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Aspects of the Geomorphology and Limnology of some mollusc-inhabited freshwater bodies in northern Nigeria

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Abstract: *A three-year study was conducted in twenty five mollusc – inhabited water bodies spread across four hydrological areas in northern Nigeria. This was done to determine some aspects of the geomorphology and limnology of the water bodies. Four sampling stations were selected along a line transect across each water body for collection of aquatic molluscs, measurement of physico-chemical factors and other parameters. A portable Combo Hanna® meter was used to measure pH, electrical conductivity, water temperature and total dissolved solids while alkalinity, sulphate, nitrate, phosphate, chloride, hardness, dissolved oxygen and biological oxygen demand were determined by titration. The specimens of freshwater molluscs collected were identified using standard procedure. The result of the study showed that a total of 14 species of freshwater molluscs belonging to 9 families were found in the water bodies. The linear regression analysis showed positive relationships between elevation and temperature, alkalinity, chloride and nitrate, indicating corresponding variations with different elevations. The negative relationship between altitude and pH, hardness and dissolved oxygen signifies that water bodies at higher elevations had lower values for these environmental variables. The Canonical Correspondence Analysis (CCA) established the relationships amongst the environmental factors that characterised the water bodies. The substrata of the water bodies showed heterogeneity. Water temperature, pH, dissolved oxygen, alkalinity, hardness, phosphate phosphorus and sulphate were the likely important factors that are significantly related in the water bodies within hydrological areas. The intense human activity associated with the water bodies could also have negative impact on the aquatic ecology of the study area.*

Key words: *Freshwater, molluscs, geomorphology, limnology, northern Nigeria*.

I. Introduction

Fresh waters of the world are collectively experiencing markedly accelerating rates of qualitative and quantitative degradation (Wetzel, 1992). Freshwater ecosystems contain approximately 12% of the Earth's animal diversity, and most other species depend on them indirectly for their survival (Abramovitz, 1996). Despite their importance, freshwater ecosystems are rapidly being modified or destroyed (Allan and Flecker, 1993; Green et al., 2002) and many species have consequently become endangered (Master et al., 1998; Duncan and Lockwood, 2001; Perez-Losada et al., 2002; Abellan et al., 2005). Limnological studies on water bodies in West Africa have mainly focused on larger waters such as River Sokoto (Holden and Green, 1960), Lake Chad (Carmouze et al., 1983) the Volta river system (Biney, 1990), Niger lakes (Segers et al., 1992) and Lake Kainji (Bidwell and Clarke, 1997). Very little attention has been given to many smaller lakes and reservoirs around, whose study could contribute significantly to the understanding of tropical freshwater ecosystems and the impact of anthropogenic activities on freshwater system (Araoye, 2002). Among other factors, total hardness, pH, altitude, size of water bodies, temperature, vegetation and pollution were among the significant factors influencing the distribution and abundance of molluscs (Dillion, 2000). Eleutheradis and Lazaridou-Dimitriadou (1995) reported that hardnesss and pH are the most important factors that both directly and indirectly influence metabolic activities and thereby growth and abundance of freshwater molluscs. Clements et al. (2006) reported the importance of six different habitats (i.e. catchment reservoirs, estuarine reservoirs, forest streams, rural streams, ponds and monsoon canals) for conserving the diversity of freshwater molluscs; key environmental factors (e.g. pH) affecting molluscan distribution; important biogeographical determinants (e.g. area) of molluscan richness within each habitat and the habitat affinities of introduced species. The geomorphologic aspects of freshwater habitats may explain the zoogeography of some species of freshwater molluscs (Kohl, 2006). Therefore this study provides information on the geomorphological and limnological features of some molluscs-inhabited freshwater bodies in northern Nigeria.

II. Materials And Methods

Study Area

Sampling sites were spread across northern Nigeria (Long. 8° – 14°N; Lat 3° – 14°E). Northern Nigeria falls within the savanna ecoregion. The guinea savanna covers the north-central and part of the north-west; the Sudan savanna covers most part of the north-east and north- west. The Sahel savanna covers a small portion in the extreme north-east zone close to Lake Chad. The inland waters in northern Nigeria include rivers (mostly seasonal), lakes, mine ponds, flood plains, reservoirs and streams (Happold, 1987). These water bodies constitute the five hydrological areas/basins that occur in the area (Ita, 1993). All of the region's lotic waterbodies drain into the Rivers Niger and Benue and Lake Chad, the three major sumps for run-off-water in the region.

Study Design

A hydrological map of Nigeria was used in the random selection of major water bodies according to their hydrological areas. Possible collection sites were determined on the basis of on-the-spot-assessment (which include presence of rich vegetation at fringes, floating algal mats, etc) of the potential sample areas. Molluscs were collected over a period of three years, during the wet and dry seasons.

Collection and Preservation of Molluscs

Heights and breadths of the shells were measured with a sliding caliper. The number of whorls characteristic of each species' shell was counted and the direction of the spiral coil noted. All live and dead aquatic shells were collected and preserved in labelled collection bottles containing 95% alcohol, and taken to the laboratory for further examination.

Measurement of Geomorphological Features

The geographic location (the longitude, latitude and elevation) of each sampling site was determined using a Global Positioning System (GPS), Model N9 GARMIN eTrexLegend™, personal navigator®. Environmental observations (such as soil texture, nature of substratum, etc) and observations of associated aquatic vegetation (using a three point scale: 1- sparse, little or no floating vegetation; 2- floating algal mats with macrophytes; 3- algal mats on dense vegetation along the shores) were recorded.

Collection and Analysis of Water Samples

Water samples were collected in triplicate from sites of molluscs' collections using 2- litre plastic bottles. Collection containers were properly washed with detergent, rinsed with distilled water and air-dried prior to sampling. Collection containers were rinsed with sampled water just before sample collection. Standard Biochemical Oxygen Demand (BOD) bottles were used to collect water samples for BOD and Dissolved Oxygen (DO) determination.

Determination of Physico-chemical Factors

A portable Combo Hanna® instrument, Model 98129, was used to measure pH, Electrical Conductivity, Water Temperature and Total Dissolved Solids at the site of collection of aquatic molluscs. The following parameters were determined by titration according to APHA (1998): Alkalinity, Sulphate, Nitrate, Phosphate, Chloride, Hardness, Dissolved Oxygen (DO) and Biological Oxygen Demand (BOD).

Identification of Molluscs

Molluscs collected were identified using the taxonomic guides by Burch (1989), Barney (2000) and Thompson (2004).

Statistical Analysis

Linear regression analysis was used to determine the relationship (if any) between elevation and physicochemical parameters using Analyse-it v.2.14 (Analyse-it, version 2008). A multivariate ordination technique (Canonical Correspondence Analysis), using Multi-Variate Statistical Package (MVSP) software, was used to establish possible relationships between the distribution of aquatic molluscs and physicochemical parameters.

III. Results

Geomorphological Characteristics of the Freshwater Bodies

A total of 25 (lotic and lentic) freshwater bodies that had one or more mollusc species, in the four hydrological areas of northern Nigeria, were investigated. The water bodies varied in their locations, sizes, elevation and aquatic vegetation (Table 1). The location of the water bodies above sea level varied considerably, with the lowest elevation of 140 (m) at Kainji Lake (Niger State), which also is the largest of the drainage systems. The highest elevation of 669 (m) was in Sabuwa (Katsina State), one of the smallest of the water bodies studied. The nature of the substratum was largely a combination of fine sand, mud and rocks. A high level of anthropogenic activities characterized most of the water bodies.

Physicochemical Characteristics of the Water Bodies Studied

The values for temperature, electrical conductivity (EC), total dissolved solids (TDS), alkalinity, sulphate, chloride and hardness of the water bodies were remarkably heterogeneous showing wide variations, with mean values of 28.14±0.65^{o}C, 69.92±13.56µs/cm, 35.65±6.88ppm, 44.89±3.86, 130.60±18.02mg/l, 52.12±9.89mg/l and 50.89±2.51 respectively (Table 2). The water pH varied between 5.37 (acidic) and 8.71 (alkaline) with a near neutral mean value of 7.17±0.20. There was slight variation in the amount of dissolved oxygen (DO) and biochemical oxygen demand (BOD) of the water bodies, with mean values of 5.48±0.31mg/l and 1.39±0.39mg/l respectively (Table 2).

Molluscs Composition of the Water Bodies

The composition of freshwater molluscs of the 25 water bodies studied had 15 species of snails belonging to 9 families (Table 3). Three of the families belong to the class Bivalvia while the others are of the class Gastropoda.

Table 1: Geomorphological Characteristics of the Freshwater Bodies of the Four Hydrological Areas of northern Nigeria.

Water Body	River Basin	Hydrological Area	Coordinate	Elevation (meters)	Area/Size (ha)†	Vegetation*	Predominant substrate type	Anthropogenic Activity
Kar'adua River	Hadejia	Lake Chad	N12°21.654′ E007°24.776′	476	NA	2	large rocks, intermediate sand	Low
Alau Lake	Hadejia	Lake Chad	N11°43.190′ E013°16.969′	315	80	3	Fine and intermediate sand	High
Tiga Reservoir	Hadejia	Lake Chad	N11°28.887′ E008°21.595′	409	17800	1	large rocks, intermediate sand	High
Zobe Reservoir	Hadejia	Lake Chad	N12°22.494′ E007°27.874′	486	5000	2	intermediate sand with fine mud	Intermediate
Challawa Gorge Reservoir	Hadejia	Lake Chad	N11°44.072′ E008°01.909′	534	10100	1	intermediate sand with fine mud	Low
Baga Lake	Hadejia	Lake Chad	N13°08.296′ E013°49.538′	274	285	2	fine sand with mud patches	High
Nguru River/ Wetland	Hadejia	Lake Chad	N12°52.381′ E010°26.762′	432	NA	3	fine sand with mud	High
Jama're River/ Flood Plain	Gongola	Upper Benue	N11°40.251′ E009°56.416′	387	NA	2	fine mud	High
Dadin Kowa Reservoir	Gongola	Upper Benue	N10°19.192′ E011°28.699′	249	29000	3	large rocks, intermediate sand	High
Gubla Reservoir	Gongola	Upper Benue	N10°52.464′ E013°33.405′	451	2.8	3	fine mud	High
Garkida River	Gongola	Upper Benue	N10°24.652′ E012°35.765′	325	NA	2	Small rocks, intermediate sand	Intermediate
Jibia Reservoir	Sokoto	Niger North	N13°04.238′ E007°13.606′	409	4000	2	fine sand with mud	Intermediate
Kainji Lake	Sokoto	Niger North	N09°54.571′ E004°33.702′	140	127000	2	fine sand with mud	High
Bakolori Reservoir	Sokoto	Niger North	N12°27.122′ E008°11.307′	385	8000	2	fine sand with mud	High
Mairuwa Reservoir	Kaduna	Niger Central	N11°35.007′ E007°14.581′	626	144	3	fine sand with mud	Intermediate
Sabuwa Reservoir	Kaduna	Niger Central	N11°10.836′ E007°07.642′	669	3.4	1	fine sand with mud	High
Shiroro Reservoir	Kaduna	Niger Central	N09°58.985′ E006°49.291′	270	31200	3	large rocks, intermediate sand	High
Kaduna River	Kaduna	Niger Central	N10°31.241′ E007°28.352′	593	NA	2	large rocks, intermediate sand	High
Kaya Reservoir	Kaduna	Niger Central	N11°14.782′ E007°14.840′	668	4.3	1	fine mud	High
Spoti Reservoir	Kaduna	Niger Central	N11°14.870′ E007°21.253′	615	3.2	2	fine mud	High
Sabon Bimi Reservoir	Kaduna	Niger Central	N11°14.400′ E007°27.678′	652	28.6	1	fine mud	Intermediate
Kubani Lake	Kaduna	Niger Central	N11°08.234′ E007°39.345′	643	5.5	2	fine sand with mud	Intermediate
Kangimi Reservoir	Kaduna	Niger Central	N10°43.272′ E007°35.242′	633	567	2	fine sand with mud	Intermediate
ABU Reservoir	Kaduna	Niger Central	N11°12.183′ E007°35.929′	674	110	3	fine sand with mud	Intermediate
Jebba Reservoir	Kaduna	Niger Central	N09°51.137′ E004°36.889′	356	35000	2	fine sand with mud	Intermediate

KEY: *1- sparse, little or no floating vegetation; 2- floating algal mats with macrophytes: 3- algal mats on dense vegetation along the shores. †Adopted from Ita (1993).

Table 2: Mean values of physico-chemical factors at the studied water bodies. s.e. in parentheses

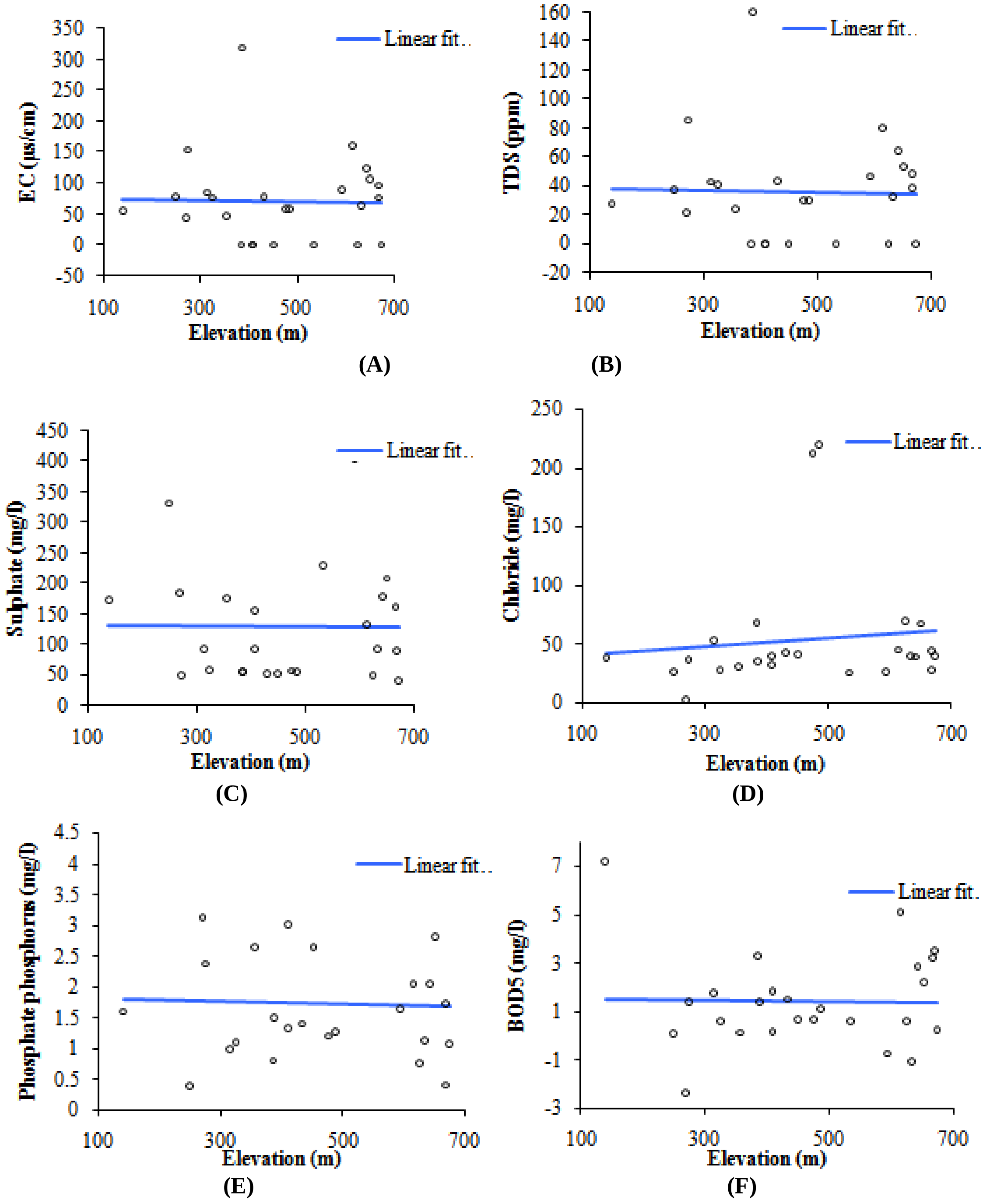
	Physicochemical Factor											
Water Body	**TEMP (°C)**	**EC (µs/cm)**	**TDS (ppm)**	**PH**	**ALK (mg/L)**	**SULP (mg/L)**	**NITR (mg/L)**	**PHOSPh (mg/L)**	**CHRD (mg/L)**	**HDNS (mg/L)**	**DO (mg/L)**	**BOD5 (mg/L)**
KAR	28.97	58.67	29.67	6.02	70.67	56.67	1.23	1.20	212.67	64.00	6.47	0.68
	(0.47)	(5.49)	(5.04)	(0.12)	(1.76)	(3.33)	(0.03)	(0.10)	(78.03)	(2.31)	(0.27)	(0.56)
ALL	23.53	85.33	42.67	7.35	42.00	91.67	0.23	0.98	53.33	54.67	4.98	1.73
	(0.07)	(0.88)	(0.33)	(0.03)	(3.21)	(10.13)	(0.03)	(0.19)	(14.15)	(8.67)	(0.43)	(0.49)
TGD	36.07	0.00	0.00	8.71	33.33	155.00	0.37	3.00	32.00	48.00	5.77	0.17
	(0.37)	(0.00)	(0.00)	(0.29)	(2.40)	(12.58)	(0.03)	(0.67)	(7.55)	(11.55)	(0.43)	(0.46)
ZBD	28.37	58.67	29.67	6.02	71.00	54.00	1.27	1.27	220.00	64.00	5.85	1.09
	(0.69)	(5.36)	(3.76)	(0.14)	(1.15)	(3.61)	(0.09)	(0.32)	(12.10)	(2.52)	(0.19)	(1.13)
CHD	35.17	0.00	0.00	8.11	27.33	230.00	0.37	4.17	25.33	41.33	5.83	0.60
	(1.20)	(0.00)	(0.00)	(0.14)	(2.03)	(8.66)	(0.03)	(0.03)	(2.96)	(7.42)	(0.09)	(0.53)
BGL	30.07	153.33	85.33	7.58	78.00	50.00	0.67	2.37	36.00	70.67	5.48	1.40
	(0.32)	(4.91)	(9.84)	(0.09)	(3.21)	(0.00)	(0.03)	(0.38)	(5.29)	(8.11)	(0.77)	(0.36)
NGR	29.50	79.00	43.00	7.60	87.00	52.00	0.80	1.40	43.00	65.00	7.80	1.50
	(0.90)	(8.21)	(3.40)	(0.87)	(6.05)	(3.56)	(0.24)	(0.02)	(4.67)	(5.43)	(1.40)	(0.23)
JUR	23.70	318.50	159.50	6.86	54.50	54.00	1.38	1.50	34.50	76.00	4.50	1.40
	(0.10)	(0.50)	(0.50)	(0.00)	(0.05)	(1.00)	(0.00)	(0.03)	(0.00)	(0.50)	(0.30)	(0.20)
DKD	30.17	79.00	37.00	7.98	36.00	331.67	0.63	0.38	25.67	38.67	4.70	0.08
	(0.12)	(8.19)	(5.13)	(0.19)	(2.00)	(3.33)	(0.03)	(0.01)	(5.36)	(4.81)	(1.83)	(2.08)
GBR	22.50	0.00	0.00	6.55	45.50	52.50	1.50	2.65	40.50	37.00	4.50	0.65
	(0.50)	(0.00)	(0.00)	(0.15)	(0.50)	(0.50)	(0.10)	(0.15)	(1.50)	(1.00)	(0.30)	(0.05)
GAR	25.55	77.00	41.00	8.20	29.00	58.50	0.85	1.10	28.00	48.50	3.95	0.60
	(0.85)	(10.00)	(2.00)	(0.04)	(3.00)	(4.50)	(0.05)	(0.20)	(6.00)	(3.50)	(0.35)	(0.10)
JBD	29.43	0.00	0.00	5.40	36.67	91.67	1.32	1.32	40.00	53.33	6.60	1.85
	(0.09)	(0.00)	(0.00)	(0.01)	(4.26)	(8.82)	(0.02)	(0.02)	(8.89)	(6.67)	(0.10)	(1.24)
KNL	27.60	54.67	27.67	7.38	28.33	173.33	0.63	1.60	37.67	50.67	11.40	7.17
	(0.15)	(1.20)	(0.33)	(0.05)	(2.33)	(8.82)	(0.02)	(0.69)	(9.68)	(3.53)	(2.43)	(1.76)
BAK	23.15	0.00	0.00	5.55	33.00	54.50	0.79	0.80	68.00	54.50	3.90	3.30
	(0.35)	(0.00)	(0.00)	(0.50)	(1.00)	(0.50)	(0.03)	(0.00)	(1.00)	(0.50)	(0.10)	(0.10)
MAI	28.97	0.00	0.00	5.39	76.00	50.00	1.30	0.75	69.67	70.67	5.88	0.58
	(0.28)	(0.00)	(0.00)	(0.03)	(5.57)	(0.00)	(0.00)	(0.05)	(6.33)	(3.53)	(0.28)	(0.33)
SBW	30.67	76.67	38.00	7.79	39.00	90.00	0.90	1.72	27.00	32.00	5.40	3.50
	(0.26)	(0.67)	(0.58)	(0.19)	(2.52)	(2.50)	(0.15)	(0.15)	(4.51)	(2.31)	(0.62)	(0.57)
SHR	27.43	43.00	21.00	7.55	24.33	185.00	0.68	3.13	2.70	41.33	4.90	-2.36
	(0.09)	(0.00)	(0.00)	(0.04)	(2.73)	(13.23)	(0.09)	(0.10)	(0.21)	(7.42)	(0.26)	(0.44)
KDR	29.17	88.67	46.33	7.15	36.33	404.00	1.65	1.65	26.50	48.00	4.50	-0.75
	(0.44)	(13.30)	(6.57)	(0.01)	(3.38)	(15.63)	(0.25)	(0.05)	(3.50)	(8.00)	(1.00)	(0.10)
KYD	30.83	96.67	48.33	7.11	24.00	160.00	4.40	0.40	43.33	42.67	3.73	3.20
	(0.88)	(4.70)	(2.33)	(0.51)	(2.89)	(0.00)	(1.55)	(0.01)	(3.18)	(2.67)	(0.46)	(0.72)
SPT	29.93	161.33	79.67	7.65	74.67	131.67	2.77	2.05	44.67	62.67	5.55	5.10
	(0.37)	(4.67)	(1.89)	(0.04)	(2.85)	(38.44)	(0.07)	(0.20)	(6.64)	(1.33)	(0.25)	(0.10)
SBD	28.87	107.00	53.33	8.10	56.33	208.33	2.35	2.82	67.00	48.00	5.20	2.20
	(0.19)	(0.58)	(0.33)	(0.07)	(0.88)	(21.28)	(0.05)	(0.36)	(16.29)	(2.31)	(0.30)	(0.70)
KUB	23.97	123.33	64.00	7.77	47.67	177.67	1.50	2.03	38.67	33.33	6.75	2.87
	(0.84)	(30.68)	(15.18)	(0.28)	(2.33)	(3.92)	(0.38)	(0.07)	(1.86)	(4.81)	(0.23)	(0.16)
KNG	28.40	63.00	32.67	61.4	29.67	93.33	1.10	1.12	39.00	40.00	4.27	-1.07
	(0.36)	(4.00)	(0.33)	(0.05)	(1.45)	(3.33)	(0.00)	(0.19)	(2.89)	(11.55)	(0.24)	(0.47)
ABU	27.53	0.00	0.00	5.37	39.33	40.00	0.67	1.08	40.00	28.00	5.67	0.23
	(1.60)	(0.00)	(0.00)	(0.03)	(1.45)	(0.00)	(0.01)	(0.02)	(0.58)	(2.31)	(0.34)	(0.19)
JED	26.03	47.00	24.00	8.18	23.67	175.00	0.83	2.64	30.00	54.67	4.45	0.12
	(0.24)	(1.00)	(0.00)	(0.19)	(2.03)	(16.07)	(0.28)	(0.20)	(6.08)	(7.42)	(0.38)	(0.86)
MIN.	**22.05**	**0.00**	**0.00**	**5.37**	**23.67**	**40.00**	**0.23**	**0.38**	**2.70**	**28.00**	**3.73**	**-2.36**
MAX.	**36.06**	**318.50**	**159.50**	**8.71**	**87.00**	**404.00**	**4.40**	**4.17**	**220.00**	**78.00**	**11.40**	**7.17**
MEAN	**28.14**	**69.92**	**35.65**	**7.17**	**44.89**	**130.60**	**1.19**	**1.76**	**52.12**	**50.86**	**5.48**	**1.39**
S.E.	**0.65**	**13.56**	**6.88**	**0.20**	**3.86**	**18.02**	**0.17**	**0.18**	**9.89**	**2.51**	**0.31**	**0.39**

Key: TEMP- Temperature, EC- Electrical conductivity, TDS- Total dissolved solids, pH-Hydrgen ion concentration, ALK- Alkalinity, SULP- Sulphate, NITR- Nitrate, PHOPh- Phosphate phosphorus, CHRD- Chloride, HDNS- Total Hardness, DO- Dissolved oxygen, BOD- Biochemical oxygen demand.
The abbreviations of water bodies are as arranged in Table 1 (column 1).

Table 3: Checklist of molluscs in the water bodies studied in northern Nigeria

Class	Family	Species
BIVALVIA	Unionidae	*Anodonta marginata*
		A. anatina
		A. implicata
	Mutelidae	*Aspatheria* sp.
	Etheriidae	*Etheria elliptica*
GASTROPODA	Viviparidae	*Bellamya crawshayi*
		B. unicolor
	Paludomidae	*Cleopatra bulimoides*
	Thiaridae	*Melanoides tuberculata*
		M. maculata
	Planorbidae	*Biomphalaria pfeifferi*
		Bulinus globosus
	Lymnaeaidae	*Lymnaea natalensis*
	Ampullariidae	*Pila ampullaceae*

Figure 1 (A-L) shows the linear regression analyses establishing the patterns of the relationships of the measured physicochemical factors with elevation. The EC, TDS, sulphate, chloride, phosphate phosphorus and BOD varied slightly with change in elevation. Temperature, alkalinity and nitrate showed a positive relationship, while hardness, pH and DO showed negative relationships with change in elevation.



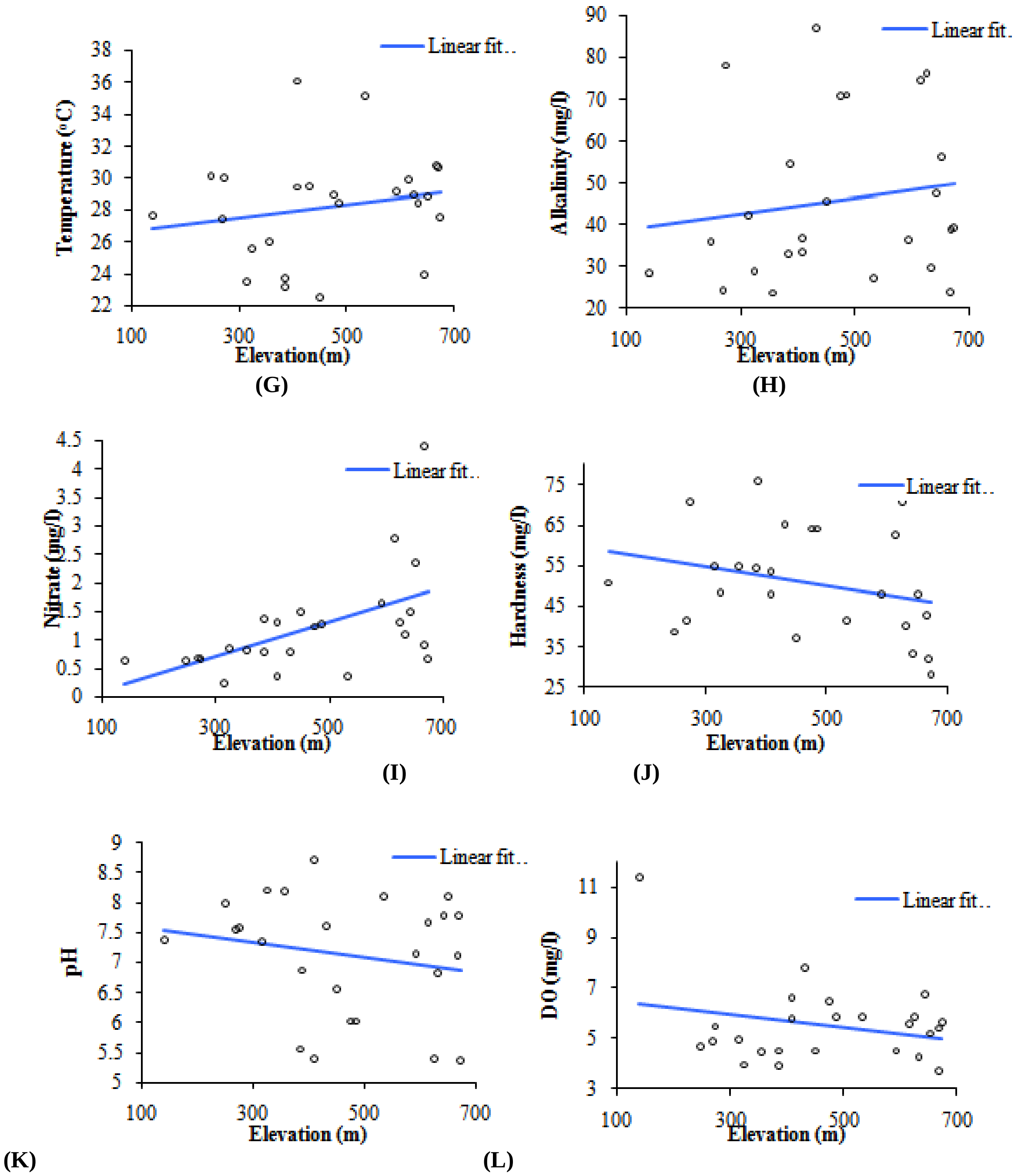
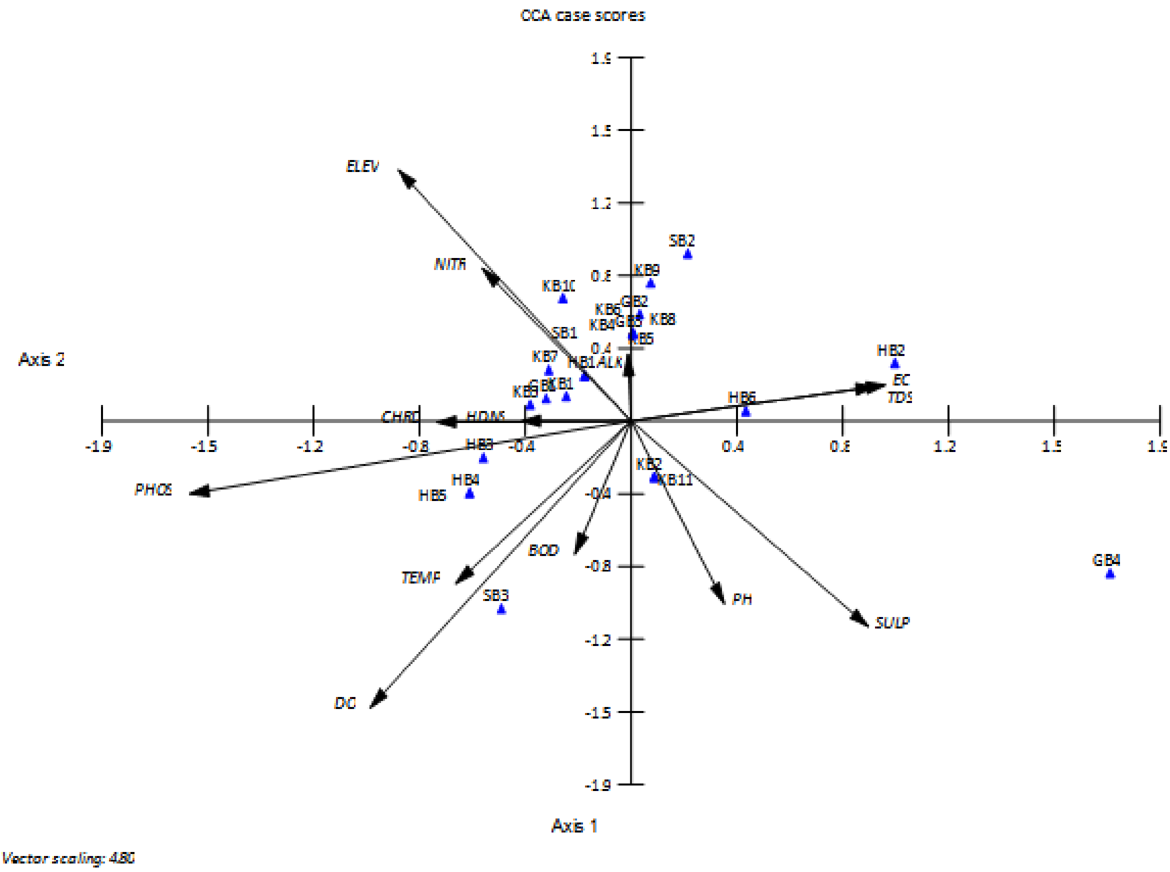


Figure 1(A-L): The linear regression analyses between measured physico-chemical factors and elevation of water bodies studied.

The Canonical Correspondence Analysis (CCA) graph (Figure 2) established the relationships between water bodies and environmental factors. Baga and Alau lakes showed high correlation with increasing TDS and EC that characterized the water bodies (Figure 2). Sabuwa and Shiroro Reservoirs showed similarities in the influence of increasing pH and sulphate contents on their species compositions. Phosphorus may be said to be responsible for determining the species composition in Tiga, Challawa and Zobe Reservoirs. The mollusc species compositions of Bakolori, Dadin Kowa and A.B.U. reservoirs appeared not to be influenced by the measured physicochemical factors.



Key: HB1- Karadua, HB2- Alau, HB3- Tiga, HB4- Zobe, HB5- Chalawa, HB6- Baga, GB1- Gubla, GB2- Jumare, GB3 – Garkida, GB4 – Dadin Kowa, SB1 – Jibia, SB2 – Bakolori, SB3 – Kainji, KB1 – Mairuwa, KB2 – Sabuwa, KB3 – River Kaduna, KB4 – Kaya, KB5 - Sabon Birni, KB6 – Sporti, KB7 – Kubani, KB8 - Kangimi, KB9- ABU, KB10 - Jebba and KB11 – Shiroro.

Figure 2: CCA ordination graph for first and second axes for water bodies and environmental factors.

IV. Discussion

In this study, the gastropods exhibited preference for still or slow-moving waters and extended their limits to irrigation systems and wetlands mostly utilized as rice field and other farming activities. The bivalves generally colonized non-turbid waters with a sandy substratum. This niche specialization agrees with observations by Prabhakar and Roy (2008) tha reported colonization of lentic and wetland habitats by gastropods while bivalves were found in clear waters buried in sands. The occurrence of bivalves is said to be indicative of non-polluted water and oxygen-rich habitat and may also be considered as bio-indicators in inland waters (Prabhakar and Roy, 2008). The elevation of the water bodies' studied here was variable. Kainji Lake, the largest of the water bodies, had the lowest elevation (140 meters) while Sabuwa Dam with 669 meters above sea level had the highest elevation. It was observed that at higher elevations, meandering water channels empty into deep and wide depressions downstream which serve as collection points in some parts of northern Nigeria. Wetzel (2001) reported that shallow water basins can originate from processes that caused modest depressions in the landscape. The tributaries to these depressions have helped to ensure availability of water midway through the dry season or for most part of the year and therefore served as good habitats for molluscs. Geomorphologic conditions could therefore be said to also contribute to the factors that affect the diversity of snail species. The non-homogenous nature of the aquatic habitats in this study could have contributed to the good representation of different mollusc taxa. The nature of the substrata of the water bodies was predominantly fine sand with mud that facilitates water retention while certain parts of the substrata were rocky. This made the habitats more diverse and provided good microhabitats for the anchorage of specialized bivalves like the Etheria elliptica, thereby increasing the mollusc species diversity of the water bodies. Kurihara et al. (2001) reported that larger substrates increase habitat heterogeneity by providing microhabitats to support high densities of molluscs. The water bodies in the study area experience high anthropogenic activities especially during the dry season. The activities include washing, bathing, fishing, watering points for animals and channeling of water for irrigation. Such activities often result in decrease in the availability of water and could lead to pollution which affects aquatic life. The positive linear relationships (simultaneous increase and decrease) between elevation and temperature, alkalinity, chloride and nitrate indicate corresponding variations with the different elevation levels. The negative relationship (inverse increase and decrease) between altitude and pH, hardness and DO signifies that water bodies on higher elevation had lower values for these environmental variables. Sturm (2007) observed the influence of altitude on environmental variables such as water temperature, pH, EC, nitrate, DO, BOD_5 and sulphate. The presence of empty shells of freshwater molluscs in the study area could be an indication of habitat loss due to environmental degradation (desert encroachment and water pollution from anthropogenic activities) which prolong the mollusc aestivation period and eventually result in death of the molluscs.

The average mean values of the twelve (12) physicochemical factors of the water bodies measured are given in Table 2. Water temperature showed wide variation of 22.05 to 36.06^{o}C, with an average value of 28.14±0.65^{o}C. The variation in water temperature is mainly related with the temperature of the atmosphere and weather conditions (Sawyer et al., 1994; APHA, 1998; Adebowale et al., 2008). The pH range in this study varied from slightly acidic (5.37) to more alkaline (8.71) conditions, with an average of 7.17±0.20. This pH range could have favoured the occurrence of freshwater molluscs. Kalyoncu et al. (2008) reported pH values of between 7.84 and 7.38 in streams in Turkey that support a good number of different molluscs. Adebowale et al. (2008) attributed variation in pH to exposure of water body to atmosphere, biological activities and temperature changes, in Ondo State Nigeria. Surface runoff and decaying vegetation also produce low pH waters, which can retard snail growth by increasing the rate of calcium dissolution (Dussart, 1976; Hunter, 1990). The Electrical Conductivity (EC) and Total Dissolved Solids (TDS) showed wide variations of 0.00 to 318.50 and 0.00 to 159.50, and average values of 69.92ppm and 35.65ppm respectively. The average values of EC and TDS in this study can be considered low. Kumar and Bahadur (2009) reported higher ranges of 347 to 433 and 525 to 485 respectively. High values of EC and TDS indicate large quantity of dissolved mineral salts (Trivedy and Goyal, 1986) and high turbidity (APHA, 1998) respectively. The mean hardness of the water bodies in this study is 50.86±2.51, which is an indication of very soft water. Eleutheradis and Lazaridou-Dimitriadou (1995) reported that hardness and pH are the most important factors that both directly and indirectly influence metabolic activities and thereby growth and abundance of freshwater molluscs. Hardness and pH of water were thought to be important in influencing mollusc shell calcium. Chatterjee et al. (2008) reported that these two factors not to have any direct influence on the total shell calcium of the limpet Septaria lineate. Odhiambo and Gichuki (2000) reported that aside seasonality, alkalinity and pH vary within and between African Lakes, ponds, streams, etc. The alkalinity of the water bodies in this study showed wide range of values (23.67 to 87.00) with mean value of 44.89±3.86 mg/l. This value is higher than 27.00±0.1and lower than 91- 130 mg/l reported by Hart (2001) and Kumar and Bahadur (2009) respectively. The wide range of alkalinity of the water bodies in this study may be indicative of their capacity to withstand acidification. Waters with low alkalinity are very susceptible to changes in pH while those with high alkalinity have the capacity to resist major shift in pH (Giller and Malmqvist, 1998). Increase in alkalinity values could result from extended dry season period, high evaporations and nature of substratum (Chindah and Braide, 2004). Water that is low in alkalinity (Calfo, 2005) but high in pH is generally unsuitable for invertebrates. The average values (1.76±0.18 and 1.19±0.17) of phosphate phosphorus and nitrate respectively, were high compared to respective values of 0.015±0.00 and 0.17±0.10 reported by Hart (2001) in Wagendrift Dam South Africa. Phosphorus is obviously an important nutrient that often accelerates the productivity of fresh waters (Wetzel, 2001). The quantity of phosphorus entering the surface drainage varies with the amount of phosphorus in soil, topography, vegetative cover, quantity and duration of runoff flow, land use, and pollution (Wetzel, 2001). Nitrate is an essential nutrient for plants but excessive levels are detrimental. The sulphate value obtained in this study was considerably high. Sulphate is widely present in natural waters. Unlike nitrate it is not toxic to aquatic life. The mean high concentration of chloride (52.12±9.89 mg/l) in this study could be as a result of the utilization of the water bodies as main source of drinking for predominantly cattle, goats and sheep. Chloride is the most common inorganic ion in water and is very dangerous to vegetation in high concentrations. It is usually not dominant in open lake ecosystems (Wetzel, 2001). Zhou and Smith (2002) reported that man and animals excrete high quantities of chloride and therefore high concentration is an indication of sewage contamination. The low Biochemical Oxygen Demand (BOD) of the water bodies may be indicative of organic pollution. Other important factors influencing BOD include types of microorganisms, pH, presence of toxins, some reduced mineral matter and nitrification process (Kumar and Bahadur, 2009). The average DO of 5.48±0.31 (mg/l) of the water bodies obtained in this study is an indication of good habitats for molluscs. Studies have shown that proper dissolved oxygen (DO) levels are essential for aquatic ecosystems. Mean DO values of 5.65 and higher were reported to support high diversity of molluscs in stream waters (Kalyoncu et al., 2008). The DO value of 5.00 mg/l or greater has been considered good for healthy growth in fish. Low DO may be as a result from mild pollution or seasonal transition of water. Chindah and Braide (2004) reported that a sudden and gradual depletion of dissolved oxygen can cause major shifts in the kinds of aquatic organisms; from pollution intolerant species to pollution tolerant species.

Despite the relative small sizes of some of the water bodies they contain quite as high diversity of indigenous species as the large water bodies and can be therefore targets for conservation initiatives. The high alkalinity values of the water bodies is an indication that the aquatic system has high capacity to withstand acidification, which could result from indiscriminate discharge of inorganic waste, agricultural waste and industrial effluents. Unlike the surface area of the water bodies, temperature, pH, dissolved oxygen, alkalinity, hardness, phosphate phosphorus and sulphate were the important factors that significantly influenced the distribution of a number of aquatic molluscs in northern Nigeria.

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