DISTRIBUTION AND TAXONOMY OF MOLLUSCS (MOLLUSCA) IN SOME PARTS OF NORTHERN NIGERIA

BY

GADZAMA, IBRAHIM MADU KATSALLAH

DEPARTMENT OF BIOLOGICAL SCIENCES, AHMADU BELLO UNIVERSITY, ZARIA, NIGERIA

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GADZAMA, IBRAHIM MADU KATSALLAH
B.TECH. (FUTY 1991), M.SC. (ABU 2000), PGDE (NTI 2008)
Ph.D. /SCIE/41843/2004-05

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DEPARTMENT OF BIOLOGICAL SCIENCES, AHMADU BELLO UNIVERSITY
ZARIA, NIGERIA

NOVEMBER 2012

DECLARATION

I hereby declare that this dissertation entitled "DISTRIBUTION AND TAXONOMY OF MOLLUSCS (MOLLUSCA) IN SOME PARTS OF NORTHERN NIGERIA" was prepared by me in the Department of Biological Sciences, under the supervision of Professor A.U. Ezealor, Professor T. Aken′Ova and Professor M.L. Balarabe. Information derived from other sources has been duly acknowledged in the text and a list of references provided. This work has not been presented in any form for another degree at any other university or institution.

Gadzama, Ibrahim Madu Katsallah

_____	_____	_____
Name of Student	Signature	Date

CERTIFICATION

This dissertation entitled "DISTRIBUTION AND TAXONOMY OF MOLLUSCS (MOLLUSCA) IN SOME PARTS OF NORTHERN NIGERIA" by Gadzama, Madu Ibrahim Katsallah meets the regulations governing the award of the degree of Doctor of Philosophy (Ph.D) (Zoology) of Ahmadu Bello University Zaria, and is approved for its contribution to knowledge and literary presentation.

Professor A.U. Ezealor

Chairman, Supervisory Committee Department of Biological Sciences, Ahmadu Bello University Zaria.	Signature	Date

Professor T. Aken′Ova

Member, Supervisory Committee Department of Biological Sciences, Ahmadu Bello University Zaria.	Signature	Date

Professor M.L. Balarabe

Member, Supervisory Committee Department of Biological Sciences, Ahmadu Bello University Zaria.	Signature	Date

Professor A.K. Adamu

Head of Department Department of Biological Sciences, Ahmadu Bello University Zaria.	Signature	Date

Professor A.A. Joshua

Dean, Postgraduate School Ahmadu Bello University Zaria.	Signature	Date

DEDICATION

I whole-heartedly dedicate this work to my wife Dagilayah (Kyir), children Nubwa (M′da) and JesseJasini (Dada), and my late parents Madu (Amin) and Dzima Jummai (Ma'aji).

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ABSTRACT

The distribution and taxonomy of freshwater and terrestrial molluscs was studied for three years in twenty five water bodies of four hydrological areas and different terrestrial habitats in northern Nigeria. This was done to determine the mollusc compositions, assess the factors that influenced their distribution and establish their taxonomic positions. Four sampling stations were selected along a line transect across each water body for collection of aquatic molluscs and the physico-chemical factors measured. A portable Combo Hanna® meter was used to measure pH, electrical conductivity, water temperature and total dissolved solids. The specimens of freshwater and terrestrial molluscs and phytoplanktons collected were identified using standard procedure. Soil pH and calcium were measured using pH meter and Atomic Spectrophotometer respectively. The result of the study showed that a total of 14 species of freshwater molluscs belonging to 9 families occurred in the water bodies. Three of the families, Unionidae, Mutelidae and Etheriidae belong to the class Bivalvia while the other six, Viviparidae, Paludomidae, Thiaridae, Planorbidae, Lymnaeidae and Ampullaridae belong to the class Gastropoda. The family Unionidae was represented by three species of the the genus *Anodonta*. The viviparids were represented by two species of mud snails of the genus *Bellamya*. The families Mutelidae, Etheriidae, Paludomidae, Lymnaeidae and Ampullaridae were represented by a single species each. 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. Simpson's Diversity Index (D) showed Kainji Lake to have the highest diversity (D = 0.88). The algal divisions Chlorophyta, Bacillariophyta, Cyanophyta and Euglenophyta were found to be associated with aquatic molluscs. A total of twelve (12) species of terrestrial molluscs belonging to six (6) families were recorded. The family Achatinidae occurred throughout the area of study. Only one family of slugs (Veronicellidae) was recorded. Five (5) of the six (6) families were represented by a single species each. Soil calcium and pH appeared to be important factors in the distribution of terrestrial molluscs and were positively correlated ($P < 0.01$; r = 0.93). The widely distributed freshwater species namely; *Anodonta marginata* and *Bellamya crawshayi* and the *Melanoides* species may be termed euryoecious species, having a wide range of tolerance for environmental factors prevailing in northern Nigeria. Species such as *Aspatheria* sp. and *Etheria elliptica* were restricted in their distribution due high niche specialization. The Canonical Correspondence Analysis (CCA) showed that temperature, pH, dissolved oxygen, alkalinity, hardness, phosphate phosphorus and sulphate were the likely important factors that significantly influenced the distribution of freshwater molluscs. The patchy distribution of some of the terrestrial mollusc species could have been influenced by the level of rainfall and moisture retention of such areas. The presence of empty shells of freshwater and terrestrial molluscs is an indication of habitat loss due to environmental degradation (desert encroachment and water pollution from anthropogenic activities) which may prolong the aestivation period and result in the eventual death of the molluscs. The intense human activity associated with the water

bodies could also have negative impact on the aquatic ecology of the study area. Therefore, habitat deterioration and loss due to human activities are probably the most serious threats to the well-being of molluscs in northern Nigeria. This study has shown that the inland aquatic and terrestrial ecosystems in northern Nigeria support a highly diversified malacofauna of ecological interest and public health significance. There is the need for information data bank to document information on molluscs of northern Nigeria. Proper conservation initiatives should be channelled towards reducing loss of mollusc habitations. The ecological roles of molluscs and the economic gains that can be achieved in utilizing mollusc resources should be appraised.

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ABBREVIATIONS AND SYMBOLS

ABU	Ahmadu Bello University
$AgNO_3$	Silver Nitrate
Bacl	Barium Chloride
BOD	Biochemical Oxygen Demand
Ca	Calcium
$CaCO_3$	Calcium Carbonate
CCA	Canonical Correspondence Analysis
CDR	Corporate Document Repository
Cl	Chloride
Cmol	Centimol
cm	Centimeter
COD	Chemical Oxygen Demand
D	Simpson's Diversity Index
DF	Degree of Freedom
DO	Dissolved Oxygen
EC	Electrical Conductivity
et al.	And Others
FAO	Food and Agricultural Organization
ha	Hectare
H_2O	Water
H_2SO_4	Hydrogen Sulphate
Kg	Kilogram
l	Litre
Lat	Latitude

Long	Longitude
m	Meter
mm	Millimetre
ml	Millilitre
$MnSO_4$	Manganous Sulphate
n	Sample Size
N	Normality
NA	Not Applicable
$Na_2S_2.5H_2O$	Sodium Thiosulphate
P	Probability
pH	Hydrogen ion concentration
PO_4	Phosphate
ppm	Parts Per Million
S.E.	Standard Error
SO_4	Sulphate
TDS	Total Dissolved Solids
US$	United States Dollars
/	Per
µs/cm	Microsiemens Per Centimeter
^oC	Degree Centigrade
%	Percentage
<	Less Than

CHAPTER ONE

1.0 INTRODUCTION

1.1 Molluscs

The words mollusc and mollusk are both derived from the French mollusque, which originated from the Latin *molluscus*, which has its root in "*mollis*", meaning soft. Molluscus was itself an adaptation of Aristotle's "the soft things", which he applied to cuttlefish (Little *et al*., 1964). The scientific study of molluscs is known as malacology (Little *et al*., 1964).

Molluscs are soft-bodied invertebrates that show a wide diversity of form on a basic body plan. They are coelomate animals with a head, ventral muscular foot, and a dorsal visceral hump mass. The mantle over the visceral hump often secretes a shell, which is largely calcareous. However, some molluscs such as the slugs have no shell at all. Some molluscs (squids, cuttlefish and sea hares) produce an internal shell (Barney, 2000).

Molluscs have developed such a varied range of body structures that it is difficult to find synapomorphies (defining characteristics) that apply to all modern groups (Giribet *et al.,* 2006). The most general characteristic of molluscs is that they are unsegmented and bilaterally symmetrical (Hayward, 1996). The following are present in all modern molluscs (Brusca and Brusca, 2003; Ruppert *et al*., 2004):

A. The dorsal part of the body wall is a mantle (or pallium) which secretes calcareous spicules, plates or shells;
B. the mantle secretes a shell that is mainly chitin and conchiolin (a protein) hardened with calcium carbonate (Ruppert *et al*., 2004; Porter, 2007), except that the outermost layer is all conchiolin (Ruppert *et al*., 2004). Molluscs never use phosphate to construct their hard parts, with the

questionable exception of *Cobcrephora* (Cherns, 2004). The shell overlaps the body with enough spare room to form a mantle cavity;

C. The anus and genitals open into the mantle cavity;

D. There are two pairs of main nerve cords (Ruppert *et al*., 2004).

1.2 Taxonomy of the Phylum Mollusca

The Phylum Mollusca is second only to the phylum Arthropoda in numbers of living animal species (Ponder and Lindberg, 2008), far behind the arthropods' 1,113,000 species but well ahead of the chordates' 52,000 species (Ruppert *et al.,* 2004), with over 80,000 living species and some 35,000 fossil species known. The classificatory scheme for the larger groups of Mollusca has reached a reasonable degree of stability (Malacological Society, 1994). According to Barnes *et al*. (1989) the Phylum is divided into eight classes namely:

i. **Chaetodermomorpha** - shell-less vermiform molluscs that construct and inhabit vertical burrows in soft marine sediments;

ii. **Neomeniomorpha-** shell-less and effectively headless marine group. Chaetodermomorpha and Neomeniomorpha were previously placed together in a single class, Aplacophora.

iii. **Monoplacophora** - are segmented limpets bearing one shell and are all deep-water marine forms;

iv. **Polyplacophora** (Chitons) - a littoral marine group bearing many shell plates;

v. **Gastropoda** - stomach-footed forms inhabiting the sea, freshwater and land;

vi. **Scaphopoda** - Tusk-shell-forms of bottom living marine group;

vii. **Bivalvia** (Pelecypoda) - two-valved forms confined exclusively to aquatic habitats. Most are marine with a few freshwater forms, and

viii. **Cephalopoda** - head-footed forms and exclusively marine (Wright, 1971; Barney, 2000).

1.3 Diversity of Molluscs

The estimated number of described living species of molluscs varies from 50,000 to a maximum of 120,000 species (Chapman, 2009). Haszprunar (2001) estimated about 93,000 named species including 23% of all named marine organisms (Hancock, 2008). It has been estimated that there are about 200,000 living species of mollusc in total, (Winston and Lindberg, 2004; Chapman, 2009) and 70,000 fossil species (Brusca and Brusca, 2003). It is believed that the total number of mollusc species that ever existed, whether or not preserved, must be many times greater than the number alive today (Raup and Stanley, 1978).

Despite the similarity in basic morphology, the molluscs display an almost bewildering diversity of form (Marshall and Williams, 2003). Molluscs have more varied forms than any other animal phylum. They include snails, slugs and other gastropods; clams and other bivalves; squids and other cephalopods; and other lesser-known but similarly distinctive sub-groups. The majority of species still live in the oceans, from the seashores to the abyssal zone, but some form a significant part of the freshwater and terrestrial ecosystems. Molluscs are extremely diverse in tropical and temperate regions but can be found at all latitudes (Giribet *et al.,* 2006). About 80% of all known mollusc species are gastropods (Ponder and Lindberg, 2008). Cephalopoda such as squids, cuttlefishes and octopuses are among the neurologically most advanced of all invertebrates (Barnes *et al*., 2001). The giant squid, which until recently had not been observed alive in its adult form (Kubodera and Mori, 2005), is one of the largest invertebrates.

1.4 Conservation of Molluscs

The importance of molluscs to humans and the environment is vastly greater than their general absence, as popular guides would lead one to believe (Kohl, 2006). Freshwater and terrestrial molluscs appear exceptionally vulnerable to extinction. Gastropoda and bivalvia are likely to be the most common group of macrobenthic fauna in aquatic ecosystems. Molluscs react strongly to environmental changes. This makes them suitable for studies of the relationship between the organism and the environment (Oktener, 2004**)**. Estimates of the numbers of non-marine molluscs vary widely, partly because many regions have not been thoroughly surveyed. There is also a shortage of specialists who can identify all the animals in any one area to species. However, in 2004 the IUCN Red List of Threatened Species included nearly 2,000 endangered non-marine molluscs. For comparison, the great majority of mollusc species are marine but only 41 of these appeared on the 2004 Red List. Forty two percent of recorded extinctions since the year 1500 are of almost entirely non-marine species of molluscs (Cherns, 2004). Molluscs ranked first on the IUCN (1996) list of endangered animals worldwide. Over 1,000 species of terrestrial pulmonates are listed by the IUCN, of which almost 200 are listed as extinct and 116 as critically endangered. Humans pose a great danger to them. With increasing environmental awareness and threats of extinction, the latter has started to change (Kohl, 2006). The absence and depletion in number of mollusc species in water bodies have been explained by their susceptibility to water pollution (Kalyoncu *et al.,* 2008).

1.5 Gastropods

The class Gastropoda constitutes the largest and most diverse group of the phylum Mollusca. The class includes about 40,000 living and more than 15,000 fossil species; it has undergone extensive adaptive radiation and, ecologically, has spread its species to a wider range of habitats than any molluscan group. The gastropods are widely represented in freshwater habitats. By developing an effective water economy and investing in a modified excretory physiology, one large sub-class, the Pulmonata, has become typically terrestrial (Marshall and Williams, 2003). Gastropods are characterized by 'torsion', a process that results in the rotation of the visceral mass and mantle on the foot (Brunt *et al.,* 1999).

1.6 Freshwater Molluscs

Freshwater molluscs, being thoroughly polyphyletic, cannot be classified independent of the rest of the phylum Mollusca (Brusca and Brusca, 1990). Only two of the eight classes of the phylum are represented in freshwater: Gastropoda (limpets, slugs and snails), and Bivalvia (clams, mussels, cockles). Gastropods are a common and conspicuous element of freshwater biota (Sturm *et al.,* 2005). Co-occurring gastropod populations may differ strikingly in anatomy, life history, habitat, food and ecological requirement. The bivalves are in some ways the most highly modified of all the molluscs. With few exceptions, all bivalves are sedentary, some of them remain anchored to the substratum or firmly cemented, as with oysters (Morton, 1968).

1.7 Terrestrial Molluscs - Pulmonates

On land or in water, not every habitat is good for molluscs. Land molluscs (pulmonates) occur in most parts of the globe, extending from hot deserts to beyond the Arctic Circle (Barker, 2002). With an estimated 35,000 species, terrestrial molluscs are one of the most successful and diverse animal groups in land-based ecosystems (Willem, 1975). Land molluscs are damp

atmosphere animals, found in habitats such as banks of water courses and ponds, marshes, damp meadows, especially such that have dead leaves, tree stumps, rotten wood and thickets of vegetation. The single most important factor determining land snail species number is area. Welter-Schultes and Williams (1999) reported that habitat diversity affected species' richness even after accounting for the effects of area; both increased elevation and greater extent of calcareous substrate on islands resulted in higher species number.

The family Achatinidae is a diverse group of large pulmonate land snails originating in western, eastern and southern Africa (Mead, 1961). Pilsbry (1919) considered natural area of distribution of *Achatina achatina* and *Archachatina* to be West African, with *Achatina* from Liberia to Nigeria, and *Archachatina marginata* from Cameroon to Zaire, with its distribution largely in less humid areas (Hodasi, 1984). *Limicolaria* are commonly found in different terrestrial habitats in West Africa and are regarded as 'tropical' (Crowley and Pain, 1970). Today, giant African land snails are found far outside their original area of distribution, everywhere on earth where the natural environment, such as climate and food, make life possible for such large snails (Mead, 1961).

Slug is a common name that is normally applied to any gastropod mollusc that lacks a shell, has a much reduced shell, or has a small internal shell. This is in contrast to the common name snail, which is applied to gastropods that have coiled shells that are big enough for them to retract into. Of the six orders of pulmonates, the Onchidiacea and Soleolifera are solely slugs. A third family, the Sigmurethra, contains various clades of snails, semi-slugs (i.e. snails whose shells are too small for them to retract fully into) and slugs (Burton, 1982). The shell-less condition has arisen many times independently during the evolutionary past, and thus the category "slug" is emphatically a polyphyletic one. The various groups of land slugs are not closely related, despite a superficial similarity in the overall body form. Slugs and snails are closely related members of the

phylum Mollusca. Snails have a large external shell used for protection against predators and adverse climatic conditions. However, snails require an environment containing large quantities of calcium-rich materials, including lime ($CaCO_3$). Materials containing calcium are necessary for the snail to develop its shell. Therefore, most snails are found in areas with calcium-rich soil (Nielsen, 1988).

1.8 Statement of the Research Problem

Molluscs as a whole have suffered from a long history of dilettante collecting, a hobby that was sufficiently popular to make commercial dealing in shells a profitable venture. This often encouraged undisciplined collecting with the result that large quantities of materials came into circulation without adequate locality or habitat data (Wright, 1971).

There is some regional information covering a limited taxonomic or geographic range of land and freshwater molluscs. Notable are the works of Clarke (1973) in Canada, Cvancara (1983) in North Dakota, Wells (1986) in Australia, Burch (1989) in North America, Chambers and Mcquid (1994) in South Africa, Dillion (2000) in North America, and Cameron and Pokryszko (2004) in Northern Europe. Fagbuaro *et al.* (2006) reported on the nutritional value of four giant African snails namely: *Archachatina marginata* (ovum) Pfeiffer, *Archachatina marginata* (saturalis) Philippi, *Achatina achatina* and *Limicolaria* sp. that occur in Nigeria.

Baseline information on the pond ecosystem status of mollusc in the northern part of Nigeria is scanty. This is evidenced by few published works on water chemistry, quality and productivity which are very important for proper utilization and management (Balarabe, 2001). Alhough it is estimated that there are about 20,000 small water bodies in Africa each with an area of less than $10km^2$, there is still limited information on their sizes, capacity, chemical status and productivity. Most studies on aquatic ecosystems are descriptive in nature; only few have dealt with the area of primary productivity with respect to quantitative and qualitative evaluation of biota, with respect to water quality (Marshall and Maez, 1994).

Northern Nigeria has long been recognized for its faunal richness and diversity. Considering that economically important taxa are usually better studied than those which are not, and information covering a limited taxonomic or geographic range of molluscs was mostly based on their roles as intermediate hosts of parasites. This study therefore seeks to establish the molluscan compositions in relation to critical environmental factors that influence the distribution of the malacan fauna of northern Nigeria.

1.9 Justification

Most of the estimated 30,000 to 35,000 land-snail species of the world are in the tropics (Solem, 1984). Majority remain undiscovered and undescribed, partly because of under-exploration, and partly because of their often minute sizes (Cowie, 1995). Freshwater molluscs are globally imperiled, particularly freshwater mussels of the bivalve order Unionoida (Lydeard *et al*., 2004). Freshwater mussels have a worldwide distribution (Graf and Cummings, 2006), and the widespread degradation of rivers and lakes suggests the potential for a significant decrease in the extant diversity (Bogan, 1993). Sooner rather than later, the malacological and conservation biology communities will need a correct understanding of the historical and contemporary processes impinging upon unionoid diversity in order to prioritize human efforts to intervene. Basic to such an understanding is an accounting of freshwater mussel species and their geographical distribution. For many areas of the world, an accurate tally is currently unavailable. For example, the freshwater mussel faunas of the tropical regions of southeastern Asia, South America, and Africa have yet to be completely described (Graf, 2007).

There are more recorded extinctions of land snails than for all other animal groups combined. This makes land snails a key group for recognising why and where extinctions are taking place and also means that snails might act as the sensitive indicators of environmental change that are needed to demonstrate that conservation measures are effective. The speed with which the current episode of extinctions happened and continued to take place means that

natural processes are negligible and losses in biological diversity are due to human impact on the environment (Naggs and Raheem, 2007).

In the past, the study of morphological characters of shells and gross anatomy led to numerous errors in the description of new species of molluscs, the very local varieties arising from differences in their habitats (Clegg, 1974; Barney, 2000). In recent years, there has been a welcome change in emphasis and a good deal of research has been directed towards distribution, ecology, x-rays, biochemistry, DNA comparison, and behavioural studies to find relationships that were previously undetectable (Barney, 2000). In contrast to molecular research on insect vectors of disease, where for example there are many mosquito DNA accessions, molluscan data are presently underrepresented and there is room for improvement. Similarly, integration of laboratory and field studies is required to understand the interactions between snail and parasite populations and it is necessary to use this knowledge to bolster interventions based upon chemotherapy as well as to explore novel methods for improving schistosomiasis control in the environment (Rollinson, 2005).

The natural areas of distribution of plants and animals provide one of the strongest lines of evidence for organic evolution. The use of geographical distribution as a classificatory character is an old established practice among taxonomists where large collections of species of more extensive genera are commonly grouped by geographical regions (Crowson, 1971).

Environmental variability is one of the primary characteristics of natural selection. Therefore, environmental factors can serve as limiting factors for many species, though not conclusive, but merely indicating a correlation between distribution of the species and that of certain habitat factors or of another species. The distribution of mollusc species and of higher taxa depends on the antiquity of the group, its power of dispersal, its adaptability to environmental variables and the effects, if any, of isolation (Fretter and Peake, 1978).

The diversity of freshwater molluscs is vast and their distribution depends on their ability to colonize and survive in a habitat. Survival, in turn, is regulated by various physico-chemical factors that ultimately play a major role in determining the ecological traits associated with a particular species. Various detailed qualitative surveys since the 1930s have shown that hardness, pH, altitude, size of water bodies, temperature, vegetation, and pollution were among the significant aspects influencing the distribution and abundance of molluscs (Dillion, 2000). The varying degrees of spatial isolation of some habitats promote ideal conditions for the study of isolated populations of animals. The isolation of freshwater habitat is more transient in character because it can be broken down by floods, changes in topography resulting from erosion, river capture, minor earth movements, and by climatic changes. These geomorphologic aspects may explain the zoogeography of some species of freshwater molluscs (Kohl, 2006).

The tropics have the greatest diversity of mollusc species both on land and in water (Janus, 1965; Fretter and Peake, 1978). Loker (2005) reported that, because of the massive scale of anticipated environmental change, studies to understand the basic ecology and ecological preferences of schistosome-transmitting snails remain critical. Despite the important roles and contributions of molluscs to natural processes, there is still a paucity of information on the molluscan fauna in northern Nigeria. Therefore, as an important part of the ecosystem, information on the species and distribution of molluscs would provide reference material on malacological diversity of northern Nigeria, and thus provide additional information on the ecology of molluscs in Africa. This research therefore focuses on the taxonomy, geographical distribution and habitats of terrestrial and freshwater snail species as reflected by samples taken from both aquatic and terrestrial habitats in northern Nigeria.

1.10 Aim

The aim of this study is to provide data on the distribution and taxonomy of aquatic and terrestrial molluscs of northern Nigeria.

1.11 Objectives of the Study

The objectives of the study are:

- To collect, identify and determine the taxonomic positions of the molluscs in some parts of northern Nigeria
- To describe habitat factors that are associated with various mollusc species
- To produce distribution maps of the molluscs of northern Nigeria
- To establish a preliminary checklist of the molluscs of northern Nigeria.

1.12 Null Hypotheses

- There is no significant difference in the diversities of mollusc species in some parts of northern Nigeria.
- There is no significant difference in the habitat factors influencing the distribution of terrestrial and aquatic molluscs in northern Nigeria.
- There is no difference in the diversity of molluscs in the different river basins/ hydrological areas in northern Nigeria.
- The differences in soil pH and calcium contents do not significantly affect the distribution of terrestrial molluscs in northern Nigeria.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 The Climate of Nigeria

Nigeria has a climate that is characterised by relatively high temperatures throughout the year. The average annual maximum varies from 35°C in the north to 31°C in the South, the average annual minimum from 23°C in the South to 18°C in the north. On the Jos plateau and the eastern highlands, altitude makes for relatively lower temperatures, with the maximum no more than 28°C and the minimum sometimes as low as 14°C. The soil temperature is almost uniform in the country both during the day and at night (Ita, 1993).

Nigeria has strong latitudinal zones which become progressively drier as one moves northwards from the coast. Rainfall is the key climatic variable and there is a marked difference between the wet and dry seasons in most areas. By April or May the rainy season is underway in most areas south of the Niger and Benue River valleys. Further north, rains do not commence until June or July. From December through February, northwest trade winds called harmattan, sweep across the country bringing moderate temperatures and lower humidity across the country (Ita, 1993).

2.2 Hydrology and Water Resources of Nigeria

Nigeria lies between Longitudes 2° 49'E and 14° 37'E and Latitudes 4° 16'N and 13° 52' North of the Equator. The climate is tropical, characterized by high temperatures and humidity as well as marked wet and dry seasons, although there are variations between South and North. Total rainfall decreases from the coast northwards. The South (below Latitude 8°N) has an annual rainfall ranging between 1,500 and 4,000 mm and the extreme North between 500 and 1000 mm.

Nigeria is blessed with a vast expanse of inland freshwater and brackish ecosystems. Their full extent cannot be accurately stated as it varies with season and from year to year depending on rainfall. These water resources are spread all over the country from the coastal region to the arid zone of the Lake Chad Basin. The hydrology of Nigeria is dominated by two great hydrologic systems, the Niger-Benue and the Chad systems (Ita,1993).

2.2.1 Inland Water Resources of northern Nigeria

With the exception of a few rivers in southern Nigeria that empty directly into the Atlantic Ocean, all other flowing waters ultimately find their way into the Chad Basin or down the lower Niger to the Atlantic Ocean. The two hydrologic systems are separated by a primary watershed extending north-east and north-west from the Bauchi Plateau which is the main source of their principal tributaries. North-west of the plateau lie the elevated, drift-covered plains of North-Central area which is drained by numerous streams all flowing outwards to join the major tributaries. The rivers flowing into Lake Chad originate both from the Jos Plateau and converge to form the Yobe River, before flowing into Lake Chad. Some rivers flowing into Lake Chad originate from the Cameroon Mountains. Only a small part of Lake Chad lies within Nigeria. Within Nigeria the River Niger is fed by rivers flowing into it from all directions with headwaters originating from the Jos Plateau in the North, from the Yoruba highlands in the South, from Benin Republic to the West and from the Eastern highlands. A significant flow from outside Nigeria comes from the watersheds stretching westwards right up to the Fouta Djallon Mountains of Guinea. The River Benue is fed by rivers emanating both from the high central plateau and also from the Cameroon Mountains and Ogoja hills (Ita, 1993).

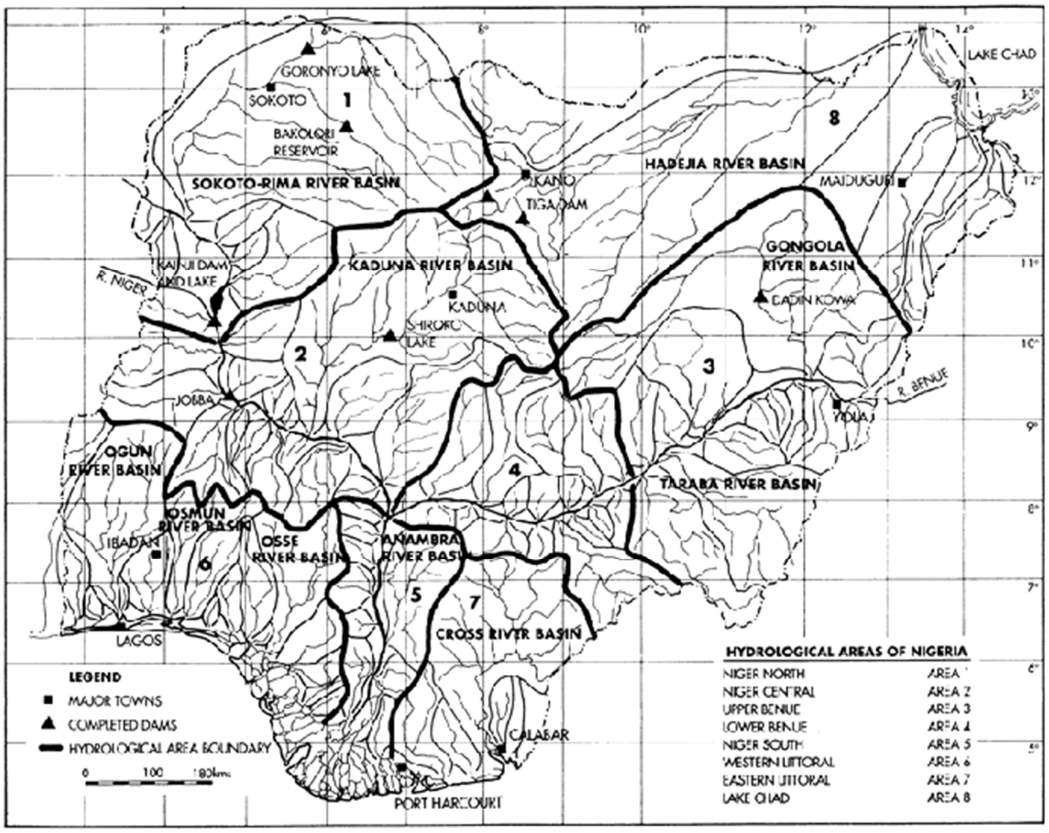


Figure 2.1: Hydrological Map of Nigeria showing the Major Inland Waters [Adopted from Ita (1993)].

2.2.2 Major Water bodies in northern Nigeria

Table 2.1: Surface Areas of Major Water Bodies in northern Nigeria.

NAME OF WATER BODY	APPROXIMATE SURFACE AREA (ha)
A. **Major Rivers**	
Benue River	129,000
Niger River	169,800
B. **Major Lakes and Reservoirs** (**Status**)	
Lake Chad (natural)	550,000
Kainji Lake (Niger State) (man-made)	127,000
Jebba Lake (Niger State) (man-made)	35,000
Shiroro Lake (Niger State) (man-made)	31,200
Goronyo Lake (Sokoto State) (man-made)	20,000
Tiga Lake (Kano State) (man-made)	17,800
Chalawa Gorge (Kano State) (man-made)	10,100
Dadin Kowa (Gombe State) (man-made)	29,000
Kiri (Adamawa State) (man-made)	11,500
Bakolori (Katsina State) (man-made)	8,000
Zobe (Katsina State) (man-made)	5,000
C. **Freshwaters**	
Niger/Sokoto Basin	470,000
Niger Kaduna Basin	150,000
Lower Niger: Jebba to Lokoja	385,500
Benue River floodplain	312,000
TOTAL	2,460,900 (Representing 2.61% of the total area of Nigeria- 94,185,000 ha). (Adopted from Ita, (1993).

2.3 Predators and Molluscs

A number of animals have been identified as predators of molluscs. Natural predators include frogs, toads, snakes, hedgehogs, Salamanders, crustaceans, eastern box turtles, rats, caecilians and also some birds and beetles and the predatory caterpillar *Hyposmocoma molluscivora* (Pekarinen, 1994; Kalyoncu *et al.,* 2008; Yem *et al.,* 2009). The domesticated duck has the reputation of being the most avid consumer of snails (Panosmarti, 1952). Shells of terrestrial snail are rarely as resistant as those of their marine counterpart, but it still remains their best and most important protection against dryness and their many enemies. Digweed (1993) reported land snails as an important food source for several carabid beetle species that are somewhat specialized in the type and size of snails that they consume.

Molluscs featured prominently in the diets of many fish species, including the humpback whitefish (*Coregonus pidschian*) and the broad whitefish (*C. nasus*), which are large, benthic-feeding salmonids in the subfamily Coregoninae (McPhail and Lindsey, 1970; Scott and Crossman, 1973). Brown (2007) reported that pea clams (Sphaeriidae), valve snails (Valvatidae), and pond snails (Lymnaeidae) recovered from the lower digestive tracts of these two fish; the gut-survival abilities of molluscs indicate that fish are dispersal agents for some freshwater molluscs. If fish predators were non-migratory or sedentary during feeding season, many molluscs would be expelled alive near the sites where they were initially ingested. Yem *et al.* (2009) reported species of freshwater molluscs namely: *Pila* sp.*, Viviparus* sp.*, Planorbis* sp. and *Bithynia* sp. as part of the food items recovered from the gut of the silver catfish *Chrysichthys nigrodigitatus* that inhabits both freshwater and brackish water of West Africa. Two carnivorous snails, *Edentulina affinis* and *Gonaxis kibweiziensis*, specifically prey on the giant snail *Achatina fulica* Bowdich (Grzimek, 1972). One potential regulator of snail populations that is generally overlooked is the parasitic larvae of trematodes, or flukes, which use the snails as intermediate hosts (Holmes, 1983).

2.4 Parasitology and Public Health Significance of Molluscs

The Class Gastropoda is the most important molluscan host group for trematodes (Fretter and Peake, 1978). Freshwater molluscs play the role of intermediate hosts for a great variety of human and other animal parasitic flatworms (Chandler and Clark, 1961; Brown, 1994). Some of the digeneans that develop in pulmonate snails are well known for their medical and veterinary importance, which is largely due to the outstanding success of their snail host in a variety of freshwater habitats. Meanwhile, the success of pulmonates in colonizing the land has provided digeneans the opportunity to move far from their aquatic origins to gain access to terrestrial vertebrates, mostly reptiles, birds and mammals as definitive hosts that have little contact with water (Fretter and Peake, 1978; Latham *et al*., 2003; Viney and Lok, 2007).

Prosobranch gastropod taxa known to be involved in parasite life-cycles include *Pila*, snails belonging to the Hydrobiidae and related families, Thiaridae including *Thiara*, Pleuroceridae including *Elimia* (*Juga*), and *Semisulcospira*, and also several marine gastropods in the related family Potamididae. Pulmonate gastropod hosts include the Planorbidae, Bulinidae (now included within the Planorbidae), and the Lymnaeidae (Chandler and Clark, 1961).

As snails have successfully colonised many areas of Africa and have evolved to meet the needs of these rather ephemeral habitats where population crash and boom is the norm, actions by humans are often circumvented. Sellin (2005) showed that the general adaptability and high reproductive rates of *Bulinus* and *Biomphalaria* have allowed them to endure within many varied environments as well as withstand chemical methods of snail control with aquatic molluscicides. Despite these frustrations field studies of molluscs remain an essential part of a multidisciplinary approach to control and to better understand the complex epidemiology of snail-borne diseases. *Biomphalaria pfeifferi* is widespread in Africa, tolerates a diverse array of habitats, and is highly

susceptible to schistosome infection (Bandoni *et al*., 1990). *Bulinus globosus* is widely distributed in Western Africa, and sub-Saharan Africa (Appleton *et al.,* 2009). Natural populations of these snails are usually found in tropical standing water or freshwater in South America and Africa, but they also reach 30° latitude in subtropical areas. Many species of these red-blooded planorbid snails are able to survive a long time when removed from their freshwater habitat (Majoros *et al.,* 2008). Of the 34 *Biomphalaria* species, four (4) namely: *B. glabrata, B. pfeifferi, B. straminea* and *B. tenagophila*, have recently expanded their native ranges. They have been introduced to areas where other *Biomphalaria* species are endemic (e.g., Congo and Egypt) or to subtropical zones that have no frost period (Majoros *et al.,* 2008).

2.5 Snail-borne Diseases

Terrestrial gastropods have also been found to harbour a number of larval nematodes including *Muellerius capillaris*, a sheep parasite; *Aleurostrongylus abstrusus* and *Anafilariodes rostratus*, both cat lung parasites, and *Angiostrongylus cantonensis*, a rat lungworm (Malek and Cheng, 1974; Roberts and Janovy, 1996; Sowemimo and Asaolu, 2004).

Achatinidae serve as vectors and intermediate hosts to different digeneans (Purchon, 1968; Soulsby, 1982; Marquardt and Demaree, 1985; Sowemimo and Asaolu, 2004; Gadzama and Ogiugo, 2008). *Archachatina marginata* and *Limicolaria aurora* are potential intermediate vectors of the Rat lungworm *Angiostrongylus cantonensis*, which causes eosinophilic meningoencephalitis in humans (Raut and Barker, 2002). Among the most important diseases of man and animal stocks associated with molluscs are fascioliasis (caused by *Fasciola hepatica* and *F. gigantica*) and opisthorchiasis (caused by *Opisthorchis felineus*) (Öktener, 2004**).**

Several species of slugs in the genera *Vaginulus* and *Veronicella* found mainly in tropical and subtropical Africa, America and Asia, are intermediate hosts of *Angiostrongylus costaricensis*

(Rosetta, 2006). Latham *et al*. (2003) also reported a number of gastropods that are paratenic hosts to larval helminths. Species of the slug family Veronicellidae have been found to carry several nematode parasites, including *Angiostrongylus cantonensis* (rat lungworm), *A. costaricensis*, and *A. malaysiensis*. *Angiostrongylus cantonensis* can cause symptoms similar to meningitis in humans including headache, stiff neck, tingling or painful feelings in the skin, lowgrade fever, nausea, and vomiting (USDA-APHIS, 2010).

2.6 Food and Feeding Habits of Molluscs

In the wild, snails eat a variety of foods, including leafy vegetation, fruits, manure and carrion. They cause damage to agricultural crops and garden plants and are therefore often regarded as pests (Mead, 1961). When kept as pets, snails will eat nearly everything, and snail owners should make sure diets are appropriate to the species involved. Prosobranchs and pulmonates feed by scrapping algae and organic debris from stones, leaves, and other substrates using their rasp-like tongues. The two groups also show some physiological differences in nutrition. The pulmonates are limited to what they can obtain by scrapping edible material with their radulae; a number of prosobranchs, however, also can trap food particles from their respiratory current in mucus which is then ingested (Hutchinson, 1993; Kellogg, 1994; Mackie, 1998).

As the head has largely disappeared in bivalves, their mouth has been equipped with labial palps (two on each side of the mouth) to collect the detritus from its mucus (Hayward, 1996). The particulate matter that served as food normally is carried in suspension in surface currents on the gills to the mouth and down the oesophagus. Feeding in filter-feeding bivalves is thus an automatized process, retention of particulate matter being determined by the capacity of the pump and concentration of food in the ambient

water (Jorgensen, 1996). Carnivorous molluscs usually have simpler digestive systems (Ruppert *et al.*, 2004).

2.7 Terrestrial Snails and Soil Characteristics

Terrestrialism in molluscs is ancient. The earliest fossils of terrestrial forms date from the mid palaeozoic, and the adaptive radiation into higher taxa that characterize extant faunas occurred in the lower cretaceous (Solem and Yochelson, 1979; Tillier *et al*., 1996). Early studies of the terrestrial malacofauna focused almost on taxonomy and geographical distribution. Land snails are terrestrial organisms with particularly low abilities for active dispersal (Cowie, 1984; Schilthuizen and Lombaerts, 1994) and as a result, they have a tendency to show short-range endemism. Most studies of the effects of edaphic environment on gastropod distribution have found the most important factors to be pH, soil moisture and calcium content (Hermida *et al*., 1995). Outeiro *et al*. (1993) also stressed the importance of soil texture and litter pH as the most important edaphic factors in determining gastropod distribution. In assessing the relationships of soil properties to land snail assemblages, Martin and Sommer (2004) reported soil moisture as the strongest determinant of snail density and species richness at undisturbed woodland sites, but effects of soil moisture and soil pH on these patterns are closely interrelated on intermediate moisture soils and wet soils. However, the quantitative species composition of the land snail assemblages is related to soil properties to a lower degree than snail density and species richness. Also other habitat characteristics such as vegetation or litter quality can be important for land snail species dominance. Wareborn (1992) reported snail abundance to be positively correlated to base saturation, to soil moisture and probably also to nitrogen content.

2.8 Freshwater Snails and Limnology

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). Since the 1930s, various detailed qualitative surveys have shown that 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. Clements *et al.* (2006)

emphasized that high sampling saturation was achieved at most study habitats with minimal sampling effort, suggesting that the utilization of molluscs as bioindicators can expedite freshwater conservation initiatives.

2.9 Physico-chemical Properties of the Aquatic Ecosystems

2.9.1 Water Temperature

Water temperature is one of the most important factors of the aquatic ecosystem. Temperature affects other important factors of the aquatic ecosystem such as the amount of oxygen that can dissolve in water and the rate of photosynthesis by algae and larger aquatic plants. The metabolic rate of aquatic organisms such as plants, bacteria and fishes depends on temperature, and the sensitivity of organisms to toxic wastes, parasites and diseases. This is because every reaction in organisms is regulated by enzymes, which function best at temperatures typical for the organism in which they are found. At extremely high temperature two things occur: reaction rates increase or the enzymes are denatured while at extremely low temperatures there is less molecular motion so the rate of chemical reaction decreases (Michand, 1991; GlennDombeck, 2005). Temperatures of waters could vary from 0^{o}C to 26^{o}C and this varies at different times of the year in the temperate regions (Freimuth and Bass, 1994). The most obvious reason for temperature changes in lakes is the change in seasonal air temperatures. Daily variation may also occur, especially in the surface layers, which are warm during the day and cool at night. In deeper lakes (typically greater than 5m for small lakes and 10m for larger ones) during summer or rainy season, water separates into layers of distinctly different densities caused by differences in temperature (Michand, 1991; Serrano and Toja, 1995).

2.9.2 Phosphorus

In general, regional chemical characteristics of surface waters are closely related to soil characteristics of their drainage basins (Keup, 1968; Lal, 1998). Soils reflect the regional geological and climatic characteristics and surface drainage is often a major contributor of phosphorus to streams and lakes. Phosphorus is obviously an important nutrient that often accelerates the productivity of fresh waters (Wetzel, 2001). The quantity of phosphorus entering 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).

2.9.3 Chloride

Chloride is the most common ion in water and is influential in general osmotic salinity balance and ion exchange, but metabolic utilization does not cause large variations in the spatial and seasonal distribution within most lakes. Chloride is therefore not usually dominant in open lake ecosystems (Wetzel, 2001).

2.9.4 Dissolved Oxygen

This is the amount of oxygen gas dissolved in a given quantity of water at a given temperature and atmospheric pressure; it is expressed in parts per million, percentage saturation or milligram per liter (Reid, 1961; Branco and Senna, 1996). Waters of consistently high dissolved oxygen are usually considered healthy and stable aquatic ecosystem capable of supporting many different kinds of aquatic organisms. Oxygen saturation percentage is influenced by phytoplankton densities and organic matter decay (Branco and Senna, 1996). Dissolved oxygen in water comes from the atmosphere, waves on lakes and slow-moving rivers and tumbling waters, and fast moving rivers. Sudden and gradual depletion in dissolved oxygen can cause major shifts in the kinds of aquatic organisms - from pollution-intolerant species to pollution tolerant species (Chindah and Braide, 2004).

2.9.5 Biochemical Oxygen Demand

The aim of BOD is to determine the amount of bio-chemical oxidisable carbonaceous matter (Srivastava and Sinha, 1996; Gupta *et al.*, 2003). The types of microorganisms, pH, presence of toxins, some reduced mineral matter and nitrification process are the most important factors influencing the BOD test. Like DO, BOD also indicates organic pollution.

2.9.6 Water pH

The pH of water refers to the amount of H^+ or OH^- (Hydrogen or hydroxyl ions) present. The operation of most biological processes is limited to a pH range of 6.5 to 8.5, outside this range, biological activities decline or cease (Talling, 1976; Pillay, 1992; Lind, 1979; Windelspecht and Harris, 2001). The pH value is influenced by changes in carbon dioxide, carbonates and bicarbonates system. At higher rates of photosynthesis, pH increases to a high level by afternoon and hydroxyl alkalinity is produced. Due to high rates of photosynthesis and the concurrent use of free carbon dioxide and bicarbonates from the euphotic zone, pH increases ($CaCO_3$ is precipitated). At high temperatures, solar radiation accelerates photosynthesis, which in turn increases carbon dioxide absorption, thus altering the bicarbonates equilibrium and producing OH which in turn raises the pH (Branco and Senna, 1996; Dublin-Green *et al*., 2003). According to Akin-Oriola (2003), the pH of water shows variability from season to season in aquatic systems in both tropical and temperate regions. Natural waters exhibit wide variations in relative acidity and alkalinity, not only in actual pH values but also in the amount of dissolved material causing the acidity or alkalinity. The concentration of these compounds and the ratio of one to another, determine the actual pH and the buffering capacity of a given water body (Wetzel, 2001).

2.9.7 Alkalinity

Alkalinity is the buffering capacity of the carbonate system in water. It is now used interchangeably with Acid Neutralizing Capacity (ANC), which is the capacity to neutralize strong

inorganic acids (Wetzel, 2001). Alkalinity in ponds is mainly determined by the bicarbonates and carbonate systems (Reid, 1961; Blaez *et al*., 1991). A slow growth result from pH levels below 6 to 6.5 and acid death point has been reported at pH 4 (Pillay, 1992). Aside from seasonality, alkalinity and pH vary within and between African lakes, ponds, streams, e.t.c. (Odhiambo and Gichuki, 2000). Waters with low alkalinity are very susceptible to changes in pH while those with high alkalinity have the capacity to resist a major shift in pH (Giller and Malmqvist, 1998). Increase in alkalinity values could result from an extended dry season period, high evaporations and nature of substratum (Chindah and Braide, 2004). Water that is low in alkalinity but high in pH is generally unsuitable for invertebrates (Calfo, 2005).

2.9.8 Total Hardness

The term hardness is frequently used as an assessment of water quality for domestic use. The hardness of water is governed by the content of calcium and magnesium salts (Wetzel, 2001), largely combined with bicarbonates and carbonates (temporary hardness) and with sulphates, chlorides and other anions of mineral acids (permanent hardness).

2.9.9 Electrical Conductivity

Electrical conductivity (EC) is determined by the amount of solids that are dissolved in water. It is affected by temperature and rainfall between seasons (Odhiambo and Gichuki, 2000; Akin-Oriola, 2003). Electrical conductivity varies from time to time in aquatic systems within the same or different seasons (Chapman and Kramer, 1991; Akin-Oriola, 2003; Chindah and Braide, 2004). The measurement of water's ability to conduct electricity is called conductivity or specific conductance and is measured in micro-mhos per centimeter or micro-siemens per centimeter. The EC of waste water tends to be high since most treatment plants do not treat waste water for dissolved solids. Different aquatic systems have different electrical conductivities. Electrical conductivity varies between and even within water bodiesSometimes even within the same water body, different points or areas may have different electrical conductivities. Soft water has less

dissolved salts (ions) and therefore less electrical conductivity when compared to hard water. The Ryder (1965) equation shows a clear relationship between Total Dissolved Solid (TDS) and EC which is always positive (Henderson and Welcomme, 1974). Rainfall, interacting with the atmosphere, vegetation, rocks and soil is the major source of dissolved solids in streams.

2.10 Importance of Molluscs to Humans

Molluscs constitute a major problem to humans in their roles as intermediate hosts for a great variety of human and animal parasitic flatworms. However, the importance of molluscs to humans and the environment is greater than their general absence (Kohl, 2006).

2.10.1 Medicinal Properties of Molluscs

The giant African snail was presumed to have great medicinal properties. Taylor (1900) not only discussed the possible curative powers of snails in curing of tuberculosis but recommended a method of puncturing the snail "to enable one suck the oozing liquor". The use of helicine snail in medicine has been traced by Cardart (1955), from the earliest times right to where it was reported that the mucus of *Helix pomatia* favours the action of penicillin. The curative substance extracted from the snail is said to be "Ishimoto Negligin" which is orthocalcium phosphate. This is perhaps the medicinal substance which the Institute of Medicine in Japan was reportedly extracting from the giant snail (Pangga, 1949). This chemical is claimed to cure kidney disease, tuberculosis, anaemia, diabetes, asthma, relieve constipation and hemorrhoids, prevent influenza, and perpetuate beauty and promote clear skin. In classical times, Pliny the Elder indicated that the flesh of "river snails" (*Fluviatilium coclearum*) was used raw or boiled, as an antidote for scorpion venom. It could either be eaten, or applied directly to the wound (Kohl, 2006).

2.10.2 Molluscs in Research

Molluscs have been widely used for biological monitoring of trace metal variations in aquatic environments (Phillips, 1977). Due to their large size, ease of handling, availability and conspicuous organ systems, molluscs are used in the study of invertebrate physiology, particularly neurology (Mead, 1979).

2.10.3 Molluscs as a Source of Income

As a profitable venture, snail-farming (especially that of the giant African snail) has in recent times received much attention in the northern parts of Nigeria. Pockets of small-time snail farmers have sprung up in areas where lush-green vegetation is available. A sizeable giant snail could be sold for □300 - □400 (equivalent to US$2). The two most common species of giant snails (brought from the southern parts of Nigeria) sold in local markets in northern Nigeria are *Archachatina marginata saturalis* Pfeifferi and *A. marginata ovum* Phillipi. In Vietnam, the use of products from molluscs has been highly enhanced. The gross earnings from export of mollusc products is well over US$27.4 million in January 2010 (**Asiapulse News**, 2010).

2.10.4 Molluscs as Passive Indicators of Environmental Degradation

Molluscs are passive indicators of environmental degradation (Parmalee, 1967; Parmalee and Bogan, 1998). Ajao and Fagade (2002) reported molluscs as indicators of organic pollution and other human-induced stress factors in lagoons. In addition, they can be used as bioindicators of productivity in aquatic ecosystems (Hart and Samuel, 1974). Molluscs have been widely used for biological monitoring of trace metal variations in the aquatic environment (Phillips, 1977). Notable are the works of Avelar *et al.* (2000) on marine mussels, *Perna perna*, in Sao Brazil, Tessier *et al*. (1994) on the short-lived gastropods, *Viviparus georgianus* and *Ellioptio camplanata* in Quebec, Canada; and Gundacker (1999) on the bivalves *Anodonta* sp. and *Unio pictorum,* and

two gastropods, *Radix ovata* and *Viviparus* sp. in Vienna, Austria. The Unionidae were among the first victims of widespread pollution. In 1922, it was observed that the mussel fauna in the Big Vermillion River had been completely destroyed for a distance of 14 miles below the sewage outfall of Urbana, Illinois (Parmalee, 1967).

2.10.5 Molluscs and Recycling in Nature

Molluscs play a major role in the recycling of organic matter and also enhance maintenance of water purity in both fresh and ocean waters. Many slug species play an important role in the ecosystem by eating dead leaves, fungus, and decaying vegetable material while other slug species eat parts of living plants.

2.10.6 Molluscs as a Source of Calcium

Calcium is the main component of snail shell. Mead (1961) reported that the shell of *Achatina fulica* to consisted of 99.8% calcium carbonate and 1.1% silicate. **The ground shells of molluscs have** been incorporated as a good source of calcium in animal feed (Van Damme, 1984; Gadzama *et al*., 2005). Snail shells are an essential source of calcium for nesting birds (Graveland and Van der Wal, 1996). Neolithic tribes living along the Nile had many uses for the large shells of the mollusc *Spathiopsis*, and the flesh formed the bulk of the Neolithic kitchen delicacy.

2.10.7 Molluscs as a Source of Protein

Gastropods have helped to feed many cultures. The chief reason why humans have deliberately introduced *Achatina* into new localities was doubtlessly in order to make use of it as a food source (Purcho, 1968). In Africa, river oysters (*Egeria*) were harvested and dried in the Belgian Congo (now Zaire) to be made into a stew. In many parts of West Africa, giant snails *Achatina fulica* provide one of the major source of protein in the diet of humans (Mead, 1961).

Snails of the family Achatinidae are harvested and sold in markets in Nigeria as good source of protein, although their consumption is more popular in the southern parts of Nigeria. Molluscs serve as a significant and essential part of the daily diet of the Efiks, Ibibios, Urhobes, Calabars, Itsekiris, Yorubas and many other coastal tribes. Molluscs constitute a cheap source of protein in Nigeria (Yoloye, 1984; Ademolu *et al.*, 2004). The land snails are non-conventional wildlife protein source in some parts of Africa; in Nigeria, snail meat is now becoming a highly relished delicacy (also popularly known as "Congo meat"). Snails constitute an important source of animal protein for many coastal communities in Nigeria (Fagbuaro *et al.,* 2006). Tribal elders in Zaire ate local *Pila* snails ritualistically at certain times of the year, and the leftover shells were worn as charms to protect against drowning, or as headdresses assuring fertility (Van Damme, 1984). *Pila* snails are eaten raw by the Ilocano people of the Philippines, but may be a source of parasitic infection (Chandler and Clark, 1961). In the Amazon basin, large apple snails such as *Pomacea canaliculata* and *P. bridgesii* are raised, and their mild-tasting muscular portions are eaten as the dish "churo". The demand for edible helicine snails has been so great that heliculture (snail farming), especially in parts of Europe, is a sizeable industry (Mead, 1961).

2.10.8 Pestilence by Molluscs

The voracious appetite of invasive mollusc species in the colonization of habitats may have catastrophic consequences on vegetation (Kohl, 2006). Crops affected by two closely related species, *Limicolaria zebra* (Pilsbry) and *L. numidica* (Reeve), in Cameroon (West Africa) include palm fruits and leguminous cover crops; in Martinique (West Indies), crops attacked by *L. aurora* include yam, bean, pepper, Jerusalem artichoke, cucumber, okra, and sweet potato (Mead and Palcy, 1992).

Slugs and snails terrestrial gastropod molluscs are capable of causing extensive damage to horticultural ornamental plants and agricultural food crops. They are omnivorous, consuming leaves, bulbs, tubers, fungi, lichens, algae and animal matter. Precise information on the extent of

slug damage is scanty, but they are known to attack a wide range of agricultural and horticultural crops throughout the world (Hunter and Runman, 1972). Agricultural food crops extensively damaged by terrestrial molluscs include leafy vegetables, green beans, strawberries and fruit trees and fruit are extensively damaged, as is horticultural gardening and ornamental plants. Annual crops such as hay and clover are also extensively damaged by molluscs (Nielsen, 1988). Tests have shown that a slug or snail can consume its own weight in food materials in a matter of days.

2.10.9 Molluscs in Water Treatment

Chitosan is found in the shells of crabs, shrimps and snails serve as natural hooks catch organic materials, such as oils, detergents, and other contaminants suspended in water. It is also good for cleaning up toxic organic compounds, such as PCBs (Horse Shoe Crab Research, 2012). Chitosan has the metal-binding properties when it is applied in wastewater treatment. Jatto *et al*. (2010) reported snail shell as a very effective coagulant in the treatment of waste water at any pH. A high level of success was achieved in reducing the dissolved solids, nitrates, sulphate, and removal of phosphate completely from waste water. There was a reduction in COD, BOD, conductivity and turbidity values, and increase in DO values after treatment, indicating that the snail shell is an effective coagulant and is economic viable in the treatment of waste water.

2.10.10 Aesthetic Value of Molluscs

Shells have long been used by man as tools, and buttons, jewellery (pearls and cameos). Presently, mussel shells are exploited for use as pearl blanks in the Japanese cultured pearl industry. Many people collect shells for their beauty and interesting shapes. The shells of molluscs have featured on many coins and postage stamps. Shells have been recovered from many Egyptian graves, their meaning and significance suggested by the existence of a beautifully carved diorite representation found in an Egyptian necropolis (Van Damme, 1984).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study Area

Sampling sites were spread across northern Nigeria (Long. 8^{o} – 14^{o}N; Lat 3^{o} – 14^{o}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.

3.2 Experimental Design

Using area sampling technique, a small-scaled grid map of northern Nigeria was used to determine potential collection sites for terrestrial molluscs, based on the different vegetation zones. 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. 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®. A 12.1 megapixel digital camera was used to take photographs of molluscs at the sites of collection and in the laboratory. Habitat factors such as vegetation, elevation and environmental observations (such as soil texture, nature of substratum etc) were recorded.

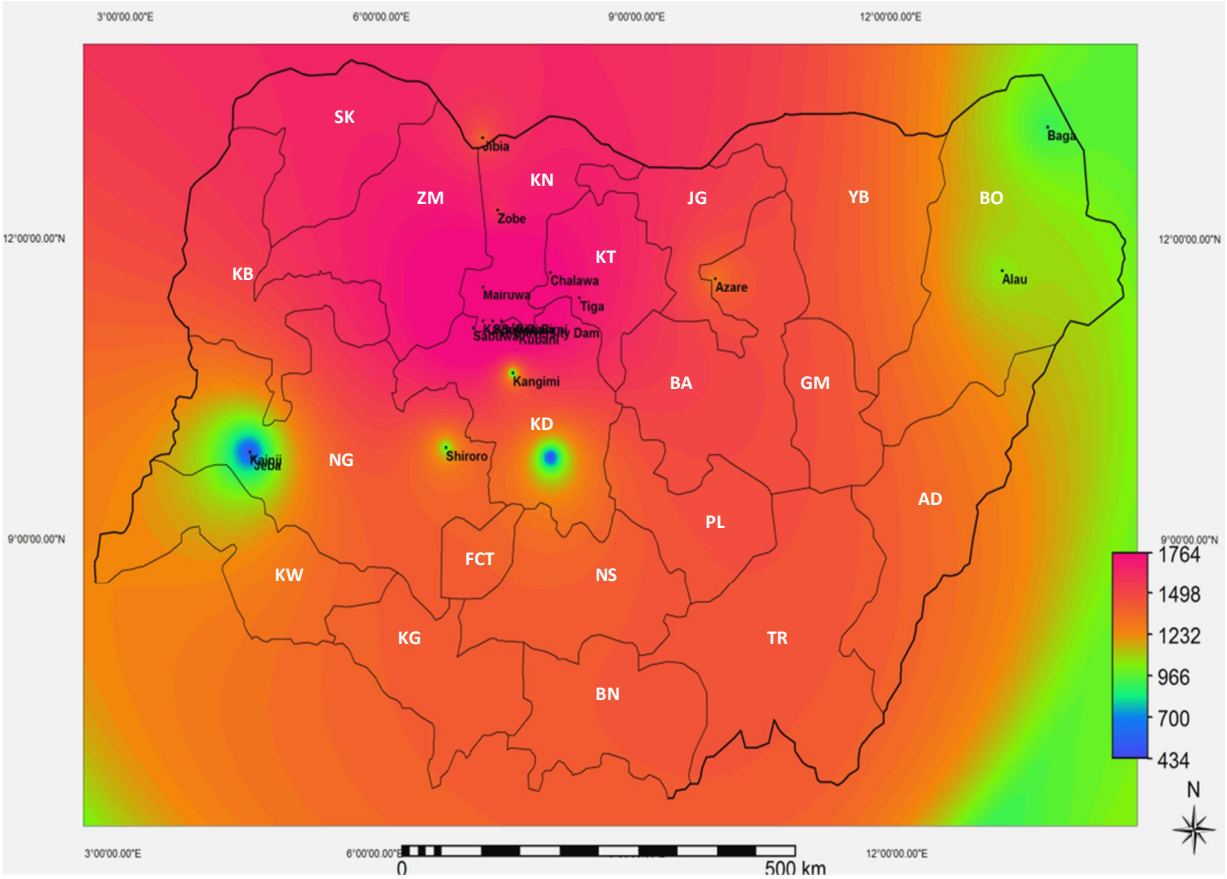


Figure 3.1: Digital Elevation Model of northern Nigeria (Source: Nigeria Landsat1, 2001).

Key: (States) AD- Adamawa, BA- Bauchi, BN- Benue, BO- Borno, FCT- Federal Capital Territory, GM- Gombe, JG- Jigawa, KB- Kebbi, KD- Kaduna, KG- Kogi, KN- Kano, KT-Katsina, KW- Kwara, NG- Niger, NS- Nassarawa, PL- Plateau, SK- Sokoto, TR- Taraba, YB- Yobe, ZM- Zamfara.

3.3 Collection of Molluscs

3.3.1 Terrestrial Molluscs

Terrestrial molluscs were collected using suitable collection methods, which included: visual observation and handpicking of small land snails in the defoliation layer and soils under low shrubs and grasses. Rake and trowel were used for searching through fallen leaves and humus, and general rummaging around. Semi-arboreal snails were searched for on herbaceous plants and low shrubs.

3.3.2 Freshwater Molluscs

Drag net and aquarist handnet (with extended handle) were used for shore and substratum sampling of molluscs in freshwater bodies. Stones, aquatic plants, floating vegetation and debris were examined (hands fitted with disposable hand gloves) for attached molluscs. Mollusc shells were collected from shores as well as fishermen.

3.3.3 Measurement 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 were counted and the direction of the spiral coil noted. All live and dead terrestrial and aquatic shells were collected and preserved in labelled collection bottles containing 95% alcohol, and taken to the laboratory for further examination. Records of habitat, coordinates, 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), soil type, physico-chemical factors and date of collection were made for each site.

Labelled two litre plastic containers packed with water plants and perforated plastic containers with surrounding soil and leaves were used to transport molluscs collected to the Department of Biological Sciences, Ahmadu Bello University, Zaria.

3.4 Collection of Phytoplankton

The samples for algal analysis were collected from the same location as molluscs and samples for physicochemical parameters, in order to enhance correlation of findings. Samples were collected using an integrated 2.5cm diameter hose pipe of 4m length with a weighted end. The weighted end was dropped into the water body and allowed to sink to a depth of 1m and then removed with the help of a rope tied to the weight. The concentrate was poured into 100ml plastic bottles and fixed immediately with Lugol's iodine solution to precipitate and preserve. The algae (APHA, 1998) contents were kept in the dark to prevent photosynthesis prior to microscopic examination. Phytoplanktons were identified using the key of Prescott (1977).

3.5 Collection and Analysis of Soil Samples

Soil samples from sites of collection of terrestrial snails were collected from depths of 0-5cm in triplicate using an Auger and placed in the labelled polythene bags. Soil pH was measured in a 1:1 (soil:water) mixture (Kalisz and Powell, 2003). Soil samples were analyzed for extractable calcium in the laboratory of the National Research Institute for Chemical Technology Zaria, using UNICAM 969 Atomic Spectrophotometer.

3.6 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.

3.7 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:

3.7.1 Alkalinity

One hundred milliliters of water sample was transferred into a conical flask, 3 drops of bromocresol green and 3 drops of methyl red were added respectively. The mixture was swirled and titrated with standard Hydrogen Sulphate, H_2SO_4 (0.02N), until the brick red colour disppeared.

Total alkalinity in $CaCO_3$ mg/l = Titer value × 10

3.7.2 Sulphate

One hundred milliliters of water sample was transferred into a conical flask and 20ml of buffer A was added and mixed thoroughly in stirring apparatus. While stirring, a spatula-full of BaCl was added and stirred for a minute. Turbidity was then measured at 5±0.5 minute at 420nmλ using Sherwood™ Colorimeter 257. $MgSO_4$/ l= $MgSO_4$ × 10

3.7.3 Nitrate

One hundred milliliters of water sample was poured into a clean dry metallic crucible and kept in an oven at102^{o}C to dry. It was then removed and allowed to cool, after which Stannous Chloride was added and swirled round uniformly, it was left to cool for 5 minutes and 5ml of Ammonium solution was added. Colour change was read at 650nmλ using Sherwood™ Colorimeter 257.

3.7.4 Phosphate

Thirty five milliliters of water sample was transferred into a volumetric flask, 10ml of Vanadate- molybdate reagent was added and made up to the 50ml mark and then allowed to stand for 10 minutes. Colour change was read at 400nmλ using Sherwood™ Colorimeter 257.

mg PO_4/ l= mg PO_4 in 50 ml vol. Flask × 1000/ ml of sample used.

3.7.5 Chloride

One hundred milliliters of water sample was transferred into a conical flask and 2-3 drops of Potassium Chromate (K_2CrO_4) was added. The mixture was swirled for few minutes and then titrated against Silver Nitrate solution until a dirty reddish precipitate was obtained.

Cl^- (mg) = volume of $AgNO_3$× 10

3.7.6 Hardness

Twenty five milliliters of distilled water was added to 25ml of water sample in a conical flask. Two ml of buffer solution of pH 10.4 was then added and stained with 0.1g of errochrome black T dye. The mixture was then titrated with Ethylenediaminetetreaacetic Acid (EDTA) titrant (0.01M). The titrant value was multipled by 40, as $CaCO_3$/l.

3.7.7 Dissolved Oxygen (DO)

Three hundred milliliters of water sample was poured into a 300ml BOD bottle and 2ml $MnSO_4$ solution and 2ml alkali-iodide azide reagent were added and the bottle stoppered with care to exclude air bubbles. It was then mixed gently by inverting the bottle a number of times until a clear supernatant was obtained. The supernatant was then allowed to settle for two minutes after which 2ml conc. H_2SO_4 was added, allowing the acid run down the neck of the bottle. It was stoppered again and mixed by gentle inversion until dissolution was complete.

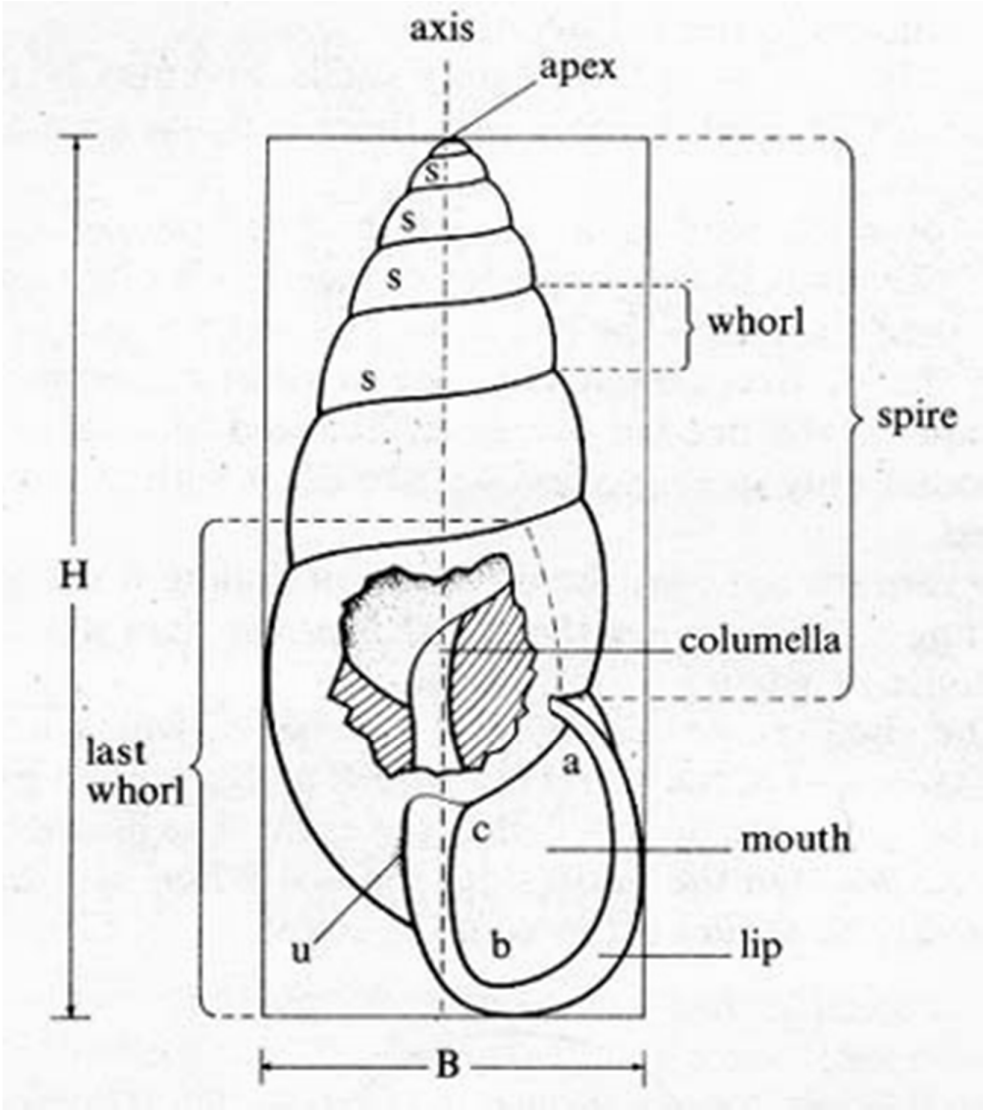
One hundred milliliters of the prepared solution was transferred into a conical flask and titrated with $Na_2S_2O_3.5H_2O$ (0.0125N) solution to a pale straw/yellow color. Two milliliters of freshly prepared starch solution was added and the color becomes blue, titration was continued by adding the thiosulphate drop wise until the blue color (obtained by starch addition) disappeared.

3.7.8 Biological Oxygen Demand (BOD)

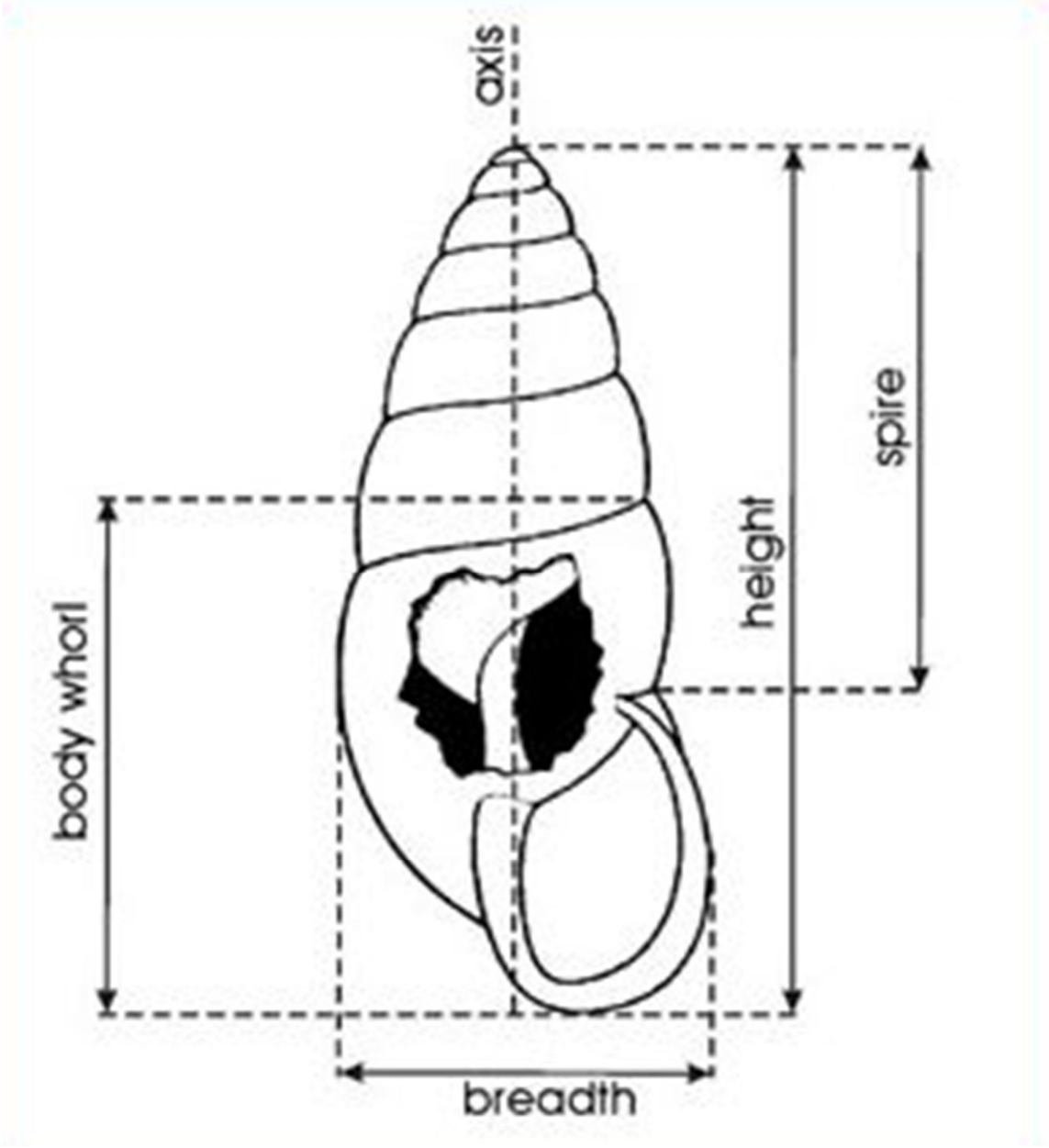
Three hundred milliliters of water sample was poured into a 300ml standard BOD bottle and covered carefully to exclude air bubbles. The bottle was then kept in an incubator for five days; after 5 days 2ml of Manganese Sulphate solution was added, followed by 2ml of alkali-iodide azide reagent. The bottle was stoppered carefully and then mixed thoroughly by inverting the bottle several times. The precipitate was allowed to settle leaving a clear supernatant after which 2ml of conc. H_2SO_4 was added. The bottle was stoppered and contents mixed by gentle inversion. One hundred milliliters of the prepared solution was transferred into a conical flask and 2ml of freshly prepared starch indicator was added. The solution was titrated against 0.0125N of sodium thiosulphate solution until the disappearance of the blue color. BOD was then calculated using the formula: $(BOD)_5$ in mg/l = DO_1- DO_5

3.8 Identification of Molluscs

Molluscs collected were identified using the taxonomic guides by Janus (1965), Burch (1989), Barney (2000) and Thompson (2004).



(A)



(B)

Key: s – Suture, **u** – Umbilicus, **a** – Outer lip, **b** – Columella lip, **c**- Parietal lip

Figure 3.2 (A and B): Identification Features and Morphometrics of Land Snail (Source: *A field guide to the land snails of Britain and north-west Europe* by Kerney and Cameron, 1979).

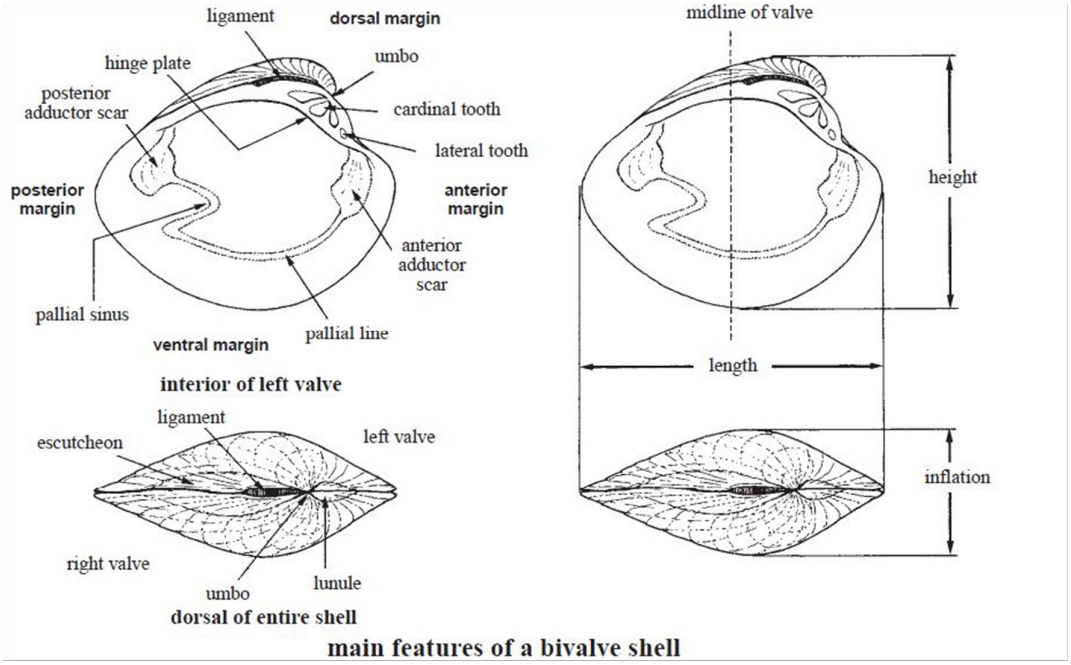
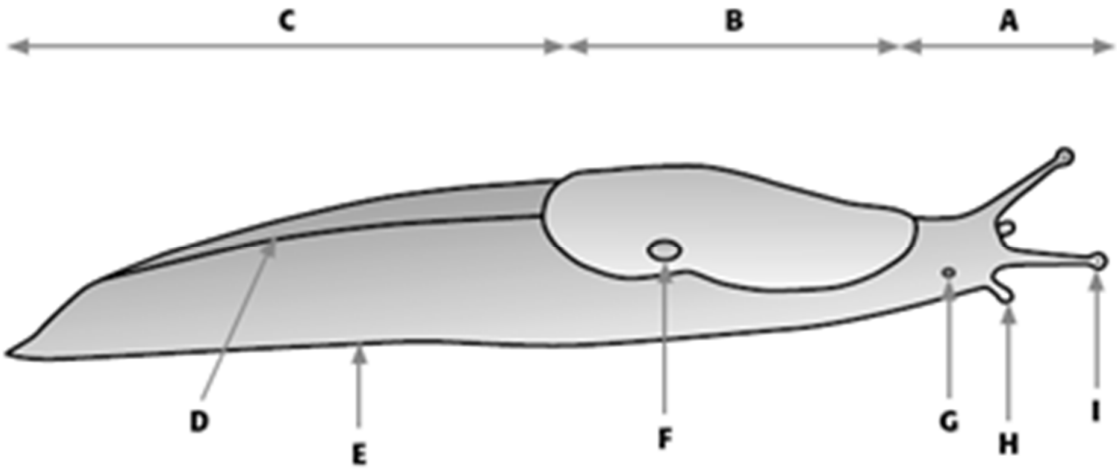


Figure 3.3: Identification Features and Morphometrics of Bivalves [(Source: *Bivalves* by Poutiers (1987)].



Key: A- Head, **B**- Mantle shield, **C**- Back and tail, **D**- Keel, **E**- Foot seam or foot sole, **F**- Respiratory opening, **G**- Genital pore, **H**- Short tentacles, **I**- Eye stalks.

Figure 3.4: Identification Characters of a Slug (Source: Slugs - A Guide to the Invasive and Native Fauna of California. *Conchology Society Page*).

3.9 Statistical Analysis

Simpson's Diversity and Shannon Weiner Indices (PAST® Package, Version: 1.81) were used to determine the diversity of freshwater molluscs in the water bodies. 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. The data for soil pH and calcium were subjected to Pearson correlation coefficient.

CHAPTER FOUR

4.0 RESULTS

4.1 Geomorphological Characteristics of the Freshwater Bodies

A total of 25 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 4.1). 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.

4.2 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 4.2). 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 4.2).


A



Plate I: Some Human Activities in Freshwater Bodies in northern Nigeria (**A**: At Lake Chad Baga Borno State, water transport and fetching water for domestic use bring humans in contact with freshwater pulmonate snails that are hosts of water-borne diseases; **B**: At Bebeji Kano State, Children bathing in a probable site of transmission of schistosomiasis are at risk of infection).

Table 4.1: Geomorphological Characteristics of the Freshwater Bodies of the Four Hydrological Areas of northern Nigeria.

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

Table 4.2: Mean Values of Physico-chemical Factors at the Studied Water Bodies (n=3). S.E. in Parentheses.

Water Body	Physicochemical Factor											
	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)	BOD_5 (mg/L)
KAR	28.97 (0.47)	58.67 (5.49)	29.67 (5.04)	6.02 (0.12)	70.67 (1.76)	56.67 (3.33)	1.23 (0.03)	1.20 (0.10)	212.67 (78.03)	64.00 (2.31)	6.47 (0.27)	0.68 (0.56)
ALL	23.53 (0.07)	85.33 (0.88)	42.67 (0.33)	7.35 (0.03)	42.00 (3.21)	91.67 (10.13)	0.23 (0.03)	0.98 (0.19)	53.33 (14.15)	54.67 (8.67)	4.98 (0.43)	1.73 (0.49)
TGD	36.07 (0.37)	0.00 (0.00)	0.00 (0.00)	8.71 (0.29)	33.33 (2.40)	155.00 (12.58)	0.37 (0.03)	3.00 (0.67)	32.00 (7.55)	48.00 (11.55)	5.77 (0.43)	0.17 (0.46)
ZBD	28.37 (0.69)	58.67 (5.36)	29.67 (3.76)	6.02 (0.14)	71.00 (1.15)	54.00 (3.61)	1.27 (0.09)	1.27 (0.32)	220.00 (12.10)	64.00 (2.52)	5.85 (0.19)	1.09 (1.13)
CHD	35.17 (1.20)	0.00 (0.00)	0.00 (0.00)	8.11 (0.14)	27.33 (2.03)	230.00 (8.66)	0.37 (0.03)	4.17 (0.03)	25.33 (2.96)	41.33 (7.42)	5.83 (0.09)	0.60 (0.53)
BGL	30.07 (0.32)	153.33 (4.91)	85.33 (9.84)	7.58 (0.09)	78.00 (3.21)	50.00 (0.00)	0.67 (0.03)	2.37 (0.38)	36.00 (5.29)	70.67 (8.11)	5.48 (0.77)	1.40 (0.36)
NGR	29.50 (0.90)	79.00 (8.21)	43.00 (3.40)	7.60 (0.87)	87.00 (6.05)	52.00 (3.56)	0.80 (0.24)	1.40 (0.02)	43.00 (4.67)	65.00 (5.43)	7.80 (1.40)	1.50 (0.23)
JUR	23.70 (0.10)	318.50 (0.50)	159.50 (0.50)	6.86 (0.00)	54.50 (0.05)	54.00 (1.00)	1.38 (0.00)	1.50 (0.03)	34.50 (0.00)	76.00 (0.50)	4.50 (0.30)	1.40 (0.20)
DKD	30.17 (0.12)	79.00 (8.19)	37.00 (5.13)	7.98 (0.19)	36.00 (2.00)	331.67 (3.33)	0.63 (0.03)	0.38 (0.01)	25.67 (5.36)	38.67 (4.81)	4.70 (1.83)	0.08 (2.08)
GBR	22.50 (0.50)	0.00 (0.00)	0.00 (0.00)	6.55 (0.15)	45.50 (0.50)	52.50 (0.50)	1.50 (0.10)	2.65 (0.15)	40.50 (1.50)	37.00 (1.00)	4.50 (0.30)	0.65 (0.05)
GAR	25.55 (0.85)	77.00 (10.00)	41.00 (2.00)	8.20 (0.04)	29.00 (3.00)	58.50 (4.50)	0.85 (0.05)	1.10 (0.20)	28.00 (6.00)	48.50 (3.50)	3.95 (0.35)	0.60 (0.10)
JBD	29.43 (0.09)	0.00 (0.00)	0.00 (0.00)	5.40 (0.01)	36.67 (4.26)	91.67 (8.82)	1.32 (0.02)	1.32 (0.02)	40.00 (8.89)	53.33 (6.67)	6.60 (0.10)	1.85 (1.24)
KNL	27.60 (0.15)	54.67 (1.20)	27.67 (0.33)	7.38 (0.05)	28.33 (2.33)	173.33 (8.82)	0.63 (0.02)	1.60 (0.69)	37.67 (9.68)	50.67 (3.53)	11.40 (2.43)	7.17 (1.76)

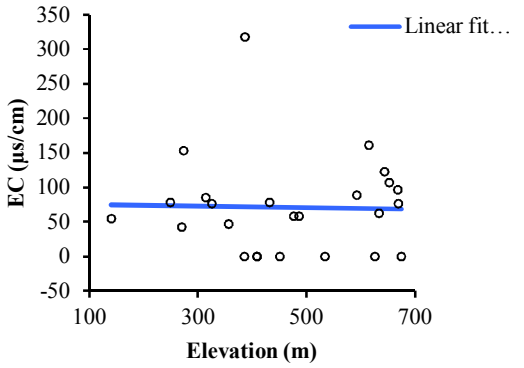
BAK	23.15 (0.35)	0.00 (0.00)	0.00 (0.00)	5.55 (0.50)	33.00 (1.00)	54.50 (0.50)	0.79 (0.03)	0.80 (0.00)	68.00 (1.00)	54.50 (0.50)	3.90 (0.10)	3.30 (0.10)
MAI	28.97 (0.28)	0.00 (0.00)	0.00 (0.00)	5.39 (0.03)	76.00 (5.57)	50.00 (0.00)	1.30 (0.00)	0.75 (0.05)	69.67 (6.33)	70.67 (3.53)	5.88 (0.28)	0.58 (0.33)
SBW	30.67 (0.26)	76.67 (0.67)	38.00 (0.58)	7.79 (0.19)	39.00 (2.52)	90.00 (2.50)	0.90 (0.15)	1.72 (0.15)	27.00 (4.51)	32.00 (2.31)	5.40 (0.62)	3.50 (0.57)
SHR	27.43 (0.09)	43.00 (0.00)	21.00 (0.00)	7.55 (0.04)	24.33 (2.73)	185.00 (13.23)	0.68 (0.09)	3.13 (0.10)	2.70 (0.21)	41.33 (7.42)	4.90 (0.26)	-2.36 (0.44)
KDR	29.17 (0.44)	88.67 (13.30)	46.33 (6.57)	7.15 (0.01)	36.33 (3.38)	404.00 (15.63)	1.65 (0.25)	1.65 (0.05)	26.50 (3.50)	48.00 (8.00)	4.50 (1.00)	-0.75 (0.10)
KYD	30.83 (0.88)	96.67 (4.70)	48.33 (2.33)	7.11 (0.51)	24.00 (2.89)	160.00 (0.00)	4.40 (1.55)	0.40 (0.01)	43.33 (3.18)	42.67 (2.67)	3.73 (0.46)	3.20 (0.72)
SPT	29.93 (0.37)	161.33 (4.67)	79.67 (1.89)	7.65 (0.04)	74.67 (2.85)	131.67 (38.44)	2.77 (0.07)	2.05 (0.20)	44.67 (6.64)	62.67 (1.33)	5.55 (0.25)	5.10 (0.10)
SBD	28.87 (0.19)	107.00 (0.58)	53.33 (0.33)	8.10 (0.07)	56.33 (0.88)	208.33 (21.28)	2.35 (0.05)	2.82 (0.36)	67.00 (16.29)	48.00 (2.31)	5.20 (0.30)	2.20 (0.70)
KUB	23.97 (0.84)	123.33 (30.68)	64.00 (15.18)	7.77 (0.28)	47.67 (2.33)	177.67 (3.92)	1.50 (0.38)	2.03 (0.07)	38.67 (1.86)	33.33 (4.81)	6.75 (0.23)	2.87 (0.16)
KNG	28.40 (0.36)	63.00 (4.00)	32.67 (0.33)	61.4 (0.05)	29.67 (1.45)	93.33 (3.33)	1.10 (0.00)	1.12 (0.19)	39.00 (2.89)	40.00 (11.55)	4.27 (0.24)	-1.07 (0.47)
ABU	27.53 (1.60)	0.00 (0.00)	0.00 (0.00)	5.37 (0.03)	39.33 (1.45)	40.00 (0.00)	0.67 (0.01)	1.08 (0.02)	40.00 (0.58)	28.00 (2.31)	5.67 (0.34)	0.23 (0.19)
JED	26.03 (0.24)	47.00 (1.00)	24.00 (0.00)	8.18 (0.19)	23.67 (2.03)	175.00 (16.07)	0.83 (0.28)	2.64 (0.20)	30.00 (6.08)	54.67 (7.42)	4.45 (0.38)	0.12 (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.

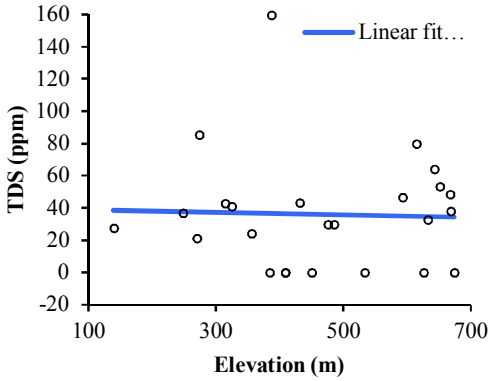
For abbreviations of water bodies see Table 4.1(columns 1 and 2).

There was no significant difference (*P*>0.05) in the physico-chemical factors of the four hydrological areas/basin (Appendix I).

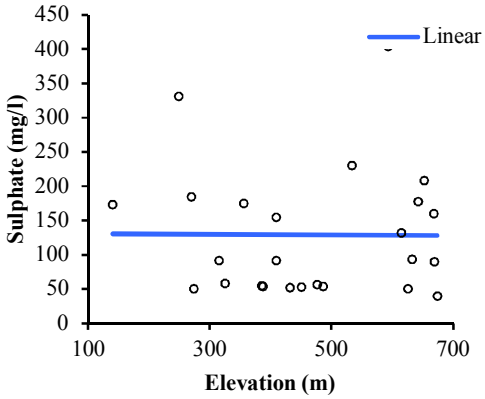
Figure 4.1 (A-L) shows the linear regression analyses establishing the patterns of the relationships of the measured physicochemical factors with elevation. The EC, TDS, sulphate, chloride, phosphate phosphorus and BOD varied slightly with change in elevation. Temperature, alkalinity and nitrate showed a positive relationship, while hardness, pH and DO showed negative relationships with change in elevation



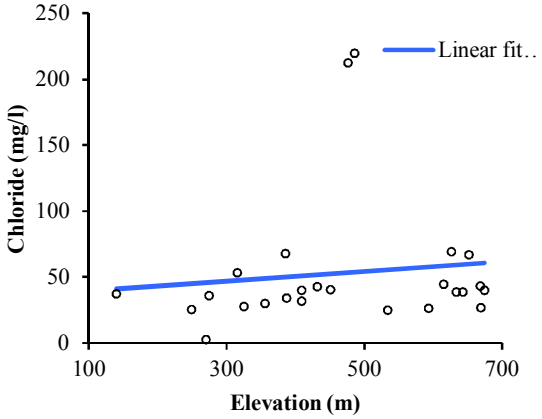
(A)



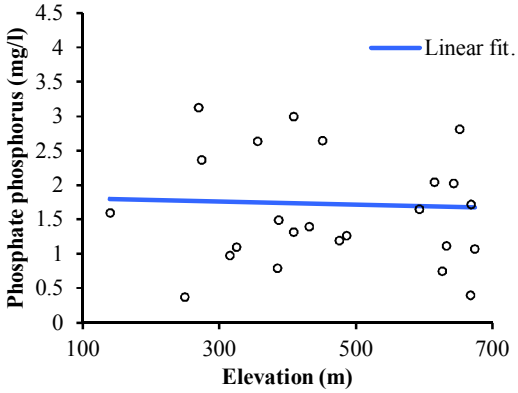
(B)


Linear fit…
Sulphate (mg/l)
450
400
350
300
250
200
150
100
50
0
100
300
500
700
Elevation (m)

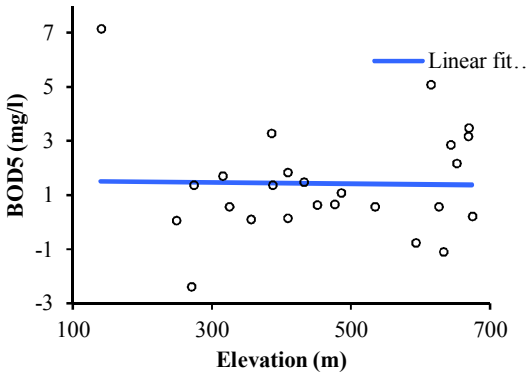
(C)


Linear fit..
Chloride (mg/l)
250
200
150
100
50
0
100
300
500
700
Elevation (m)

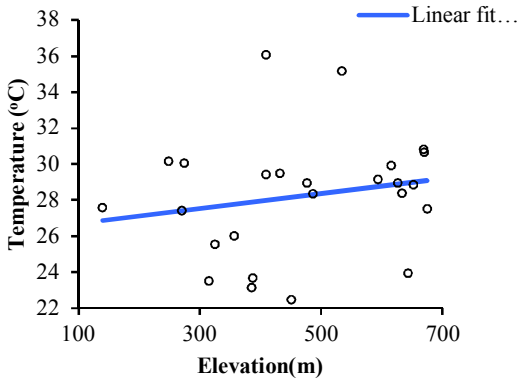
(D)


Linear fit..
Phosphate phosphorus (mg/l)
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
100
300
500
700
Elevation (m)

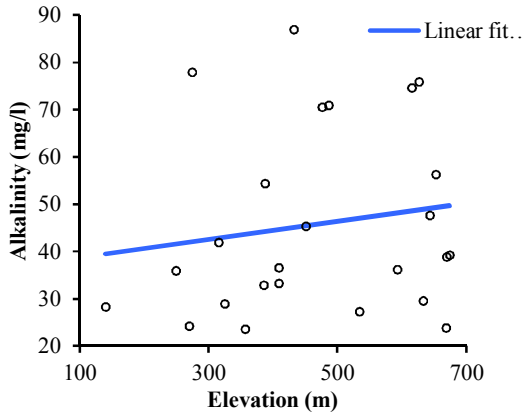
(E)


Linear fit..
BOD5 (mg/l)
7
5
3
1
-1
-3
100
300
500
700
Elevation (m)

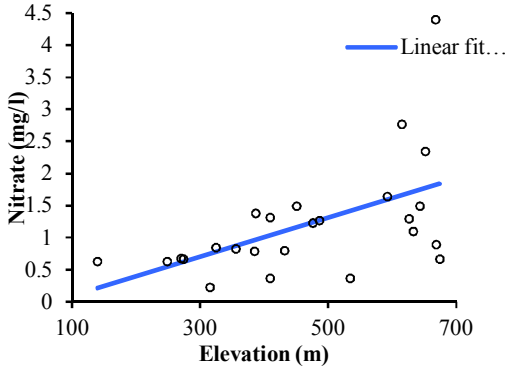
(F)


Linear fit…
Temperature (°C)
38
36
34
32
30
28
26
24
22
100
300
500
700
Elevation(m)

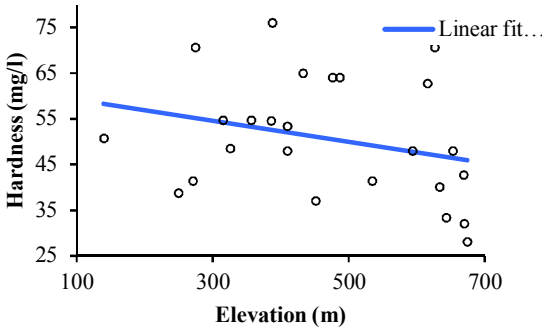
(G)


Linear fit..
Alkalinity (mg/l)
90
80
70
60
50
40
30
20
100
300
500
700
Elevation (m)

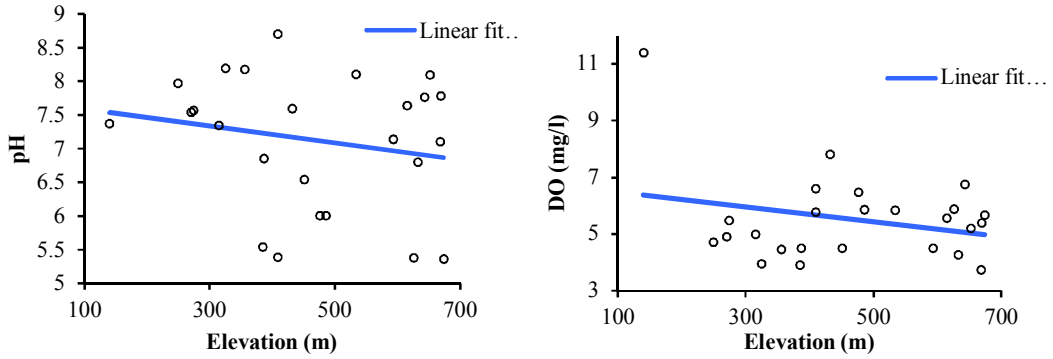
(H)


Linear fit…
Nitrate (mg/l)
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
100
300
500
700
Elevation (m)

(I)


Linear fit…
Hardness (mg/l)
75
65
55
45
35
25
100
300
500
700
Elevation (m)

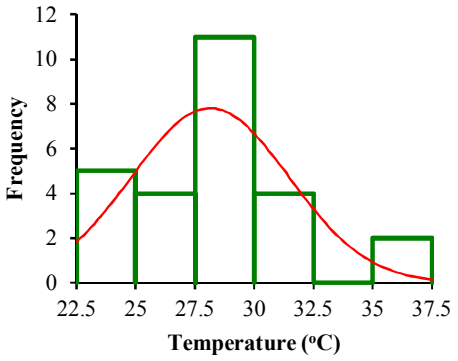
(J)



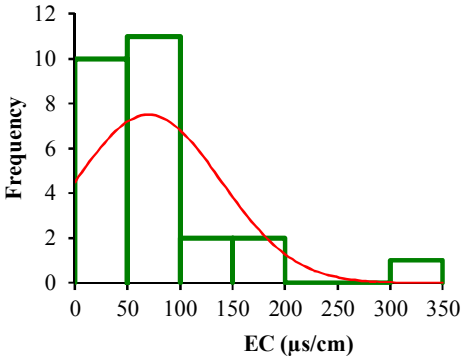
(K) **(L)**

Figure 4.1(A-L): The Linear Regression Analyses between measured Physico-chemical Factors and Elevation of Water Bodies studied.

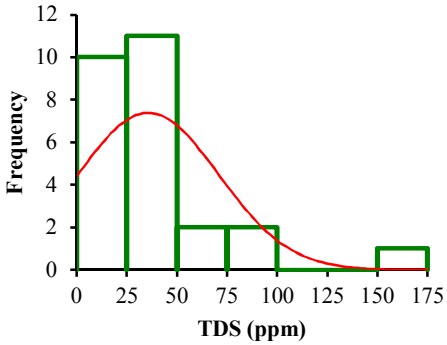
The histograms with the line of best-fit (Figure 4.2: A-L) represent the normality of the data and identified the outliers of the physicochemical factors measured. The distribution of all the factors was normal. However, higher values of nitrate, sulphate, chloride and DO were observed to be of low frequency outliers.


Frequency
12
10
8
6
4
2
0
22.5 25 27.5 30 32.5 35 37.5
Temperature (°C)

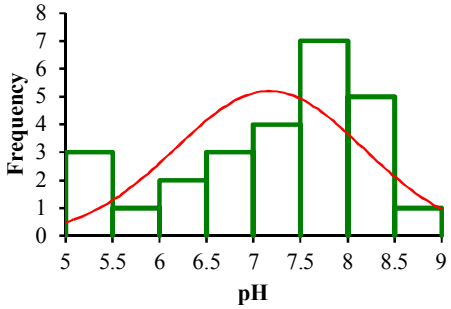
(A)


Frequency
12
10
8
6
4
2
0
0 50 100 150 200 250 300 350
EC (µs/cm)

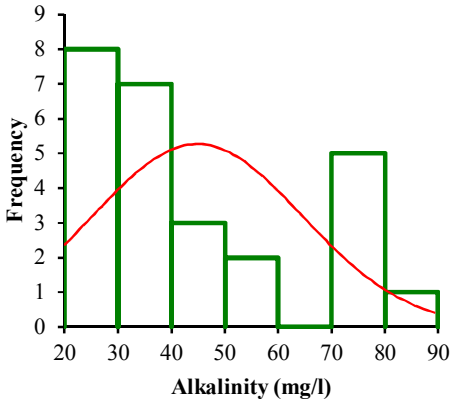
(B)

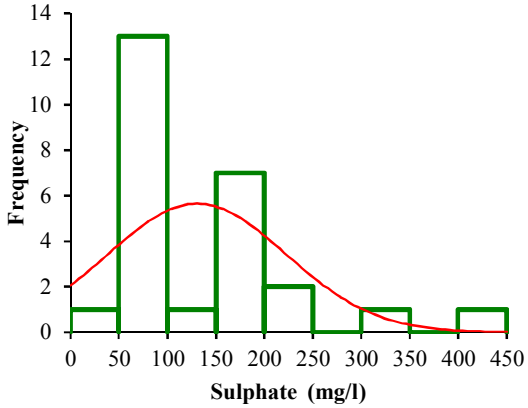

Frequency
12
10
8
6
4
2
0
0 25 50 75 100 125 150 175
TDS (ppm)

(C)

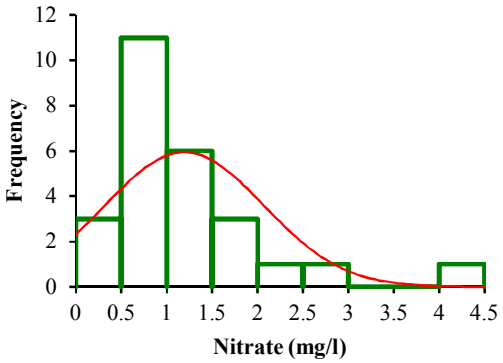

Frequency
8
7
6
5
4
3
2
1
0
5 5.5 6 6.5 7 7.5 8 8.5 9
pH

(D)

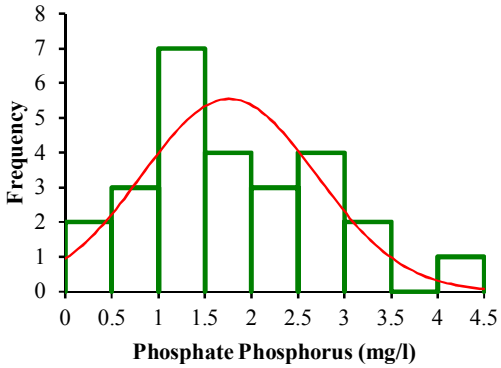

Frequency
9
8
7
6
5
4
3
2
1
0
20 30 40 50 60 70 80 90
Alkalinity (mg/l)


Frequency
14
12
10
8
6
4
2
0
0 50 100 150 200 250 300 350 400 450
Sulphate (mg/l)

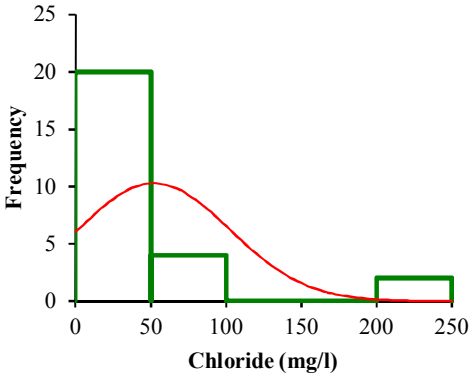
(E)


Frequency
12
10
8
6
4
2
0
0 0.5 1 1.5 2 2.5 3 3.5 4 4.5
Nitrate (mg/l)

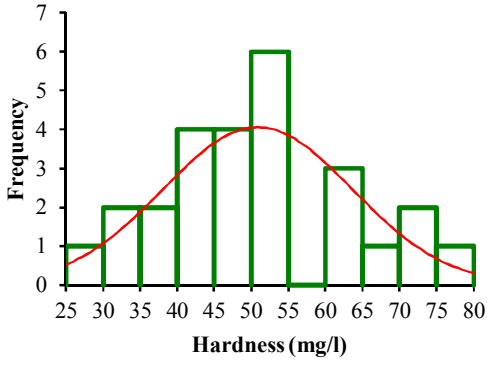
(F)


Frequency
8
7
6
5
4
3
2
1
0
0 0.5 1 1.5 2 2.5 3 3.5 4 4.5
Phosphate Phosphorus (mg/l)

(G)

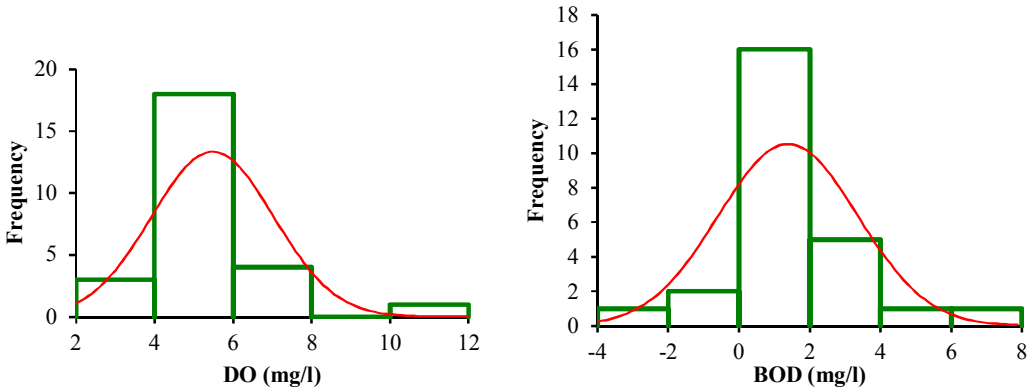

Frequency
25
20
15
10
5
0
0 50 100 150 200 250
Chloride (mg/l)

(H)


Frequency
7
6
5
4
3
2
1
0
25 30 35 40 45 50 55 60 65 70 75 80
Hardness (mg/l)

(I)

(J)



(K) **(L)**

Figure 4.2: Normality Curves and Frequency of the Physico-chemical Factors in the Water Bodies studied (A-L).

4.3 Taxonomy, Description and Distribution of the Molluscs Sampled

4.3.1 Taxonomic Positions of the Freshwater Molluscs Collected

A total of 14 species of freshwater molluscs belonging to 9 families were collected from the 25 water bodies of the 4 river basins studied. Three of the families, Unionidae, Mutelidae and Etheriidae belong to the class Bivalvia while the others, namely, Viviparidae, Paludomidae, Thiaridae, Planorbidae, Lymnaeidae and Ampullaridae belong to the class Gastropoda (Plates I -

XIV). The family Unionidae is represented by three species of the the genus *Anodonta*. The viviparids are represented by two species of mud snails of the genus *Bellamya*. The families Mutelidae, Etheriidae, Paludomidae, Lymnaeidae and Ampullaridae are represented by single species (Table 4.3).



Plate II - *Anodonta marginata*

Sites of Collection: Dutsin-ma, Alau, Kano, Karaye, Baga, Jamare, Dadin Kowa, Gubla, Jibia, Kainji, Funtua, Kaduna, Kaya, Spotti, Sabon Birni, Zaria, Kangimi, Jebba, Garkida, Bakolori, Nguru.

Kingdom: Animalia (Linnaeus, 1758)

Subkingdom: Bilateria (Hatschek, 1888)

Superphylum: Eutrochozoa

Phylum: Mollusca (Linnaeus, 1758) Cuvier, 1795

Class: Bivalvia

Order: Unionoida

Family: Unionidae

Genus: *Anodonta* (Lamarck, 1799)

Species: *Anodonta marginata*





Plate III - *Anodonta anatina*

Sites of Collection: Alau, Dadin Kowa.

Phylum: Mollusca (Linnaeus, 1758) Cuvier, 1795

Class: Bivalvia

Order: Unionoida

Family: Unionidae

Genus: *Anodonta* (Lamarck, 1799)

Species: *Anodonta anatina* (Linnaeus, 1758)



Plate IV - *Anodonta implicata*

Sites of Collection: Dadin Kowa, Kaduna, Garkida.

Phylum: Mollusca (Linnaeus, 1758) Cuvier, 1795

Class: Bivalvia

Order: Unionoida

Family: Unionidae

Genus: *Anodonta* (Lamarck, 1799)

Species: *Anodonta implicata* (Say, 1829)





Plate V- *Etheria elliptica*

Sites of Collection: Dadin Kowa, Kainji, Shiroro.

Phylum: Mollusca (Linnaeus, 1758) Cuvier, 1795

Class: Bivalvia

Order: Unionoida

Family: Etheriidae

Genus: *Etheria*

Species: *Etheria elliptica* (Larmack, 1807)



Plate VI - *Aspatheria* sp.

Site of collection: Kainji.

Phylum: Mollusca (Linnaeus, 1758) Cuvier, 1795

Class: Bivalvia

Order: Unionoida

Family: Mutelidae

Genus: *Aspatheria*

Species: *Aspatheria* sp.



Plate VII - Mud snail

Sites of Collection: Dutsin-ma, Kano, Karaye, Baga, Dadin Kowa, Gubla, Jibia, Kainji, Funtua, Kaduna, Kaya, Shiroro, Spotti, Sabon Birni, Zaria, Kangimi, Garkida, Bakolori, Nguru.

Phylum: Mollusca (Linnaeus, 1758) Cuvier, 1795

Class: Gastropoda (Cuvier, 1795)

Subclass: Orthogastropoda (Ponder & Lindberg, 1996)

Order: Sorbeoconcha (Ponder & Lindberg, 1997)

Family: Viviparidae (Gray, 1847)

Subfamily: Bellamyinae

Genus: *Bellamya*

Species: *Bellamya crawshayi* (Smith, 1893)



Plate VIII - Mud snail

Sites of Collection: Alau, Baga, Funtua, Zaria.

Phylum: Mollusca (Linnaeus, 1758) Cuvier, 1795

Class: Gastropoda (Cuvier, 1795)

Subclass: Orthogastropoda (Ponder & Lindberg, 1996)

Order: Sorbeoconcha (Ponder & Lindberg, 1997)

Family: Viviparidae (Gray, 1847)

Subfamily: Bellamyinae

Genus: *Bellamya*

Species: *Bellamya unicolor* (Livier, 1806)




Plate IX - Banded river snail

Sites of Collection: Alau, Zaria, Jebba, Bakolori.

Phylum: Mollusca (Linnaeus, 1758) Cuvier, 1795

Class: Gastropoda (Cuvier, 1795)

Superfamily: Cerithioidea

Family: Paludomidae (Gill, 1871)

Subfamily: Cleopatrinae

Genus: *Cleopatra*

Species: *Cleopatra bulimoides* (Olivier, 1804)





Plate X - Red-rimmed melania

Sites of Collection: Dutsin-ma, Alau, Kano, Karaye, Baga, Dadin Kowa, Gubla, Jibia, Kainji, Funtua, Kaduna, Shiroro, Zaria, Bakolori, Nguru.

Phylum: Mollusca (Linnaeus, 1758) Cuvier, 1795

Class: Gastropoda (Cuvier, 1795)

Superorder: Caenogastropoda (Cox, 1960)

Order: Sorbeoconcha (Ponder & Lindberg, 1997)

Family: Thiaridae (Troschel, 1857)

Genus: *Melanoides*

Species: *Melanoides tuberculata* (Muller, 1774)





Plate XI - *Melanoides maculata*

Sites of Collection: Dutsin-ma, Alau, Kano, Karaye, Gubla, Jibia, Kainji, Kaduna, Shiroro, Zaria, Bakolori, Nguru.

Phylum: Mollusca (Linnaeus, 1758) Cuvier, 1795

Class: Gastropoda (Cuvier, 1795)

Superorder: Caenogastropoda (Cox, 1960)

Order: Sorbeoconcha (Ponder & Lindberg, 1997)

Family: Thiaridae (Troschel, 1857)

Genus: *Melanoides*

Species: *Melanoides maculata* (Born, 1780)



Plate XII - *Biomphalaria pfeifferi*

Sites of Collection: Dutsin-ma, Kano, Karaye, Gubla, Funtua, Kainji, Kaduna, Jebba, Zaria, Bakolori.

Phylum: Mollusca (Linnaeus, 1758) Cuvier, 1795

Class: Gastropoda (Cuvier, 1795)

Family: Planorbidae

Subfamily: Planorbinae

Tribe: Biomphalariini

Genus: *Biomphalaria* (Preston, 1910)

Species: *Biomphalaria pfeifferi* (Krauss, 1848)



Plate XIII - *Bulinus globosus*

Sites of Collection: Dutsin-ma, Kano, Karaye, Kainji, Zaria, Bakolori.

Phylum: Mollusca (Linnaeus, 1758) Cuvier, 1795

Class: Gastropoda (Cuvier, 1795)

Order: Hygrophila

Family: Planorbidae

Subfamily: Planorbinae

Genus: *Bulinus*

Species: *Bulinus globosus* (Morelet, 1866)



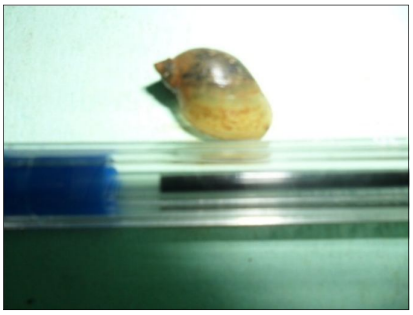


Plate XIV - *Lymnaea natalensis*

Sites of Collection: Dutsin-ma, Baga, Kainji.

Phylum: Mollusca (Linnaeus, 1758) Cuvier, 1795

Class: Gastropoda (Cuvier, 1795)

Superfamily: Lymnaeoidea

Family: Lymnaeaidae

Subfamily: Lymnaeinae

Genus: *Lymnaea*

Species: *Lymnaea natalensis* (Linnaeus, 1758)



Plate XV- Apple snail

Sites of Collection: Alau, Baga, Dadin Kowa, Nguru.

Phylum: Mollusca (Linnaeus, 1758) Cuvier, 1795

Class: Gastropoda (Cuvier, 1795)

Superfamily: Ampullarioidea

Family: Ampullariidae

Subfamily: Ampullariinae

Genus: *Pila*

Species: *Pila ampullaceae* (Linnaeus, 1758)

Table 4.3: Checklist and Distribution of the Species of Freshwater Molluscs in the Water Bodies of the Four Hydrological Areas of northern Nigeria.

Freshwater molluscs	Freshwater																									
	KAR	ALL	TGD	ZBD	CHD	BGL	JUR	DKD	GBR	JBD	KNL	MAI	SBW	SHR	KDR	KYD	SPT	SBD	KUB	KNG	ABU	JED	GAR	BAK	NGR	(%) Occurrence
BIVALVIA																										
Unionidae																										
Anodonta marginata	3	2	2	3	3	3	2	1	2	3	2	1	0	0	*	2	1	2	1	2	1	2	1	2	2	**91.7**
Anodonta anatina	0	1	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**8.0**
Anodonta implicata	0	0	0	0	0	0	0	3	0	0	0	0	0	0	3	0	0	0	0	0	0	0	*	0	0	**12.0**
Mutelidae																										
Aspatheria sp.	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**4.0**
Etheriidae																										
Etheria elliptica	0	0	0	0	0	0	0	3	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	**12.0**
GASTROPODA																										
Viviparidae																										
Bellamya crawshayi	*	0	1	1	1	1	0	2	1	1	2	2	1	1	*	1	1	1	0	1	1	0	1	2	1	**88.0**
Bellamya unicolor	0	2	0	0	0	*	0	0	0	0	0	1	0	0	0	0	0	0	3	0	2	0	0	0	0	**20.0**
Paludomidae																										
Cleopatra bulimoides	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	*	1	0	1	0	**16.0**
Thiaridae																										
Melanoides tuberculata	1	1	2	1	2	*	0	2	1	2	1	3	3	2	1	0	0	0	1	0	3	0	0	1	1	**72.0**
Melanoides maculata	1	2	2	2	2	0	0	0	1	1	1	0	3	2	1	0	0	0	1	0	2	0	0	1	*	**60.0**
Planorbidae																										
Biomphalaria pfeifferi	0	0	1	1	*	0	0	0	1	0	1	*	0	0	*	0	0	0	1	0	0	1	0	1	0	**40.0**
Bulinus globosus	0	0	1	1	*	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	1	0	**20.0**
Lymnaeaidae																										
Lymnaea natalensis	0	0	0	1	0	*	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**12.0**
Ampullariidae																										
Pila ampullaceae	0	1	0	0	0	*	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	**16.0**
Simpson_(1-D)	**0.67**	**0.84**	**0.81**	**0.82**	**0.80**	**0.78**	**0.00**	**0.84**	**0.78**	**0.69**	**0.88**	**0.75**	**0.61**	**0.72**	**0.78**	**0.44**	**0.50**	**0.44**	**0.82**	**0.44**	**0.80**	**0.63**	**0.67**	**0.84**	**0.78**	

KEY: (0) **-** Absent, (1) **–** Uncommon: 1 to 3, (2) **–** Common: 4 to10, (3) **-** Very Common: 11 to 25, (*) **-** Dead shell present. For abbreviations of water bodies see Table 4.1(columns 1 and 2).

4.3.2 Description and Distribution of Freshwater Mollusc Species Sampled

4.3.2.1 *Anodonta marginata* (Plate II)

Description: The shell is elongate-elliptical in shape and dark brown, swollen and narrowed interiorly, with the outer surface usually sculptured with concentric ridges and strongly striated. The dorsal umbo is slightly raised and eroded giving it a silver-colour. The hinge-plate is without elevations. The inner surface of shell has a pallial line that connects the scars of the anterior and posterior adductor muscles.

Distribution: This species was the most frequently encountered as it was found to occur in 18 of the 21 water bodies sampled, representing 91.7% (Table 4.3). Its distribution cuts across water bodies in all the hydrological areas of the study area. It occurred in rivers, lakes and dams regardless of the nature of the substratum.

4.3.2.2 *Anodonta anatina* (Plate III)

Description: Resembles *A. marginata* but the shell of this species is markedly swollen, slightly oval in shape and the umbo is markedly raised and arched dorsally giving it a “comma” shape.

Distribution: Unlike *A. marginata* this species is rare in its distribution and occurred in flowing water bodies with a predominantly sandy bottom. It was encountered in Alau Lake and Dadin Kowa Reservoir (Table 4.3).

4.3.2.3 *Anodonta implicata* (Plate IV)

Description: The species is relatively large. The shell is dark green-brown, with the anterior part of the shell closely narrowed forming an angle with the dorsal stretch of the hinge. The posterior end of the shell forms a trapezoid-shape with the dorsal stretch. The umbo is flattened and the width of the posterior part is almost as qtwice that of the anterior region. The inner surface of the shell is glossy, having a reflection of purple and pink.

Distribution: This species is the rarest of all the anodontas. It was encountered only in Dadin Kowa Reservoir and River Kaduna (Figure 4.10), under grass overgrowth by the edge of sandy side pools (quiet and standing water) formed by the river flow.

4.3.2.4 *Etheria elliptica* (Plate V)

Description: This species is a large heavy triangular bivalve that measured up to over 30 cm in length. The shell is either brown or grey in colour, has sharp-cutting edges and is characterized by dense cover of thick short spines projecting about 45^{o} to the entire shell surface. A number of individuals were found crowded and joined together forming a colony-like group.

Distribution: The distribution of the spiny bivalve is restricted as it showed preference for rivers with rocky-bottom, where it lives firmly attached to the rocks in deep and rapidly flowing part of the water. It was found in Kainji Lake, Dadin Kowa Reservoir and Shiroro Lake (Table 4.3), all with a partly rocky-bottom substratum.

4.3.2.5 *Aspatheria* sp. (Plate VI)

Description: The shell of this bivalve is chalky white in colour with eroded black patches probably a reminiscent of its original colour. The shell is oblong and trigonal with a conspicuous pallial line

connecting the muscle scars. The surface is sculptured with lines and the umbones are prominent and slightly beaked. The cardinal tooth and socket lie ventrally to the umbones.

Distribution: This species of bivalve is very rare and limited in its distribution. It was found only in Kainji Lake (Figure 4.10).

4.3.2.6 *Bellamya crawshayi* (Plate VII)

Description: The shell is ovate and the lip is not flared but with a stripe of darker coloration lines round the inner lip of the aperture. The shell is dextral (coiled to the right) thin and smooth, brown with shades of green. Sutures are deep and the umbilicus pitted. The body whorl is conspicuously globose and the apex pointed. Number of whorls ranged from 4 – 4½.

Distribution: It is commonly found in slow moving parts of rivers towards the banks and overflows with substratum predominantly mud. Also commonly found in lakes and rice fields.

4.3.2.7 *Bellamya unicolor* (Plate VIII)

Description: This species differs from *B. crawshayi* in being pale/light brown in colour, with slightly darker vertical ribs. It is much smaller in size and lacks the dark round stripe on the inner lip of the aperture.

Distribution: Its distribution is similar to that of *B. crawshayi* only that it occurs in clear waters in lakes. It was encountered in five of the water bodies sampled (Table 4.3).

4.3.2.8 *Cleopatra bulimoides* (Plate IX)

Description: The shell is smooth, axial and incised, brown with darker spiral bands (banded river snail). It is dextral and ovate in shape with the umbilicus closed and apex pointed. The aperture is

obliquely oval, the lip not flared and the operculum convex/oval with a nucleus at the edge towards the umbilicus.

Distribution: This snail is not common in most water bodies in the study area but showed preference to lakes with sandy banks. It was found in Alau Lake (Borno State), Kubani Lake (Kaduna State) and Bakolori Reservoir (Sokoto State).

4.3.2.9 *Melanoides tuberculata* (Plate X)

Description: The shell is light brown and is frequently mottled with rust-colored spots that form spiral lines bellow the sutures. Shell is elongate and conical (i.e turriform), with regular increasing whorls with the apex (last whorl) usually broken. The shell is incised and sculptured with much finer spiral striations. The lip is not flared and the umbilicus is closed. The aperture is pear-shaped with no operculum.

Distribution: This species has a wide distribution and it ranged across most of the small and large water bodies in the hydrological areas (Figure 4.10).

4.3.2.10 *Melanoides maculata* (Plate XI)

Description: The shell is light brown, elongated and conical in shape, with the whorls increasing in size as in *M. tuberculata.* The shell is speckled with dark brown patterns along its length and the apex of the last whorl is peaked. The lip is not flared and the umbilicus closed. The aperture is pear-shaped and operculum absent.

Distribution: With the exception of few water bodies, the distribution of this species almost coincided with that *M. tuberculata*.

4.3.2.11 *Biomphalaria pfeifferi* (Plate XII)

Description: Shell is thin-walled and translucent, disc-like and coiled in a plane spiral (planospiral). The whorls are well-rounded and increasing regularly and rapidly. Apex is depressed. The mouth is oval and not flared. The spire is deeply sunken.

Distribution: Present in few water bodies mostly Dams across northern Nigeria.

4.3.2.12 *Bulinus globosus* (Plate XIII)

Description: Shell is small, light brown, thin-walled with fine striations. The body whorl and the aperture are large; the spire is short and blunt apex.

Distribution: Kubani and Kainji lakes, Zobe and Tiga Reservoirs. Empty shells were found in Chalawa-Gorge Reservoir. *Bulinus globosus* occurred in shallow parts of water bodies that are rich in vegetation.

4.3.2.13 *Lymnaea natalensis* (Plate XIV)

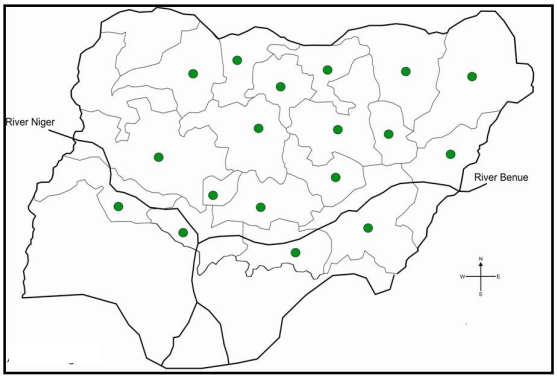
Description: Shell is small, thin-walled with a short spire and short pointed apex. The body whorl is very swollen and the aperture large and oval.

Distribution: The distribution of this species is limited to Zobe Reservoir and Kainji Lake.

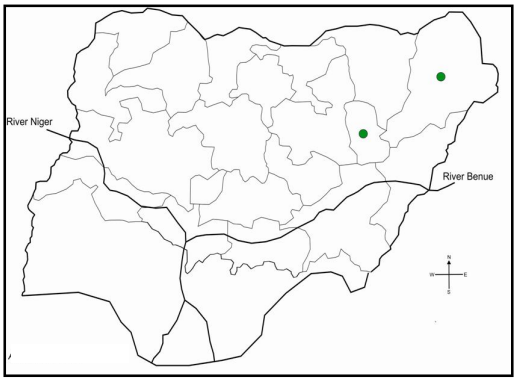
4.3.2.14 *Pila ampullaceae* (Plate XV)

Description: The shell is large, moderately thick, glossy and globose, spirally coiled around collumella. The shell is green brown with transverse faint dark bands and incised with vertical ribs. The spire is less depressed. It has operculum that is horny. It has 3-4 whorls that are well developed and less inflated. The body whorl constitutes the bulk of the shell. Umbilicus is larger and perforated.

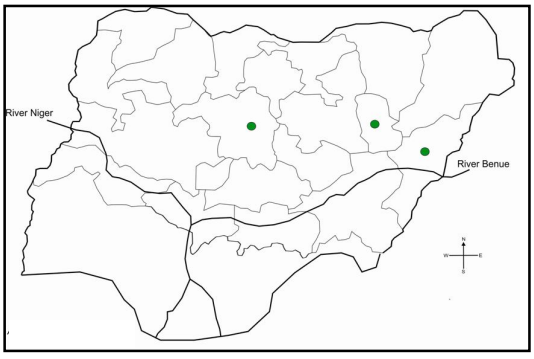
Distribution: When present, it occurs in large numbers. *P. ampullaceae* showed preference to clear waters with a lot of waves and sandy substratum. *P. ampullaceae* was present in Dadin Kowa Reservoir, Nguru and Alau Lakes. Dead shells were found along the shore in Baga Lake.



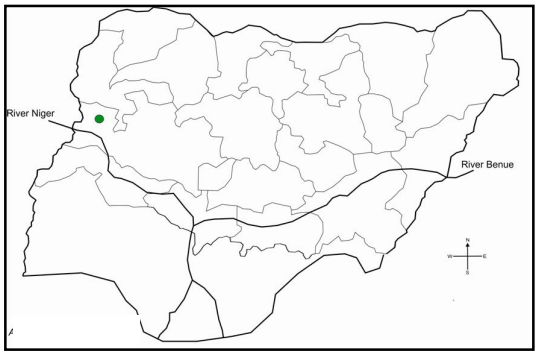
Anodonta marginata



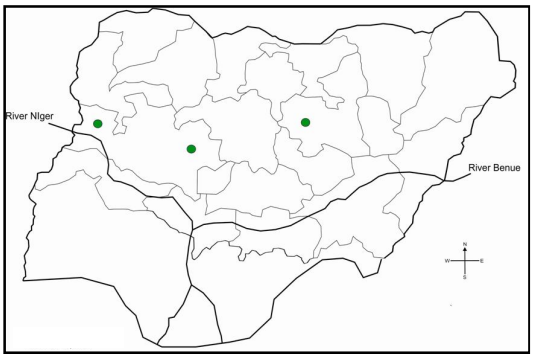
Anodonta anatina



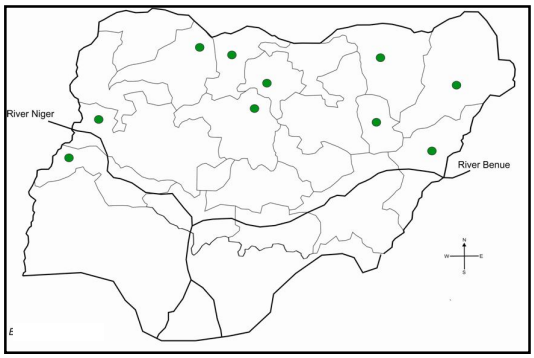
Anodonta implicata



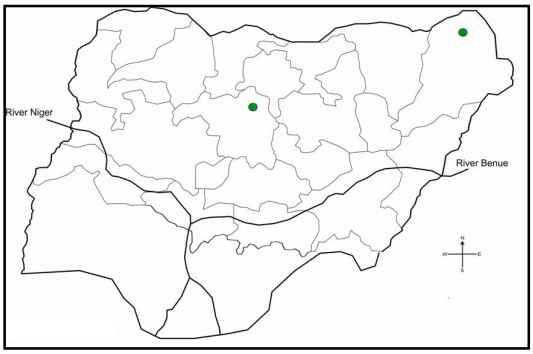
Aspatheria sp.



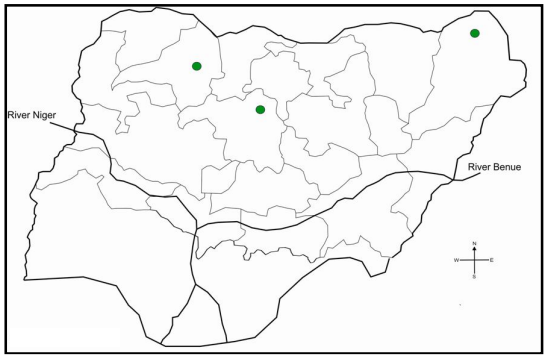
Etheria elliptica



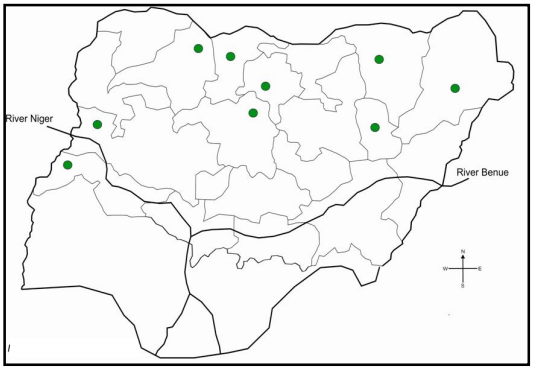
Bellamya crawshayi



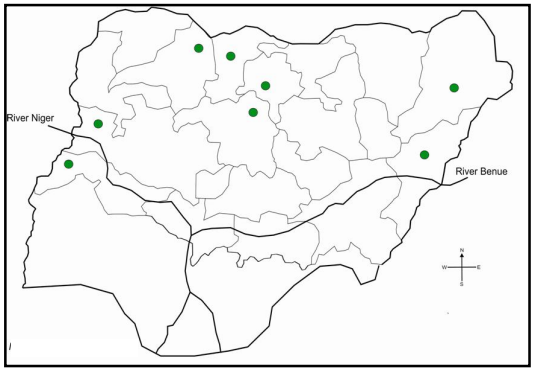
Bellamya unicolor



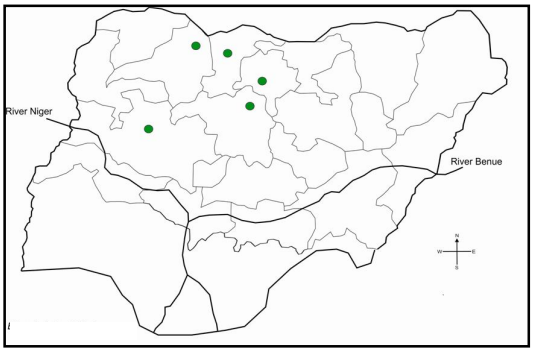
Cleopatra bulimoides



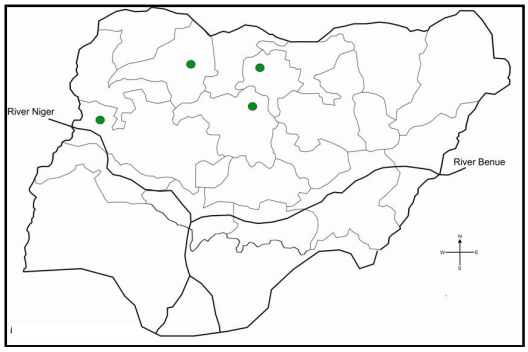
Melanoides tuberculata



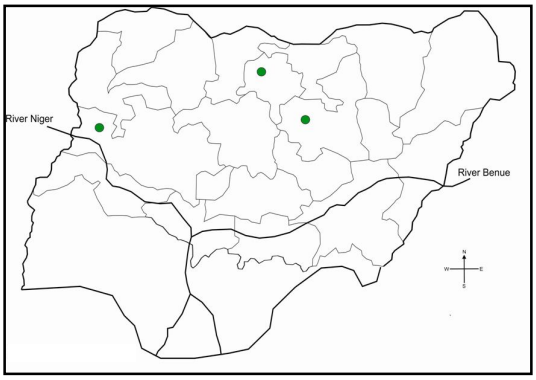
Melanoides maculata



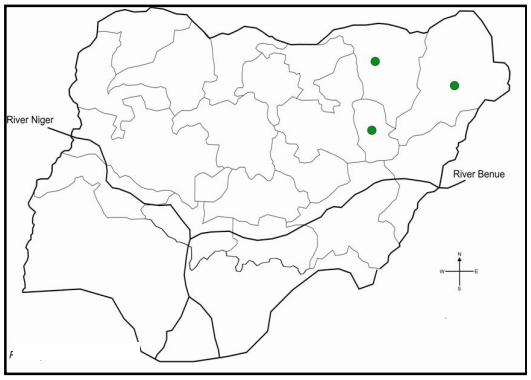
Biomphalaria pfeifferi



Bulinus globosus



Lymnaea natalensis



Pila ampullaceae

Figure 4.3: Distribution Maps of Terrestrial Molluscs in northern Nigeria.

4.3.3 Diversity of Freshwater Molluscs in the Water Bodies Sampled

Figure 4.4 (A and B) represent the taxonomic tree and freshwater lineages of the two classes of freshwater molluscs, Bivalvia and Gastropoda, in northern Nigeria. The most common

species recorded in the water bodies studied are *Anodonta marginata* (Bivalvia) with a percentage occurrence of 91.7% and *Bellamya crawshayi* (Gastropoda) with 88.0% (Table 4.3). However, the distribution of *Etheria elliptica* (12.0%) and *Lymnaea natalensis* (12.0%) is restricted to three water bodies. The Simpsons diversity index showed that Kainji Lake had the highest diversity value of 0.88 reflecting the highest number of species (9) represented by four (4) bivalve and five (5) gastropod species. This is followed by water bodies with seven 7 species: Alau and Kubani Lakes (each with two bivalves and five gastropods), Zobe and Bakolori lakes (each with one bivalve and six gastropods), and Dadin Kowa (with four bivalves and three gastropods) (Table 4.3). The lowest species diversity was recorded in Jumare River/ flood plain with only a single species (*A. marginata*). Of the 25 water bodies studied, Dadin Kowa Reservoir and Kainji Lake had the highest diversity of bivalve species.

Figure 4.4 (A): Taxonomic Tree of Freshwater Lineages of Bivalvia in northern Nigeria (☆Modified after Kohl, 2006).

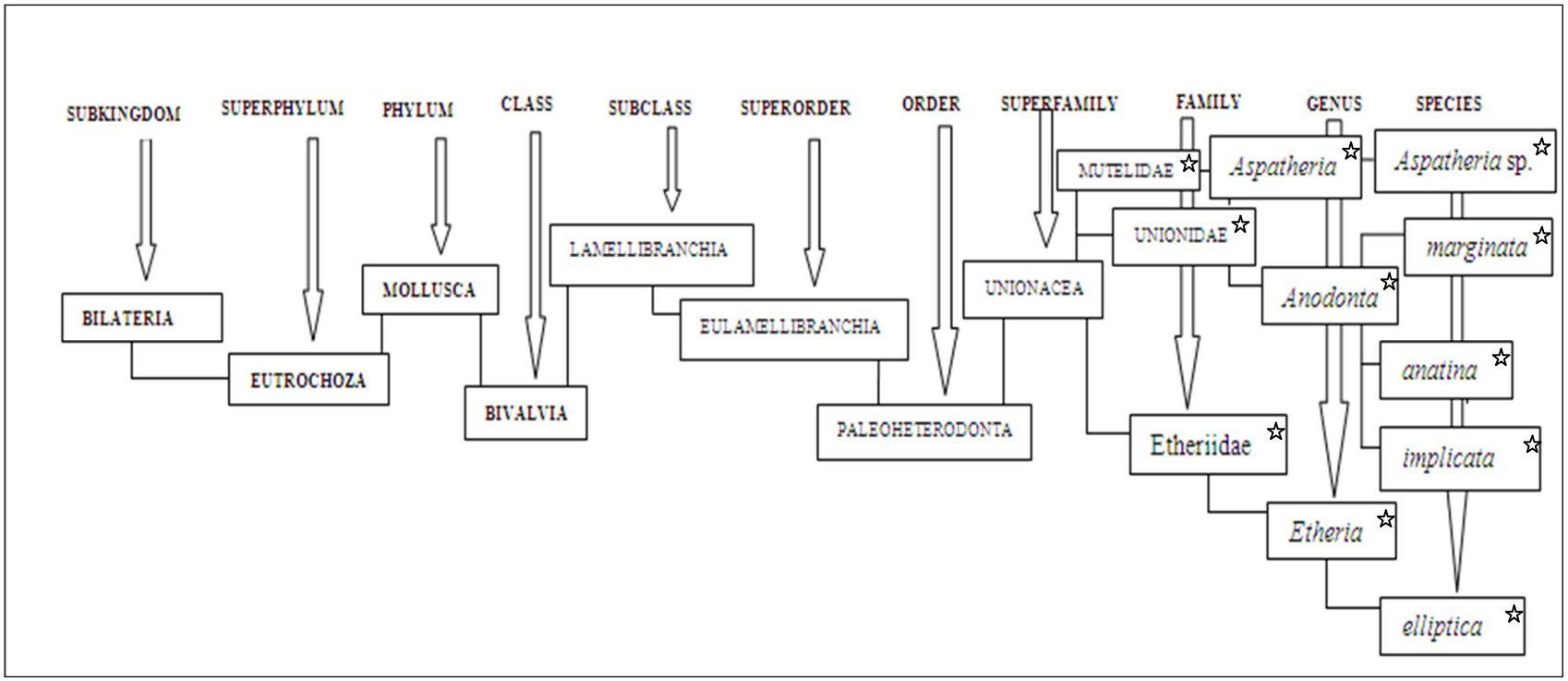
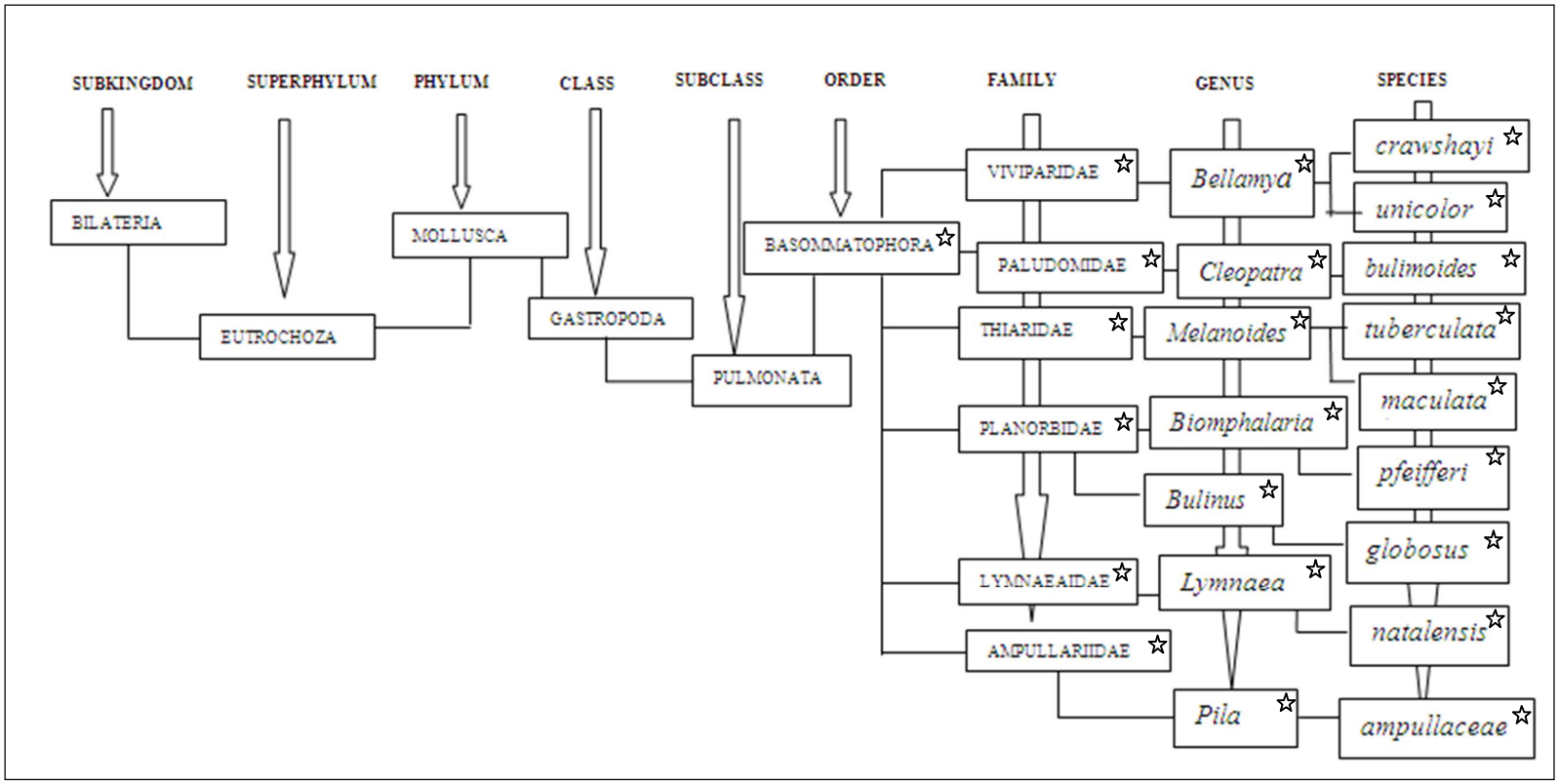


Figure 4.4 (B): Taxonomic Tree of Freshwater Lineages of Gastropoda in northern Nigeria (☆Modified after Kohl, 2006).



The Shannon-Weaver index gave the highest taxonomic diversity in Kainji Lake with a total of eight (8) genera representing three (3) bivalves and five (5) gastropods, followed by Zobe and Kubani Reservoirs with six (6) genera each (Figure 4.5). The figure established a pattern where water bodies with high species diversity showed lower species dominance and vice versa. The lowest diversity of one (1) genus and highest species dominance was in Jumare River and flood plain.

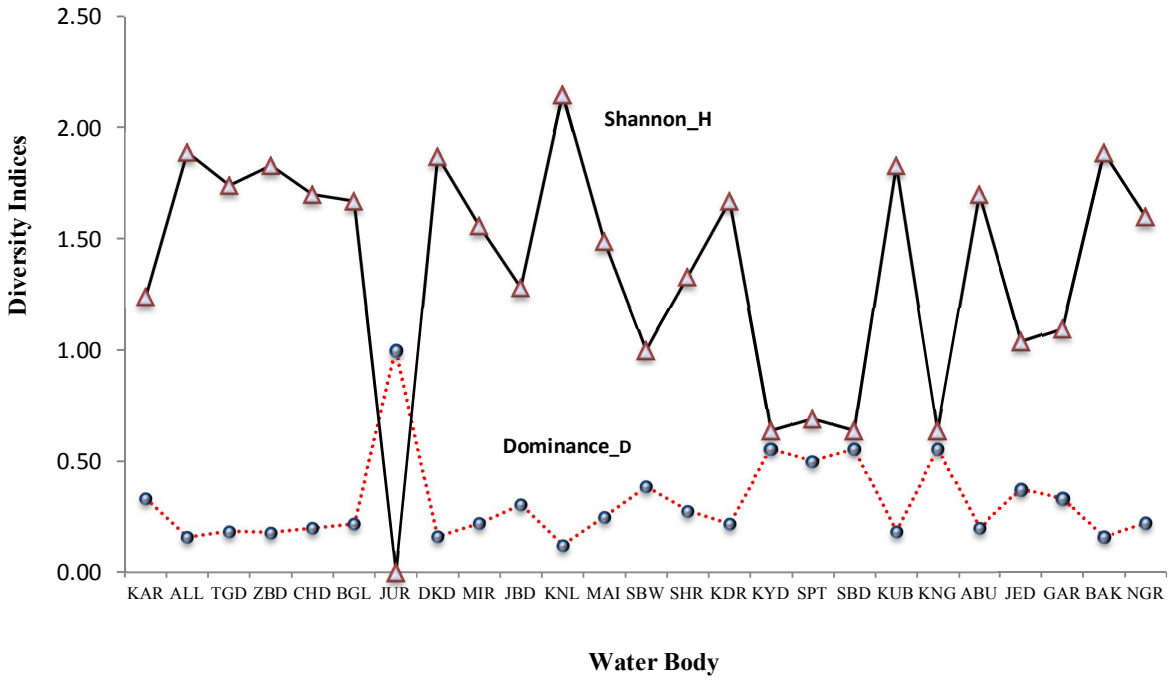


Figure 4.5: Patterns of Species Diversity Indices of the Water Bodies studied.

Key: For abbreviations of water bodies see Table 4.1(columns 1 and 2).

Figure (4.6) represents the distribution map of the mollusc species in the 4 basins while Figure (4.7) shows that Sokoto basin had the highest varity of molluscs with 10 species while Gongola basin with 8 species had the lowest. Although the total number of species is not

significantly different, the analysis of variance indicated that variation in species composition of the water bodies that constitute the Gongola basin was significant (P<0.01).



Figure 4.6: The Distribution Map of Freshwater Molluscs in Hydrological Areas of northern Nigeria.

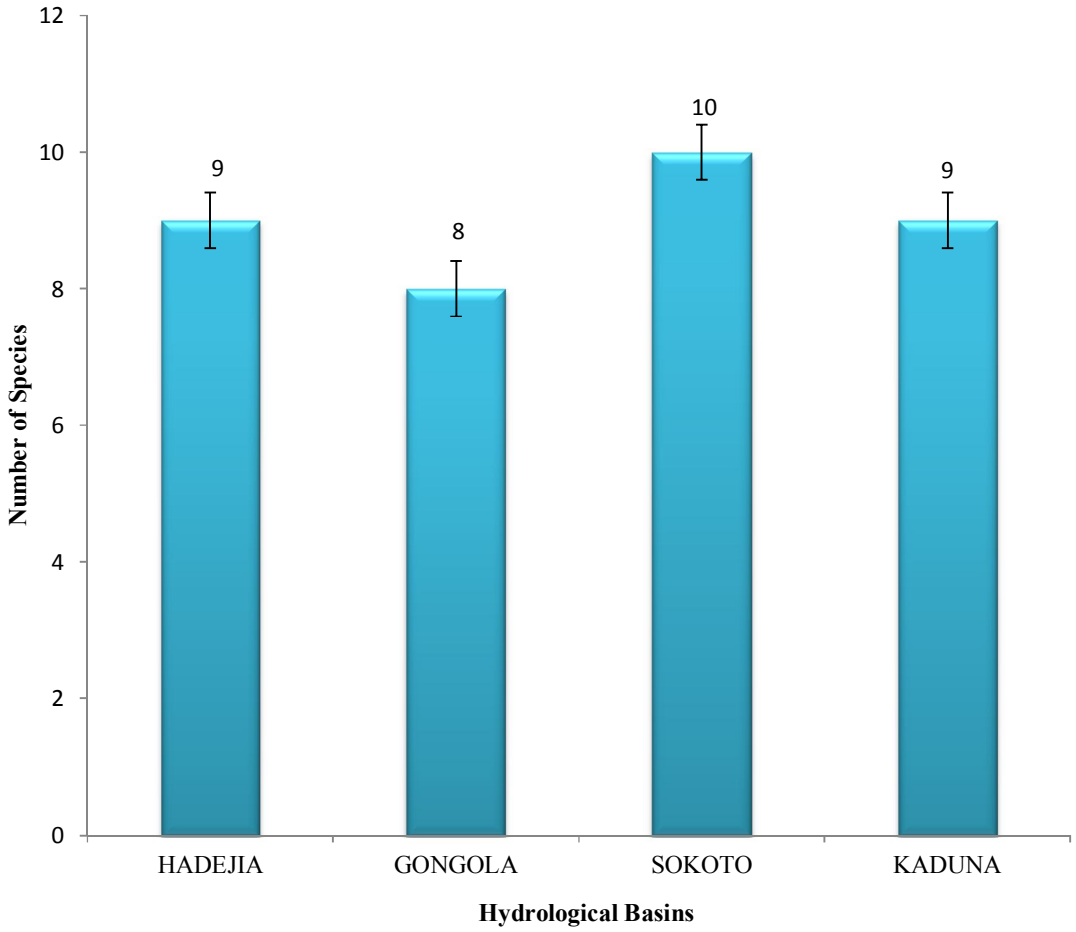

12
10
8
6
4
2
0
Number of Species
9
8
10
9
HADEJIA
GONGOLA
SOKOTO
KADUNA
Hydrological Basins

Figure 4.7: Mollusc Species Richness of the Hydrological Basins.

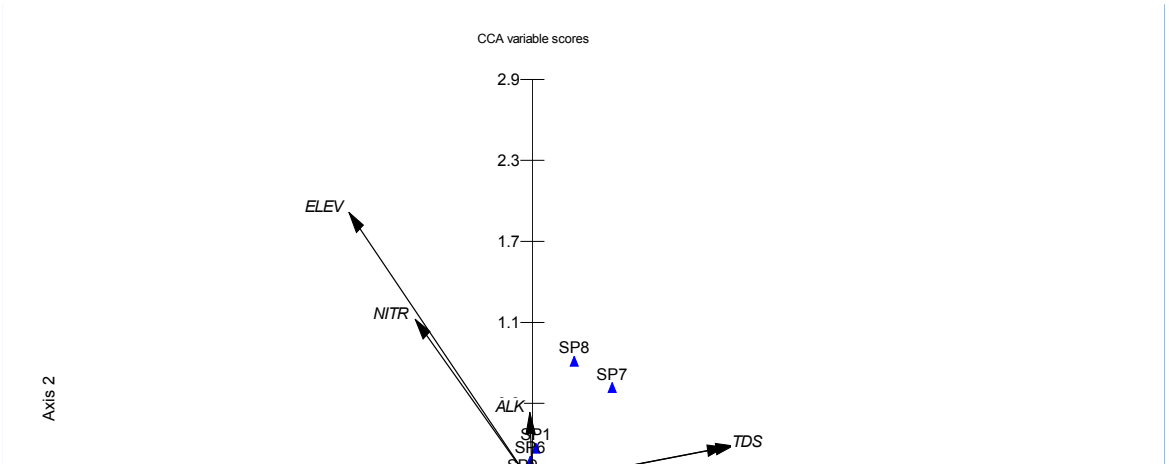
4.4 Influence of Physicochemical Factors on the Distribution of the Freshwater Molluscs

The Canonical Correspondence Analysis (CCA) graph (Figure 4.8) established the relationships of the physicochemical factors and the distribution of freshwater molluscs. The length of the arrows depicts the magnitude of change in that direction and strength of relationship between variables and mollusc species composition of the water bodies. Elevation (of the water bodies), phosphorus, dissolved oxygen, and sulphate showed a large change and strong correlation with the ordination axes and molluscan composition of the water bodies, while alkalinity, chloride and hardness

are weakly correlated with the axes. The relationship within the parameters showed TDS and EC, elevation and nitrate, and temperature and dissolved oxygen were positively correlated with each other (Figure 4.8).

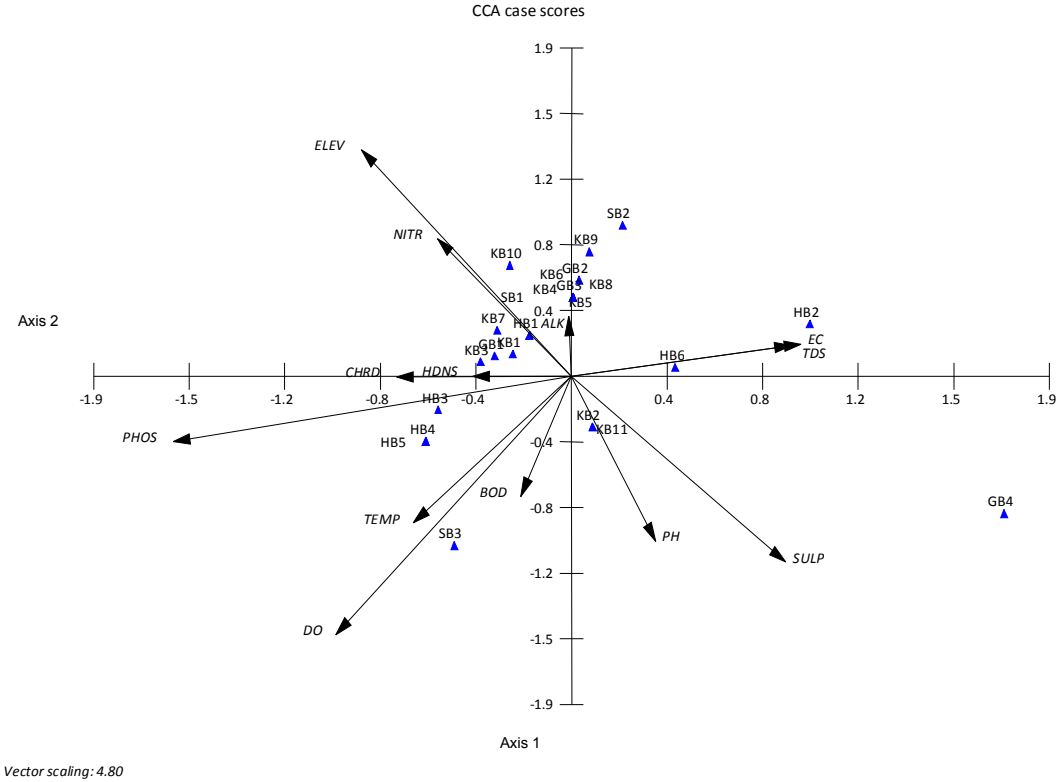
The distribution of *B. unicolor* and *C. bulimoides* was negatively correlated with elevation and nitrate, while *E. elliptica* showed positive correlation to increase in sulphate and pH values. *A. marginata*, *B. crawshayi* and *M. tuberculata* exhibited high relationship with alkalinity and strong positive correlation with elevation and nitrate in the water bodies (Figure 4.8). The distribution of *Aspatheria* sp. is correlated with Kainji Lake and strongly influenced by high amount of dissolved oxygen and showed preference for conditions with higher DO and lower pH. The distribution of *A. implicata* is completely independent of the environmental variables measured.

In establishing the relationship between water bodies and environmental factors, Baga and Alau lakes showed high correlation with increasing TDS and EC that characterized the water bodies (Figure 4.9). 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: SP1- *A. marginata,* SP2 - *A. anatina,* SP3 - *A. implicata,* SP4 – *Aspatheria* sp., SP5 – *E. elliptica,* SP6 – *B. crawshayi,* SP7 – *B.unicolor,* SP8 – *C. bulimoides*, SP9 – *M. tuberculata,* SP10 - *M. maculata,* SP11 – *B. pfeifferi*, SP12 – *B. globosus***,** SP13 – *L. natalensis***,** SP14 – *P. ampullaceae.*

Figure 4.8: CCA Ordination Graph for First and Second Axes for Species and Environmental Factors.



Vector scaling: 4.80

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 4.9: CCA Ordination Graph for First and Second Axes for Water Bodies and Environmental Factors.

4.5 Phytoplankton and Freshwater Molluscs

Fifteen species of phytoplankton were found to be associated with the occurrence of molluscs in the water bodies. These algal taxa belonged to the following four (4) algal divisions: Chlorophyta, Bacillariophyta, Cyanophyta and Euglenophyta (Table 4.5).

Table 4.5: The Main Genera of Phytoplanktons recorded in Water Bodies in northern Nigeria.

Chlorophyta	**Bacillariophyta**	**Cyanophyta**	**Euglenophyta**
Cosmarium	*Synedra*	*Microcystis*	*Euglena*
Scenedesmus	*Frustulia*	*Nodularia*	

Staurastrum	*Denticula*	*Synechosistis*
Closterium	*Cymbella*	*Chlorococcus*
Closteridium	*Tabellaria*	

4.6 Taxonomy of the Terrestrial Molluscs Studied

A total of twelve (12) species of terrestrial molluscs belonging to six (6) families were recorded (Plates XV - XXV). The family Achatinidae occurred throughout the study area. Only one family of slugs (Veronicellidae) was recorded. Five (5) of the six (6) families were represented by single species. The taxonomic lineage of the terrestrial gastropods is represented in Figure 4.8.



Dorsal view





Plate XVI - Leatherback slug Ventral view

Kingdom: Animalia **(**Linnaeus, 1758)

Subkingdom: Bilateria (Hatschek, 1888)

Superphylum: Eutrochozoa

Phylum: Mollusca (Linnaeus, 1758) Cuvier, 1795

Class: Gastropoda (Cuvier, 1795)

Subclass: Orthogastropoda (Ponder & Lindberg, 1996)

Superorder: Heterobranchia (Gray, 1840)

Order: Pulmonata (Blainville, 1814)

Suborder: Systellommatophora (Pilsbry, 1948)

Superfamily: Veronicelloidea (Gray, 1840)

Family: Veronicellidae

Genus: *Veronicella* (de Blainville, 1817)

Species: *Veronicella* sp.



Plate XVII - *Lamellaxis* sp.

Phylum: Mollusca (Linnaeus, 1758) Cuvier, 1795

Class: Gastropoda (Cuvier, 1795)

Order: Eupulmonata

Family: Subulinidae

Genus: *Lamellaxis*

Species: *Lamellaxis* sp.





Plate XVIII - Yellow-shelled semi-slug

Phylum: Mollusca (Linnaeus, 1758) Cuvier, 1795

Class: **Gastropoda** (Cuvier, 1795)

Subclass: Pulmonata (Blainville, 1814)

Order: Stylommatophora

Superfamily: Helicarionoidea

Family: Helicarionidae




Plate XIX - *Macrochlamys* sp.

Phylum: Mollusca (Linnaeus, 1758) Cuvier, 1795

Class: Gastropoda **(**Cuvier, 1795**)**

Order: Stylommatophora

Family: Ariophantidae

Subfamily: Macrochlamydinae

Genus: *Macrochlamys*

Species: *Macrochlamys* sp.



Plate XX - *Rhytida* sp.

Phylum: Mollusca (Linnaeus, 1758) Cuvier, 1795

Class: **Gastropoda (**Cuvier, 1795**)**

Subclass: Pulmonata (Blainville, 1814)

Order: Stylommatophora

Family: Rhytididae (Pilsbry, 1893)

Genus: *Rhytida*

Species: *Rhytida* sp.



Plate XXI - *Achatina achatina*



Plate XXII - *Achatina fulica* (Bowdich, 1822)



Achatina achatina



Achatina achatina



Achatina achatina



Achatina achatina

Phylum: Mollusca (Linnaeus, 1758) Cuvier, 1795

Class: **Gastropoda (**Cuvier, 1795**)**

Subclass: Pulmonata (Blainville, 1814)

Order: Stylommatophora

Family: Achatinidae

Genus: *Achatina*

Species: *Achatina* sp.

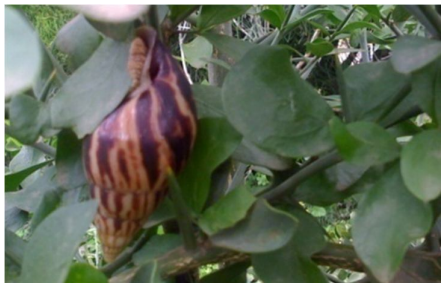



Plate XXIII - *Limicolaria flammea* (Müller, 1774)





Plate XXIV - *Limicolaria turris* (Pfeiffer,1861)



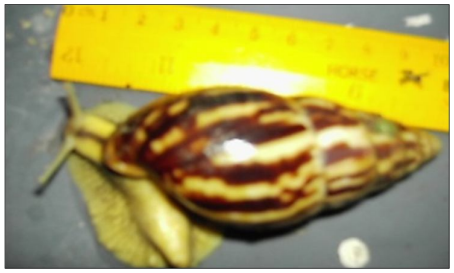


Plate XXV- *Limicolaria kambeul* (Bruguiere, 1792)

Phylum: Mollusca (Linnaeus, 1758) Cuvier, 1795

Class: **Gastropoda (**Cuvier, 1795**)**

Subclass: Pulmonata (Blainville, 1814)

Order: Stylommatophora

Family: Achatinidae

Genus: *Limicolaria*

Species: *Limicolaria* sp.



Plate XXVI - *Archachatina marginata* (Swainson, 1821)



Plate XXVII - *Archachatina marginata suturalis* (Philippi, 1849)

Phylum: Mollusca (Linnaeus, 1758) Cuvier, 1795

Class: **Gastropoda (**Cuvier, 1795**)**

Subclass: Pulmonata (Blainville, 1814)

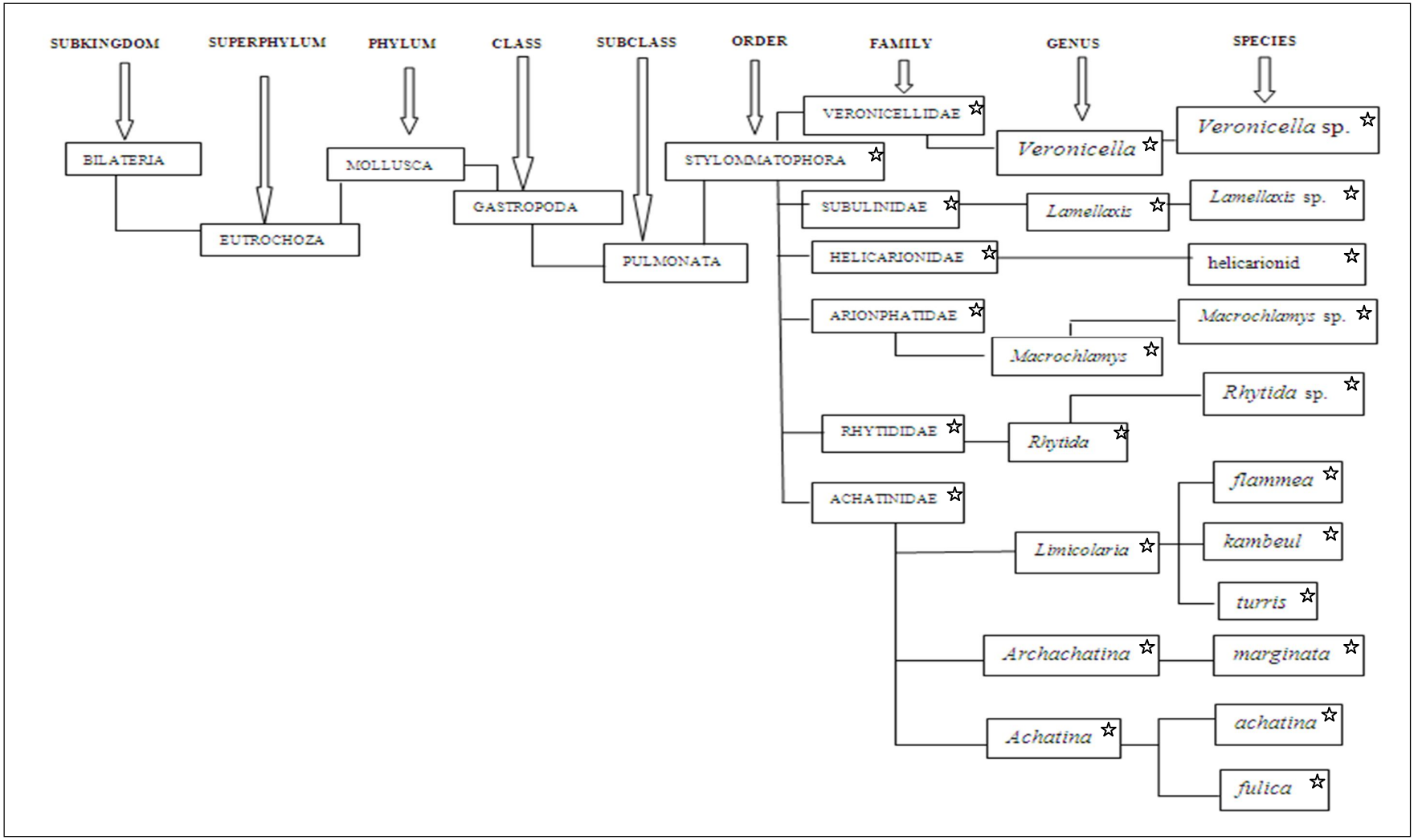
Order: Stylommatophora

Family: Achatinidae

Genus: *Archachatina*

Species: *Archachatina marginata* (Swainson, 1821)

Figure 4.10: Taxonomic Tree of Terrestrial Molluscs in northern Nigeria (☆Modified after Kohl, 2006).


SUBKINGDOM
SUPERPHYLUM
PHYLUM
CLASS
SUBCLASS
ORDER
FAMILY
GENUS
SPECIES
BILATERIA
EUTROCHOZA
MOLLUSCA
GASTROPODA
PULMONATA
STYLOMMATOPHORA
VERONICELLIDAE
Veronicella
Veronicella sp.
SUBULINIDAE
Lamellaxis
Lamellaxis sp.
HELICARIONIDAE
helicarionid
ARIONPHATIDAE
Macrochlamys
Macrochlamys sp.
RHYTIDIDAE
Rhytida
Rhytida sp.
ACHATINIDAE
Limicolaria
flammea
kambeul
turris
Archachatina
marginata
Achatina
achatina
fulica

4.7 Description and Distribution of the Terrestrial Molluscs

4.7.1 *Veronicella* sp. (Plate XVI)

Description: This slug is grayish in colour and has no shell. The head bears two ocular and sensory tentacles. The large mantle covering the entire dorsal part of the slug is smooth. Its underside is white with a longitudinal groove along the length of its sole. The pneumostome is completely absent on the mantle shield.

Distribution: This species appears to be nocturnal. It was encountered only in Barikin Ladi Jos, Plateau State. It was found in pairs close to a lit-building.

4.7.2 *Lamellaxis* sp. (Plate XVII)

Description: Shell is small, conical with a straight lip, a pointed apex and 9-10 whorls. The shell is of two colours: the body whorl is light brown and the spire is dark brown to black. The columella is not truncated.

Distribution: Like most terrestrial snails, *Lamellaxis* is crepuscular in habit, found in sites with high amount of humus; very moist and loose soil in gardens and functional water tanks and reservoirs. Sometimes found a few centimeters beneath the soil surface, a sign of subterranean way of life.

4.7.3 Unidentified helicarionid (Plate XVIII)

Description: The shell is light yellow to brown in colour located dorsally half way (a semi-slug) along the tapering length of the snail. Shell is very lightly calcified and reduced in size. This snail

has a conspicuous longitudinal yellow line (a keel) from the posterior end of shell to its tail end and a thick dark line on its underside (foot).

Distribution: This semi-slug was found only in the Kagoro forest of Kaduna State. This forest is characterized by lush vegetation, with high precipitation and humidity.

4.7.4 *Macrochlamys* sp. (Plate XIX)

Description: Shell is translucent and brownish, smooth with no striation. It is planospiral, thin and depressed with a straight lip and a slightly raised apex. The umbilicus is closed and the whorls are convexly rounded and increasing regularly.

Distribution: It occurred in the southernmost part of Sudan savanna regions and around human habitation. It showed preference for narrow areas between highly humid cement-block walls lined with green mosses, with low sunlight penetration and with little or no human interference.

4.7.5 *Rhytida* sp. (Plate XX)

Description: The shell is mainly uniformly coloured, sometimes yellow to dark honey. Shell is depressed with a straight lip and narrow umbilicus, and without color bands. The number of whorls varies from 5 to 5½.

Distribution: In highly humid and lush green forests of Kagoro forest outcrops of Kaduna State (Figure 4.11).

4.7.6 *Achatina achatina* (Plate XXI)

Description: The shell is dextral usually with 7 to 8 whorls, broadly ovate, with a conspicuously swollen body whorl and truncated columella. The shell is streaked with irregular brown colour and cream blotches. The sutures are not sunken or deep but shallow.

Distribution: Found near present or former human habitation, abandoned building project, decaying logs, along road-side vegetation. It is widely distributed in northern Nigeria.

4.7.7 *Achatina fulica* (Plate XXII)

Description: The shell is dextral, broad and conical in shape, and is pale brown in colour with faint white vertical markings. It has 7 to 9 whorls with a pointed apex.

Distribution: Occurs in areas of high vegetation cover, on shrubs and short trees supported by high rainfall. *Achatina fulica* graze in a group of quite a number of individuals. Commonly found in undisturbed or protected areas in Kaduna, Niger, Nasarawa, Bauchi and Plateau States.

4.7.8 *Limicolaria flammea* (Plate XXIII)

Description: The shell is oblong, conical-broad with 6 to 7 body whorls and a pointed apex. It has dark brown vertical and irregular streaks. The vertical ribs are faint making the shell smooth.

Distribution: This species was the most commonly encountered of the achatine snails in northern Nigeria. It occurs in gardens, open grass fields, refuse dumps, car scraps, cement-walled drainages etc. Several ecotypes also occurred in different terrestrial habitats with variable wet conditions. It occurred in all the northern States visited.

4.7.9 *Limicolaria turris* (Plate XXIV)

Description: The shell is conical-broad in shape with a pointed apex. The vertical brown colour patterns are broad, gradually expanding from the apex and permeate to form a dark brown body whorl with 2-3 vertical white bands. The transverse ribs are conspicuous giving the shell a slightly rough texture.

Distribution: The distribution of this species was more towards the southerly part of the Sudan Savanna, as it showed preference for areas of relatively high rainfall than *L. flammea*. It occurs in gardens and grass fields in association with *L. flammea.*

4.7.10 *Limicolaria kambeul* (Plate XXV)

Description: The shell is bulimoid in shape with a pointed apex. It has an irregular vertical light brown colour pattern on a white to yellow background. The brown streaks are continuous independently to the edge of the body whorl.

Distribution: Though not a common species, its distribution extended from the Sudan to the Sahel Savanna and to parts of the northern region that have very low rainfall. Shells of dead *L. kambeul* were found in arid parts of Baga towards the Lake Chad in Borno State (Figure 4.11).

4.7.11 *Archachatina marginata* (Plate XXVI)

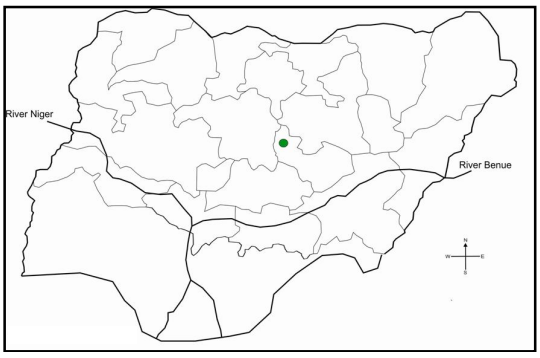
Description: The shell is conspicuously striated, large with a broad body whorl and a blunt apex. The body whorl forms more than 2/3 of the shell. The sutures are deep and not crenulated. The shell colour is variable: fine chestnut brown streaks, dark brown broad vertical bands and sometimes blue-black in appearance.

Distribution: The distribution of this introduced species is restricted as it was found only in protected areas and hedges with little human activities or as possible escapee from nearby snail breeding outfits. It is a rarely encountered snail in northern Nigeria.

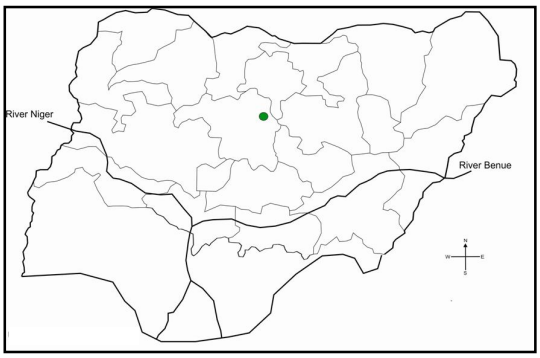
4.7.12 *Archachatina marginata suturalis* (Plate XXVII)

Description: The shell of this subspecies is oblong and usually smaller and less robust than other *Archachatina* snails. The body whorl is narrower than that of *A. marginata* and the columella is reddish in colour in the juveniles encountered. The apex is reddish in the matured snails.

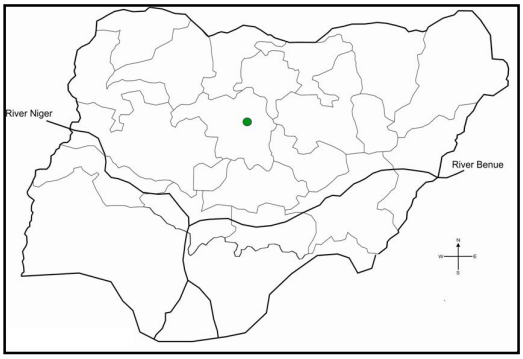
Distribution: As in *Archachatina marginata* above. It was encountered in Kaduna State.



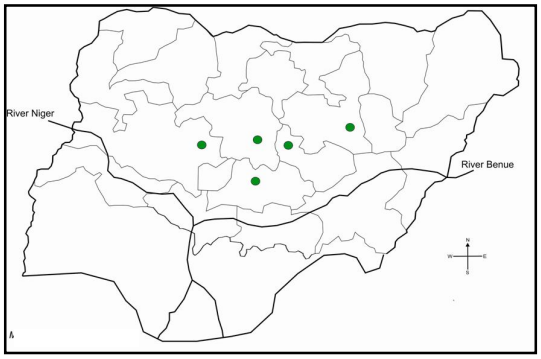
Veronicella sp.



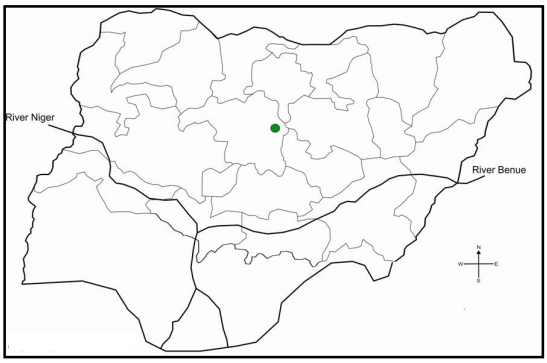
Unidentified Helicarionid



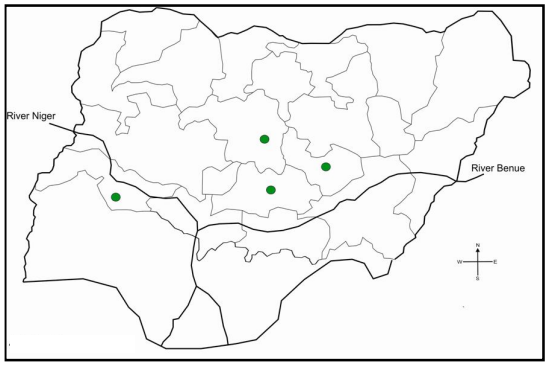
Lamellaxis sp.



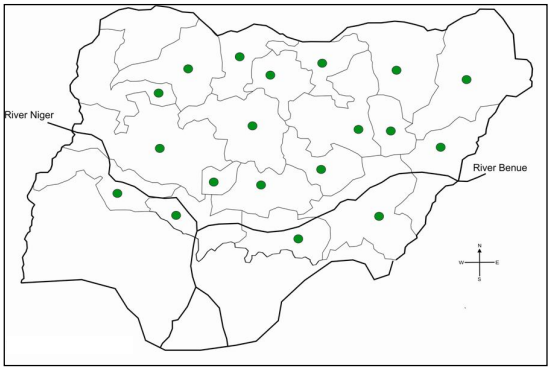
Macrochlamys sp.

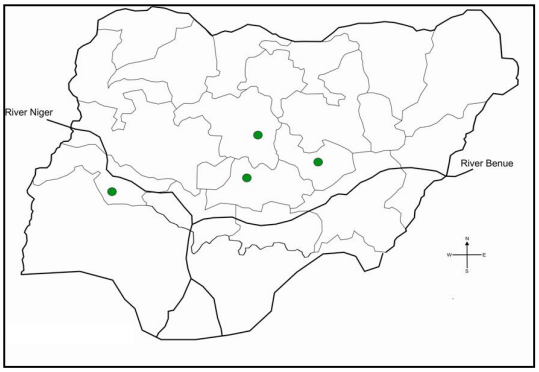


Rhytida sp.



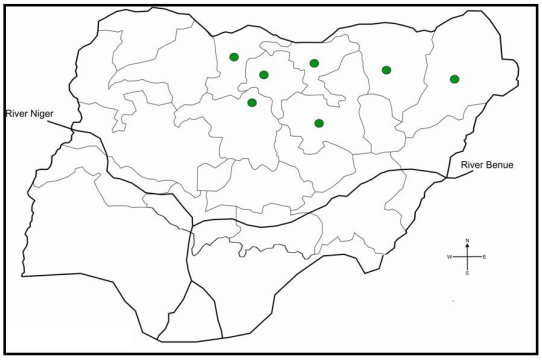
Achatina fulica

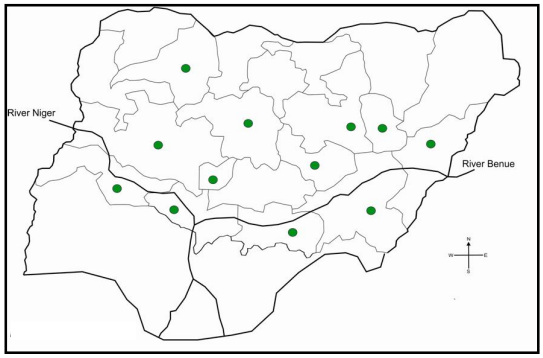




Limicolaria flammea

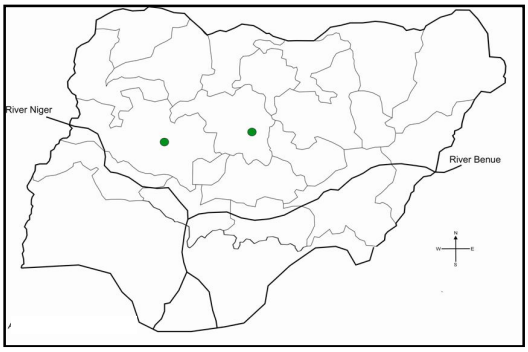
Achatina achatina

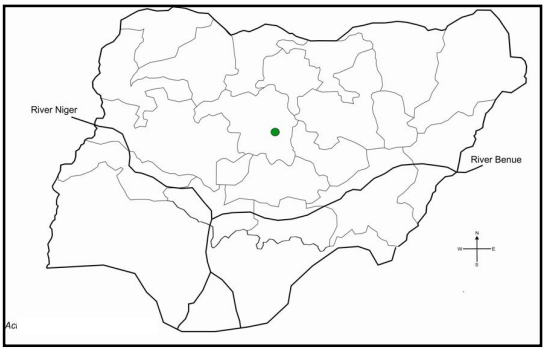




Limicolaria kambeul

Limicolaria turris





Archachatina marginata

Archachatina marginata saturalis

Figure 4.11: Distribution Maps of Freshwater Molluscs in northern Nigeria.

4.8 Diversity of the Terrestrial Molluscs

Ten of the twelve species of terrestrial snails found in the study area were indigenous species. The other two species, *Acharchatina marginata* Swanson and *Acharchatina marginata suturalis*, were presumed to be introduced. With the exception of the achatinidae, the distribution of most of the families of the terrestrial gastropods was restricted to specific habitats (Table 4. 6). The soil texture at the sites of collection of terrestrial molluscs was mostly loamy. The soil calcium content of these sites varied from 1.44 – 2.52 Cmol/kg, with an average value of 1.98 (SD = 0.31) Cmol/kg and pH of 6.69 (SD = 0.39) 0.05 (Table 4.7). Terrestrial snails showed preference for soil calcium level of 1.75 to 2.00 Cmol/kg (Figure 4.12) and pH levels between 6.25 and 6.50 and 7.0 to 7.25 (Figure 4.13). There was a high positive correlation ($P < 0.01$; $r = 0.93$) between soil calcium and pH (Appendix III).

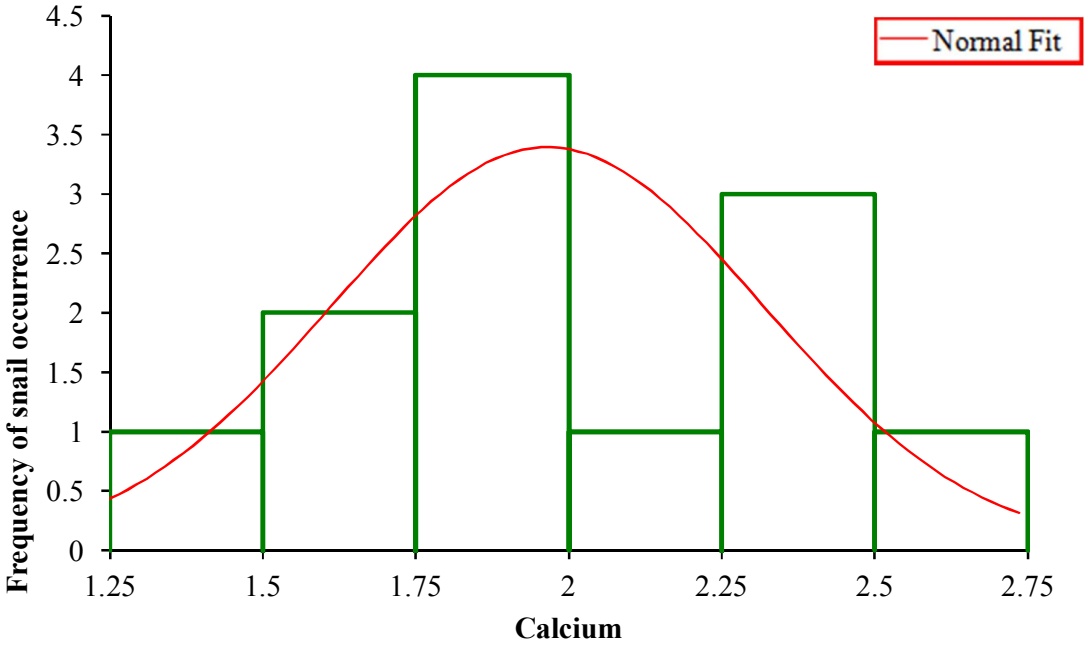


Figure 4.12: Normality Plot and Variation in Soil Calcium of Terrestrial Molluscs in northern Nigeria.

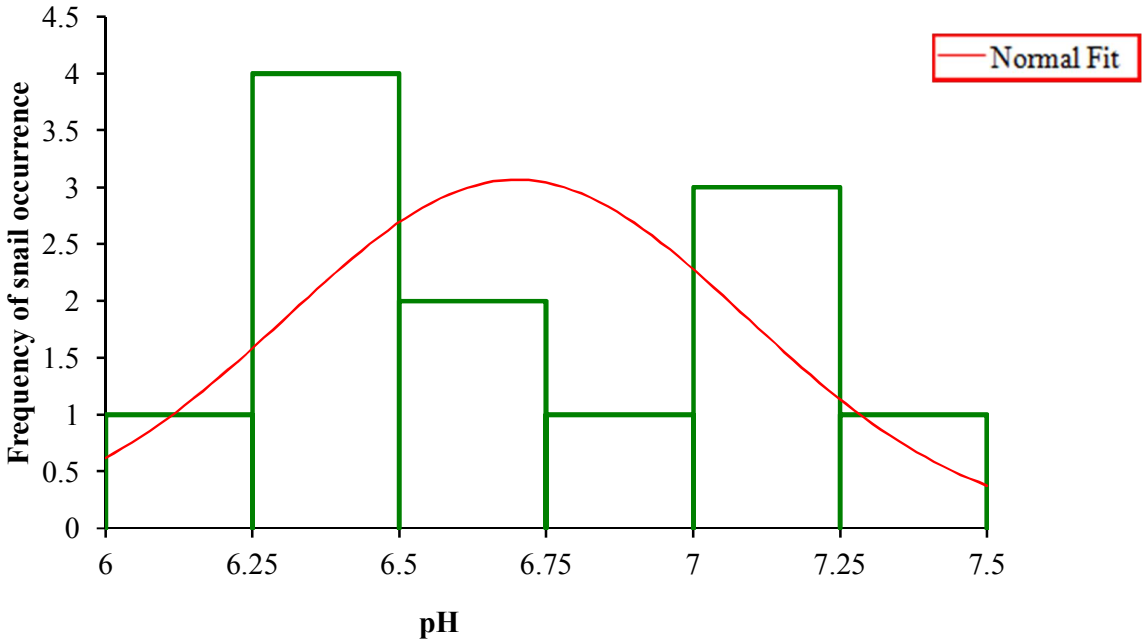


Figure 4.13: Normality Plot and Variation in Soil pH of Terrestrial Molluscs in northern Nigeria.

Table 4.6: Distribution and Abundance of Terrestrial Molluscs.

Family	Species	Abundance	Regional status	Habitat Range/Type
Veronicellidae	*Veronicella* sp.	+	Indigenous	Areas of high humidity and near to well- lit structures.
Subulinidae	*Lamellaxis* sp.	++	Indigenous	Very moist, high humic soil, forested areas.
Helicarionidae	helicarionid	+	Indigenous	Very moist, high humic soil. Forested areas.
Ariophantidae	*Macrochlamys* sp.	+	Indigenous	Areas of high humidity and vegetation.
Rhytididae	*Rhytida* sp.	+	Indigenous	Very moist, high humic soil. Forested areas.
Achatinidae	*Achatina achatina*	+++	Indigenous	Dry to very moist savannas.
Achatinidae	*Achatina fulica*	+	Indigenous	Semi-dry to very moist,

				high humic soil to forested areas.
Achatinidae	*Limicolaria flammea*	+++	Indigenous	Dry to very moist savannas.
Achatinidae	*Limicolaria kambeul*	++	Indigenous	Dry to very moist, high humic soil.
Achatinidae	*Limicolaria turris*	++	Indigenous	Dry to very moist, high humic soil.
Achatinidae	*Archachatina marginata*	+	Introduced	Very moist, high humic soil protected areas.
Achatinidae	*Archachatina marginata suturalis*	+	Introduced	Very moist, high humic soil.

Key: **+ =** Rare; **++** = Uncommon; **+++ =** Common.

Table 4.7: Terrestrial Mollusc Species and Mean Calcium and pH values of Soils in northern Nigeria.

Species	**Mean Soil Calcium** (Cmol/kg)	**Mean Soil pH**
Veronicella sp.	1.53 ± 0.01	6.38 ± 0.12
Lamellaxis sp.	1.56 ± 0.04	6.46 ± 0.07
Unidentified helicarionid	1.44 ± 0.02	6.23 ± 0.15
Macrochlamys sp.	2.32 ± 0.12	7.12 ± 0.26
Rhytida sp.	1.76 ± 0.10	6.36 ± 0.23
Achatina achatina	1.99 ± 0.56	6.75 ± 0.44
Achatina fulica	2.28 ± 0.45	7.15 ± 0.11
Limicolaria flammea	2.34 ± 0.78	7.06 ± 0.22
Limicolaria kambeul	2.52 ± 0.69	7.41 ± 0.34
Limicolaria turris	2.06 ± 0.36	6.56 ± 0.56
Archachatina marginata	1.86 ± 0.19	6.34 ± 0.07
Archachatina marginata suturalis	1.92 ± 0.63	6.57 ± 0.03

CHAPTER FIVE

DISCUSSION

5.1 General Diversity of Freshwater Molluscs of northern Nigeria

The freshwater molluscs in northern Nigeria can be described as being highly diversified. The family Unionidae was represented by three species of one genus *Anodonta,* with *Anodonta marginata* being the most common freshwater mollusc. This species can be said to be widespread (found in a variety of inland aquatic habitats**) and abundant where ever it occurred in the study area. The high diversity and wide distribution of the unionids could be because they are more tolerant in ecological needs than the other mollusc taxa. Other g**enera of the family Unionidae that occur in Africa include; ***Unio*****, *Psilunio*** and ***Caelatura*** **(**Pilsbry and Bequaert, 1927). The bivalves are in some way the most highly modified of all the molluscs. With a few exceptions, all bivalves are sedentary. Some of them remain anchored to the substratum or firmly cemented, as with oysters (Morton, 1968). The unionids can be said to be prone to the effects of pollution because of their sedentary way.

The family **Mutelidae** occurs only in Africa, but is probably related to the South American Mycetopodidae (Banarescu, 1990). In northern Nigeria, it is represented by the genus *Aspatheria*, one of the five genera in the family. The distribution of *Aspatheria* sp. was confined to only one (Kainji Lake) of the twenty five water bodies sampled. The family Etheriidae is represented by a single species, *Etheria elliptica,* in 12.0% (Kainji Lake, Dadin Kowa and Shiroro Reservoirs) of the water bodies studied. This species is reported to be widely distributed throughout the African continent and Madagascar and is unique among African bivalves for its habit of cementing to firm substrate (Graf and Cummings, 2009).

Etheria elliptica was found in freshwater water bodies, demonstrating a preference for fast flowing rivers, lakes, rapids and waterfalls and attaching to hard substrates such as oyster shells or rocky shores (Yonge, 1962). *Etheria elliptica* has been assessed as "Least Concern" as it has a widespread and abundant distribution throughout Africa and Madagascar, with no major threats affecting its global population (Van Damme, 2011). It was widely used by native peoples for food, and as a source of lime by early Belgian settlers (Pilsbry and Bequaert, 1927). **The genus *Bellamya* in the family Viviparidae is widely distributed in waters of northern Nigeria and is represented by *B. crawshayi* and *B. unicolor*.** The species in Africa belong to the subfamily Bellamyinae (Applesnail.net). Burch (1982) listed a total of 17 species for North America, Preston (1915) lists fourteen for India, Yueyin (1979) includes twelve for China, and Zhadin (1952) lists five for the territory of the former USSR. The Viviparidae are remarkable in their wide selection of foodstuffs. Brown (1991) indicated they can function both as grazers, consuming algae growing on any submerged surface, and detritivores, utilising fine particulate organic matter and the bacteria and other microorganisms therein.

The small-banded snail, *Cleopatra bulimoides* in the family Paludomidae, occurred in only a few of the water bodies studied (Alau, Kubani, Jebba and Bakolori Reservoirs). It occurred in small lakes and reservoirs. Tohamy and Shaimaa (2006) reported the habitat of the species to include slow-running freshwater streams. *Cleopatra* serves as an intermediate host for *Prohemistomum vivax* infecting dog, cat and kite and occasionally man, and *Gastrodiscus aegypticus,* as well as several other trematodes in Egypt. (Wykoff, 1965; Aly *et al.,* 2011).

The family Thiaridae is represented by two species of *Melanoides* occurred in small and large water bodies across the hydrological areas. *Melanoides* is a genus of small aquatic herbivorous snails which are very common over most of their native Africa and Asia, and serve as vectors for several diseases (Subda Rao and Mitra, 1982). One of the two species encountered in 14 (60.0%) water bodies in this study, *M. maculata*, is of special interest within the Arabian Gulf

ecosystem because it serves as a transmission vector for several dangerous parasites (Murray, 1971; Russo, 1973; Jacobson, 1975; Dundee and Paine, 1977). This species serves as a host for *Clonorchis sinensis* (Murray, 1964, 1971; Kotrla, 1975), the Chinese liver fluke and *Paragonimus westermani*, the Oriental lung fluke (Murray, 1971; Roessler *et al*., 1977) both of which can infest humans. This species primarily feeds on microalgae (Roessler *et al*. 1977; Subda Rao and Mitra, 1982). Lee (1973) reported *M. maculata* as an agricultural pest in Hong Kong, primarily in Chinese white cabbage plantations. The second species, *M. tuberculata*, is considered an invasive species (Giovanelli *et al*., 2005; Cowie *et al*., 2009). *Melanoides tuberculata* was reported to harbour several species of cercariae and acts as first intermediate host for *Lecithodendrium pyramidum*, which has the adult stage in bats (Aly *et al.*, 2011).

The two species of planorbid snails in this study, *Biomphalaria pfeifferi* and *Bulinus globosus*, occurred in water bodies (Zobe, Tiga, Chalawa Gorge, Kainji, Kubani and Bakolori) with high human activities. The presence of *Bulinus* snails in the water bodies is an indication of potential transmission sites of urinary schistosomiasis, as human activities such as fishing, swimming, washing and quick bath by farmers were observed. Wright (1971) and Rozendaal (1997) reported *Biomphalaria pfeifferi* and *Bulinus globosus* as hosts for *Schistosoma mansoni* and *S. haematobium* in Africa respectively. Species of *Bulinus*, *Biomphalaria, Cleopatra* and *Lymnaea* occurred (Madsen *et al.,* 1988) in relatively large numbers in irrigation schemes in Sudan.

Only one species of the genus *Lymnaea*, (*L. natalensis*) was encountered at Zobe Reservoir and Kainji Lake in this study. Lymnaeidae is a family of small to large aquatic pulmonate gastropod molluscs that belong to the clade Hygrophila within the informal group Basommatophora (ZipcodeZoo.com) that occur in freshwater bodies. The Lymnaeidae have been implicated as intermediate hosts for a great variety of human and animal parasitic flatworms (Chandler and Clark, 1961). *Lymnaea natalensis* is a host for *Fasciola gigantica* in Africa (Wright, 1971), a parasitic flatworm of the class Trematoda, which causes fascioliasis. Tropical fascioliasis is

regarded as one of the most important single platyhelminth infections of ruminants in Asia and Africa.

The distribution of *Pila ampullacea* is restricted as it occurred in four (16.0%) water bodies in this study. Thaewnon-ngiw *et al*. (2003) reported limited distribution in all native apple snails of the genus *Pila* in Thailand except *P. polita,* as described by Brandt (1974) and Keawjam (1986). *Pila ampullaceae* aestivates during the dry season by burying itself deep into the mud and can be found to depts of upto one meter (Applesnail.net). The snails are of medicinal value to both Chinese and Indians (TROPMED Technical Group, 1985). Due to their relatively large size and nutritional value, pilid snails serve as human food in much of their area of distribution and are often preferred to be eaten raw. Pilid snails mediate a serious disease in Southeast Asia, angiostrongyliasis or eosinophilic meningoencephalitis, caused by the rat lung worm, *Angiostrongylus cantonensis* (University of Michigan Website). The golden apple snail, *Pomacea canaliculata* (Lamarck), has become a serious rice pest in most Southeast and East Asian countries, because it damages the young rice seedlings (Halwart, 1994; Naylor, 1996; Yusa and Wada, 1999).

5.2 Distribution and Diversity of Freshwater Molluscs

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 of Prabhakar and Roy (2008). They 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).

Geomorphologic conditions also contribute to the factors that affect the diversity of snail species. The geomorphologic aspects of an isolated freshwater habitat may explain the zoogeography of some species of freshwater molluscs (Kohl, 2006). The elevation of the water bodies' studies 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.

The freshwater molluscs were found in association with different species of phytoplankton, floating algal mats, macrophytes and dense vegetation along shores. The presence of Chlorophyta as the predominant division of algae in a water body is indicative of a relatively "clean" water (Holmes, 1987). The dominance of the phytoplankton by green algae and diatoms, and the sparse presence of cyanophytes jointly reflect desirable water quality characteristics which are indicative of a healthy lentic system (Hart, 2001). Eleutheradis and Lazaridou-Dimitriadou (1995) reported that freshwater snails aggregate on filamentous algae and diatoms clusters. These algae serve as food for aquatic molluscs, as they are known to be active browsers and filter feeders, which feed on algae, zooplanktons and excreta of all aquatic vertebrates (Gopinathan and SobhanaAmma, 2009).

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 high diversity of molluscs observed in all four hydrological areas together could be due to non-homogenous nature of the aquatic habitats of the areas. The bivalve *A. marginata* was the most common species occurring in 91.7% and *B. crawshayi* in 88.0% of the water bodies studied. These wide distributions may be attributed to their tenacity and probably abilities to tolerate shifts in pollution levels of the water bodies.

Sturm (2007) quoted Gloer and Meier-Brook (2003) who reported that Pill clams (bivalves), which are widely distributed in middle Europe, are extremely tolerant of any changes in environmental conditions (ie temperature, pH and $CaCO_3$ content), and, in many cases, are abundant. The narrow range of the bivalve, *Aspatheria* sp., which occurred only in Kainji Lake, could be as a result of the preference of high dissolved oxygen (DO) by the species. Therefore, high DO can be considered a critical environmental factor in the distribution of *Aspatheria* sp.

The mollusc species composition of the water bodies showed good representation of different taxa of molluscs. The Simpson's Diversity Index (D) showed Kainji Lake to have the highest diversity (D = 0.88). This high diversity may be attributed to the relatively large size of the water body. Dillion (2000) reported size of water body among other factors as influential in the distribution and abundance of molluscs. The lowest species diversity (D = 0.44) which was observed in Kaya, Sabonbirni and Kangimi water bodies, may not be unrelated to their relatively small sizes or may be as a result of the drastic seasonal reduction in water levels, almost to dryness, in the dry season. Water bodies with a low Shannon Weiner Index had the least number

of species and directly proportional to high species dominance, and vice versa. Such low number and high dominance could be indicative of the presence of pollution-tolerant species. High values of the Shannon Index (Shannon and Weaver, 1963), as it approaches the value of 1, is an indication of higher diversity of molluscs while lower values of this index are taken as an evidence of pollution.

5.3 Environmental Factors and Freshwater Molluscs

Various detailed qualitative surveys since the 1930s have shown that hardness, pH, altitude, size of water bodies, temperature and pollution were among the significant aspects of the aquatic system that influence the distribution and abundance of molluscs (Dillion, 2000).The average mean values of the twelve (12) physicochemical factors of the water bodies measured are given in Table 4.2. In this study, 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 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 pH value of water is related to a large number of substances and is therefore a good indicator of the quality of the water. Low pH values (<6.0) were reported to be unfavourable for mollusc growth (Dussart, 1976).

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 alkalinity of the water bodies in this study is 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.

The linear regression analysis shows the relationships between physicochemical factors and elevation (Figure 4.1). The positive relationships (simultaneous increase and decrease) between elevation and temperature, alkalinity, chloride and nitrate indicate corresponding variations with 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.

5.4 Influence of Physico-chemical Factors on the Distribution of Freshwater Molluscs

The diversity of freshwater molluscs is vast and their distribution depends on their ability to colonize a habitat and survive there. Survival, in turn, is regulated by various physicochemical factors that ultimately play a major role in determining the ecological traits associated with a particular species (Chatterjee *et al*., 2008). The Canonical Correspondence Analysis shows that phosphate phosphorus, temperature, BOD and DO are important factors influencing the distribution of *Biomphilaria pfeifferi*, *Bulinus globosus* and *Lymnaea natalensi*s (Figure 4.6) in Tiga, Challawa (Kano State) and Zobe (Katsina State) water bodies, while high DO is critical in determining the presence of *Aspatheria* sp. in Kainji Lake. Alkalinity greatly influenced the distribution of *A. marginata, M. tuberculata* and *B. crawshayi* and is a determining factor in many water bodies in the Kaduna Basin.

Elevation and nitrate are important factors in a number of water bodies in this study but did not appear to influnce the presence or absence of molluscs. Investigation by Sturm (2007) noted that the dependence of mollusc distribution upon altitude resulted from changing environmental conditions. Observations by Beran (2002) showed that altitude above sea level influenced the distribution and diversity of freshwater gastropods in the Czech Republic. Similar effects of terrain configuration were observed by Palmer (1999) in the snail fauna of southwest England. EC and TDS were the most important determinants in Alau and Baga Lakes (Borno State) and correlated to the occurrence of *B. unicolor*. This influence could be attributed to the fine sandy nature of the substrata of these lakes.

5.5 Distribution and Diversity of Terrestrial Snails

Of the twelve (12) species recorded, *Archachatina marginata* and a subspecies *A. m. saturalis* are native snails of southern Nigeria that have been introduced to northern Nigeria. With the exception of the family Achatinidae, all the other families were represented by single species. The pattern of distribution of terrestrial snails in northern Nigeria is ubiquitous and restricted in some cases. The Achatinidae are the dominant land snails and inhabit most part of the study area. Pilsbry (1919) considered the natural area of distribution of *Achatina achatina* and *Archachatina* to be West Africa (Achatina from Liberia to Nigeria and Archachatina from Cameroon to Zaire), whose species are distributed in less humid areas (Hodasi, 1984). The *Archachatina marginata* in northern Nigeria are non-native and purposely introduced and rared in farms, protected areas and Botanical Gardens for economic and research reasons. The subspecies *A. m. suturalis* encountered were likely to be escapees from poorly managed snail farms. Moisture availability and lush vegetation could be considered as important factors in their distribution. In this study, the genus *Limicolaria* is the dominant taxon of the family Achatinidae, with three different species namely: *L. flammea, L. kambeul* and *L. turris*, with *L. flammea* being the most common. Passive dispersal agents (such as human activities involving transportation of old tyres, fuelwood, car scraps etc with the snail attached) could be responsible for the high dispersal of *Limicolaria flammea* in the region. *Limicolaria* are commonly found in different terrestrial habitats in West Africa and are regarded as 'tropical' (Crowley and Pain, 1970). Many achatinids are able to secrete a protective epiphragm in order to temporarily close the shell aperture, which for species living in the drier parts of Africa is considered of great survival value (Raut and Barker, 2002). Oke and Alohan (2006) reported the occurrence of species of the families Veronicellidae, Subulinidae and Achatinidae in the tropical rainforest of Okomu National Park in Edo State Nigeria.

The genera *Achatina* and *Limicolaria* can cause extensive damage to agricultural crops and therefore are pests (Crowley and Pain, 1970; Hunter and Runman, 1972; Mead and Palcy, 1992). Achatinidae are also vectors and intermediate hosts to different digeneans (Purchon, 1968; Soulsby, 1982; Marquardt and Demaree, 1985; Sowemimo and Asaolu, 2004; Gadzama and Ogiugo, 2008). *Limicolaria* and *Achatina* were suggested to be possible snail hosts of *Dicrocoelium hospes* in Ghana (Odei, 1966) while Bourgat *et al*. (1975) found larval stages of that trematode from *Limicolaria flammea.*

The Family Subulinidae is represented by *Lamellaxis* sp. Subulinidae is a family of elongate terrestrial pulmonate gastropod snails which is widespread throughout most tropical and warm temperate regions. Wu *et al*. (2007) reported *Lamellaxis gracilis* as abundant snails commonly found under shrubs. Too little is known of the pest potential of the subulinids; they are rarely mentioned in the pest literature (Cowie *et al*., 2009). **Oke and Chokor (2009) reported Subulinidae and Achatinidae among the dominant taxonomic groups in tropical rainforest in south western Nigeria.** *Macrochlamys indica* is believe to represent a potentially serious threat as an invasive pest species which could have negative effects on agriculture, natural ecosystems, human health or commerce (Cowie *et al*., 2009).

The only slug encountered in this study is of the family Veronicellidae. This slug was encountered in habitats with high humidity on the Jos Plateau (Jos metropolis). This veronicellid slug exhibited nocturnal habits and appears to be restricted in its range of distribution. Its nocturnal habit and preference for highly humid areas could be an adaptative feature to avoid the high temperatures during the day and the consequent water loss. This family of herbivorous slugs is widely distributed in tropical regions of South America, Southern Asia, Africa, Madagascar, and Indian Ocean Islands (Herbert and Kilburn, 2004). **Oke and Chokor (2009) also reported a single species of the family Veronicellidae** in the tropical rainforest of Edo State in South-Western Nigeria**.** Slugs within this family Veronicellidae have been found to harbour several

nematode parasites including *Angiostrongylus cantonensis* (rat lungworm), *A. costaricensis*, and *A. malaysiensis*. (USDA-APHIS, 2010). The distribution of the helicarionid snail is highly restricted to humid forests of the Northern Guinea Savanna (Kagoro forest, Kaduna State). The Helicarionidae is a family of air-breathing land snails or semi-slugs, terrestrial pulmonate gastropod molluscs in the order Stylommatophora (ZipcodeZoo.com). The family is widely distributed globally and species are both ground-dwelling and arboreal. The Helicarionidae serve as a good example of how snails could gradually evolve into slugs (Rudman, 2006). Hollingsworth *et al*. (2007) reported the helicarionid, *Parmarion martensi,* as a potential vector for human angiostrongyliasis.

The snail *Rhytida* sp. (Rhytididae) occurred in the same habitat as the helicarionid and was found on wide leaves of lushy herbaceous trees in the humid forest. During the day, this snail remained inactive and characteristically enveloped itself in numerous small white bubbles which may be repellent to potential intruders. The Rhytididae is a family of medium-sized predatory air-breathing land snails, carnivorous terrestrial pulmonate gastropod molluscs (ZipcodeZoo.com).

5.6 Soil Factors and Terrestrial Snails

Two important soil factors, soil calcium and pH, were considered in this study. The soil calcium range (1.44 – 2.52 Cmol/kg) obtained in this study may be considered adequate for growth and shell development of terrestrial molluscs. The high significance between sites where snails were collected showed preference for calcium-rich soils by the snails. Soil chemistry is known to influence the occurrence of terrestrial snails (Kerney, *et al*., 1983). Molluscs are reported to occur in soil with calcium range of 0.8 – 10 g/kg (Kappes *et al*., 2006). Tompa (1980) reported that insoluble salt of calcium carbonate was one of the major steps in colonization of land by various groups of gastropods. Mand *et al.* (2000) reported on the unusual quantity of calcium required by animals such as crustaceans, molluscs and birds at certain stages of their life. Calcium in the diet of terrestrial gastropods is an essential nutrient for growth and reproduction

and construction of the shell (Boycott, 1934; Tompa and Wilbur, 1977). The most important site of calcium deposition in the gastropods is the shell, where it constitutes 97% of the shell weight (Heller and Magaritz, 1983) and it is laid down almost exclusively as calcium carbonate (Ireland and Marigomez, 1992). Calcium is also deposited in the digestive gland, connective tissue cells, foot tissue and around major blood vessels (Tompa and Watabe, 1976; Simkiss and Mason, 1983; Ireland and Marigomez, 1992). Impairment of oviposition and high mortality were reported in achatine snails deprived of calcium (Egonmwan, 2008).

The high positive correlation (r = 0.93) (Appendix III) between soil calcium and pH could be because they jointly influence the occrrence of molluscs. Burch, (1955), Hotopp, (2002), Martin and Sommer, (2004) and Kappes *et al*. (2006) reported soil calcium to be positively correlated to pH and snail abundance. The soil pH range of 6.23 to 7.41 obtained in this study is within the range of 6.7 to 7.8 for terrestrial molluscs as reported by Kappes *et al.* (2006). The pH of soil is reported to affect snail density and diversity (Wareborn, 1992; Gardenfors *et al*., 1995; Martin and Sommer, 2004).

5.7 Conclusions

Most of the attention paid to freshwater molluscs over time has been on their roles as disease mediators. This study has shown that the inland aquatic and terrestrial ecosystems in northern Nigeria support a highly diversified malacofauna **of ecological and probably of public health significance.**

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 widely distributed species namely; *Anodonta marginata, Bellamya crawshayi* and the species of *Melanoides* may be classified as euryoecious species, i.e, having a

wide range of tolerance for environmental factors prevailing in northern Nigeria. *Aspatheria* sp. and *Etheria elliptica* showed high niche specialization and, therefore, were restricted in their distributions. **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.**

Alhough some of the aquatic molluscs exhibited no direct relationship with the physico-chemical factors measured in this study, the ability to withstand wide variation in the factors could be an indication of high adaptability in aquatic molluscs. **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.

Soil pH and calcium are important factors in the distribution of terrestrial molluscs. The patchy presence of some of the molluscs was due mainly to level of precipitation and moisture retention of areas of occurrence. *Limicolaria flammea* is the most common terrestrial snail in northern Nigeria. **Although the distributional range of** *Archachatina* **snails is restricted, t**heir invasive nature could be a threat to the relatively smaller native *Achatina* and *Limicolaria* snails.

The presence of empty shells of freshwater and terrestrial molluscs in the study area is 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 high level of human activities associated with the water bodies greatly influenced their ecology. Thus, habitat loss and humans are probably the most serious threats to the stability of molluscs diversity in northern Nigeria.

5.8 Recommendations

On the basis of the findings of this study, I recommend as follows:

i. Further studies should be carried out in order to understand the basic ecology and ecological preferences of freshwater and terrestrial molluscs in northern Nigeria.

ii. Data bank should be created for repositing information on the ecologic-economic correlates of aquatic and terrestrial molluscs in northern Nigeria.

iii. Due to anticipated environmental changes, there is the need for a conservation assessment of the shell fish potentials of both small and large water bodies in northern Nigeria for implementation of proper conservation initiatives.

iv. The public should be educated on the health, agricultural and ecological roles of molluscs and the economic gains of utilizing mollusc resources.

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Appendix I

Anova Table: Variation of the physico-chemical factors of the hydrological basins.

Source of Variation	SS	df	MS	F	P-value	F crit
Hydrological Basins	4041.489	3	1347.163	2.03469	0.1281	2.891564
Factors	86910.84	11	7900.986	11.93327	<0.0001	2.093254
Error	21849.21	33	662.0974			
Total	112801.5	47				

Appendix II

Anova Tables: Variations in mollusc species in the water bodies studied in the

hydrological basins.

Source of variation	Sum squares	DF	Mean square	F statistic	*p*
Hadejia Basin	0.6	6	0.1	0.67	0.6767
Species	12.3	13	0.9	6.62	<0.0001
Residual	11.1	78	0.1		
Total	24.0	97			

Source of variation	Sum squares	DF	Mean square	F statistic	*p*
Gongola Basin	7.5	3	2.5	8.13	0.0003
Species	13.9	13	1.1	3.46	0.0013
Residual	12.0	39	0.3		
Total	33.4	55			

Source of variation	Sum squares	DF	Mean square	F statistic	*p*
Sokoto Basin	0.6	2	0.3	1.37	0.2722
Species	19.6	13	1.5	7.24	<0.0001

Residual	5.4	26	0.2		
Total	25.6	41			

Source of variation	Sum squares	DF	Mean square	F statistic	p
Kaduna Basin	6.6	10	0.7	1.75	0.0773
Species	33.6	13	2.6	6.85	<0.0001
Residual	49.1	130	0.4		
Total	89.2	153			

Appendix III

Correlation (r) between soil calcium and pH for terrestrial snails.

	Ca	**pH**
Ca	1	
pH	0.927162	1