., Paris (France), 543p.

Legendre L., Legendre P. 1979. Ecologie Numérique. Masson (Eds), Paris (France), 1-2, 247p.

Lévêque C., Balian E. 2005. Conservation of freshwater Biodiversity: does the real world meet scientific dream? *Hydrobiologia*, 542: 25-26.

Lioris D., Rhcababo J. 1984. Guide d'identification des ressources marines vivantes au Maroc; M.2274/140: 193-201.

Luoto T. 2010. The relationships between water quality and chironomid distribution in Finland- a new assemblage-based tool for assessments of long-term nutrient dynamics. *Ecological indicators* doi: 10.1016/j.ecolind.2010.05.002. .

Magha Alice, Tita Margaret, Gus Djibril Kouankap, Pierre Wotchoko, Mispa Ayuk, Veronique Kamgang. 2015. Physico-Chemical and Bacteriological Characterization of Spring and Well Water in Bamenda III (N.W Region, Cameroon), *American Journal of Environmental Protection*, 4(3): 163-173.

Manikannan R., Asokan S., Ali A. 2011. Seasonal variations of physicochemical properties of the Great Vedaranyam Swamp, Point Calimere Wildlife Sanctuary, South-east coast of India. *African Journal of Environmental Science and Technology,* 5(9): 673–681.

Manly B. 1991. Randomization and Monte Carlo Methods in Biology. Chapman & Hall, London, 281p.

Mansor M., Mohammad-Zafrizal M., Nur-Fadhilah M., Khairun Y., Wan-Maznah W. 2012. Temporal and spatial variations in fish assemblage structures in relation to the physicochemical parameters of the Merbok Estuary, Kedah. *Journal of Natural Sciences Research,* 2(7): 110–127.

Martin P., Aït Boughrous. 2012. Guide taxonomique des oligochètes dulçaquicoles du Maghreb. Ed. NUR 910, Bruxelles, Belgique, 12, 194p.

Martinez M., Rogowski D. 2006. Use and apparent partitioning of habitat by an imperiled Spring snail (Hydrobiidae) and a Cosmopolitan pond snail (Physidae). *The Southwestern Naturalist*, 56: 216-223.

Mary N. 1999. Caractérisations physicochimique et biologique des cours d'eau de la Nouvelle-Calédonie, proposition d'un indice biotique fondé sur l'étude des macroinvertébrés benthiques. Thèse de Doctorat, Université Française du Pacifique, France, 200p.

Marziali L., Armanini D., Cazzola M., Erba S., Toppi E., Buffagni A., Rossaro B. 2010. Responses of chironomid larvae (Insecta, Diptera) to ecological quality in Mediterranean river mesohabitats (South Italy). *River Research Applications,* 26: 1036–1051.

Marzoli A., Piccirillo E., Renne P., Bellien G., Facumin G., Nyobe J., Tongwa A. 2000. The CVL Revisited: petrogenesis of continental Basaltic mangmas form lithospheric and Asthenospheric Mantle sources. *Journal of petrology*, 41(1): 87-109.

Mateusz Płóciennik, Ioannis Karaouzas. 2014. The Chironomidae (Diptera) fauna of Greece: ecological distributions and patterns, taxalist and new records. *International Journal of Limnology,* 57 (1): 47 – 52.

McDonald R., Kareiva P., Forman R. 2008. The implications of current and future urbanization for global protected areas and biodiversity conservation. *Biological Conservation journal,* 141: 1695-1703.

McKinney M. 2008. Effects of urbanization on species richness: a review of plants and animals. *Urban Ecosystems*. 11: 161 - 176.

McKinney, M.L., 2002. Urbanization, biodiversity, and conservation. *BioScience* 52 (10): 883 – 890.

McQuoid M., Godhe A. 2004. Recruitment of coastal planktonic diatoms from benthic versus pelagic cells: Variations in bloom development and species composition. *Limnology and Oceanography,* 49: 1123-1133.

Meregalli G., Bettinetti R., Pluymers L., Vemuelen A., Rossaro B., Ollevier F. 2000. Mouthpart deformities and nucleolus activity in field-collected Chironomus, measures of toxic stress in fresh water ecosystems: Indexing antennal deformities in

Chironomus Meighen. *Canadian Journal of Fisheries and Aquatic Sciences,* 42: 1881-1914.

Meregalli G., Bettinetti R., Pluymers L., Vemuelen A., Rossaro B., Ollevier F. 2002. Mouthpart deformities and nucleolus activity in field-collected Chironomus, measures of toxic stress in fresh water ecosystems: Indexing antennal deformities in Chironomus Meighen. *Canadian Journal of Fisheries and Aquatic Sciences,* 42: 18811914.

Merritt R., Cummins K. 1996. An Introduction to the Aquatic Insects of North America (3rd ed.) Kendall Hunt Publishing, Dubuque, Lowa, U.S.A., 1150p.

Merritt R., Cummins K., Berg M. 2008. An Introduction to the Aquatic Insects of North America. 4th edition, Kendall Hunt Publishing, Dubuque, Lowa, U.S.A., 1159p.

Michael S., Ian S., Litay R., Robert A., Claire N., Albania G. Mark C. 2004. Relationship between macroinvertebrate fauna and environmental variables in small streams of the Dominican Republic. *Water Research,* 38: 863-874.

Moisan J. 2010. Guide d'identification des principaux Macroinvertébrés benthiques d'eau douce du Québec, surveillance volontaire des cours peu profonds. Direction du suivi de l'état de l'environnement, Ministère du Développement Durable, de l'Environnement et des Parcs, 13 : 82p.

Moisan J., Pelletier L. 2008. Guide de surveillance biologique basé sur les macroinvertébrés benthiques d'eau douce du Québec - Cours d'eau peu profonds à substrat grossier. Direction du suivi de l'état de l'environnement, Ministère du Développement Durable, de l'Environnement et des Parcs, 86p.

Monique E. 1987. Evaluation biologique de la qualité des cours d'eau; méthode simplifiée. Centre technique et pédagogique de l'enseignement de la communauté française. Route de Bavay, 70 B- 7080 FRAMERIES, pp 7-63.

Monoury E. 2013. Fonctionnement écologique des zones de dépôt dans les ruisseaux: contribution des invertébrés benthiques aux processus de décomposition des litières et de bioturbation. Thèse de Doctorat, Université Paul-Sabatier, Toulouse III, 283p.

Montgomery C. 1992. Environmental Geology. Brown Publishers, New York, USA, 465p.

Moore N. 1997. (Compiler). Dragonflies - status survey and conservation action plan. Switzerland: IUCN/SSC/ *Odonata Specialist Group*. 28 p.

Mora A., Csabai Z. 2008. First annotated checklist of Chironomidae of Rhodos, Greece (Insecta, Diptera). *Spixiana*, 31 (2): 223–231.

Morse J., Bae Y., Munkhjargal G., SangpraDub N., Tanida K., Vshivkova T. 2007. Freshwater biomonitoring with macroinvertebrates in East Asia. *Frontiers in Ecology and the Environment*, 5(1): 33–42.

Morse J., Yang L., Tian L. 1994. Aquatic Insects of China Useful for Monitoring Water Quality. Hohai University Press, China. 678p

Mougeot L., 2000. Urban agriculture: definition, presence, potentials and risks. Growing cities, growing food: Urban agriculture on the policy agenda, 1-42.

Mousavi S., Primcerio R., Amundsen P. 2003. Diversity and structure of Chironomidae (Diptera) communities along a gradient of heavy metal contamination in a subarctic watercourse. *Science of the Total Environment*, 307: 93– 110.

Mousavi S., Primicerio R., Amundsen P. 2003. Diversity and structure of Chironomidae (Diptera) communities along a gradient of heavy metal contamination in a subarctic water course. *Science of the Total Environment*, 307: 93-110.

Naranjo C., Riviaux S., Moreira F., Court R. 2010. Taxonomy and distribution of aquatic and semiaquatic Heteroptera (Insecta) from Cuba, *International Journal of Tropical Biology (Rev Biol Trop)*, 58: 897-907.

Nazarova L., Riss H., Kahlheber A., Werding B. 2004. Some observations of buccal deformities in Chironomid larvae (Diptera: Choronomidae) from the Cienaga Grande de Santa Marta, Columbia. *Caldasia*, 26(1): 275-290.

Neba A., 1999. Modern geography of the Republic of Cameroon, 3rd Edn. Neba Publishers, Bamenda.

Newman M. 1995. Quantitative Methods in Aquatic Ecotoxicology. Lewis Publishers, USA. 254p.

Nisbet M., Verneaux J. 1970. Composantes chimiques des eaux courantes. Discussion et proposition de classes en tant que bases d'interprétation des analyses chimiques. *Annales de Limnologie*, 2: 161-190.

Nkwemoh C. 1999. *The impact of agro-pastoral activities in the Mezam-Ngoketunja area*. Ph.D Thesis University of Yaoundé 1, 278p.

Nyamsi Tchatcho N., Foto Menbohan S., Zébazé Togouet S., Onana Fils M., Adandedjan D., Tchakonté S., Yémélé Tsago, Koji E. Njiné T. 2014. Indice Multimétrique des Macroinvertébrés Benthiques Yaoundéens (IMMY) pour l'évaluation biologique de la qualité des eaux des cours d'eau de la Région du Centre Sud Forestier du Cameroun. *European Journal of Scientific Research*, 123: 412-430.

Odume Oghenekaro, 2011. Application of macroinvertebrate based biomonitoring approaches to assess anthropogenic impacts in the swartkops river, South Africa, Master of Science thesis, 269p.

Olivier D., Gessner O., François G., Eric C. 2004. Impacts of stream acidification on litter breakdown: implications for assessing ecosystem functioning. *Journal of Applied Ecology*, 41: 365-378.

Osmulski P., Leyko W. 1986. Structure, function and physiological role of *Chironomus* haemoglobin. *Comparative Biochemistry and Physiology–Part B*, 85: 701–722.

Ouro-Boya B. 1979. *Evaluation de l'état d'une eau de rivière par l'analyse multidimensionnelle utilisant des paramètres caractéristiques de la matière organique dissoute*. Thèse de Doctorat, Université de Poitiers, France, 216p.

Ouro-Boya B. 2004. *Evaluation de l'état d'une eau de rivière par l'analyse multidimensionnelle utilisant des paramètres caractéristiques de la matière organique dissoute*. Thèse de Doctorat, Université de Poitiers, France, 216p.

Petersen L., Petersen R. 1983. Anomalies in hydropsychid capture nets from polluted streams. *Freshwater Biology*. 13:185-191.

Philippeau G. 1992. Comment interpréter les résultats d'une analyse en composantes principales. Service des Etudes Statistiques – ITCF, 63p.

Pinder L. 1986. Biology of Freshwater Chironomidae, Annual Review of Entomology, 31:1-23.

Porinchu D., MacDonald G. 2003. The use and application of freshwater midges (Chironomidae: Insecta: Diptera) in geographical research. *Progress in Physical Geography* 27(3): 378-422.

Porinchu D., MacDonald G. 2003. The use and application of freshwater midges (Chironomidae: Insecta: Diptera) in geographical research. *Progress in Physical Geography* 27(3): 378-422.

Qiu Z. 2013. Comparative Assessment of Stormwater and Nonpoint Source Pollution Best Management Practices in Suburban Watershed Management. *Water,* 5: 280-291.

Quinn J., Williamson R., Smith R., Vickers M. 1992. Effects of riparian grazing and channelisation on streams in Southland, New Zealand. Benthic invertebrates. *New Zealand Journal of Marine and Freshwater Research,* 26: 259–273.

Ramade F. 2005. Eléments d'écologie: Ecologie appliquée. 4e édition, Dunod, Paris, France, 864p.

Remsburg A., Turner M. 2009. Aquatic and terrestrial drives of dragonfly (Odonata) assemblages within and among north- temperate lakes. *Journal of the North American*
Benthological Society, 28 (1): 44-56.

Rodier J., Legube B., Marlet N, Brunet R. 2009. L'analyse de l'eau. 9 E édition, DUNOD, Paris, 1579p.

Rothrock J., Barten P., Ingman G. 1998. Land use and aquatic biointegrity in the Blackfoot river watershed Montana. *Journal of American Water Resources Association*, 34: 565-581.

Rueda J., Camacho A., Mezquita F., Hernandez R., Roca J. 2002. Effect of episodic and regular sewage discharges in the water chemistry and macroinvertebrate fauna of a Mediterrenean stream. *Water, Air and Soil Pollution*, 140: 425-444.

Sæther O., Spies M. 2013. Fauna Europaea: Chironomidae. In Beuk P. and Pape T. (eds.), Fauna Europaea: Diptera Nematocera. Fauna Europaea version 2.6. http://www.faunaeur.org.

Saha F., Tchindjang M. 2017. Rainfall variability and floods occurrence in the city of bamenda (northwest of cameroon). *DE GRUYTER*. 11 (1) : 65-82.

Salman Al-Shami, Che Salmah M., Rawi Siti, Nor Abu, Arshad Alil. 2010. Morphological Deformities in *Chironomus* spp. (Diptera: Chironomidae) Larvae as a Tool for Impact Assessment of Anthropogenic and Environmental Stresses on Three Rivers in the Juru River System, Penang, Malaysia, *Environmental Entomology*. 39(1): 210-222

Samé Ekobo A. 1984. *Faune malacologique du Cameroun (description, répartition des Mollusques dulçaquicoles et foyers de trématodoses humaines)*. Thèse de Doctorat d'Etat, Université de Rennes I, 632p.

Saulich A., Musolin D. 2007. "Times of the Year: the Diversity of Seasonal Adaptations and Ecological Mechanisms Controlling Seasonal Development of True Bugs (Heteroptera) in the Temperate Climate," *Trudy Biol. NII SPbGU,* 53: 25–106.

Scherrer B. 1984. Biostatistiques. Gaëtan Morin Edition, Boucherville, Canada, 520p.

Schuetze T., Chelleri L. 2013. "Integrating Decentralized Rainwater Management in Urban Planning and Design: Flood Resilient and Sustainable Water Management Using the Example of Coastal Cities in The Netherlands and Taiwan" Water,Science and Tech nology. 5(2): 593-616.

Schuwirth N., Reichert P. 2012. Prévoir la présence des organismes dans les rivières. *Eawag News*, 72: 14-17.

Seger K., Smiley P., King K., Fausey N. 2012. Influence of riparian habitat on aquatic macroinvertebrate community colonization within riparian zones of agricultural headwater streams. *Journal of Freshwater Ecology*, 27: 393-407.

Selvakumar C., Sivaramakrishnan K., Janarthanan S., Arumugam M., Arunachalam M. 2014. Impact of riparian land use patterns on Ephemeroptera community structure in river basins of the southern Western Ghats, India. *Knowl Managt Aquatic Ecosyst*, 412: 11

Shannon C., Weaver W. 1963. The mathematical theory of communication. Urbana University. Press, Illinois, 117 p.

Silva D., DE Marco-Júnior P., Resende D. 2010. Adult Odonate abundance and community assemblage measures as indicators of stream ecological integrity: a case study. *Ecological Indicators*, 10: 744-752.

Song M., Leprieur F., Thomas A., Lek-Ang S., Chon T., Lek S. 2009. Impact of agricultural land use on aquatic insect assemblages in the Garonne river catchment (SW France). *Aquatic Ecology*, 43:999-1009.

Soumi Nandi, Gautam Aditya, Goutam K. 2012. Nutrient condition and ChironomidAssemblege in Kolkata, India: assessment for boiomonitoring and Ecological monitoring. *Journal of Limnology*, 71 (2): 19p.

Sreedharan S., Damodaran P. 2011. Environmental Impact Assessment of Sand Mining from the Small Catchment Rivers in the Southwestern Coast of India: A Case Study. *Environmental Management*, 47: 130–140

Stals R., De Moor I. 2007. Guides to the Freshwater Invertebrates of Southern Africa, Volume 10: Coleoptera. Water Research Commission Report, No. TT 320/07, Pretoria-South Africa, 275p.

Stark J., Boothroyd K., Harding J., Maxted J., Scarsbrook M. 2001. Protocols for Sampling Macroinvertebrates in Wadeable Streams. New Zealand Macro-invertebrates working group, report no.1, Ministry for the Environment and Sustainable Management, fund project no. 5103, 57p.

Stevens M., Helliwell S., Cranston P. 2006. Larval chironomid communities (Diptera: Chironomidae) associated with establishing rice crops in southern New South Wales, Australia, *Hydrobiologia* 556:317-325.

Suhling F., Goertzen D. 2013. Promoting dragonfly diversity in cities: major determinants and implications for urban pond design. *Journal of Insect Conservation*, 17: 399-409.

Sun Z., Deal B., Pallathucheril V. 2009. The Land-use Evolution and Impact Assessment Model: A Comprehensive Urban Planning Support System. *URISA Journal*, 21 (1): 119- 199.

Svenskt Vatten. 2010. Dricksvattenteknik 3; Ytvatten. Svenskt Vatten AB.

Swales S. 1982. Environmental effects of river channel works used in land drainage improvement. *Journal of Environmental Management*, 14: 103–126.

Tachet H., Richoux P., Bournaud M., Usseglio-Polatera P. 2010. Invertébrés d'eau douce: systématique, biologie et écologie. CNRS édition, Paris, France, 588p.

Takhelmayum K., Gupta S., Singh N. 2013. Diversity and Density of Aquatic Insects in the Lower Reach of River Moirang, Manipur, North East India. Proceedings of the National Academy of Sciences, *Biological Sciences*, 83(4): 575-584.

Tan Peck Y., Rohasliney H. 2013. Status of water quality subject to sand mining in the Kelantan River, kelantan. *Tropical life sciences research*, 24 (1): 19-34.

Tchakonté S., Ajeagah G., Diomandé D., Camara A., Konan K., Ngassam P. 2014. Impact of anthropogenic activities on water quality and Freshwater Shrimps diversity

and distribution in five rivers in Douala, Cameroon. *Journal of Biodiversity and Environmental Sciences (JBES)*. 4 (2): 183-194.

Tchakonté Siméon, Ajeagah Gideon, Nyamsi Tchatcho N., Adama Idrissa C., Dramane Diomandé, Pierre Ngassam. 2015: Stream's water quality and description of some aquatic species of Coleoptera and Hemiptera (Insecta) in Littoral Region of Cameroon. *Biodiversity Journal*, 6 (1): 27–40.

Ter Braak C., Smilauer P. 2002. CANOCO Reference Manual and CanoDraw for Window user's guide: Software for Canonical Community Ordination (Version 4.5). Micro-computer Power, Ithaca, New York, USA, 351p.

Tita M., Kuitcha D., Magha A., Ndjama J., Kamgang K. 2012. Occurrence of macrophytes in the Mezam river system in Bamenda (Cameroon) and their role in nutrient retention. *Syllabus Review Science Series*. 3:1-10.

Tokeshi M. 1995. Life cycles and population dynamics, In P. Armitage, P.S. Cranston, and L.C.V. Pinder (Eds.). The Chironomidae: The Biology and Ecology of Non-Biting Midges. Chapman & Hall, London, UK. Pp. 225–268.

Tomanova S., Goitia E., Helesic J. 2006. Trophic levels and functional feeding groups of macroinvertebrates in Neotropical streams. *Hydrobiologia*, 556: 251-264.

Tomanova S., Usseglio-Polatera P. 2007. Patterns of benthic community traits in Neotropical streams: relationship to mesoscale spatial variability. *Fundamental and Applied Limnology*, 170: 243-255.

Tonkin J., Death R., Collier K. 2013. Do productivity and disturbance interact to modulate macroinvertebrate diversity in streams? *Hydrobiologia*, 701: 159-172.

Toyoshima T., Nakano S., Inoue M., Ono Y., Kurashige Y. 1996. Fish population responses to stream habitat improvement in a concrete-lined channel. *Japanese Journal of Ecology*, 46: 9–20.

Tuffery G. 1980. Incidences écologiques de la pollution des eaux courantes; Révélateurs biologiques de la pollution. In: P. Pesson (édition). La pollution des eaux continentales; Incidence sur les biocénoses aquatiques, Paris, Bordas, pp 243-280.

Usseglio-Polatera P., Bounraud M., Richoux P., Tachet H. 2000. Biomonitoring through biological traits of benthic macroinvertebrates: how to use species trait databases? *Hydrobiologia*, 423: 153-162.

Vannote R., Minshall G., Cummins K., Sedell J., Cushing C. 1980. The River Continuum Concept. *Canadian Journal of Fishery and Aquatic Science*, 37: 130-137.

Vermeulen A. 1995. Elaborating chironomid deformities as bioindicators of toxic sediment stress: the potential application of mixture toxicity concepts. *Annales. Zoologici Fennici* 32: 265-285.

Verneaux J. 1970. *Cours d'eau de France – Comité (massif du Jura): Recherches écologiques sur le réseau hydrographique du Doubs – essai de biotypologie.* Thèse de Doctorat d'état, Faculté des Sciences, Université de Besançon, 260 p.

Villanueva M. 2004. *Biodiversité et relations trophiques dans quelques milieux estuariens et lagunaires de l'Afrique de l'Ouest: adaptations aux pressions environnementales*. Thèse de Doctorat, Institut National Polytechnique (Toulouse), 219p.

W.H.O. 2006. World Health Organization. Guidelines for drinking-water quality [electronic resource] incorporating first addendum. 1 (3): 1 – 144.

Wang B., Liu D., Liu S., Zhang Y., Lu D., Wang L. 2012. Impacts of urbanization on stream habitats and macroinvertebrate communities in the tributaries of Qiangtang River, China. *Hydrobiologia*, 680: 39-51.

Warwick W. 1985. Morphological abnormalities in Chironomidae (Diptera) larvae as measures of toxic stress in fresh water ecosystems: Indexing antennal deformities in Chironomus Meighen. Canadian Journal of Fisheries and Aquatic Sciences 42: 18811914.

Wierderholm T. 1986. Chironomidae of the Holoarctic region. Key and diagnoses, Part 2: Pupae. *Entomologica Scandinavica. Supplement*, 28: 482p.

Williams C., Scott A., Wilson H. Xenopoulos M. 2012. Effects of land use on water column bacterial activity and enzyme stoichiometry in stream ecosystems. *Aquatic Sciences*, 74: 483-494.

Williams W., Lance G., Dale M., Clifford H. 1971. Controversy concerning the criteria for taxonometric strategies. *Computer Journal*, 14: 1-162.

Willigalla C., Fartmann T. 2012. Patterns in the diversity of dragonflies (Odonata) in cities across Central Europe. *European Journal of Entomology*, 109 (2): 235-245.

Wilson R., McGill J. 1982. A pratical key to the genera of pupal exuviae of the British Chironomidae (Diptera, Insecta). Bristol University printing office. England, 61p.

Wilson R., Ruse L. 2005. A guide to the identification of genera of chironomid pupal exuviae occurring in Britain and Ireland (including common genera from northern Europe) and their use in monitoring lotic and lentic fresh waters. *The Freshwater Biological Association Cumbria, UK*. 176 p.

Wright I., Burgin S. 2009. Effects of organic and heavy metal pollution on chironomids within a pristine upland catchment. *Hydrobiologia* 635: 15-26.

Xu M., Wang Z., Duan X., Pan B. 2013. Effects of pollution on macroinvertebrates and water quality bio-assessment. *Hydrobiologia*, 703: 176-189.

Yamane I., Nakazawa T. 1986. Development of zeolitefor non-phosphated detergents in Japan. *Pure & Appl. Chem*. 58(10): 1397-1404.

Yunakov N., Germann C. 2012. Brachysomus (Hippomias) *Samos* sp. from Greece first island endemism in the genus (Coleoptera: Curculionidae: Entiminae). *Zootaxa*, 3408, 59 –68.

Zahradnik J., Chvala M. 1991. La grande Encyclopédie des Insectes. Collection Grund, Paris, France, 511p.

Zettel H., Yang C., Tran A. 2009. Descriptions of two large water striders of the genus *Limnometra* MAYR, 1865 (Insecta: Heteroptera: Gerridae) from the Philippines and Malaysia, *Raffles Bulletin of Zoology*, 11 (3): 14 – 38.

Zhang Y., Zhao R., Kong W., Geng S., Bentsen C., Qu X. 2013. Relationships between macroinvertebrate communities and land use types within different riparian widths in three headwater streams of Taizi River, China. *Journal of Freshwater Ecology*, 28: 307-32

APPENDIX

Appendix 1: minimum, maximum annual mean and standard deviation of physicochemical parameters as well as those of the Organic Pollution Indice (OPI) measure during the study period. The codes mf1, mf2, mf3, F1, F2, F3, mk1, mk2 mk3, A1, A2, A3 and mz indicate sampling stations.

Variables		SAMPLING STATIONS											
		Mf_1	**Mf2**	**Mf3**	**F1**	**F2**	**F3**	**MK1**	**MK2**	**MK2**	**A_1**	**A_2**	**A_3**	**MZ**
Temperature (°C)	Mean ± σ	18.88±1.87	19.35±1.60	19.77±1.36	19.56±1.90	20.69±1.65	21.69±1.63	20.79±0.73	22.38±2.46	23.12±1.52	21.12±1.58	23.28±2.48	23.31±1.93	21.19±1.33
	Min-Max	16-22	16-22	17-22	16-22	18.5-23	19-24	20-22	19-26.5	21-26	19-25	19-27	19.5-27	19-23
pH (UC)	Mean ± σ	7.27±0.56	7.05±0.36	7.14±0.38	7.13±0.36	7.30±0.33	7.50±0.30	7.39±0.30	7.64±0.26	7.71±0.42	7.56±0.38	7.88±0.33	7.82±0.54	7.63±0.30
	Min-Max	6.06-8.07	6.20-7.85	6.38-7.96	6.52-7.79	6.75-8.03	6.99-7.86	6.89-7.88	7.19-7.97	7.01-8.70	6.69-7.93	7.31-8.70	6.29-8.33	7.11-8.24
Dissolved Oxygen (mg/L)	Mean ± σ	28.48±11.1	19.59±11.7	17.39±7.63	23.58±8.07	27.68±10.86	30.78±22.35	30.01±16.58	25.66±10.01	26.86±11.57	30.84±12.96	25.66±12.48	25.77±9.53	27.05±12.01
	Min-Max	13.17-46.48	6.6-39.26	8.54-38.49	10.46-36.6	6.93-43.13	7.55-86.37	11.33-54.99	5.5-42.04	10.89-49.36	14.3-59.39	10.19-48.51	8.08-38.14	15.01-52.46
Electrical Conductivity (µS/cm)	Mean ± σ	28.46±5.58	75.6±42.8	82.1±49.3	91.8±154.3	98.2±53.9	145.2±67.5	130.5±66.1	223.2±97.3	231.5±59.4	117.2±108.3	302.7±71.4	337.6±69.3	115.0±56.7
	Min-Max	21-39	24-198	38-233	19-602	25-200	49-242	60-315	23-399	100-335	34.0-466.0	186-420	181-420	34-203
TDS (mg/L)	Mean ± σ	14.154±3.24	37.54±21.05	41.15±24.77	44.5±72.2	48.92±26.77	72.46±33.27	64.77±32.06	110.6±46.8	115.77±29.83	57.7±50.6	151.51±35.57	168.85±34.52	57.54±28.23
	Min-Max	21-Oct	Dec-97	19-117	9-283	Dec-99	25-117	30-153	12-118	50-168	17-220	93-210	91-210	17-101
Salinity (‰)	Mean ± σ	0.01±0.004	0.03±0.01	0.03±0.01	0.02±0.01	0.04±0.02	0.07±0.03	0.06±0.02	0.10±0.05	0.10±0.04	0.04±0.02	0.14±0.03	0.16±0.04	0.05±0.01
	Min-	0.01-	0.01-	0.02-0.05	0.01-	0.01-0.09	0.02-0.11	0.03-0.08	0.01-	0.01-0.16	0.01-0.07	0.09-0.20	0.08-0.22	0.01-0.10

	Max	0.02	0.04		0.04				0.18					
Turbidity	Mean ± σ	20.77±17.36	28.15±32.36	28.3±38	35.9±41.9	48.8±105.0	20.15±17.25	41.5±47.1	36.0±76.2	38.46±35.07	41.5±64.5	39.4±57.7	36.7±46.3	25.69±23.04
(NTU)	Min-Max	2--54	2-113	3-142	2-153	3-393	3--63	4-185	1-285	4--99	6-239	1-174	3-159	2--71
S.S (mg/L)	Mean ± σ	11.69±7.95	17.15±21.52	12.54±9.47	17.54±13.9	32.4±72.2	11.62±6.58	25.15±34.15	37.8±103.4	21.46±21.03	28.8±48.9	22.0±35.72	26.46±34.29	17.23±13.25
	Min-Max	4--31	2--80	4--39	6--53	4-271	4--27	4-132	2-381	3--74	2-182	5-138	6-131	4-- 48
Colour (Pt-Co)	Mean ± σ	59.5±44.3	128.8±193.3	106.6±127.1	123.5±84.5	80.5±63.6	96.2±56.4	114.7±114.7	115.1±176.1	154.5±161	205±371	175.5±304.1	159.5±225.3	95.0±78.7
	Min-Max	9-165	27-754	6-495	31-317	19-200	31-197	6-479	4-626	31-458	31-1248	11-1156	2-870	29-285
Alcalinity	Mean ± σ	14.31±16.51	9.54±7.26	9.54±7.26	8.0±6.22	9.54±6.06	12.15±7.09	14.62±11.47	12.77±6.14	14.92±8.23	12.77±7.05	19.08±19.42	16.0±6.93	10.15±5.06
(mg/L $CaCO_3$)	Min-Max	2--60	4--22	2--26	2--22	4--20	4--28	4--36	6--24	6--28	4--26	8--78	8--30	4--22
Nitrates	Mean ± σ	0.58±0.92	1.41±3.06	0.87±1.29	0.73±0.71	1.07±0.80	0.98±0.88	1.14±0.84	2.42±5.20	2.12±2.85	3.46±8.45	3.18±5.43	2.57±5.43	1.27±1.65
(mg/L NO_3^-)	Min-Max	0-3.40	0.03-10.90	0.03-460	0.02-2.30	0.007-2.30	0.01-3.40	0.01-2.60	0.01-19.30	0.09-9.40	0-31	0.02-20.40	0.04-17	0.01-6.20
Ammonium	Mean ± σ	0.11±0.11	0.23±0.30	0.16±0.19	0.17±0.16	0.13±0.14	0.16±0.15	0.18±0.31	0.23±0.37	0.28±0.29	0.37±0.60	0.28±0.48	0.31±0.46	0.21±0.23
(mg/L NH_4^+)	Min-Max	0.02-0.38	0.04-1.07	0.01-0.62	0.01±0.48	0.01-0.48	0.02-0.41	0.01-1.15	0.01-1.40	0.01-0.83	0.02-2.15	0.02-1.84	0.01-1.74	0.02-0.87

Orthophosphates (mg/L PO_4^{3-})		Mean ± σ Min-Max	0.76±0.96 0.04-3.10	1.17±1.59 0.01-4.60	1.07±1.14 0.01-3.60	1.45±2.23 0.01-7.70	1.29±2.0 0-6.30	1.38±2.46 0.01-8.70	0.96±1.45 0-4.90	0.73±0.82 0.01±2.50	0.77±0.97 0-2.90	0.78±1.15 0-3.9	1.11±1.78 0.02-5.40	1.15±1.29 0-4.40	1.0±1.13 0.01-3.60
Oxydability (mg/L)		Mean ± σ Min-Max	2.99±1.84 0.39-6.32	2.35±1.70 0.39-5.33	2.06±1.49 0.19-5.13	3.08±2.35 0.39-7.02	2.07±2.31 0.39-7.02	3.16±2.31 0.19-7.70	3.05±2.68 0.19-8.69	2.94±2.32 0.39-8.29	3.84±2.65 0.59-9.48	3.87±3.92 0.59-15.60	2.85±1.43 0.39-4.93	3.10±2.15 0.19-6.91	3.54±3.73 0.19-11.25
OPI	Analysis	Mean ± σ Min-Max	4.28±0.46 3.33-5	4.17±0.39 3.33-4.6	4.20±0.55 3.33-5	3.66±0.72 2.66-4.66	3.89±0.76 2.66-5	3.72±0.56 3--5	3.77±0.63 3--5	3.64±0.67 2.66-5	3.61±0.57 2.66-4.66	3.59±0.68 2-4.66	3.69±0.55 3-4.33	3.51±0.63 2.66-4.66	3.66±0.78 2.33-4.66
	Pollution level		**Low**	**Low**	**Low**	**Moderate**	**Moderate**	**Moderate**	**Moderate**	**Moderate**	**Moderate**	**Moderate**	**Moderate**	**Moderate**	**Moderate**

Appendix 2: concentration metallic elements in water colon at the different sampling stations and their mean values ± standand deviation for each stream. the codes mf1, mf2, mf3, F1, F2, F3, mk1, mk2 mk3, A1, A2, A3 and mz indicate sampling stations.

Stream	stations	Metalic elements in water (mg/L)							
		Fe	Pb	Cd	Zn	Cu	Cr	Co	Ni
Mufueh	Mf1	0.021	0	0	0	0	0.136	0.012	0.052
	Mf2	0.177	0	0	0	0	0.105	0.012	0.046
	Mf3	0.008	0	0	0	0	0.049	0.007	0.036
	Mean±SD	0.069±0.09	0	0	0	0	0.097±0.04	0.01±0.003	0.045±0.008
Formuki	F1	0.12	0	0	0	0	0.025	0.013	0.043
	F2	0	0	0	0	0	0.08	0.01	0.036
	F3	0.988	0	0	0	0	0.066	0.017	0.054
	Mean±SD	0.369±0.54	0	0	0	0	0.057±0.029	0.013±0.004	0.044±0.009
Mankon	Mk1	0.049	0	0	0	0	0.071	0.015	0.048
	Mk2	0	0	0	0	0	0.023	0.007	0.05
	Mk3	0.031	0	0	0	0	0.116	0.012	0.041
	Mean±SD	0.027±0.025	0	0	0	0	0.07±0.05	0.011±0.004	0.046±0.005
Ayabah	A1	0	0	0	0	0	0.012	0.002	0.046
	A2	0	0	0	0	0	0.065	0.015	0.044
	A3	0.003	0	0	0	0	0.055	0.012	0.043
	Mean±SD	0.001±0.002	0	0	0	0	0.044±0.028	0.01±0.007	0.044±0.002
Mezam	Mz	0.005	0	0	0	0	0.11	0.012	0.033

Appendix 3: concentration metallic elements in sediments at the different sampling stations and their mean values ± standand deviation for each stream. the codes mf1, mf2, mf3, F1, F2, F3, mk1, mk2 mk3, A1, A2, A3 and mz indicate sampling stations.

Stream	stations	Metalic elements in sediments (mg/Kg)					
		Fe	Pb	Cd	Zn	Cu	Cr
Mufueh	Mf1	20173.6	29	4.6	53.4	17.5	118.1
	Mf2	14011	28	0	57	16	123.5
	Mf3	56899.6	21	0	104.6	25.2	118.2
	Mean±SD	30361.4±13387.8	26±4.36	1.5±2.7	71.67±28.58	19.57±4.94	119.9±3.09
Formuki	F1	22757.8	44	0	79.4	12.6	84.2
	F2	55942	22	0	120.3	23.9	179.8
	F3	26414.7	20	0	90.3	35.7	144.8
	Mean±SD	35038.2±18195.4	28.67±13.32	0	96.67±21.18	24.07±11.55	136.27±48.37
Mankon	Mk1	33162.4	35	0	95.2	12.7	102.5
	Mk2	32218	25	0	94.9	74.6	60.8
	Mk3	36824.2	6	0	138.4	14	38.5
	Mean±SD	34068.2±2433.03	22±14.73	0	109.5±25.03	33.78±35.36	67.27±32.49
Ayabah	A1	30600.2	15	0	71.6	11.7	57.8
	A2	12638.6	34	0	76.4	21.2	0
	A3	11117.1	22	0	71.7	14.3	0
	Mean±SD	18118.63±1083.6	23.67±9.61	0	73.23±2.75	15.73±4.91	19.26±33.37
Mezam	Mz	10969.7	18	0	24	11.6	4.8

Appendix 4: List of taxa of aquatic macrofaune collected in the various sampling stations during the study period; the codes mf1, mf2, mf3, F1, F2, F3, mk1, mk2 mk3, A1, A2, A3 and mz indicate sampling stations.

Phylum	**Class**	**Order**	**Family**	**Genus**	**Species**	mufueh			Furmuki			mankon			Ayabah			mezam
						mf1	mf2	mf3	F1	F2	F3	mk1	mk2	mk3	A1	A2	A3	mez
Arthropoda	Crustacea	Decapoda	Potamolidae	NI	NI	0	0	0	0	0	0	0	0	0	2	0	0	2
	Insecta	Coleoptera	Chrysomelidae	Donacia	*Donacia* sp.	1	1	2	0	0	0	0	0	0	0	0	0	0
			Gyrinidae	Gyretes	*Gyretes* sp.	63	4	0	0	0	2	3	0	0	1	2	3	4
				Dineutus	*Dineutus* sp.	3	4	0	0	0	0	0	0	0	0	0	0	0
				Gyrinus	*Gyrinus* sp.	56	16	0	1	0	0	0	0	0	0	1	2	0
			Hydrophilidae	Helobata	*Helobata* sp.	3	0	2	0	0	0	0	0	0	0	0	0	2
				Derallus	*Derallus* sp.	2	0	5	0	0	0	0	0	0	0	0	0	0
				Sperchopsis	*Sperchopsis* sp.	0	0	1	0	0	0	0	0	0	0	0	0	0
				Berosus	*Berosus* sp.	0	0	13	0	0	0	0	0	0	0	0	0	0
			Dytiscidae	Cybista	*Cybista* sp.	0	0	11	0	0	0	6	0	0	0	0	9	0

				Agabetes	*Agabetes* sp.	0	0	2	0	0	0	0	0	0	0	0	0	0
				copelatus	*copelatus* sp.	2	0	10	0	0	5	3	0	0	0	0	0	0
				Desmopachria	*Desmopachria* sp.	5	0	6	0	0	0	0	0	0	0	0	0	2
				Hydroptrapes	*Hydroptrapes* sp.	0	0	1	0	0	0	0	0	0	0	0	0	2
				Ilybius	*Ilybius* sp.	12	0	1	0	0	0	0	0	0	2	0	0	0
			Dryopidae	Dryops	*Dryops* sp.	1	0	0	1	0	2	0	0	0	0	0	0	2
			Georissidae	Georissue	*Georissue* sp.	2	0	0	0	0	0	0	0	0	0	0	0	0
			Salpingidae	Aegilites	*Aegilites* sp.	2	4	0	7	0	7	4	1	2	0	0	3	4
			Haliplidae	Peltodytes	*Peltodytes* sp.	1	0	25	0	0	0	3	0	0	0	0	0	0
			Psephenidae	psephenus	*psephenus sp.*	0	1	0	0	0	0	0	0	0	0	0	0	0
			Elmidae	Lara	*Lara* sp.	0	0	0	5	0	0	0	0	2	0	2	0	0
		Odonata	Libellulidae	Pantala	*Pantala falvesceus*	38	19	85	17	1	18	27	22	38	9	14	15	29

				Tramea	*Tramea* sp.	51	36	107	11	9	49	40	31	43	19	21	25	43
				Miathyria	*Miathyria* sp.	0	0	2	0	0	0	0	0	0	0	0	0	0
				Orthemis	*Orthemis* sp.	0	0	0	0	0	0	0	0	0	0	0	0	0
			Gomphidae	Hagenius	*Hagenius* sp.	0	0	4	0	0	0	0	0	0	0	0	0	0
			Coenagrionidae	Hagen	*Hagen* sp.	0	9	2	0	0	0	0	0	0	0	0	0	13
				Enallagma	*Enallagma cyathijerum*	0	0	12	0	0	0	0	0	0	0	0	0	0
				Nehalennia	*Nehalennia spaciosa*	1	0	16	0	3	7	0	1	1	0	0	0	7
			Calopterygidae	Calopteryx	*Calopteryx maculata*	13	63	21	27	10	106	30	47	51	37	16	22	73
				Hetaerina	*Hetaerina titia*	16	39	15	20	4	60	22	29	38	14	13	8	44

			Aeshnidae	Gynacantha	*Gynacantha nervosa Rambus*	0	5	3	3	0	0	0	0	0	0	0	0	0
				Aeshna	*Aeshna* sp.	3	0	3	0	0	0	0	0	0	0	0	0	0
		Hemiptera	Gerridae	Limnogonus	*Limnogonus metrobates*	4	0	0	0	0	0	0	0	0	0	0	0	0
					Limnogonus sp.	2	0	0	0	0	0	0	0	0	0	0	0	0
				Ventidius	*Ventidius pulai*	3	0	0	0	0	0	3	0	0	0	0	0	2
					Ventidiusmodulatus	10	0	0	0	0	0	4	0	0	0	0	0	1
					Ventidius malayensis	13	0	0	0	0	0	8	0	0	0	0	0	2
				Metrocoris	*Metrocoris nigrofasciutus*	0	0	0	0	0	0	2	0	0	0	0	0	0

				Limnometra	*Limnometra ciliata*	8	0	0	0	0	0	1	0	0	0	0	0	0
					Limnometra sp.	10	0	0	0	0	0	3	0	0	0	0	0	0
					Limnometra matsudai	4	0	0	0	0	0	0	0	0	0	0	0	0
				Aselepios	*Aselepios* sp.	0	0	0	0	0	0	2	0	0	0	0	0	0
				Tenagogonus	*Tenagogonus* sp.	0	0	0	0	0	0	2	0	0	0	0	0	0
			Corixidae	Palmacorix	*Palmacorix* sp.	0	4	2	0	0	0	0	0	0	2	0	0	0
			Macroveliidae	Macrovelia	*Macrovelia hornii Uhler*	0	1	10	0	0	0	0	13	14	10	0	2	1
			Veliidae	Steinovelia	*Steinovelia* sp.	18	0	0	0	0	0	0	0	0	0	0	0	0
				Microvelia	*Microvelia* sp.	1	2	8	0	0	0	0	0	0	4	0	0	3
				Rhagovelia	*Rhagovelia mayr*	3	13	0	0	16	0	0	6	0	3	0	0	3
			Nepidae	Nepa	*Nepa* sp.	1	0	4	3	3	1	11	3	1	3	6	0	0

				Curictini	*Curictini* sp.	21	2	10	0	0	2	0	0	0	0	0	0	0
				Laccotrephes	*Laccotrephes* sp.	1	0	0	0	0	0	0	0	0	0	0	0	0
				Ranatra	*Ranatra fabricius*	2	5	12	0	0	2	1	0	3	2	0	0	0
			Belostomatidae	Lethocerus	*Lethocerus* sp.	42	0	2	0	0	0	0	0	0	0	0	0	0
				Abedus	*Abedus* sp.	0	7	0	6	11	15	3	4	7	3	1	2	15
				Belostoma	*Belostoma latreille*	0	26	16	30	12	64	18	18	30	11	20	20	14
			Hungerford	Graptocorixa	*Graptocorixa* sp.	0	0	0	0	0	0	0	0	0	0	0	0	0
			Notonectidae	Notonecta	*Notonecta Linnaeus*	4	0	0	0	0	0	3	0	0	0	0	0	0
			Hydrometridae	Hydrometra	*Hydrometra australisay*	5	0	0	0	0	0	0	0	0	0	0	0	0
			Naucoridae	Pelocoris	*Pelocoris shoshone*	0	7	13	11	0	9	0	0	2	2	8	3	0

		Ephimeroptera	Caenidae	Caenis	*Caenis femina*	0	19	4	63	101	66	0	64	29	44	24	23	8
				Brachycerus	*Brachycerus* sp.	4	11	1	41	52	13	0	33	14	12	12	9	2
			Siphlonuridae	Siphlonurus	*Siphlonurus* sp.	0	0	0	2	0	0	0	0	0	0	0	0	0
			Polymitalyiidae	Ephoron	*Ephoron* sp.	4	2	0	7	5	13	3	12	11	8	0	0	12
			Potamanthidae	Potamanthus	*Potamanthus* sp.	4	0	0	0	0	0	0	0	0	0	0	0	0
			Baetidae	Procloeon	*Procloeon pennulatum*	0	18	0	112	223	43	0	46	5	48	13	2	20
			Oligoneuriidae	Oligonurella	*Oligonurella* sp.	0	0	0	0	0	0	0	0	0	0	0	0	0
			Leptophlebiidae	Hydrosmelodon	*Hydrosmelodon* sp.	0	0	0	0	0	0	0	0	0	0	0	0	0
		Trichoptera	Hydroptilidae	Orthotrichia	*Orthotrichia* sp.	0	0	1	0	0	0	0	0	0	0	0	0	0

				Palaeagapetus	*Palaeagapetus* sp.	9	0	0	0	0	0	0	0	0	0	0	0	0
			Limnephilidae	Anabolia	*Anabolia* sp.	0	0	0	4	1	0	0	0	0	0	0	0	0
			Lepidostomatidae	Theliopsche	*Theliopsche* sp.	17	0	0	0	0	0	0	0	0	0	0	0	0
			Phryganeidae	Phryganus	*Phryganus* sp.	0	0	0	0	0	0	0	0	0	0	0	0	3
			Brachycentridae	Brachycentrus	*Brachycentrus* sp.	0	0	0	7	2	0	0	0	0	0	0	0	2
			Goeridae	Goeracea	*Goeracea* sp.	5	0	0	0	0	0	0	0	0	0	0	0	0
			Sericostomatidae	Agarodes	*Agarodes* sp.	9	0	0	0	0	0	0	0	0	0	0	0	0
			Philopotamidae	Dolophilodes	*Dolophilodes* sp.	20	0	0	0	0	0	0	0	0	0	0	0	0
				Chimarra	*Chimarra* sp.	2	1	0	5	0	0	0	0	0	0	0	0	0
			Hydropsychidae	Hydropsyche	*Hydropsyche* sp.	0	18	2	68	2	12	0	0	8	2	0	0	17
		Plecoptera	Perlolidae	Clioperla	*Clioperla llio*	1	0	0	0	0	0	0	0	0	3	0	0	3

		Diptera	Ephydridae	Allotrichoma	*Allotrichoma* sp.	0	0	0	0	0	0	0	0	0	1	4	0	0
			Dolichopodidae	Rhaphium	*Rhaphium campestres*	2	0	0	0	3	0	0	3	2	0	1	2	0
			Empididae	Hemerodrominae	*Hemerodrominae* sp.	0	0	0	0	0	0	0	0	0	2	0	0	0
			Sciomyzidae	Dictya	*Dictya pictipes*	0	0	0	3	1	0	0	0	0	2	0	0	0
				Ilybius	*Ilybius* sp.	8	0	0	2	0	0	0	0	0	0	0	0	0
				Sepedon	*Sepedon* sp.	0	0	0	1	8	0	0	0	0	0	0	0	0
				Tetanocera	*Tetanocera vicinan*	2	0	0	8	2	0	0	3	0	43	2	0	0
			Syrphidae	Eristalis	*Eristalis tenax*	5	4	0	3	10	4	0	2	9	4	8	12	0
			Tipulidae	Tipula	*Tipula eluta loew*	3	0	0	3	2	0	0	1	0	3	0	0	0
				Hexatoma	*Hexatoma* sp.	8	0	0	0	0	0	0	1	0	0	0	0	0

			Simullidae	Simulium	*Simulium* sp.	2	0	0	36	25	12	0	67	6	14	6	8	0
			Chironomidae	Chironomous	*Chironomous riparious*	15	36	4	61	61	14	3	76	18	19	129	98	0
					Chironomous staegeri	18	14	3	46	22	2	1	31	8	14	65	68	0
					Chironomous stigmaterus	14	10	4	97	64	10	5	42	14	20	48	52	0
					Chironomous crassicaudatus	1	9	6	45	70	12	2	59	19	31	117	132	0
					Chironomous plumosus	0	7	3	13	6	3	1	31	4	9	53	30	0
				PseudoChironomous	*PseudoChironomous* sp.	2	0	0	3	0	0	0	0	0	1	0	0	0

				Dicrotendipes	*Dicrotendipes neonodestus*	0	0	2	2	0	0	0	0	0	0	0	0	0
				Ablabesmyia	*Ablabesmyia peleensis*	0	0	0	2	1	1	0	2	0	0	1	0	0
				Eukiefferiella	*Eukiefferiella* sp.	1	0	1	0	0	1	0	2	0	5	0	0	4
				Zalutschia	*Zalutschia* sp.	0	0	1	6	1	1	0	0	0	0	1	0	4
				micropsectra	*micropsectra* sp.	6	0	0	1	2	0	0	0	0	0	0	0	0
				Denopelopia	*Denopelopia atria*	15	0	0	0	0	0	0	0	0	0	1	3	0
				Polypedilum	*Polypedilum beckae*	9	0	3	23	29	8	2	32	7	18	24	21	1
					Polypedilum illinoense	0	8	4	63	69	19	4	48	14	33	41	45	6
					Polypedilum laetum	2	3	4	29	36	8	3	21	10	17	22	19	0

				Tanypus	*Tanypus* sp.	0	0	0	3	0	0	4	0	0	0	0	0	0
				Procladus	*Procladus bellus*	2	6	4	31	58	16	3	24	11	23	24	26	0
				Catopilopia	*Catopilopia gesta*	25	0	0	0	1	0	0	0	1	0	0	3	0
				Brundiniella	*Brundiniella eumorpha*	0	2	1	0	1	2	0	3	2	2	13	6	3
				Radotanypus	*Radotanypus florens*	0	19	12	90	86	27	5	78	27	46	77	75	0
Annelida	Achaeta	Rhynchobdellida	Glossiphoniidae	Haementeria	*Haementeria Costata*	0	0	1	9	4	30	30	19	12	6	13	20	0
				Helobdella	*Helobdella stagnalis*	0	0	0	18	77	63	11	26	50	17	34	23	2
Mollusca	Gastropoda	Basommatophora	Physidae	Petrophysa	*Petrophysa zionis*	0	0	0	0	172	37	15	63	33	0	35	44	0
				Archephysa	*Archephysa lordi*	0	0	5	0	608	109	37	263	106	1	86	120	3
			Planorbidae	Vorticfex	*Vorticfex* sp.	0	8	8	0	4	0	0	0	0	0	0	0	0
Total	4	10	55	104	113	642	463	500	1049	1878	875	328	1227	652	572	958	955	358

Appendix 5: Spearman correlation coefficients between biotic metrics and environmental variables; Toxonomic richness of EPT, EPTD, EPTC, EPTH; Dipt.% = Relative abundance of Diptera, Chiro.% = Relative abundance of Chironomidae

Variables	EPT	EPTD	EPTC	EPTH	Dipt.%	Chiro.%
Temperature	-0,82**	-0,82**	-0,83**	-0,82**	0,82**	0,09
pH	-0,61*	-0,61*	-0,63*	-0,63*	0,62*	0,37
Dissolved Oxygen	0,97**	0,98**	0,96**	0,98**	-0,97**	-0,43
Conductivity	-0,55*	-0,55*	-0,59*	-0,57*	0,55*	-0,17
TDS	-0,55*	-0,55*	-0,58*	-0,56*	0,54*	-0,17
Salinity	-0,58*	-0,58*	-0,62*	-0,60*	0,58*	-0,15
Turbidity	-0,71**	-0,71**	-0,72**	-0,70**	0,70**	-0,02
SS	-0,71**	-0,71**	-0,72**	-0,72**	0,70**	-0,07
Coulor	-0,64*	-0,64*	-0,64*	-0,64*	0,62*	-0,20
Alcalinity	-0,59*	-0,59*	-0,61*	-0,59*	0,58*	-0,19
Nitrates	-0,66*	-0,66*	-0,68*	-0,66*	0,65*	-0,10
Ammonium	-0,89**	-0,89**	-0,88**	-0,89**	0,89**	0,46*
Orthophosphates	-0,80**	-0,80**	-0,82**	-0,81**	0,79**	0,10
Oxydability	-0,56*	-0,56*	-0,58*	-0,56*	0,55*	-0,22
IPO	0,99**	0,99**	0,98**	0,97**	-0,98**	-0,49*

LIST OF PUBLICATIONS

Enah Dickson Achuo, Ajeagah Gideon Aghaindum, Foto Menbohan S., Timothy Biswick T., Mbouombouo Mama, Yogback Gertrude Estelle, Chrispin Kowenje, Samuel Pare, 2018. Distribution of Chironomidae (Diptera: Insecta): Bio-Indicators of Organic Pollution in the Bamenda River Basin, North West Region, Cameroon, The International Journal of Science & Technoledge, 6(7): 99 – 110.

Ajeagah Gideon Aghaindum, **Enah Dickson Achuo** and Foto Menbohan S. 2016. Chironomid bio-ecology in an anthropisized aquatic ecosystem in Yaounde (Cameroon): community diversity and relationship with the environmental variables of the water system. *Entomology and Applied Science Letters*, 3 (5):196-203.

Ajeagah Gideon Aghaindum, **Enah Dickson Achuo** and Foto Menbohan S. 2017. A Study of the Morphological Structure of Chironomidae (Diptera) in a Tropical Urban Polluted Water System. *International Journal of Sciences*, 6 (o6): 2305-3925.

LIST OF SCIENTIFIC COMMUNICATIONS

ENAH Dickson ACHUO, TCHAKONTÉ Siméon, AJEAGAH Gideon AGHAINDUM, Climate variability on drinking water availability in rural areas: a case study in the North West Region of Cameroon. Sub-Sahara Africa, the Special Students Exchange 2017 in Bahir Dar University, Ethiopia,

Enah Dickson Achuo, Ajeagah Gideon Aghaindum, Foto Menbohan S., Morphological Deformity in Chironomidae (Diptera: Insecta) as indicators of polluted rivers in Mezam River, North West Region, Cameroon. 6TH Life Science Conference, 8-10, 2018, University of Dschang, Cameroon.

Enah Dickson Achuo, Ajeagah Gideon Aghaindum, Foto Menbohan S., Vibrio cholerae reservoir, indicators of pollution: community structure of chironomidae (Dipteria) in an urban stream, Cameroun. *Meilleur Accès aux Soins de Santé/Better Access to Health Care*, July 2017, Yaounde Congress Hall.