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The influence of land-use activities on nutrient inputs into upland catchment streams, Ghana

Life is simple. Man complicates it when he doesn’t follow the simple pathways that govern. An honorable intension is the beginning; persistent questioning, the direction; and inner guidance, the key. Then man works with life to create magnificence.

- Adelina Mensah, July 17 2008 -

To my parents, for giving me the opportunity to create

ABSTRACT

In Ghana, increasing agricultural productivity is seen as an essential component of most development programs. The main objective of this study was to assess the implications of increased land-use activities on in-stream nutrients and impacts on the quality of water for domestic use and on aquatic ecosystem health. To guide the evaluation of the land-water interlinkages, the conceptual structure defined by the DPCER (*Driving forces-Pressure-Chemical state-Ecological state-Response*) framework was used, which is an adapted version of the traditional DPSIR (*Driving forces-Pressure-State-Impact-Response*) model. The study compares three small upland sub-catchments in the same geo-morphologic Ofin Basin of the Ahafo-Ano South District. Based on the percentage cover of natural land to agricultural land, the catchments were categorized as low (Nyamebekyere), medium (Dunyankwanta), and high (Attakrom) land-use intensities. With simple mathematical tools and selected indicators, the performance of each link within the DPCER framework was evaluated, and with the comparison of each set of indicators between catchments, changes as a function of land-use intensity were assessed.

Despite overall minimal fertilizer use in Ghana, there were significant differences between the sub-catchments regarding the proportion of farmers who applied fertilizers. Attakrom showed the highest numbers of farmers (20.5%) as compared to Dunyankwanta (12.3%) and Nyamebekyere (0.0%), with applications mainly to cash crops such as cocoa and maize. Simple logistic regression explained that fertilizer use was considerably influenced by the farmer's access to services such as farm loans and agricultural extension services, in addition to property rights and residential status. The Beale's Ratio method, used to calculate the total annual load (kg yr^{-1}) and yield (kg ha^{-1}) for major nutrients (Ca, K, Mg, Na, NO_3-N, NH_4-N, and PO_4-P), showed that the highest nutrient export was from Dunyankwanta at a relative magnitude of up to 3-fold the values of the other two catchments. The annual water yield was highest in Dunyankwanta (79.91 mm yr^{-1}) as compared to Nyamebekyere (41.33 mm yr^{-1}) and Attakrom (22.87 mm yr^{-1}). Total annual water yield was the main determinant of the total nutrient loads/yields, and ranged between 2.3% and 6.2% of the total annual precipitation. 48-hour grab water samples confirmed that in-stream nutrient concentrations increased with increasing land-use intensity, with significant differences between catchments for the major cations (Ca, Mg, K and Na). Median values for all nutrients were in the optimal range of the Ghana Target Water Quality Range (TWQR) for domestic use and for aquatic ecosystem health. The distribution of macroinvertebrate taxa as a function of stream chemistry also showed significant differences in the ecological states of the upland catchment streams.

The DPCER framework with a comparative catchment component was an effective methodology for describing changes as land-use intensifies. Water yield is important in estimating total nutrient export, and the inclusion of a hydrological component in the DPCER framework is proposed - to form a D***H***PCER model (*Driving forces-**Hydrology**-Pressure-Chemical state-Ecological state-Response*). The significant differences observed in each component of the framework strongly suggest anthropogenic influence. With Ghana's objectives for increased agricultural productivity, the results of this study demonstrate the need for incorporating integrated water resource management into development agendas.

KURZFASSUNG

Die Auswirkungen der zunehmenden Landnutzung auf die Nährstoffe in den Flussaufwärtsläufen in Ghana

In Ghana wird eine Steigerung der landwirtschaftlichen Produktivität als notwendiger Bestandteil der meisten Entwicklungsprogramme betrachtet. Das Hauptziel dieser Studie ist die Bewertung der Auswirkungen der zunehmenden Landnutzungsaktivitäten auf die Nährstoffe in den Wasserläufen sowie auf die Qualität des Wassers für den häuslichen Gebrauch und der Wasserökosysteme. Um die Ermittelung der Land-Wasser-Zusammenhänge zu unterstützen, wurde das DPCER-Modell (Driving forces-Pressure-Chemical state-Ecological state-Response) eingesetzt, eine überarbeitete Version des traditionellen DPSIR- Modells (Driving forces-Pressure-State-Impact-Response). Die Studie vergleicht drei kleine Wassereinzugsgebiete im Hochland im gleichen geo-morphologischen Becken im Ahafo-Ano South Distrikt. Auf der Grundlage des Anteils von Land mit natürlicher Vegetationsbedeckung im Vergleich zu landwirtschaftlichen Flächen wurden diese drei Bereiche klassifiziert als Gebiete mit niedriger (Nyamebekyere), mittlerer (Dunyankwanta) bzw. hoher (Attakrom) Landnutzungsintensität. Mit einfachen mathematischen tools und ausgewählten Indikatoren wurde die Leistung jeder Verknüpfung innerhalb des DPCER bewertet und die Veränderungen als Funktion von Landnutzungsintensität durch den Vergleich der einzelnen Indikatorgruppen der Einzugsgebiete bestimmt.

Trotz einem insgesamt geringen Verbrauch von Dünger in Ghana zeigen sich signifikante Unterschiede zwischen den drei Gebieten in Bezug auf den Anteil der Farmer, die Dünger benutzten. In Attakrom war die Anzahl der Farmer am höchsten (20.5%) verglichen mit Dunyankwanta (12.3%) und Nyamebekyere (0.0%), wobei der Dünger hauptsächlich beim Anbau von Cash Crops wie Kakao und Mais eingesetzt wurde. Die einfache logistische Regression deutet daraufhin, dass der Gebrauch von Dünger stark durch den Zugang der Farmer zu, z.B., Krediten und landwirtschaftlicher Beratung beeinflusst wird sowie durch Landbesitzrechte und Wohnstatus. Die Beale's Ratio-Methode, die für die Berechnung der jährlichen Gesamtmenge (kg $Jahr^{-1}$) und Menge per Hektar (kg ha^{-1}) der wichtigsten Nährstoffe (Ca, K, Mg, Na, NO_3-N, NH_4-N, and PO_4-P) eingesetzt wurde, zeigt den höchsten Nährstoffexport aus Dunyankwanta mit einem relativen Wert von bis zu dreimal der Werte der anderen beiden Gebiete. Der jährliche Wasservolumen per Hektar war am höchsten in Dunyankwanta (79.91 mm Jahr-1) verglichen mit Nyamebekyere (41.33 mm Jahr-1) und Attakrom (22.87 mm Jahr-1). Dieser Wert war der Hauptfaktor bei der Bestimmung der Gesamtnährstoffe und lag zwischen 2.3% und 6.2% des jährlichen Niederschlags. Die Ergebnisse der 48-stündlichen Wasserproben (grab sampler) bestätigen, dass die Nährstoffkonzentrationen in den Wasserläufen mit der Landnutzungsintensität steigen mit signifikanten Unterschieden zwischen den Einzugsgebieten bei den wichtigsten Kationen (Ca, Mg, K und Na). Die mittleren Werte für alle Nährstoffe waren im optimalen Bereich der Ghana Target Water Quality Range (TWQR - Qualitätsgrenzwerte) für Haushaltswasser und Wasserökosysteme. Die Verteilung der Taxa der Makrowirbellosen, die von den chemischen Zusammensetzungen der Flüsse beeinflusst ist, zeigte signifikante Unterschiede im ökologischen Zustand der Einzugsgebiete im Hochland.

Das DPCER Modell mit einer Komponente zum Vergleich der Einzugsgebiete ist eine effektive Methode zur Beschreibung der Veränderungen als Folge von zunehmender Landnutzungsintensität. Der Wasservolumen per Hektar ist wichtig bei der Ermittlung des gesamten Nährstoffexports; die Einbeziehung einer hydrologischen Komponente im DPCER zur Bildung eines DHPCER Modells (Driving forces-Hydrology-Pressure-Chemical state-Ecological state-Response) wird vorgeschlagen. Die beobachteten signifikanten Unterschiede deuten stark auf menschlichen Einfluss hin. Ghana hat eine Steigerung der landwirtschaftlichen Produktivität zum Ziel und die Ergebnisse dieser Studie zeigen, dass es notwendig ist, integriertes Wassermanagement bei Entwicklungsprogrammen hierbei zu berücksichtigen.

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ACRONYMS

CSIR	Council for Scientific and Industrial Research
CWSA	Community Water and Sanitation Agency
DO	Dissolved Oxygen
DPCER	Driving forces-Pressure-Chemical state-Ecological state-Response
DPSIR	Driving forces-Pressure-State-Impact-Response
DSR	Driving Force-State-Response
EC	European Commission
EEA	European Union Agency
EPA	Environmental Protection Agency
EPT	Enteromorpha Plecoptera Trichoptera
ET_0	Potential Evapotranspiration
ET_a	Actual Evapotranspiration
ETO	Enteromorpha Trichoptera Odonata
EU	European Union
FAO	Food and Agriculture Organisation
FPC	Flood Pulse Concept
GPRS	Ghana Poverty Reduction Strategy
GVP	GLOWA-Volta Project
IDA	Irrigation Development Authority
MA	Millennium Assessment framework
MCA	Millennium Challenge Account
OECD	Organization for Economic Co-operation and Development
PCA	Principal Component Analysis
PRIMER	Plymouth Routines in Multivariate Ecological Research
PSR	Pressure-State-Response
PURC	Public Utilities Regulatory Commission
RCC	River Continuum Concept
SEA	Strategic Environmental Assessment
TWQR	Target Water Quality Range
UNCSD	United Nations Commission for Sustainable Development
UNEP	United Nations Environment Programme
UNSD	United Nations Statistics Division
WFD	Water Framework Directive
WRC	Water Resources Commission
WRI	Water Resources Institute

1 INTRODUCTION

A critical environmental resource that forms the basis of ecosystem functioning and human well-being is the availability and quality of freshwater (MA 2005a; UNEP 2006a). With global population growth and related increasing land-use activities, the integrity of aquatic ecosystems has become compromised by point and non-point sources of pollution. The latter is comparatively more difficult to quantify and control, as input and its impacts are usually the combined effects of the type of land-use and the biophysical processes that influence transport and in-stream dynamics of the pollutants. In many developed countries, the interactions between human and biophysical factors have been incorporated into integrated management policies to improve the sustainable use of water. Scientific evaluations to assess, monitor, and advise policy makers are guided by conceptual frameworks, e.g., the well known Pressure-State-Response (PSR) structure developed by the Organization for Economic Co-operation and Development (OECD) (OECD 1998), which eventually evolved into the Driving forces-Pressure-State-Impact-Response (DPSIR) framework currently used by the European Union (EC 2003). These frameworks consist of sets of indicators that represent major elements in the interlinkages of driving forces of land-use, the ecological state of the aquatic system, and policy responses.

With escalating global fuel and food prices, Ghana is reinforcing development strategies for increasing agricultural productivity, especially for rural smallholder farmers (GNA, May 2008). The environmental implications of agricultural activities to freshwater systems are currently not assessed, as water quality monitoring programs have been limited to routine physico-chemical assessments and minimal integrated evaluations of terrestrial sources of contribution. With downstream users depending directly on rivers for their domestic water supply and the environmental/social implications of increased nutrients to vulnerable freshwater/coastal/marine ecosystems, there is the need for an integrated research approach to evaluate these interactions across the human-environment spectrum. The overall objective of this study is, therefore, to adapt the well-known DPSIR conceptual framework to evaluate the interlinkages in small catchments in Ghana, between land-use intensification and impacts on water quality for domestic use and on aquatic ecosystem health.

1.1 Land-use and impacts to the aquatic ecosystem

According to the Human Development Report 2006 (UNDP 2006), water gives life to everything and is essential to human development and freedom, and therefore crucial in providing human security and attaining the Millennium Development Goals (MDGs). Conversely, increased agriculture is a main negative influence on freshwater quality and quantity (UNEP 2006b). Food security (i.e., availability, affordability, access) has been identified as the key solution to poverty alleviation and economic development in sub-Saharan Africa (General Assembly Resolution 55/2 2000; MA 2005a; World Development Report 2008). In attempts to address this, considerable effort has been devoted to strategies for increasing agricultural production in smallholder farming (i.e., access to loans, improved seed quality, access to agro-chemicals and technical advice), as the local communities of the rural poor are highly dependent on subsistence farming (World Bank 2008a). In Ghana, this effort promises a strong potential for poverty reduction, as agriculture accounts for 60% of employment and 37.2% (in 2006) of the GDP (CIA 2008; World Bank 2008b). Various national programmes such as the revised Ghana Poverty Reduction Strategy (GPRS II), the Food and Agriculture Sector Development Plan, and internationally supported grants such as the $500 million US-supported Millennium Challenge Account (MCA) have been launched to ensure increased agricultural production and productivity of high value cash and food crops in Ghana. More recently (effective from July 4, 2008), this has included the subsidization of fertilizers, with prices reduced by 40-50% for poor small holder farmers.

The land-use and land-cover changes (LUCC) that accompany the conversion of natural lands to agricultural production reduce vegetative cover and deteriorate soil properties, thus invariably altering hydrological patterns and increasing the potential for runoff and erosion (DeFries and Eshleman 2004). The increased application of fertilizers and pesticides to improve productivity per unit area, in addition to inputs from livestock manure, accumulates nutrient content in soils. Depending on the physical location, chemical speciation, fate and environmental availability of the agrochemicals in the soil, they are transported via surface runoff and other hydrological routes and contribute to pollution of surface water bodies. With significant nutrient enrichment in the streams during rainfall, the more sensitive taxa within the aquatic community structure are affected such that the natural balance in community dynamics and ecosystem functioning is modified to affect productivity and biodiversity (Rabalais 2002). Services provided by the freshwater ecosystem such as water for human consumption, nutrient cycling and retention, water filtering, water storage and aquifer recharge, shoreline protection and erosion control, and a range of food and material products (fish, shellfish, timber and fiber), are therefore affected (MA 2005a). The cumulative impacts downstream affect the very productive but fragile coastal wetlands and marine systems and result in reduced biodiversity, reduced numbers in economically valuable species, algal blooms, increased sedimentation, and reduced ecosystem health (Anderson et al. 2002; Seitzinger and Harrison 2005). Significant amounts of fertilizer have been released into the environment in the past century, impacting freshwater systems, estuaries and semi-enclosed and enclosed seas (IMBER 2005). Projected increases over the next three decades has suggested a 10-20% global increase in river nitrogen flows to coastal ecosystems, continuing the trend of an increase of 29% between 1970 and 1995 (MA 2005a).

In addition to environmental factors, e.g., climate, soil, and hydrogeology, that affect the transport of nutrients into the aquatic systems, there are also cultural and socioeconomic influences which explain how and why farmers relate to the soil (e.g., intensity and patterns of cropping and tillage). In sub-Saharan Africa, land tenure arrangements which are not well established and the practice of shifting cultivation can influence a farmer's indifference to loss of future economic returns to the land, since they are not directly affected by the declining land productivity associated with nutrient mining (Henao and Baanante 2006). Farmers under pressure to engage in the market may abandon more environmentally friendly practices to produce improved crops (UNEP 2006b). The Millennium Assessment framework (MA 2005b) illustrates how the changes in drivers that indirectly affect biodiversity (such as population, market, governance, technology, lifestyle, etc.) can lead to changes that directly affect biodiversity (e.g., change in land use, species introduction, technology adaptations, harvest and resource consumption), which result in changes to ecosystem services that eventually influence human wellbeing.

Although sub-Saharan Africa is reported to use less than 10% of the world's average in fertilizers, i.e., 8 kg ha^{-1} compared to 100 kg ha^{-1} worldwide (Henao and Baanante 2006; Kelly 2006; UNEP 2006b), higher food productivity is being advocated for by increasing agro-chemical use. Increasing disposable income, in addition to growing commercialization and the focus of development agencies on improving yields of small farmers, is likely to increase the demand for chemical products (UNEP 2006b). Concerns about the severity of soil degradation and soil nutrient depletion for African grasslands suggests the need for careful management in strategies for optimizing productivity (Bationo et al. 1998; Drechsel et al. 2001; Vlek 2005). With the potential range of negative environmental impacts on soil and water quality, exacerbated by inappropriate fertilization and irrigation practices, improving the resource base, i.e., soil, in order to increase productivity in a way which conserves the natural resource and prevents further degradation is a serious challenge. Trends already show an increase in the concentration of nitrates and phosphates at river mouths in Africa, mirroring trends observed in southeast Asia (UNEP 2002).

1.2 Conceptual framework and research objectives

The conceptual framework for this research, i.e., the organizational structure with sets of indicators that represent the various elements that interact with each other, places the environment as its central focus, although acknowledging the equal importance of societal wellbeing. The Driving forces-Pressure-State-Impact-Response (DPSIR) concept, developed for environmental reporting purposes by the European Commission (EC 2000, 2003), provides a general framework for organizing information about an environmental issue by formalizing the relationship between various sectors of human activity and the environment. An environmental indicator developed under the DPSIR model can be categorized as a driving force, pressure, state, impact or response indicator, according to the type of information it provides. Together, these indicators demonstrate how people's activities and environmental effects are interconnected, and the effectiveness of policy and management responses to environmental issues. The framework elaborates the cause-effect relationships between interacting components of complex social, economic and environmental systems and has been widely applied internationally.

For this study, the conceptual definitions for each link within the framework is based on adaptations provided by the Driving forces-Pressure-Chemical state-Ecological state-Response (DPCER) method (Rekolainen et al. 2003). According to the authors, the change from 'state' (S) and 'impact' (I) to 'chemical state' (C) and 'ecological impact' (E) was justified by the fact that surface water status has been defined by chemical quality elements and ecological quality indicators by the European Union Water Framework Directives (WFD).

The DPCER framework assumes that there is a dynamic interaction between land-use activities and aquatic ecosystem functions. In the absence of established risks and obvious policies that have been taken to improve the chemical or ecological status of the studied streams, the response component (R) is not assessed. The adaptation of the DPCER model, therefore, is unidirectional for this study, i.e., begins with assessing the driving forces in agricultural activities that lead to an observed ecological state. At each level in the framework, the following specific parameters are defined;

- Driving forces of change are underlying factors that influence the intensity of land-use (in this case, agriculture) in each of the catchments. In this study, agrochemical use, for example, can also be influenced by socio-economic parameters such as education or access to market.
- Pressure is represented by the measurement of the variables which directly lead to environmental problems. For this study, this is assessed by quantitative estimates of nutrient loads, measured in kg yr^{-1}, and nutrient yields (kg ha^{-1}) into streams.
- Chemical state is described by indicators which reveal the condition of the environment, i.e., the stream physico-chemistry and nutrient ion concentration is affected by nutrient loads and greatly influences biological and ecological functioning of the system.
- Ecological state is assessed by indicators that represent the ecological effects of the changes in the chemical state. For this study, community dynamics of macroinvertebrates are assessed.

There are simple to complex models available to calculate, simulate and account for various elements within the DPCER framework and their interactions, depending on the needs of the research (Rekolainen et al. 2003). However, due to the unavailability of data on hydrological and biophysical processes linking the terrestrial and aquatic habitats for the studied catchments, the relatively short research period as compared to required timelines for effective modeling, and the logistical limitations of detailed assessments of these processes based on the scope of this research, each of the elements within the framework are evaluated by simple indicators. The choice of indicators for each link and the mathematical tools for assessment are discussed, including the uncertainties inherent in the individual fields and assumptions about cause-effects in each sub-set of the linkages.

The study was carried out in three small inland valley catchments (approximately 5 km^2 each): (i) Nyamebekyere, a natural forested reserve, (ii) Dunyankwanta, a moderately cultivated catchment area, and (iii) Attakrom, an intensively cultivated area, based on classification by the VINVAL project (Meijerink et al. 2003). These catchments are located in the same agro-ecological basin and share similar geo-morphological characteristics except for their degree of land-use intensity, an attribute that is assumed to minimize the natural environmental variations that may occur. This scenario establishes major factors (based on literature review) that influence agricultural activities as the main Driving forces (D) and contribute to the input of nutrients in the streams, represented by Pressure (P) in the framework. Due to the similarities of the catchments, and lack of information on the hydrological pathways of nutrients from these soils to the streams, it is assumed that the estimates of total nutrient loads (P) in the catchment streams are representative of the dilutions of terrestrial nutrients, via surface runoff, into the streams. The catchment streams are all upland, ephemeral, and flow only during the rainy season, and in-stream observations are assumed to be influenced predominantly by land-use intensity and nutrient loads. With consideration to the financial budget of the research, analyzed nutrients within the streams (Chemical state, C) were specifically limited to compounds linked to fertilizer application (nitrogen compounds and orthophosphates) and soil quality (major cations calcium, magnesium, potassium and sodium). Given the high diversity of aquatic fauna, macroinvertebrates have been the most widely researched as indicators of aquatic ecosystem health, and there is a large database on general characteristics, albeit mostly for temperate taxa. However, with the general standards established for representative taxa, this research assesses the dynamics of the macroinvertebrate community structure to reflect the state of the aquatic system (Ecological state, E).

1.2.1 Research structure

Based on the conceptual framework described above, specific parameters were measured in order to quantify each of the major components. As there are no standard indicator sets for specific environmental issues, the selection of indicators was based on the clearly outlined DPCER framework, with each indicator having a particular function in the analytical problem solving the logic of the issue (Niemeijer and de Groot 2008a). A diagrammatic representation of the indicators used for each link within the DPCER conceptual framework is shown in Figure 1.1. For each element of the framework, the indicator, method and specific objectives are presented below.

Overall, the research initially assesses specific measures within each of the component disciplines involved within the framework, compares them to assess whether there are *relevant* differences in the nutrient load/chemistry/ecology of streams in upland catchments of varying degrees of land-use, and finally discusses possible factors that may contribute to these differences.

DPCER framework

<u>Driving forces</u>	Land-use intensity (agriculture)
Indicator	Household characteristics and wealth, farming methods, land-use, water use
Methods	Structured questionnaire

- Describe socio-economic factors associated with land-use and agricultural activities within each catchment at household level
- Statistically determine the significant differences between catchments.

<u>Pressure</u>	Total nutrient load/yield in each catchment stream
Indicator	Nutrient loads/yields of Ca, K, Mg, Na, NH_4-N, NO_3-N and PO_4-P
Methods	Hydrology, nutrient ion concentration and stream flow data

- Establish basic hydrology for each upland catchment stream.
- Estimate total load (kg yr^{-1}) and yield (kg ha^{-1}) of nutrients transported out of each of the upland catchment streams in defined periods (monthly, seasonally, and annually).
- Compare nutrient yields between the catchments.

<u>Chemical state</u> Temporal dynamics in stream physico-chemistry

Indicator Dissolved oxygen, electro-conductivity, pH and temperature. Concentrations of Ca, K, Mg, Na, NH_4-N, NO_3-N and PO_4-P

Methods Hydrology, physico-chemistry, nutrient ion concentration

- Establish temporal patterns in flow-weighted concentrations (mg L^{-1}) of ionic components of the stream.
- Compare stream physico-chemistry and nutrient ion concentrations to Ghana's Target Water Quality Ranges (TWQRs) established for domestic use and aquatic ecosystem health for freshwater
- Assess relevant differences in concentrations between the catchments.

<u>Ecological state</u> Distribution of biotic communities in response to abiotic parameters

Indicator Community structure of macroinvertebrates

Methods Periodic sampling of macroinvertebrates

- Assess the degree of site similarity or differences based on biotic composition and the distribution of abiotic variables for the upland catchments.
- Link the patterns of observed taxa distribution to the differences in abiotic parameters, and identify the specific abiotic variables that may be significant.
- Describe the macroinvertebrate community patterns and occurrences within and between similarly grouped sites and examine the inter-relationship and contribution of the observed taxa.

To conclude, the DPCER synthesis discusses significant factors in the application of the conceptual framework, in order to evaluate interlinkages between land-use, nutrient concentration and macroinvertebrate distribution in small upland catchments in Ghana.

This study contributes to the existing agro-economical information base created by the VINVAL project. The 5-year project funded by the EU (2000-2005) compared the same three catchments (in addition to a similar setup in Burkina Faso) to examine how various degrees of land-use influence agricultural productivity and impact terrestrial ecological functions. The effects of the observed changes in land-use/agricultural management and ecological functions were to be used to develop tools for integrated land-use planning on the catchment level (yet unpublished). These tools are mainly TechnoGIN, a technical coefficient generator, OSARIS, a GIS-based knowledge system, and VINVAL Land Use Viewer, a community mapping method and sociological tool for supporting participatory land-use planning (Verzandvoort et al. 2005). The analysis of the impact of different land-use development scenarios on the ecological and production functions are to be supported by these tools in village participatory land use planning workshops, where the decision-making process of land development is carried out.

The research also contributes to the Analysis of Long-Term Environmental Change component of the overall objectives of the Global Change in Hydrological Cycle (GLOWA) Volta Project (GVP) that this study forms part of. The GVP assesses sustainable water use under changing land-use patterns, rainfall reliability and water demand in the Volta Basin by analyzing the physical and socio-economic determinants of the basin's hydrological cycle. The Volta Lake is the largest man-made lake (45% of Ghana's total surface area) created to generate hydropower, and has been the focus of large-scale research on the socio-economic implications of ecosystem changes.

1.2.2 Research question and main objectives

The main research question of this study is "What is the influence of increasing land-use activity on nutrient inputs into small upland catchment streams in Ghana?" The DPCER framework provides a conceptual guideline to evaluate each of the contributory components that describe the cause-effect interlinkage from land to stream. The general objective of the study is to assess the extent of increasing land-use activity (mainly agriculture) on in-stream nutrient inputs, and the impacts on water quality for domestic use and on aquatic ecosystem health for upland catchments. Specifically, the objectives are to:

- Describe the major socio-economic factors, or driving forces (D), that contribute significantly to land-use intensity and the farming systems observed in the three upland catchments.

- Estimate the total in-stream nutrient loads and yields, which represent the land-use pressure (P) that directly impacts the stream ecosystem.
- Evaluate the specific physico-chemical parameters and nutrient ion concentrations (Ca, K, Mg, Na, NH_4-N, NO_3-N, and PO_4-P) that describe the chemical state (C) of each stream, and assess the differences between catchments.
- Examine macroinvertebrate taxa distribution as a function of the chemical state of each catchment stream, in order to establish the ecological state (E).
- Explain the interlinkages between different components of the conceptual model as land-use intensity increases, and assess the efficacy of the DPCER framework in illustrating these changes.

1.3 Justification of the study

The fundamental concepts in the cause-effect chain described by the DPSIR framework (EEA 1999; EC 2003) have been used effectively for a variety of environmental systems to assess the interaction between drivers of land-use and the environmental consequences in order to propose and monitor appropriate policies. In Ghana, there is a lack of integrated research on agricultural activities and its impacts on freshwater systems. Related issues have been mainly disciplinary, since establishing patterns of the interacting elements between the different study fields requires extensive data to incorporate processes such as nutrient export, hydrology, transport and fate of nutrients, toxicology of aquatic biota, etc. To circumvent these limitations, this study proposes and tests an adapted version of the traditional DPSIR framework, using the DPCER conceptual definitions, and includes a comparative catchment component. With the framework as a guideline, selected indicators representing links in the land-water interaction are assessed for three small catchments in the same geo-morphologic basin with varying degrees of land-use intensity, i.e., from natural or low intensity to mainly agricultural or high land-use intensity. As the catchments are located in the same basin, the comparative approach assumes that the influence of climatic and biophysical factors on nutrient export and aquatic ecosystem dynamics are similar. The small upland catchments provide an ideal platform for investigating agricultural impacts on nutrient export, as the response time of the streams is shorter than for larger systems. In addition, social assessments on a smaller scale contribute more information on the internal household factors that influence agricultural activities in Ghana. The framework enables the assessment of how specific indicators perform in each catchment, and compares the behavior between catchments to evaluate interlinkages as a function of land-use intensity.

1.4 Structural overview

The thesis is divided into eight chapters. Chapter 1 introduces the research objectives and the need for integrated research to evaluate the interlinkages between development objectives of society, land-use and aquatic ecosystem health. The research structure is presented based on the traditional DPSIR conceptual framework. Chapter 2 presents the theoretical background of the interdisciplinary focus of research in land-use and the aquatic ecosystem with references to fundamental theories and assessment methodologies in the various disciplines covered in the study, i.e., agriculture, hydrology, nutrient loading, physico-chemistry, and macroinvertebrates as bioindicators. Chapter 3 describes the study area in Ghana and presents a more detailed account of the sampled sites and associated catchment areas. Chapter 4 presents the results and discussion of administered questionnaires on community characteristics and farming practices, with focus on influencing socio-economic parameters on the households in the catchments, as well as their farming/cropping systems and water resource use. Chapter 5 describes the field, laboratory and statistical methods used to determine water yield, assess physico-chemical dynamics and estimate nutrient load/yield, with the results discussed. Chapter 6 presents a description of the investigations undertaken for sampling of macroinvertebrate communities, with results and discussions of the linkages between the observed community patterns and stream physico-chemistry/nutrient ion concentrations. Chapter 7 addresses the over-arching issue of the study and discusses the interlinkages between the three different disciplines covered independently in Chapters 4, 5 and 6, in addition to the challenges of integrated research. Chapter 8 summarizes key points and new observations of the research, with recommendations for significant issues.

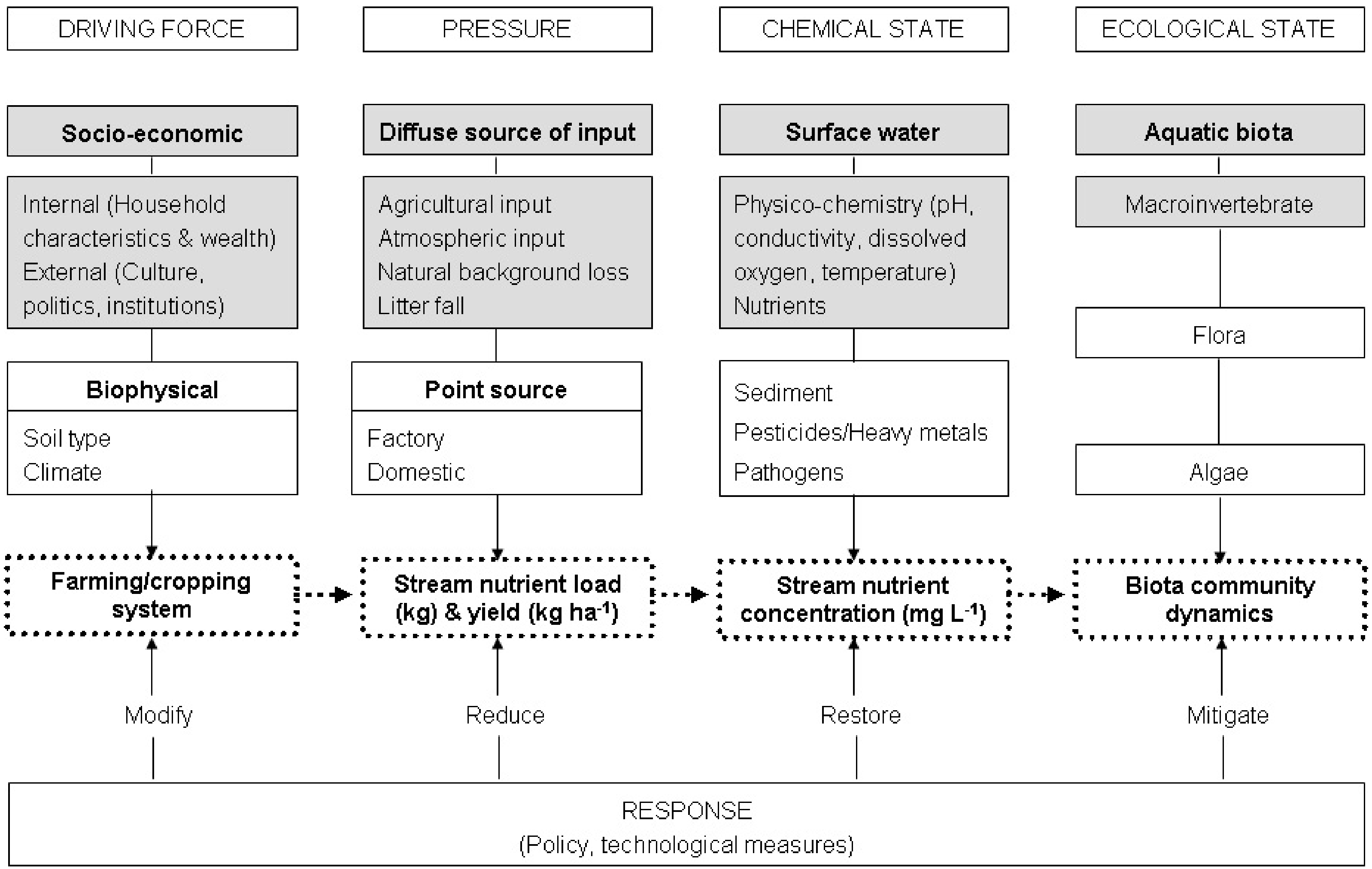


Figure 1.1 Adapted DPCER framework (shaded box - major factors investigated; dotted box - assessed or estimated variable)

2 LITERATURE REVIEW

2.1 Introduction

Land as an asset is used as a means to sustain livelihoods with activities based on needs or underlying driving forces which affect production and consumption – e.g., property rights, population density, development, available technology, pricing policies, among others. In explaining the linkages between humans and their environments, most theorists agree that human pressure on the environment is a product of three factors, population, affluence and technology (Ehrlich and Ehrlich 1990). The impact of these factors are depicted in the IPAT formula, where Impact (I) is the product of population (P), affluence (A) or consumption per capita, and technology (T), which determines how many resources are used and how much waste or pollution is produced for each unit of consumption. This relationship, however assumes that the factors are independent of each other and excludes interactions such as the improvement of technology when affluence increases or the influence of culture and institutions. Classical theories such as neo-Malthusianism state that human populations will increase exponentially to exceed the earth's capacity for resource renewal and lead to ecological consequences, whilst other theories have suggested that population growth provides increased labor and capital inputs (Boserupian) as well as improved human ingenuity and market substitution to avert future resource crises (Cornucopian). For others, neither theory is totally accurate, as they may all operate at the same time but under different regional or national economies (de Sherbinin et al. 2007). The authors believe that inspite of this, continued discussions of interlinkages can lead to improved policies on important issue areas including agricultural land degradation, water resource management, and climate change.

Earlier research needing a quantifiable approach to analyze the interactions between man and the environment focused mostly on population dynamics (size and growth); however, the importance of other variables such as age, gender, household demographics and the elements maintaining population equilibrium (fertility, mortality and migration) have also been realized (McCusker and Carr 2006; de Sherbinin et al. 2008). More recently, the influence of other interacting non-quantitative factors such as institutions, policies, markets and cultural change are being incorporated (Lambin et al. 2001), with models such as the PEDA (Population, Environment, Development, and Agriculture) integrating factors such as population, education, rural development, land degradation, water, food production and food distribution for more effective communication of these interactions to policy makers (Lutz et al. 2000). The cross-scale dynamics of social-ecological systems (SESs) has also been described by the Panarchy Theory (Gunderson et al. 1995) to explain the importance of adaptive evolution by both systems and the multiple connections between different levels of organization and scales (Walker et al. 2006). According to the theory, natural systems are linked together in adaptive cycles of growth, accumulation, restructuring, and renewal. Changes can be categorized into (i) gradual change, where human responses to ecological changes do not involve a regime shift, (ii) adaptive change, to describe the ability of social components to respond to shifts in ecological regimes, and (iii) transformative shifts, where both social and ecological components transform into new regimes (Gunderson et al. 2006). Currently, the understanding of the huge number of potential variables suggests the establishment of a multilevel framework for SESs, where theories are tested as a subset when addressing a particular issue (Ostrom 2008). Although considering all variables in addressing a specific problem is close to impossible, users of the SES framework should bear in mind that causal interactions between factors occur within the investigated system as well with progressive upwards and downwards layers to larger or smaller systems.

2.2 Landscape and river ecosystems

Landscape ecology, which involves the interactions between aspects of geography, ecology and social anthropology, considers humans as a significant component of the landscape, and their perceptions and actions determine its relevance. From this viewpoint, the river is another element of the landscape that is useful (e.g., for transportation, water sources, waste disposal) or functional (e.g., exchange of materials, organisms, energy). From the environmentalists point of view, the river is a dynamic entity of its own with spatial linkages and processes related to its longitudinal (upstream to downstream), lateral (channel bank and floodplain) and vertical (atmospheric, stream channel and subsurface) dimensions

(Vannote et al. 1980; Junk et al. 1989; Ward and Stanford 1989), with land use activities influencing the ecological integrity and impacting habitat, water quality, and biota through a variety of complex pathways (Johnson et al. 1997; Strayer et al. 2003; Turner and Rabalais 2003; Zampella et al. 2007). With the consideration of river ecosystems as ‘riverscapes’ closely connected with the catchment landscape (Fausch et al. 2002; Wiens 2002), new methodologies for land-use studies are being required, especially when necessary for the formulation of land-use policies (Rosegrant and Cline 2003). Sustainable options for development require knowledge and skills from the biophysical system dynamics, the multiple positions, perceptions, values, beliefs and interests of relevant stakeholders, and the decisions required to apply simulated linkages to reality (van Paassen et al. 2007).

2.2.1 Integrated assessment

The concept of connectivity and integration of biophysical, social and economic factors for efficient environmental monitoring and management schemes requires an explicit structure of the essential components and their interactions for the appropriate measures to be taken. The system theory, defined as the description of a complex situation that is composed of a number of elements and interactions within a specified boundary, provided a method for conceptualizing the interactions between subsystems found in a society and the aquatic environment in Bossel’s systemic framework (Bossel 1999, 2001). These interactions were expanded to include the bi-directional interactions between the drivers that act on the environment, the changes that as a consequence take place in the environment, and the societal reaction to those changes. This forms the basis of three main water quality conceptual frameworks: the pressure-state-response (PSR) typically used by the Organization for Economic Co-operation and Development (OECD), driving forces-state-response (DSR) used by the UN Commission on Sustainable Development, and the driving forces-pressure-state-impact-response (DPSIR) used by the European Union Agency (EEA) and European institutions (OECD 1998, 1999; Smeets and Weterings 1999; EEA 2000; Washer 2000; OECD 2001). In comparison, frameworks such as the Millennium Assessment (MA) is of a different ethical focus and concerned with the interaction of indirect and direct drivers that affect ecosystem services for human wellbeing and poverty reduction. Depending on the context of the issue, therefore, different frameworks offer different possibilities for interpreting and integrating data into various conclusions and policy recommendations – for example, the MA framework concentrates on sustainability science and the DPSIR's circular approach tends towards learning oriented management thinking (Stoll-Kleeman et al. 2006).

Frameworks have various limitations, and the DPSIR and related frameworks have been criticized for over-simplifying reality, ignoring other linkages within the socio-ecological system, not incorporating the relations between the elements where responses to one pressure can become pressure on another part of the system, and not addressing the fact that some elements may be more relevant than others (Berger and Hodge 1998; Rekolainen et al. 2003). Other comments suggest that the DPSIR has shortcomings in its function as a neutral tool and is biased because it was designed to establish proper communication between researchers and stakeholders/policy makers; and as such there is the need to research into effective incorporation of the social and economic concerns of all stakeholders (Svarstad et al. 2008). Due to these criticisms, parameters have to be based on appropriate definitions, for example, definitions of driver and pressure given by the Water Framework Directive (WFD) Guidance (EC 2003), before being applied to a specific issue such as pressures from agricultural land use and impacts on surface water and groundwater (Giupponi and Vladimirova 2006). In other cases, the framework can be further developed to suit implementation processes, such as the DPCER (driving forces-pressure-chemical state-ecological state-response) framework designed for the implementation of the WFD (Rekolainen et al. 2003).

To qualitatively describe the dynamics within a framework, the representative aspects are defined and characterized by selected parameters that can be measured. Environmental indicators, known as key evaluators of the pressures, state, and response to the environment, are now commonly used in environmental assessments to influence management and policy making at different scales. An indicator is defined as a parameter or a value that points to, provides information about, or describes the state of a phenomenon/environment/area with a significance extending beyond that directly associated with its value, and relays a complex message from numerous sources in a simplified and useful manner (OECD 2003). Based on the conceptual framework, a different rationale is used in the selection of indicators, thus the need to define the context/purpose for monitoring such that the appropriate parameters are investigated. Although indicators have been found useful, there have been some concerns that selected indicators fail to capture the full complexity of the ecological system (Dale and Beyeler 2001; Bockstaller and Girardin 2003) and, more recently, the need to incorporate an indicator's analytical use or interaction within a set of selected indicators (Niemeijer and De Groot 2008b). In an extensive list of common criteria for effective indicators, there is very little mention of the inter-relation of indicators (i.e., integrative, linkable to societal dimension and links with management), with the most common criteria being measurability, low resource demand, analytical soundness, policy relevance and sensitivity to changes within policy time frames (Niemeijer and De Groot 2008a). To incorporate the real complexities, the interacting and interconnecting multiple causal chains were included by the authors in a systematic indicator selection procedure known as the enhanced-DPSIR framework (eDPSIR).

As the priorities of environmental policies have evolved, the need for more reliable, synchronized and easily understandable information has also grown. Various international and national programmes have established standardized criteria/guidelines or sets of indicators to enable the exchange of experiences for strengthening environmental monitoring and assessment – UN Statistics Division (UNSD), UN Environment Programme (UNEP), UN Commission for Sustainable Development (UNCSD), European Union (Commission of the European Communities, Eurostat, the European Environment Agency – EEA) in addition to specialized agencies and non-governmental agencies (NGOs) – with collaboration in order to build up synergies and avoid duplication of efforts in data collection.

2.3 Interlinkages - using the DPCER approach

Accurate predictions of the impacts that landscapes have on stream ecosystems are complicated by the complex interactions between natural and anthropogenic processes, the influence of scale on responses, the uncertainties of long-term consequences after the source of a disturbance is removed, and the fact that the magnitude of impact is not always directly proportional to the pressure (Allan 2004). Different disturbances exert their influence at different scales and by multiple pathways, which makes the matching of a response to a specific stressor difficult. Natural variability makes these processes more complex, and it is impossible to assess the degree of impairment accurately as there is less certainty regarding the cause (Gergel et al. 2002; Thoms 2006). At various spatial scales, the aquatic ecosystems are influenced by the prevailing characteristics, for example, stream fauna is influenced by habitat quality, or the channel morphology by riparian vegetation and supply of water and sediments. The appropriate temporal scales are also necessary when delineating pressure and impact analysis, since some pressures may result in future impacts, and some impacts may be related to past pressure no longer existent (EC 2003). In addition, the response of stream conditions to a gradient of increasing land-cover change is not always typical, due to the combined effects of separate responses of various parameters. A study in West Africa, for example, showed no significant impacts on water yield and river discharge when deforestation was below 50% of the forested area, overgrazing below 70% of savanna and 80% of grasslands (Li et al. 2007).

The use of indicators in the cause-effect linkage between components of the agriculture-water quality interaction enables the description of the relationships between the pressures caused by land-use activities and the impacts on the aquatic ecosystem. Although criticized for its generic structure and bias, the clear definition of terms in the DPSIR framework has enabled water resource researchers to identify appropriate indicators to measure linkages within the framework. According to the WFD (EC 2003), driving forces refers to an anthropogenic activity that may have an environmental effect, with economic, social and demographic changes in the society being common indicators. With intensive production and consumption, pressure is exerted that alter the use of the land and resources to release substances or emissions. The state indicators describe the changes in quantity and quality of the physical, chemical and biological characteristics of the environment. The impact describes the environmental effect of the pressure (e.g., modified ecosystem), and response, the measures taken to improve the state of the water body (e.g., policies to develop best practices for agriculture). To improve the analytical utility of indicators, the inter-relationship between selected indicators should be seen within a 'causal chain network', where there are multiple interconnections and interactions between the links in the framework instead of a single connection (Niemeijer and De Groot 2008a). Here, the indicators are categorized as 'root', 'central' and 'end-of-chain' nodes, which describe the source of problem to environmental impacts. This means that indicators are assessed according to their function within the framework such that (i) those which provide information on the source of the issue, e.g., fertilizer and manure inputs from agricultural practices, are associated with the 'root' node, (ii) those interlinking indicators which assess the impact of multiple processes occurring at the same time form the 'central' nodes, and (iii) indicators located at the end of the series of cause-effect chains are the 'end-of-chain' nodes. Typically, biological organisms reflect the state or end-of-chain nodes, as they develop morphological, physiological and/or life-history traits that minimize the impact of disturbances over evolutionary time (Díaz et al. 2008). The driving forces-pressure-chemical state-ecological state-response model (DPCER), for example, is a modified form of the DPSIR concept, which incorporates cause-consequence relationships and is policy relevant for monitoring, assessing, and improving water quality resources (Rekolainen et al., 2003). In this framework, driving forces refer to the specific land-use activities that lead to the input of material (nutrients, sediments, toxins) (defined as pressures) to change the chemical state of the environment (i.e., the physicochemical characteristics of the water body) and result in changes to the ecological state (ecosystem modifications such as changes in biota), with responses as societal measures to improve the state of the water body. The assessment of the changes of the 'state' and the 'impacts' are the key indicators used in selecting the appropriate 'responses' to influence the 'driving forces' or 'pressure' to the system.

The following sections discuss fundamental concepts for each of the links within the DPCER framework. They include the assessment of the relationship between socio-economic trends and land-use intensity, calculation of nutrient loading estimates, accounting for physico-chemical processes, simulation of causal relationships between chemical status and ecological status, and evaluation of environmental policies and regulatory measures.

2.3.1 Driving forces - land-use and agriculture

Sustainable land-use has been defined as a unifying concept in which socio-economic (production and consumption, economic efficiency and social equity) and agro-ecological (resource stock, effect of land use on natural resources, etc.) variables coincide (Kruseman et al. 1996). Land-use change is a complex process resulting from the interaction between natural and social systems at different temporal and spatial scales (Fresco and Kroonenberg 1992; Lambin and Geist 2001; Veldkamp and Lambin 2001), with interactions between the driving factors and impacts often referred to as feedback mechanisms (Claessens et al. 2008). This feedback of changes in land-use on human well-being, affects future land-use decisions in a series of complex interactions and plays an important role in land-use studies (Verburg 2006; Young et al. 2006).

To understand this complexity, a broad array of models and modeling methods are available to researchers, with each type having certain advantages and disadvantages depending on the objective of the research (Lambin et al. 2000; Veldkamp and Lambin 2001; Agarwal et al. 2002). In a detailed review of the functionality and ability of different land-use models, the authors characterize three dimensions incorporated in land-use models (space, time and human decision-making) and two distinct attributes for each dimension (scale and complexity) (Agarwal et al. 2002). More recently, models such as the agent-based models (ABMs) or multi-agent systems (MASs) (both are synonymous terms) are more case specific, multi-scaled, multi-actor and data-intensive, and simulate the simple to complex representations of the behavior and cognitive processes of the actors who make land and resource use decisions (Robinson et al. 2007; Valbuena et al. 2008). In these models, decision-making entities are represented by agents, and biophysical environment is defined by spatial data. Five empirical approaches have been identified for obtaining information on human and social actors, and include (i) sample surveys, (ii) participant observation, (iii) field and laboratory experiments, (iv) companion modeling, and (v) GIS and remotely sensed data, each of which has its inherent strengths and weaknesses (Robinson et al. 2007).

Some authors have debunked myths that worldwide only population growth and poverty are the major underlying causes of land-use change, but rather people's responses to economic opportunities, influenced by both local and national markets and policies (Lambin et al. 2001). In developing countries, land-use dynamics are found within the agricultural sector, which is the main source of livelihood (Lambin et al. 2000; Soini 2005; McCusker and Carr 2006; World Bank 2008a). Individual farms, generally for the purpose of producing food and meeting other household goals, vary due to unique conditions of available resources and household circumstances, and function within an existing social, economic and institutional environment (Dixon et al. 2001). Individual farms are usually grouped into farming systems, i.e., groups categorized by available natural resource base, dominant patterns of farm activities, and household livelihoods (Ker 1995; Dixon et al. 2001). The analysis of farming systems incorporates the different key internal and external factors that affect the farming system characteristics, performance and evolution over time (Figure 2.1).

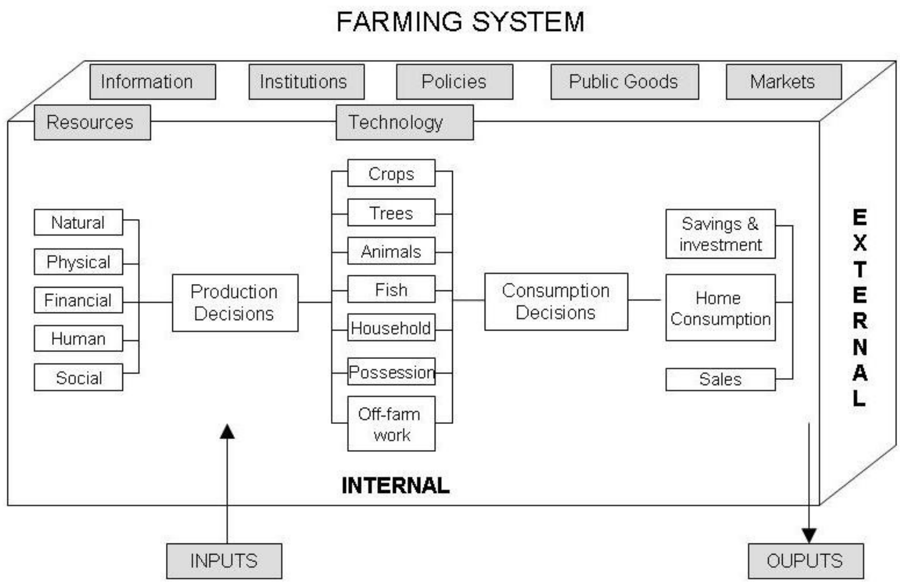


Figure 2.1 Farming system diagram. (Adapted from Dixon et al. 2001)

In the Sudano-Sahelian region, colonial forestry policies have been suggested as the key determinants of the current land-use patterns with historical and cultural interactions embedded within the complex social, economic and ecological processes that occur spatially and temporally (Wardell et al. 2003). Others have modeled the driving forces of land-use change in the region in two processes - agricultural expansion into uncultivated lands and deforestation, followed by agricultural intensification once some land threshold was achieved (Stéphenne and Lambin 2001). Agricultural intensification results from increased demand for output, and occurs as increasing gross outputs, with or without technological changes and/or more valuable outputs to raise the value of output per hectare. In the region, this has also been observed as the shortening of fallow cycles, and increased use of labor and agricultural inputs (e.g., organic or mineral fertilizers) (Carswell 1997; Stéphenne and Lambin 2001). Although positive in terms of improving livelihoods overall, there are some negative effects of intensification on the quantity and quality of livelihoods, as well as on agricultural sustainability (environmental, economic, etc.). For example, mechanized labor can affect the numbers of available jobs, lead to the deterioration of yields with increasing intensification as a result of environmental issues such as the loss of micronutrients or pest increase, and constrain production due to lack of water supply or appropriate infrastructure, etc. (Kelly 2006; Poulton et al. 2006; Woelcke 2006).

Land use/agriculture in Ghana

As with most of sub-Saharan Africa, the most common type of farming system in Ghana, used to be ‘shifting cultivation’ or ‘slash and burn’, where short periods of continuous cultivation is followed by relatively longer periods of fallow (FAO Forestry Department 1985). In the past, this traditional method of cultivation seemed appropriate in maintaining ecological and economic equilibrium, since population growth was slow and there was abundant land, limited capital and limited technical knowledge (Cleaver and Schreiber 1994). As population densities increased, new cash crops were introduced and land availability decreased. The bush fallow became the more dominant farming system, a modification of the shifting cultivation in that fallow periods are shorter and vegetation is cleared by fires. Simple implements such as the machete or hoe are used for cultivation, and crops utilize the accumulated nutrients from the fallow period with observable high yield in the first season but subsequent decline as the reserves are depleted. In addition to reduced labor costs, farmers perceive some positive aspects of burning the vegetation, such as the soil being improved by the provision of carbonates and phosphates obtained from the ash to the soil surface, an increase in the availability of soil nutrients to plants via leaching, and the eradication of fungal diseases and harmful insects (FAO 1997). The natural biophysical cycle of nutrient uptake and return to the soil has been the basis of this farming system, but with the declining fertility of soils due to shorter fallow periods, which affects the efficiency of the nutrient cycle, this traditional method is becoming less appropriate (FAO Forestry Department 1985). In response to this, farmers currently practice additional soil management techniques such as the preservation of fallow trees in the field, placement of crops at nutrient-rich sites, mulch with weeds and crop residues, as well as the application of mineral fertilizers, manure and household refuse (Drechsel and Zimmerman 2005). Agricultural systems such as rotational bush fallow, permanent tree crops, compound farming, mixed farming with food and cash crops, and special horticultural farming systems for reducing malnutrition and improving agricultural productivity, are also being encouraged in Ghana, all of which affect soil properties differently (IAC 2004; Diao and Sarpong 2007).

The relationship between property rights, natural resources and the environment also influence how farmers use the land (Quisumbing et al. 1999; Sandberg 2007). In Ghana, property rights operate within traditional land-tenure systems, which form an integral part of the culture. Land is generally not privately owned, as it is considered ancestral property, with authority vested in a traditional chief or community leader on behalf of the group. The system varies from region to region, but two broad categories exist between the north and south, as both areas differ in geography, cultural practices and colonial impact (Kasanga 2001). In the south, 'stool lands' are represented by paramount chiefs or queen mothers with delegation and day-to-day matters administered by sub-chiefs or caretakers in the villages. In the north, the title of 'skin lands' rather belongs to a spiritual leader or 'tendana', who is responsible for agriculture rituals and land allocation (Gildea Jr. 1964). Leases and rentals are available over a period of time for economic or commercial activities, with permission, but the land eventually reverts to the community at the end of the lease. Currently, 80% of the land in Ghana is under this customary system, although under the 1992 Constitution of Ghana, four categories of land ownership are recognized - public/state, stool/skin, clan/family, and private heads (Kuntu-Mensah 2006). In general, public/state lands are not owned by the government, except lands acquired by statutory procedures, and are held in trust for the people of Ghana. In some settlements, lands are owned and controlled by families, i.e., a group of persons all related through a family through a matrilineal or patrilineal line. Individuals, on the basis of member of family or lineage group, have usufruct rights over land and in some cases purchase or inherit parcels of land not subject to family sanctions.

The land-tenure system was generally considered a progressive structure, as it enabled communities to be self-sufficient in land requirements and subsistence farming (GoG/NDPC 2003). However, with the modernization process and advent of new religions, the traditional religion/culture weakened, local reserves and sacred groves were sacrificed, informal environmental regulations and enforcement procedures became increasingly unclear, and social conflicts over land arose (Kasanga 2001). With the subsequent state land acquisition laws and practices, failed land policy interventions, modernity, commercialization and urbanization, land-use patterns changed and resulted in land insecurity and generally weakened poor people's access to land (Gadzekpo and Waldman 2005).

Access to land and security of land stimulates investments by small scale farmers in technologies, farm inputs, and off-farm outputs, especially soil improvement investments that take a longer period to generate benefits (Codjoe 2004). Poor farmers who cannot afford high rent for farms have no guarantee of long-term access, and incentives for investment are low. Patterns of land-use are also influenced by socio-economic factors such as location, availability of roads, communication, markets, prices, credit, or subsidies that affect the profitability of farming systems (Oduro and Osei-Akoto 2008). A farmer's choice in fertilizer purchase, for example, is based on his perception of whether it will be profitable (relative to alternative expenditures) and whether the right amount of fertilizer can be acquired and used efficiently (Kelly 2006). With the information, technical and institutional constraints faced by the farmer, the profit maximizing potential of fertilizer use is usually not achieved. In addition, inadequate and expensive credit, unsatisfactory marketing arrangements for the produce, dependence on rain and small irrigation areas, insufficient funding of agricultural projects and inefficient use of fertilizers by farmers, have been further constraints (FAO 2005).

Individual social characteristics such as social status, knowledge, experience, perceptions, ambition, farm size, etc., can vary within the community structure and are factors that affect individuals' relationships with their farmlands (Ruben 2005). In one study, the major variable that explained fallowing periods in the eastern region of Ghana was the individual's position in the social hierarchy, and not the result of wealth or quality and quantity of land (Goldstein and Udry 2008). The farmers' wish to alter their farming methods has also been recognized as an important component of current innovative agricultural practices to optimize agricultural systems and increase productivity (Drechsel and Zimmerman 2005). Personal choices, based on a farmer's appraisal of the biological and economic resources at their disposal, strongly influences farming decisions in addition to biophysical, cultural, economic and social factors (Benneh 1973; Dixon et al. 2001; Drechsel and Zimmerman 2005).

Assessment

To understand the circumstances and needs that influence a farmer's perspectives and underlying causes of practices, and to determine the social, economic and ecological factors that may influence the choice of options, baseline surveys are usually carried out by researchers. Common methods are rapid rural appraisals (RRAs), key informant interviews, focus group interviews and farmer surveys. The most applied form of evaluation are the RRAs, which involve teamwork, focused collection of information, qualitative analyses and strategic analyses (Chambers 1994). An earlier study assessing the range of approaches and techniques for RRAs based on cost of collection and learning, relevance, timeliness, accuracy and actual beneficial use of information, identified two types of research methods - the quick-and-dirty and the long-and-dirty, where 'dirty' meant not cost-effective (Chambers 1981). According to the author, biases in quick investigations include misleading replies, failure to listen, reinforced misperceptions and prejudice, activities and relationships that are not apparent to the researcher, with results often being snapshots that do not represent trends. The more detailed multi-disciplinary questionnaires of the long-and-dirty appraisals were considered academically excellent but generally worthless due to the extensive data generated and long timelines required for data collection and analyses. The author suggested more appropriate techniques (i.e., less rigid and exhaustive but rigorous in cost and use) which included the use of existing information, indigenous technical knowledge, key indicators, multi-disciplinary research, local researchers, direct observation, key informants, group interviews, guided (or informal) interviews, and aerial inspection and surveys.

More recently, participatory and RRA methods are being advocated as a means of improving the relevance and adoption of technologies (Dorward et al. 2007). Although still criticized for not generating quantitative data and lacking statistical analyses, participatory methods document farmers' perceptions to improve the relevance of technologies and enhance collaboration among farmers and researchers for developing appropriate strategies for local problems (Gladwin et al. 2002; Phiri et al. 2004). These methods help researchers understand how farmers experiment on their own and seek partnership when developing technologies. Furthermore, the incorporation of participatory methods with quantitative analyses benefits researchers with enhanced accuracy and statistical rigor, and rural communities benefit from using participatory methods to assess their member's needs and practices (e.g., Temu and Due 2000; Gladwin et al. 2002; Phiri et al. 2004).

2.3.2 Pressure - Nutrient loading

Freshwater quality is dependent on wide range of physical, chemical, biological and societal factors, with the contribution of hydrology as a key element (Walter et al. 2000), since the hydrological distinctiveness of a catchment influences the dynamics of water flow. Understanding the various hydrologic processes involved in the transport of solutes and sediments to streams leads to a more successful implementation of water resource management guidelines and policies.

Hydrology

The hydrologic cycle is a complex system of interactions, and on a catchment scale involves atmospheric moisture (precipitation, evaporation, interception, and transpiration), surface water (overland flow, surface runoff, subsurface and groundwater outflow, runoff to streams and ocean), and subsurface water (infiltration, groundwater recharge, subsurface flow and groundwater flow). All these interactions direct the changes in the morphology and habitat of rivers and are intimately connected with climate, geology, topography and general catchment features (Molnar et al. 2002).

Evapotranspiration is the main process responsible for annual changes in water yield as a result of alterations in vegetation. Changes in vegetation caused by various land-use activities have been the focus of many hydrological studies, with four main categories of vegetation change – afforestation, deforestation, forest conversion and re-growth. Depending on the activity, water yields from catchments are affected including changes on a temporal scale (Brown et al. 2005). Water yield changes can be the result of changes in surface runoff, in base flow or both. In West Africa, hydrological responses are non-linear and when thresholds are exceeded, lead to dramatic increases in water yield (Li et al. 2007).

Runoff response, where surface flow is generated when the soil is fully saturated, i.e., Hortonian flow (Horton 1933), or when precipitation exceeds the infiltration capacity of the soil, i.e., Hewlettian flow (Hewlett and Hibbert 1967), are strongly dependent on the initial soil moisture content, slope length, infiltration properties and saturated hydraulic conductivity (which determines the maximum capacity of soil to transit water). These are factors that also influence flow paths and rainfall runoff responses (Ajayi 2004). In the West Africa region, the generation of runoff after a storm is dominated by the Hewlettian flow, or 'infiltration capacity excess overland flow'. This process begins when rainfall intensity exceeds the infiltration capacity of the soil such that runoff flows downhill towards the valley due to the combination of high intensity rainfall (>100 mm/hr, for between 10 and 30 minutes) and poor infiltration properties of the soils in West Africa (Ajayi 2004; van de Giesen et al. 2005). The rate of surface runoff is the difference between the rainfall intensity and the infiltration rate, assuming that evaporation during and immediately after the event can be considered statistically negligible (Shahin 2002). The amount of runoff varies depending on the scale of investigation, with reducing discharge rates as scale and slope lengths increase. Field measurements have shown significant reduction in runoff of 40-75% on 12-m slopes as compared to runoff from 1.25-m slopes (van de Giesen et al. 2005). These differences are due to functions of rainfall duration and intensity, slope length and gradient, surface roughness and infiltration capacity – features important in the understanding of how modifications to land-use and cultivation techniques can influence water and solute transport at different scales. High nonlinearity of the rainfall-runoff response also contributes to the observed discharge, as in the Volta Basin, for example, 340 km^3 of rainfall has to occur before a significant amount of runoff can be observed, with half of the rainfall generated as runoff when the threshold is surpassed (Andreini et al. 2000). Runoff into streams may occur only from some parts of the catchment, or source areas, which vary in performance during a storm event (Shahin 2002). Modifications of any parameters involved in the hydrological processes can therefore have dire consequences on the entire cycle.

The hydrological regime of a catchment, essential to its ecological functioning, is significantly influenced by two main parameters – the nature of the flow (intensity and duration), and the stream flow variability (seasonal cycle, recurrence and predictability) (Molnar et al. 2002). Extensive ecological consequences can, therefore, result from changes to the regime caused mainly by anthropogenic activities such as deforestation, land-use changes, natural variability in large-scale atmospheric circulation patterns, and climate change due to increase in greenhouse gases and global warming. In Ghana, the hydrological effects of changes due to anthropogenic land-use, despite the global impacts of climate change, has been seen in the significant reductions in rainfall amounts in the humid zone of the south western rivers system (which historically has higher levels of land use change and deforestation) when compared to the semiarid northern savannah regions. With the higher annual variability of discharge (57%) than rainfall (7%) in the Volta Basin, for example, such changes in annual rainfall can lead to considerable changes in discharges (Gyau-Boakye and Tumbulto 2006). The conversion of natural land and forests into agricultural lands results in significant changes to hydrological patterns, such as higher water yields resulting from lower transpiration rates and reduced infiltration due to reduced forest cover, with negative effects on soil fertility and water quality (Mungai et al. 2004). In addition, the practice of burning cleared vegetation in the traditional bush fallow system exposes the underlying soils, and changes physical and chemical composition of the soils. This increases sand proportions (Bagamsah 2005) and reduces the rate of infiltration of precipitation into the soil (Bijker et al. 2001) due to soil crusting (Mills and Fey 2004), further affecting surface runoff and stream hydrology.

There is a wide variety of hydrological models that estimate the hydrological processes within a catchment driven by interactions between climate, soil, vegetation and surface topography. These models are usually grouped under four main categories – (i) physics-based or fully distributed models, (ii) conceptual models, (iii) metric models, and (iv) hybrid metric-conceptual (HMC) models (Amisigo 2005). Physics-based models are the most complex, with partial differential equations representing all the component processes of subsurface and surface flow. These equations are based on the physics of the processes and the model requires the estimation of numerous parameters. Examples of the fully distributed models include the Système Hydrologique Européen (SHE) model (Abbot et al. 1986), the Institute of Hydrology Distributed Model (IHDM) (Bevern et al. 1987) and the Swiss Water balance Simulation Model ETH (WaSiM-ETH) (Schulla and Jasper 1999). The best known model is the SHE, later developed into MIKE SHE, which simulates the entire land phase of the hydrologic cycle and allows components to be used independently and to be customized to local needs (Molnar et al. 2002). Conceptual models are relatively less complex and identify the structure of the model based only on selected component processes. One major type of this model is the simplified distributed model, which uses distribution functions to describe the spatial variability of surface runoff. Examples of such models are the TOPMODEL (Bevern and Kirkby 1979), Xinanjiang (Zhao et al. 1980), and the Probability Distributed Model (PDM) (Moore and Clarke 1981). A second type of conceptual model is the Explicit Soil Moisture Accounting (ESMA) model, which uses a number of conceptual reservoirs to describe subsurface water storage and transformation into discharge. Examples of ESMA models include the Sacramento Soil Moisture Accounting (SAC-SMA) (Burnash et al. 1973; Burnash 1995) and the Australian Large Scale Catchment Model (LASCAM) (Sivapalan et al. 1996a; b; c).

Since physically based and conceptual models are designed to mathematically simulate the physical mechanisms that determine the hydrological cycle, the model calibration is complex and requires a comprehensive knowledge of the studied basin. Metric models, on the other hand, are data-based and rely mostly on statistical estimations of observed data to describe the runoff responses. These models are usually based on time-series data and are inadequate for interpreting physical processes. Examples include the Box-Cox type discrete-time transfer functions (Box and Cox 1964) and neural network models (Bowden et al. 2005a; b), which have been applied successfully to forecast rainfall-runoff processes at different temporal stages, (e.g., Castellano-Méndez et al. 2004). The final category of models, the HMC, integrates the advantages of the statistical characterization of metric models and the prescribed physical interpretations of conceptual models, as transfer function models. They are able to represent the rainfall-runoff non-linearity and adequately characterize the physical processes of the flow mechanisms. Statistical procedures to assess the validity and quantify the uncertainties in parameter estimates and model outputs are also well developed (Young and Bevern 1994). Two main HMC approaches are the Deductive Approach and the Data-Based Mechanistic (DBM) model. The conceptual model is specified a priori in the deductive approach; the Identification of unit Hydrographs And Component flows from Rainfall, Evaporation and Streamflow data (IHACRES) model, for example, estimates only 6 to 7 parameters and has been widely applied in several regions and climatic conditions (e.g., Hansen et al. 1996; Littlewood and Marsh 1996). The second approach, DBM modeling, allows the data to suggest an appropriate model structure that is compatible with the available input-output information, and then evaluates the resulting model for mechanistic interpretation, (e.g., Mwakalila et al. 2001).

With the wide range of simple to complex process-driven hydrologic models available, researchers have compared the efficiency of numbers of competing models in order to select the most appropriate one (e.g., Lee et al. 2005; Clarke 2008; Das et al. 2008). The assessment of whether input data with high spatial resolution and high model resolution leads to improved model results for stream flow simulation, for example, has shown that more finely resolved input data and model resolution does not necessarily improve the model performance unless the input data corresponds to an increase of information (Perrin et al. 2001; Das et al. 2008). How a model performs depends on several factors such as the scale of the catchment, physiographic characteristics of the catchments, availability of the data required to set up the selected model, the dominating rainfall type, seasonality of precipitation, season of the year and dominating runoff producing mechanisms. There is no single model that can perform consistently over the range of catchment types and conditions, and the choice of a model depends on the researcher's preference and familiarity with a particular model, the objectives and available data. In some cases, instead of selecting a single model, the combination of results from several hydrologic models by the use of Bayesian statistical techniques can be advantageous in providing more accurate uncertainty estimates; although this can limit the usefulness of different models at different times (Niggli and Marsh 2005; Marshall et al. 2007). There are criticisms, however, that procedures used for comparison are not satisfactory because (i) they provide no measure of the uncertainty in model differences or model performance, (ii) validations and calibrations are usually carried out by persons familiar with the use of the model which results in less effectiveness for the general hydrological community, and (iii) there are relatively limited practices of good experimental design (i.e., replication and randomization) as compared to other fields of applied science (Clarke 2008).

Upland Streams

The catchment of a river system is conceptually divided into the headwater basins, the low-order stream system and the main river corridor, with the headwater basin as the area of most dynamic response to intense rainfall (White and Garci-Ruiz 1998). The topography, vegetative cover and soil properties are crucial variables for runoff production and erosion (Molnar et al. 2002). First- and second-order streams, whose total lengths form more than 70% of the total stream length in a river network, are important as they connect upland and riparian systems with river systems (Leopold et al. 1964). Their contribution to downstream stream flow (Winter 2007), nutrient cycling and watershed water quality (Alexander et al. 2007), biodiversity (Meyer et al. 2007), and organic material (Wipfli et al. 2007) is essential in watershed ecosystem functioning. The understanding of how lower-order streams influence water quality and flow of downstream systems is fundamental to the effective management of all water resources. For example, first-order streams have been found to contribute to 70% of the mean annual water volume and 65% of nitrogen fluxes in second-order streams, and 55% and 40%, respectively, in fourth- and higher order rivers (Alexander et al. 2007). Since every important aspect of the river ecosystem, i.e., the river geomorphic system and the river chemical system, begins in lower-order streams, any change has the potential to reduce ecological integrity on much larger spatial scales (Freeman et al. 2007) .

Nutrient loads

The riverine ecosystem, as a dynamic system, connects the headwater streams to the landscape and transfers energy downstream to sites such as estuaries, coastal and marine ecosystem. The temporal and spatial variability in channel processes and features control how nutrient transfers along this longitudinal linkage undergo multiple cycles of uptake, biological, chemical and physical storage and re-mineralization – processes which are described by the nutrient spiraling concept (Newbold et al. 1981). Ecological models that have described processes in the natural river ecosystem include the River Continuum Concept (RCC) (Vannote et al. 1980), an earlier model that considers the river system as one ecological unit with physical and biological changes along the length of the river as a result of its terrestrial surroundings. The headstream, shaded by riparian forest canopies with poor light penetration, obtains energy sources mainly from riparian vegetation. The wider middle reaches, which are less shaded by vegetation, have increased primary productivity due to higher irradiation. The lower reaches, characterized by higher turbidity, depth and substratum instability, and reduced photosynthesis and energy inputs, mostly process organic material from upstream. The RCC, however, assumed a perennial river system based on temperate river systems with managed areas, and excluded the irregularities in small stream flows strongly influenced by local rainfall that resulted in breaks in the continuum. The Flood Pulse Concept (FPC) (Junk et al. 1989), although more applicable to larger rivers and the floodplains of downstream sites, suggested that periodic changes in the water level that led to lateral exchanges between river channel and the floodplain (the area on the sides of the channel that is inundated by floodwaters at intervals) rather contributed to the energy sources of the river ecosystem. The FPC surmised that, in addition to the dissolved and suspended material from upstream, the nutrient status and associated aquatic fauna were influenced strongly by internal processes and nutrient transfer mechanisms caused by interaction with the terrestrial phase.

Increased contributions from land-use activities are either through a single source (point source), and thus generally easier to identify, quantify and control, or those that are from diffuse sources (non-point sources) which are more difficult to control. Fertilizer production, fossil fuel consumption and planting of leguminous crops, for example, have doubled the rate at which biologically available nitrogen enters the terrestrial biosphere (Galloway and Cowling 2004). Phosphate mining and its use in fertilizers have doubled phosphorus inputs over the natural weathering process (Bennett et al. 2001). There are multiple loss pathways for nutrients from fields to streams, and although there is much interest in understanding the nutrient loadings in soil in order to control their input into aquatic systems, the diffusion and delivery of these pollutants are independent of the source, and pathways, therefore, are not easily predictable.

One way of establishing nutrient loads in water bodies with respect to the land-use type, is by the use of an export coefficient, which estimates the mass of a specific nutrient exported from a particular land use in one year. Computer models have been developed to estimate pollutant loading from terrestrial sources into the water body, which range from simple export coefficient models (Arnold and Allen 1996), regression models such as SPARROW (Newham et al. 2004), to complex models such as SWAT (Matthies et al. 2006), CatchMODS (Dise 2004), and MONERIS (Sharpley et al. 2002). Export coefficient models estimate organic matter, nutrient sources and nutrient transport as a function of land area, with assumptions on export characteristics for a specific climatic regime and land-use types. The Integrated Nitrogen in Catchments (INCA) in Europe, for example, takes all nitrogen sources, processes them through crops, semi-natural vegetation, microbes and soil, to predict how much nitrogen will come out into the river or stream. Above 50 mg L^{-1} which is the EU maximum, different options are used, such as cutting back on fertilizer application, changing crops or crop rotations, planting forests, shutting down or upgrading sewage works, or a combination of these strategies (McFarland and Hauck 2001). These models are better at predicting annual averages than daily events or transient peaks that may come from unknown sources or poorly understood internal processes.

For smaller scale studies, field-scale nutrient load data are required to understand the nutrient transport mechanisms and variability in soil, land use, climate, topography and management (Wickam et al. 2003). Small watersheds with a predominant land use and field plots established to collect runoff from storm events are used for these investigations, although difficulties exist in identifying and monitoring catchments having a single homogenous land-use type (Sahoo et al. 2006), or data obtained might not represent the average conditions and practices such as soils, planting and harvesting dates, slopes, tillage practices, or proximity to streams (Duan et al. 2003). Partially understood physical processes that interact at complex non-linear scales and influence solute turnover in the soil, groundwater and stream water can also lead to underestimates of loads (Rousseau et al. 2002).

In some cases, more accurate estimates of nutrient losses from drainage basins are needed to predict responses of ecological systems to nutrient inputs; for instance, when direct estimation of pollutant loading is needed to either calibrate hydrological and water quality models (Letcher et al. 2002; Quilbé et al. 2006; Shrestha et al. 2008), or there is an interest in the load-based targets, i.e., the receiving water, where there are requirements to improve water quality such as the Total Maximum Daily Load (TMDL). Loads are estimated from measurements of pollutant concentrations in-stream and stream flow data, although adequate data are not always available due to the time, expense and effort required to collect and analyze field data. Generally, as continuous flow data are more readily obtainable than concentrations, several estimation techniques are available with guidelines to assess the most appropriate method based on the type of available data. Reviews carried out on various estimation techniques have shown that there are no universal methods available with precise or minimum variance, and little has been done about quantifying the uncertainties which surround the estimate loads (Littlewood 1992; Littlewood et al. 1998; Mukhopadhyay and Smith 2000; Letcher et al. 2002; Etchells et al. 2005; Quilbé et al. 2006). Different methods can even give different results when applied to the same data set (Walling and Webb 1988).

Overall, there are three main classes of methods, with variations available in each depending on the type of available data: (i) averaging estimators or interpolation methods, (ii) ratio estimators, and (iii) regression methods. Averaging or interpolation techniques use the product of the sum of discharge volume and average concentration data sampled at different frequencies. They are generally biased when the period between sampling times increase, or if the data set does not represent the entire range of flows and concentration values; in such cases they are used for a first approximation (Dolan et al. 1981). The ratio estimator uses the available sampled concentration and flow time series to compute a fraction that accounts for the covariance between the two parameters. These estimators are considered unbiased when the relation between load and discharge is linear with an intercept of zero and when the variance of load is proportional to discharge. Both of these conditions are often approximately satisfied by the relationships between discharge and load, and the estimators are considered comparatively more statistically robust (Mukhopadhyay and Smith 2000; Vieux and Moreda 2003; Quilbé et al. 2006). Regression analyses generally perform well, but require a strong correlation between stream flow and nutrient concentration for a wide range of stream flow values, such that the concentration of non-sampled periods can be inferred from the flow data (Endreny and Hassett 2005; Johnes 2007). Three modifications are known, which include the quasi-maximum likelihood (QMLE) (Ferguson 1986), the non-parametric smearing estimator (Duan 1983), and the minimum variance unbiased estimator (MVUE) or Bradu-Mundlak estimator (Cohn et al. 1989; Cohn 1995). Fairly accurate estimates are obtained from the three modifications when (i) the assumed linear model is correct, (ii) the model is based on 30 or more observations, and (iii) the model does not extrapolate beyond the range of calibration data (Cohn 1995). If only the first condition is satisfied, the MVUE estimate is considered the best option, if all conditions are met, the QMLE is preferable as it is relatively easier to compute, and if the regression residual is not normally distributed, the smearing estimate is most appropriate. Regression methods have been applicable mostly to sediments, particulate and total P as well as pesticides, but more rarely to mobile nitrates (Preston et al. 1989; Coats et al. 2002). In some cases however, such as in agricultural catchments, poor correlation has been found with P because of sparse data or the influence of temporal fertilization or dilution effects (Mukhopadhyay and Smith 2000).

To compare the effectiveness and accuracy of various estimators, the analyses of full sampling records have been artificially reduced and compared to a calculated 'true' load. Two examples of this approach are the systematic sub-sampling and Monte Carlo simulation, which either reduce heavy datasets into subsamples to represent a period, or randomly sample from observations to produce a simulated sample set, respectively. In these studies, the ratio estimators were assessed to perform better as unbiased estimators with a correction factor to the estimates, especially in cases with a large number of flow data but few available concentration data (Mukhopadhyay and Smith 2000; Quilbé et al. 2006; Johnes 2007). In one study that estimated a wider range of pollutants to include Ca, Mg, and Na parameters, the three best methods were in the order MVUE>Beale>Mean, although a large variation was observed between NH_4 estimates (at 13.7% deviation from MVUE when estimated with the Mean method but 0.1% with Beale) and NO_3 (at -27.5% deviation with Beale but 0.0 with Mean) (Endreny and Hassett 2005).

To improve the accuracy of load estimates, sampling during periods of high flow (stratified sampling) has also been recommended to provide increased precision for a specified number of samples (Stevens and Smith 1978; Dolan et al. 1981). Here, the assumption is that flows are highly variable and concentration increases with flow, with most of the load occurring during storm runoff events. Stratification is recommended if concentrations at high flow are higher than those at low flow, and if at least 70% of the annual discharge occurs during 30% of the time with the highest flows (Richards 2000), or when there is a large number of data (Quilbé et al. 2006). To summarize, although there are well documented advantages and disadvantages of each method, the review of available research shows that depending on the analysis objective and data constraint, all findings eventually support the range of averaging, ratio, regression or stratified methods (Alexander et al. 2002).

Estimates of efficient sampling frequency rates have also been investigated with the aim of reducing costs of water quality sampling procedures, which involve personnel, specialized sample handling and transport as well as laboratory analysis. At low sampling frequencies, the incidence of high flow volumes with high pollutant concentrations is more likely to be missed, which leads to significant underestimations. Overall, the selection of load estimation techniques determines the sampling frequency, which is influenced by catchment character. Earlier studies indicate that samples collected on a fortnightly basis were sufficient to obtain accurate estimates using interpolation methods (Kronvang and Bruhn 1996); more recently, stratified sampling programs with daily sampling on the 35 highest flow days in the year, combined with weekly sampling during the remainder of the year return estimates with low bias and imprecision (Johnes 2007). However, as these suggestions are established for particular areas, extrapolations to other hydrological systems may not always be appropriate.

2.3.3 Chemical state - Stream physico-chemistry

Primarily, there are three main mechanisms that control natural water chemistry, (i) atmospheric precipitation, which determines the amount of dissolved salts, (ii) rock dominance, i.e., the types of rocks and soils that are the dominant source of dissolved salts, and (iii) the evaporation-fractional crystallization process, which increases the concentration of dissolved substances (Gibbs 1970; Bluth and Kump 1994). Based on the combination of interactions, each aquatic system has unique physical (e.g., temperature, transparency, total solids, electrical conductivity) and chemical characteristics (e.g., pH, Ca, Mg, nitrogen, phosphates, hardness, dissolved oxygen) (Chapman 1996).

Since water interacts with the rocks and soils before entering streams, the climate and geology of the catchment have the most significant impacts on stream chemistry, there are contributions from factors such as the initial chemical composition, amount and distribution of rain; vegetation, which influences the concentration of ions in the soil and the delivery rates of ions to streams; and the influence of human activity and land-use in the catchment (e.g., Hem 1985; Dow et al. 2006). Anthropological and land-use activities have been the focus of a vast number of water-related studies, with strong associations established between the scale and type of land-use and the increased impacts on aquatic ecological integrity (e.g., Allan et al. 1997; Johnson et al. 1997; Scott et al. 2002; Donahue et al. 2006; Fitzpatrick et al. 2007). Various categories of land-use, i.e., urban, residential, agricultural or forested catchments, have been assessed to understand the dynamics and variations of nutrients (e.g., Thornton and Dise 1998; Tong and Chen 2002; Salvia-Castellvi et al. 2005). The comparison of increased nitrates in streams draining forested, residential and agricultural catchments, for example, has shown that measured values were constant throughout the year for the residential and forested catchment, but showed seasonal variations in the agricultural catchments, attributed to fertilizer application periods (Poor and McDonnel 2007). In agricultural catchments, fluxes of nitrogen and phosphorus to surface waters have been measured to determine the influences of rate, season, chemical form, and methods of nutrient application (Carpenter et al. 1998; Schröder et al. 2004). In addition, there are natural chemical processes that influence cation exchange in upper soil horizons, weathering release of elements, and production of organic forms of chemicals (Salmon et al. 2001). Nutrient release from organic sources is more difficult to predict than from mineral fertilizers although this usually occurs during periods of low crop uptake. Vegetation builds up stores of nutrients in organic material that accumulate on top of the soils and bases and is recycled after decomposition. The cultivation of soils leads to the removal of topsoil litter and reduces the nutrient cycling capabilities of the soils. Also important is the relationship between amount of water moving through soil and the probability that individual molecules or ions will be entrained in the flow. The residence time of the rain water in the soil profile is uncertain as this depends on the surface vegetation, soil physical processes, slope, drainage, as well as antecedent rainfall which determine the soil moisture status at the start of the rainfall event (Allan 2004). Even with heavy rainfall and intense leaching, forest and riparian vegetation can serve as buffers in nutrient cycling.

The solutes of natural water represent the net effect of chemical, biological and physical processes that have dissolved material from another phase, altered previously dissolved components or eliminated them from solution by precipitation (Hem 1985). Anthropogenic activities not only directly contribute nutrients to surface waters but also interfere with natural functional processes. One example is the disruption of in-stream nutrient retention processes by which nutrients are stored, transformed and removed from the water column, reducing loads and impacts to downstream sites. Riparian vegetation planting, used for stream restoration, serves as vegetation traps and reduces the amount of nutrients and sediments from land. The increased vegetation limits light availability due to shading. This changes the way the streams transform and process nutrients by limiting the growth of the primary producers that assimilate dissolved inorganic nutrients in the water column (Parkyn et al. 2005; von Schiller et al. 2008). Primary producers upstream convert inorganic dissolved nutrients to plant biomass, such that the nutrient transport downstream is of particulate matter and dissolved organic nutrients that have lower bioavailability than the dissolved inorganic forms.

Nutrient export and in-stream concentration may also vary due to the influences of flow seasonality or storm events on hydrological connections. For example, both landscape and geological factors in the US have a strong influence on stream chemistry during summer stormflows when hydrological connections are strongest, than during autumn baseflows, when only geological influences are significant (Johnson et al. 1997; Pionke et al. 1999). Pollutant concentrations for different sites and environmental phases can therefore be highly variable spatially and temporally, and evaluations and interpretations have to be carried out carefully (Interlandi and Crockett 2003; Skoulikidis et al. 2006; Ayoko et al. 2007).

There are many national and international water quality classification schemes designed to give an indication of the status of a water body, and are based on chemical and general physico-chemical parameters, on biological indices, and in some cases on a combination of both (Dallas et al. 1999). These classifications are, fundamentally, comparisons of measured values of the concentration of a particular pollution parameter with defined limit values, usually on the basis of water use criteria. In Ghana, for example, water quality guidelines for both surface and ground water in major river basins have been established for use in domestic, recreational, industrial, livestock watering, irrigation water, aquaculture, and the protection of aquatic systems (WRC 2003a). Based on these guidelines, the three main river networks that drain Ghana have been assessed and described according to water use criteria (WRC 2003b; c; d). The Water Quality Index (WQI), is an index that characterizes Ghanaian aquatic systems into four categories – good, fairly good, poor and grossly polluted (WRC 2003a). The index describes the state of water quality compared to the objectives of its natural state, i.e., the degree to which the natural water body has been affected, and is calculated from dissolved oxygen (% saturation), biochemical oxygen demand (BOD), ammonium nitrogen (NH_4-N), faecal coliform, pH, nitrate as nitrogen (NH_3-N), phosphate as phosphorus (PO_4-P), total suspended solids, conductivity and temperature. In the south-western river drainage system, where the catchments of the current study are located, almost all the major rivers assessed belong to Class II category (fairly good) (Ansa-Asare and Darko 2006).

Effective surface water monitoring programs require the monitoring of a wide range of physical, chemical and biological parameters, and yield a complex data set of multiple parameters, monitoring times and monitoring stations, that need to be evaluated. Chemometric methods, for example, are multivariate statistical techniques that provide various assessment methods for water quality data sets, and are used to identify the natural clustering pattern and group variables on the basis of similarities between samples. Common applications involve (i) basic statistical methods for determination of mean and median values, standard deviations, minimal and maximal values of measured variables, and correlation coefficients, (ii) cluster analysis (CA), (iii) principal component analysis (PCA), (iv) factor analysis (FA), (v) discriminant analysis (DA), etc., and have been increasingly used in environmental studies (e.g., Brodnjak-Vončina et al. 2002; Kowalkowski et al. 2006; Kannel et al. 2007). Some studies have attempted to identify the most effective chemical discriminant variables for river water quality to minimize the costs associated with multiple parameter analyses, whilst others have identified chemical variables that can also be used to assess biological groupings that are more expensive and time-consuming to measure (e.g., Brodnjak-Vončina et al. 2002). Non-parametric multi-criterion decision-making methods, PROMETHEE and GAIA, for example, assessed the relationship between physico-chemical properties and water quality in developing countries, and found that water quality rankings was dependent on calcium, sulfate, sodium and chloride contents, which can therefore be used to predict a wider range of water chemistry characteristics (Ayoko et al. 2007)

2.3.4 Ecological state - Biotic fauna

The use of biological assemblages as indicators in environmental monitoring protocols, or bio-monitoring, has been invaluable since physico-chemical information only describes the condition of the stream at the time of sampling, is limited to a defined set of parameters that may exclude other important contributory factors, and possible toxic effects on biological individuals, populations or communities are not indicated (Barbour et al. 1999; Zhou et al. 2008). Biodiversity (species richness and evenness) has been identified as a central issue in ecosystem processes, as it describes other properties such as biological productivity, habitat heterogeneity, habitat complexity and disturbance (Pielou 1975). Theories to explain the patterns in biodiversity include the Intermediate Disturbance Hypothesis (IDH) (Connell 1978), which proposes that biodiversity is highest when disturbance is neither too rare nor too frequent. With low disturbance, competitive exclusion by the dominant species arises. With high disturbance, only species tolerant of the stress can persist.

Various groups such as benthic diatoms (Potapova and Charles 2003, 2007), macrophytes (Schorer et al. 2000; Haury et al. 2006), invertebrates (Sponseller et al. 2001; Moore and Palmer 2005) and fish (Karr 1981; Moerke and Lamberti 2006) are used, as the rates and pathways of response to various types of environmental stress depends on their life cycle, longevity and mobility (Triest et al. 2001; Sawyer et al. 2004; Mazor et al. 2006). In some cases, the multiple use of indicators has been advocated to provide a more comprehensive overview than single assemblages, since the contribution of responses from each group improve the overall sensitivity of the biological assessments (Dolédec et al. 1999; Statzner et al. 2001; Passy et al. 2004; Griffith et al. 2005; USEPA 2005; Carlisle et al. 2008). Studies have shown that the different assemblages show a weak concordance, since each responds to different environmental factors, and extrapolations of environmental conditions from one taxonomic group to another should be done with care (Paavola et al. 2003).

Aquatic macro-invertebrates are, however, most widely used and considered the most effective bioindicators of land use due to (i) their widespread occurrence, (ii) species richness, which offers a spectrum of environmental responses, (iii) basic sedentary nature, which facilitates spatial analysis of pollution effects, (iv) long life cycles, which incorporates pollution effects over longer periods, (v) compatibility with inexpensive sampling equipment, (vi) well described taxonomy, (vii) established sensitivities for different types of pollution, and (viii) suitability for experimental pollution studies (Rosenberg et al. 1986; Bonada et al. 2006a).

Macroinvertebrates as bioindicators

Freshwater benthic macroinvertebrates – composed primarily of insect larvae, mollusks, and worms – are an essential link in the aquatic food web, providing food for fish and consuming algae and aquatic vegetation. The most frequently observed macroinvertebrate response to increased nutrient levels in streams is a change in abundance or density (Cao et al. 1997; Perrin and Richardson 1997; Stevenson 1997). Macroinvertebrates are also used as indicators of recovery, although the actual recovery depends not only on the persistence of residual pollutants in waters and sediments after removal of the source, but also on the proximity of unpolluted waters that acts as a source of supply of new colonists, with mobile species re-colonizing much more rapidly than slow moving, such as mollusks (Besley and Chessman 2008).

The presence and distribution of macroinvertebrates in streams vary across geographic locations based on elevation, stream gradient, and substrate (Richards et al. 1996; Barbour et al. 1999). However, as indicators of water quality, natural factors such as dislodging from high river discharge can decrease invertebrate abundance, with density increasing with the amount of time since the last storm (Ramírez and Pringle 2006; Bonada et al. 2006a). During periods of no rainfall, the loss of longitudinal and lateral hydrologic connectivity, or low flows can also cause direct or indirect changes in stream nutrient concentration, dissolved oxygen or pH, and lead to fluctuations in insect density and biomass throughout the year (Parr and Mason 2003; Bonada et al. 2006a)

The response of macroinvertebrates to land-use activities, especially agriculture, has been the most extensively studied ecological topic (Paul and Meyer 2001; Bruns 2005; Moore and Palmer 2005). The distribution of communities in agricultural fields is influenced by many factors, such as pesticides (Thiere and Schultz 2004; Berenzen et al. 2005), organic matter (Woodcock and Huryn 2006), or water chemistry (Ometo et al.

2000). Some studies have indicated that the detection of impacts on macroinvertebrate patterns is more sensitive when carried out on a smaller scale (Sponseller et al. 2001; Mykrä et al. 2007), while others have shown that activities measured at larger scales (sub-basin and 8-km radius) were linked to decline in taxonomic richness, increase in numerical and biomass densities, and shifts in size structure (Martel et al. 2007).

Bio-monitoring protocols

Different taxonomy levels (family, genus, or species) have been used in aquatic invertebrate biomonitoring based on available finances, the precision of the information provided which differs among taxonomic levels, purpose of a study, the budget provided, the study area, and its taxon richness (Bailey et al. 2001; Lenat and Resh 2001; Bonada et al. 2006b). Most indices are based on family level identification, although with increasing taxonomic resolution, the level of detection of biological change also increases, thus giving greater detail in the results of stream assessment studies (Haase and Nolte 2007). It has been suggested that although family-level indictor values may be as effective as genus-level in some biological assessments, exclusive use of family-level values may be inadequate to detect some types of stressors (Carlisle et al. 2007).

Community-level approaches (as compared to sub-organismal, organismal, population, or functional feeding groups) are currently the most widely used method of monitoring, the concept being that with organic enrichment, taxa that are sensitive to the stressor reduce in numbers or are eliminated (Bonada et al. 2006b). The more tolerant taxa persist or multiply with less competition or predation, and their food supply is increased with organic enrichment. Although this provides useful information about the quality of the stream habitat, the presence or absence of expected indicator species is limiting when describing the condition of the stream, as there may be instances when certain streams do not support these particular species. In designing biomonitoring programmes, information such as the stream type being addressed, the types of stressors potentially affecting the integrity of the stream ecosystem, and the time frame of the study are therefore important (Hering et al. 2006).

To overcome these shortcomings, indices which incorporate all species within any macroinvertebrate community have been developed to characterize the stream community with the complexity of physical, biological and chemical data summarized as a single number, which statistically describes this relationship with the stream health. Biotic indices, for example, are numerical values assigned to a specific organism at a particular taxonomic level, and represent tolerance levels based on generally accepted organism sensitivities to pollution and habitat disturbance (Armitage et al. 1983; Rosenberg and Resh 1993). Metric indices, on the other hand, are calculated measures of the structure, function or other characteristics of the entire biological assemblage, which change with increased human impact.

The earliest biotic index was the Saprobian Index (Kolkwitz and Marson 1909) which used only oxygen as its major criterion of water quality. Other indices were based on the presence or absence of indicator groups or species, for example the Trent Biotic Index (T.B.I.) (Woodiwiss 1964), or on simple values that described the degree of pollution, such as the Chutters empirical biotic index of water quality (Chutter 1972) and Hilsenhoff's biotic index (Cook 1976; Hilsenhoff 1987). Recent indices establish a scale of eutrophication with assigned tolerance levels of taxa based on their distribution in different ranges of specific environmental variables, e.g., the land-cover optima (Black et al. 2004), or the nutrient biotic index (NBI). These score thresholds and corresponding nutrient concentrations for total phosphorus (NBI-P) and nitrate (NBI-N) (Smith et al. 2007) for macroinvertebrates, such that a taxon will be in greatest abundance at a site with environmental variables closest to its optimum. Because biotic indices incorporate the pollution tolerances of indigenous taxa, values and distribution of macroinvertebrates have been modified to be regionally specific, e.g., Britain's Biological Monitoring Working Party (B.M.W.P) (BMWP 1978), SIGNAL in Australia (Chessman 1995, 2003), the ASPT index in Britain (Hawkes 1997), the ASPT index of the South African Scoring System (SASS) (Dickens and Graham 2002), or the Spanish average Biological Monitoring Water Quality (a-BMWQ) score (Carmago 1993).

The most common metrics used in environmental health assessments include the various diversity indices, e.g., Simpson's and Shannon diversity index, which describe the distribution of individuals within a taxa, taxa richness, EPT (Enteromorpha Plecoptera Trichoptera) index, EPT and Chironomidae index, which indicates the balance of community between sensitive (EPT) and less sensitive Chironomidae taxa, ETO (Ephemeroptera, Trichoptera and Odonata) index which are sensitive to pollution, percent (%) contribution of dominant family, community loss index, among others (Plafkin et al. 1989). The more traditional measures of evenness, richness or abundance can, however, be strongly influenced by sampling size, sampling effort, habitat type of complexity, and may not be entirely representative of human impacts (Leonard et al. 2006).

To overcome diversity problems resulting from natural variations, the measure of the average degree to which individuals in an assemblage are related to each other (taxonomic distinctness) has been proposed. Although applied to marine environments (Warwick and Clarke 1995, 1998), the theory is that as a result of anthropogenic impacts, disturbed communities tend to have reduced taxonomic distinctness and are composed of more closely related species than those in pristine areas, where taxonomic distinctness is greater due to more taxonomically distant species (Clarke and Warwick 2001a). When applied to inland waters, the taxonomic diversity measures were not able to identify human disturbance effects, and did not perform as well as other metrics (Abellán et al. 2006).

Multivariate approaches also assess human impacts, but rather compare patterns observed at test sites absent of human impact and use statistical analysis to predict expected patterns at impacted areas. Biological classifications, e.g., the River InVertebrate Prediction and Classification System (Wright et al. 1984; Clarke et al. 1996), BEnthic Assessment SedimenT (BEAST) (Reynoldson et al. 1995), and Assessment by Nearest Neighbor Analysis (Linke et al. 2005), are developed for macroinvertebrates at an unstressed or reference site, and predictions are made for impacted sites based only on physical and chemical features of the environment, with the contribution of influencing natural conditions taken into consideration (Prins and Smith 2007). While metrics reduce complicated data sets into single values, making it more understandable to non specialists, potentially important information is lost in the calculation process. The use of biotic indices in general requires careful interpretation as, in places where human impacts are widespread and severe, the dominant patterns may be closely related, but where impacts are subtle or affect only a few study sites, the dominant patterns may reflect natural variation (Besley and Chessman 2008). In contrast, multivariate techniques retain more of the information on taxa within a sample and are more effective in determining the effects of changes in water quality on biological assemblages (Bonada et al. 2006b).

2.3.5 Policy response

In developed countries, extensive assessment and monitoring programmes have formed the basis of various integrated water policies for the protection and improvement of sustainable use of all waters, for example, the Water Framework Directive of the European Union (EC 2003). Although the specifics vary between countries and regions, four main components generally contribute to comprehensive management strategies, (i) policy and sector work, (ii) research and technology, (iii) knowledge sharing and extension, and (iv) incentives, expenditure priorities and modes of financing (World Bank 2006). Policies are in response to established linkages between the objectives of the ecological state and the responses needed to solve the problem. They consist of different decision-making frameworks for setting environmental objectives, designing and implementing measures to achieve environmental objectives, and assessment of policies (Rekolainen et al. 2003). In addition to biophysical parameters, policies incorporate the complex social complexes that govern human perceptions of their living conditions and ecological conditions. In sub-Saharan Africa, one major constrain to effective policies is the poor investment in research, less than 5% GDP, needed for appropriate nutrient monitoring and management at the appropriate scales (World Bank 2006). There is inadequate knowledge and access to appropriate knowledge and technology to assess, for example, cropping patterns and practices, extent of degradation, unfamiliar farming systems by immigrants, downstream impacts, etc.

There is a strong dependency on the availability of natural resources in sub-Saharan Africa, and the socio-economic implications of deteriorating ecosystem health and biodiversity loss are serious enough to compromise community livelihoods, such as fishing and agriculture. Vulnerability to the threats of environmental change is increased by poverty, and results in intensified pressure on the environment such that the ultimate goal of sustainable development is eventually retarded. With high poverty rates in Africa, vulnerability to environmental threats is also high, as the poor tend to have much lower coping capacities (UNEP 2007). Sub-Saharan Africa remains the only region in the world where there was an increase by 23 and 30% of the number of people without access to potable water and sanitation, respectively (WHO/UNICEF JMP 2006). This means that more than 300 million people depend on natural streams and rivers for all domestic purposes like drinking, washing, cooking and bathing. Deteriorating water quality as a result of increased inputs not only affects the health of those who rely directly on the water for domestic activities but also can have serious social consequences, as parasitic hosts may become dominant and leads to increased incidences of bilharzia, malaria, and onchocerciasis (Shahin 2002).

In Ghana, the Ghana Poverty Reduction Strategy (GPRS), a comprehensive framework of policies and strategic initiatives that was initially launched in 2002 for the purpose of achieving economic growth and poverty reduction (GoG/NDPC 2003), was criticized for not addressing the essential aspects of environmental consequences. The Strategic Environmental Assessment (SEA) carried out from May 2003 to August 2004 assessed GPRS policies to determine the potential environmental opportunities and risks involved, and recommended the incorporation of environmentally sustainable policies into its implementation (GoG/NDPC 2003). In 1996, a Water Resources Management (WARM) study provided an overview of major water resources issues that enabled the establishment of institutional frameworks, such as the Water Resources Commission (WRC), for integrated water resource management (IWRM) on a sustainable basis. Water allocation and use is the Commission's major task, and is mandated with regulating and managing the country's water resources and coordinating government policies in relation to them. The main implementing and research institutions for setting environmental standards are the Environmental Protection Agency (EPA) in collaboration with the Water Research Institute (WRI) of the Council for Scientific and Industrial Research (CSIR). In support of the IWRM principles, the Danish International Development Agency (DANIDA) has provided institutional collaboration and capacity building to WRC, and between 2004 and 2008, focused on introducing IWRM at decentralized level through the creation of river basin based water management structures, and capacity building and awareness raising at the District Assembly level (WRC 2009).

Regardless of the types of institutional organization or agricultural intensity, nutrient losses from agricultural land occur in different countries, and choosing appropriate policies is a complicated process since farm management responses and environmental effects do not always coincide in time and space (Novotny 1999). Effective environmental policies and regulatory measures range from economic incentives and stimulate nutrient management practices to fees on undesired practices and outputs (Pagiola et al. 2004). There is a wide variety of indicators available for evaluating the effectiveness of farm management objectives, with each having its own pros and cons and none being effective, comprehensive, efficient, responsive and attributable at the same time (Pannel and Glenn 2000; van der Werf and Petit 2002; Schröder et al. 2004; Yli-Viikari et al. 2007). Despite validation limitations, indicators that are based on the environmental effects of farmer practices (effect-based) have been found preferable to those based on farmer production practices (means-based), since the link with the objective is direct and the choice of means is left to the farmer (van der Werf and Petit 2002).

3 STUDY AREA

3.1 General description

The study area is located in the Ahafo-Ano South District, northwest of the capital city Kumasi of the Ashanti Region (Figure 3.1). The sites are upland sub-catchments of the Ofin River Basin, within the south western river system of Ghana. The district capital is Mankranso, 32 km away from Kumasi, on the Kumasi-Sunyani road. The district covers an area of 1,126 km^2 and has a population of 133,874 (Ghana Districts 2006). Ahafo Ano is derived from the Akan word 'ahayo', which means hunting - as the district formed part of the hunting grounds for the Asantehene (the king of the Ashanti ethnic group).

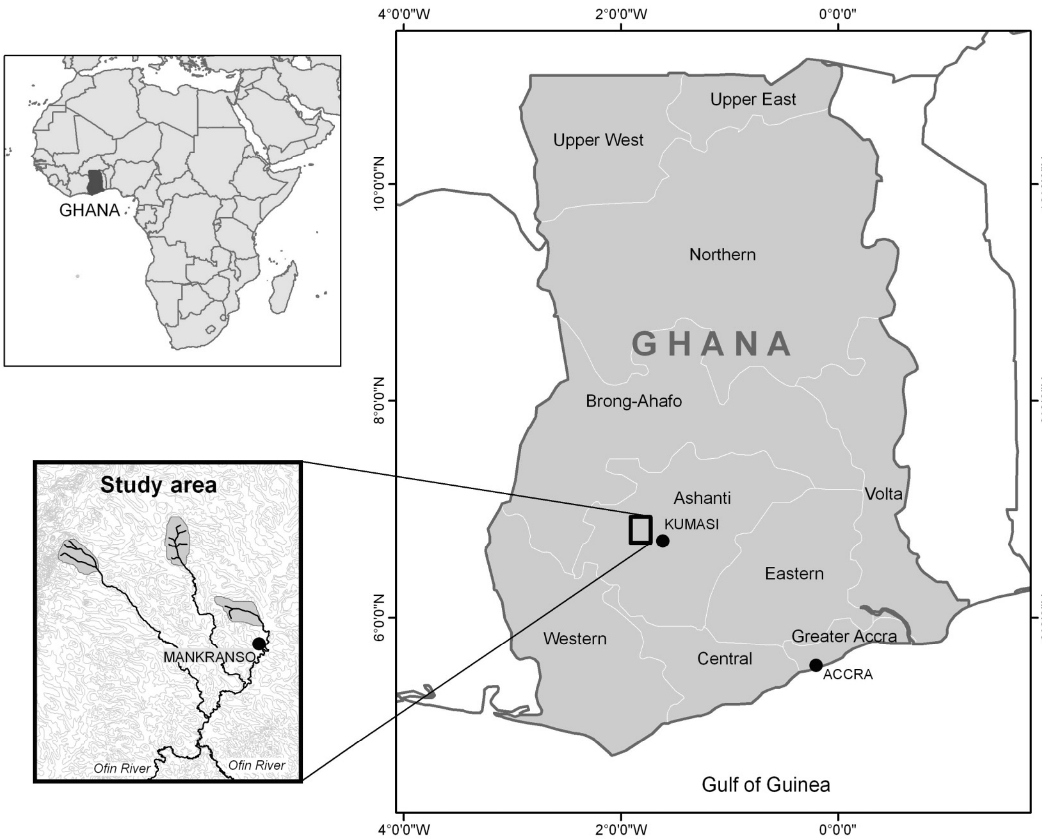


Figure 3.1 Map of Ghana showing the three upland sub-catchments and general study area in the Ashanti Region.

3.1.1 Climate

The climate of Ghana, as in the rest of West Africa, is influenced by the position of the Inter Tropical Convergence Zone (ITCZ) (FAO 2004a). The ITCZ is the boundary between two air masses: (i) the dry tropical continental air mass which gives rise to the North East (NE) Trade Winds ('harmattan') and blows from the northeast across the Sahara during in the dry season, and (ii) the South Atlantic Maritime Air Mass referred to as the South Westerly (SW) Monsoon which brings moisture into the area from the sea during the rainy season.

The Ashanti Region has a bi-modal rainfall regime typical of a moist semi-deciduous forest zone. Two defined rainfall seasons occur annually: (i) a major season with heavier rains from mid March to the end of July with peak rainfall in June, and (ii) a minor season with lighter rains between September and November, with a relatively short dry period in July and August. The warm moist SW monsoon winds dominate during the rainy seasons, and the NE harmattan winds from December to March.

Rainfall

Rainfall in Ghana generally decreases from south to north. The wettest area is the extreme southwest, where annual rainfall is over 2000 mm, and the driest is a strip in the east (Takoradi) that extends up to 40 km inland, where rainfall is less than 750 mm (FAO 2004a). In the Ahafo-Ano district, the mean annual rainfall is 1200 mm (Ghana Districts 2006), although monthly and annual totals as well as seasonal distributions vary from year to year.

Relative humidity

Mean monthly humidity values range from 87-91% from 0900 hours and decrease to 62-78% by 1500 hours. The relative humidity is usually lowest during the harmattan period from February to April (83-87% in the morning and 48-67% in the afternoon), and the highest during the wet season from June to October (Adu 1992).

Temperature

Temperatures are uniformly high throughout the year. Mean annual figures are around 26°C, with the hottest periods in February and March (28°C), and the coolest in July and August (24°C) (Meijerink et al. 2003). Variations between day and night temperatures are greater during the dry than wet seasons. The period July-August is markedly cool, dry and more cloudy than the rest of the year. The main dry season is less cloudy but more hazy. The cloud cover is at its maximum in the early mornings and slowly decreases until 2100 hours (Adu 1992).

Wind

Wind speeds are generally low with an average speed of 8 km hr^{-1} (Adu 1992). Speeds are lowest at night and during the early morning, during which a high percentage of calm occurs, and highest in the middle of the afternoon when average values rise to 8-16 km hr^{-1}.

3.1.2 Physical features

Geology

Geomorphologically, the Kumasi region forms part of a dissected peneplain from which inselbergs or mountain ranges rise. Soils are developed over phyllites, granites, Tarkwaian and Voltaian sandstone rocks (Junner 1940; Moon 1962). Underneath, most of the Ahafo-Ano South District is made up of lower Birrimain rocks, which consist mostly of phyllites, greywackes, schists and gneisses. These contain clay deposits subsequently hardened and altered by heat and pressure, and due to few soil minerals present, are not rich. Two to three meters below the surface is weathered phyllite, which is soft and easily broken. During weathering, uneven distribution of veins and stringers of quartz in the phyllite break up and produce varying abundance of stones and gravel, which greatly reduce the capacity of the soil to store water and plant nutrients (Adu 1992).

Drainage

The Ahafo-Ano South District is part of the Ashanti Plateau and has an undulating landscape with a medium highland area between 150 to 600 m above sea level. Among the hills with high elevation are Aya, Kwamisa and Tunte. The major rivers in the district are the Mankran, Abu and Aboabo. River Abu, the largest river, originates from the Kwamisa Hills and flows south-west (Ghana Districts 2006). Within the catchment area of the Ashanti Region, the Ofin River is fed by a number of secondary rivers and streams such as the Oda and the Jimi.

Soils

The soils in the study area form the *Bewai-Nzima/Oda* (Class 1) compound association (Orthi-ferric acrisol classification), and the *Bekwai-Zongo/Oda* (Class 4) complex association (Plinthosol classification) (Adu 1992). Associations are defined as larger groupings of soil series that have related parent material and similar profile morphology but are differentiated by relief and drainage. The *Bewai-Nzima/Oda* association occupies a large part (55%) of the Ashanti region, and the component soils occur in a definite topographical sequence: soils on the summits, upper and middle slopes are red, well drained (*Bekwai* series) and brown, moderately well drained (*Nzima* series) concretionary, silty clay loams; soils on the middle to lower slopes are brown to yellow brown imperfectly drained silty clays and silty clay loams (*Kokofu* series) developed from colluvium or hill wash material; and soils on the valley bottoms are grey, poorly drained alluvial loamy sands (*Temang* series) and clays (*Oda* series). The *Bekwai-Zongo/Oda* class is similar, but is characterized by large exposures of seepage ironpan soils (*Zongo* series), which consist of about 30 cm yellow brown imperfectly drained, clay loams containing ironpan boulders, which grade below into 90 cm of vesicular ironpan. This layer occurs above weathered phyllite and occurs extensively on lower slopes to flat land (0-2%) and about 6 m above the major streams traversing the tract.

3.1.3 Land use and agriculture

Based on the *Bewai-Nzima/Oda* compound association, the soils of the upland sub-catchments have been classified as Moderately Good Lands for agriculture (Adu 1992). These lands are generally medium textured, highly or moderately gravely, or deep and non-gravely, and well, moderately well and imperfectly drained. They occur on gently undulating topography (3-8% slopes), where exposure to erosion is slight to moderate under mechanical tillage and careful management. The upland and slope soils are recommended for all tree and arable crops, and the valley bottom soils for rice, sugarcane and vegetables.

Further downstream are the *Bekwai-Zongo/Oda* compound association soils, which have been classified as Fair Lands for agriculture. These soils are very shallow or shallow, very stony, very gravely or have ironpan subsoils, and range from well to imperfectly drained and occur along lower slopes to summits (3-12% slopes). Water holding capacity is fair to very low, and the soils are easily susceptible to drought. Hand cultivation only has been recommended with land-use being restricted to tree crops or woodland, and the valley bottom soils used for rice, sugarcane and vegetables.

3.1.4 Vegetation

The natural vegetation is typical of semi-deciduous rain forest and is characterized by plant species of the *Celtis-Triplochiton* association (Adu 1992). None of the original vegetation exists outside of the forest reserves, since most of the lands have been converted to agriculture. There is also a long history of intensive shifting cultivation such that the current vegetation is a variety of fallow farmlands consisting of secondary forests, thicket, forb re-growth and swamp vegetation. There are six forest reserves (Tinte, Opuro River, Kwamisa, Asufufu, Shelta Basin and Offin North) which cover a total area of 300 km^2 (Ghana Districts 2006).

3.1.5 Social Setting

All land in the Ashanti Region is controlled by the Asantehene, with farms owned by residents through inheritance or leased by immigrants. Production of crop farms is based on shifting cultivation, and crops are usually grown in mixed stands especially during the first few years of cocoa farming. Cocoa is considered the main cash tree crop, although small citrus and oil palm plantations are scattered throughout the region. The major agricultural cash crops are plantain, cocoyam, cassava, and vegetables such as tomato, okra and garden egg (Asomaning unpublished in Meijerink et al. 2003).

The district is mainly populated by Ashantis with settler farmers from the Dagomba, Ewe Gonja and Basare ethnic groups. The population is 45% Christian, 30% Muslim and 25% animists, with 80 primary schools, 30 junior secondary schools and one senior school in the district (Meijerink et al. 2003). There is no district hospital, although there are three health centres located at Mankranso, Mpasaso and Sabronum. There are also four private clinics managed by the Roman Catholic and Methodist churches and two village health posts. In many villages, there are herbalists and chemical sellers.

3.2 Sample site description

In addition to the three upland sub-catchments (Attakrom, Dunyankwanta and Nyamebekyere), eight sites were also assessed for ecological response to stream physico-chemistry (see Chapter 6). These include Mankranso, Kunsu, Nyasi, Borosase, Afrensini, Akuapem, Ntabanu and Beposo, located along the three river systems (Mankrankese, Mankrankuma and Nyasi) that originate from the upland catchments (Figure 3.2).

The three upstream sub-catchments were characterized by the VINVAL Project based on the proportion of agricultural and natural land, into three major classes: (i) Attakrom, a well established community with high land-use intensity, (ii) Dunyankwanta, with ample land, is characterized as medium land-use intensity, and (iii) Nyamebekyere, a village that was established relatively recently, is demarcated on one side by the Tano national forest reserve and has relatively low land-use intensity (Meijerink et al. 2003). The labeling of the mid- and downstream sites is based only on the typology of the upland catchments that each stream originates from, and is not representative of nearby land-use intensity (Table 3.1).

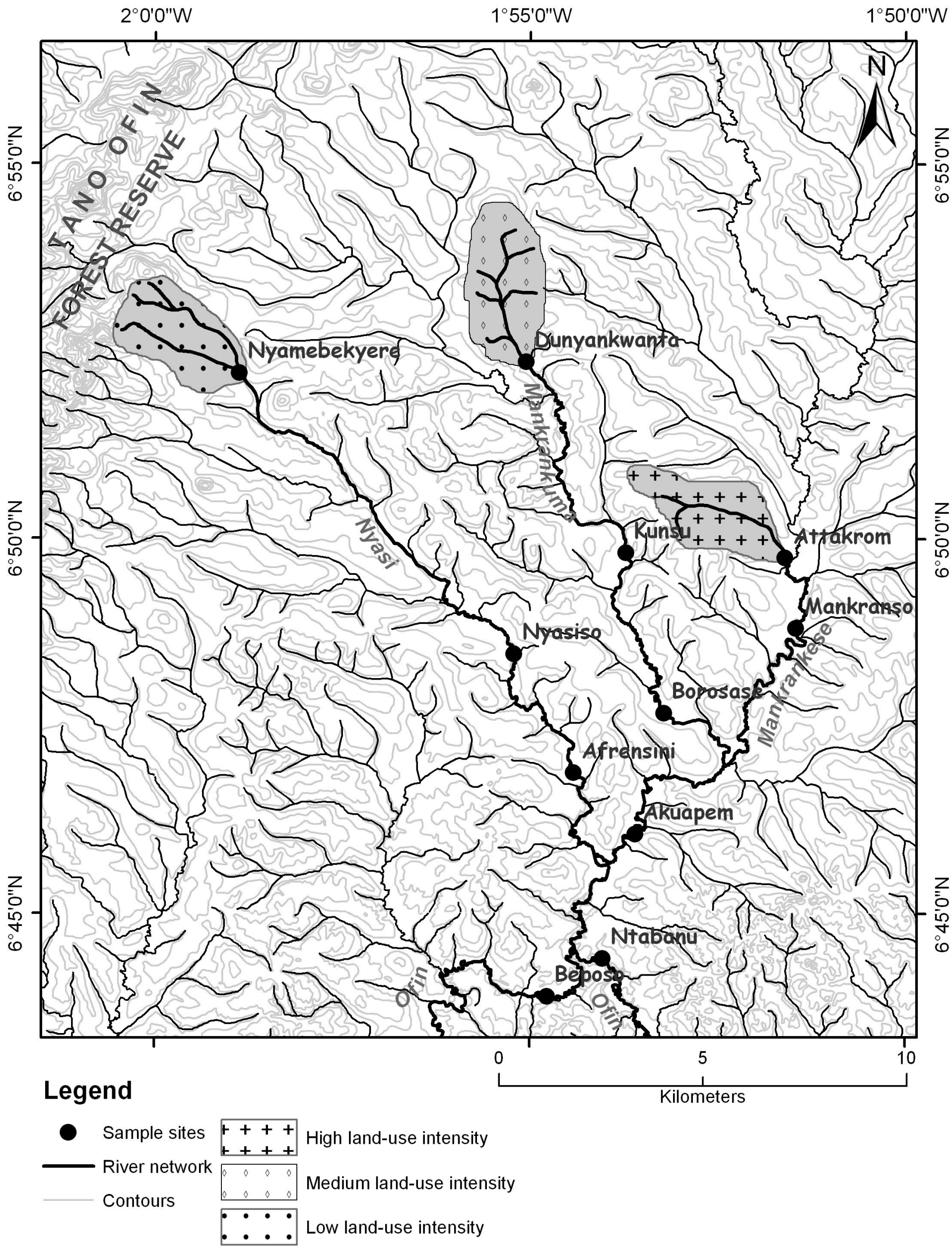


Figure 3.2 Map of study area showing upland sub-catchments and downstream sites

Table 3.1 Sampled sites with river systems, identified by stream level and upstream land-use intensity; L=low intensity, M= medium intensity, H = high intensity, 1 = upstream, 2 = midstream, 3 = midstream lower sites; HM4 = merged midstream lower sites (M3 + L3); Ofin1&2 = Ofin River 1 (pre-entry) and 2 (post-entry).

Name of Area	Site #	River	GPS reading	
Attakrom	H1	Mankrankese	06°49.030’	001°51.474’
Dunyankwanta	M1	Mankrankuma	06°50.137’	001°51.724’
Nyamebekyere	L1	Nyasi	06°52.228’	001°58.777’
Mankranso	H2	Mankrankese	06°49.025’	001°51.483’
Kunsu	M2	Mankrankuma	06°49.359’	001°53.893’
Nyasiso	L2	Nyasi	06°48.689’	001°55.197’
Borosase	M3	Mankrankuma	06°47.834’	001°53.246’
Afrensini	L3	Nyasi	06°.46.983’	001°54.366’
Akuapem	HM4	(Mankrankese + Mankrankuma)	06°44.184’	001°53.574’
Ntabanu	Ofin1	Ofin (before Mankrana merges)	06°46.179’	001°53.575’
Beposo	Ofin2	Ofin (after Mankrana merges)	06°44.535′	001°55.595′

3.2.1 Upland Catchments

The three upland catchments with varying degrees of land-use intensity were the main focus of the research. The following sections describe each catchment, with general characteristics summarised (Table 3.2).

Attakrom

The Attakrom catchment covers an area of 5.14 km^2, and represents the high intensity land-use category. In addition to the main Kumasi-Sunyani road that passes near the village, there are other minor motor roads and footpaths to the surrounding villages. During the dry season when there is no water in the stream, the villagers go for water to neighboring villages such as Bronikrom and Amakom. The rivers there are associated with diseases such as bilharzia, guinea worm, and leaches, especially when water flow is low (Meijerink et al. 2005).

The Obinpeiopyie stream passes through a double opening culvert, under a bridge on the major road to Sunyani, into the Mankrankese. Stream flow varies depending on the frequency and duration of storms, and dries up when subsequent rains are more than two weeks apart.

Dunyankwanta catchment

The Dunyankwanta catchment is classified as medium land-use intensity and covers an area of 6.41 km^2. Farming of food crops is the dominant activity, although about 30% of the farmers own some livestock (sheep) and poultry (Meijerink et al. 2003). In the early 1980's, three boreholes were constructed, which have water all year round and are used for domestic purposes. The main stream is the Mankrankuma that joins the main Mankran River. The Mankrankuma has 5 tributaries: Ayiwora, Adjuku, Senai, Amapenso and Danyame. It starts flowing in June and dries up in December.

The Senai stream flows through a constructed W-weir outlet, into the Mankrankuma. The stream flows at varying periods and depths throughout the rainy season depending on the intensity and frequency of rainfall. Flows may last up to 5 days after a heavy storm, and water color varies from clear to reddish-brown as a result of bamboo leaves and other decaying vegetation. During low flows, there is only one isolated small deep pool (artificially made by the locals) and the immediate riparian zone consisted of a thick brush of large bamboo plants and various kinds of natural vegetation.

Nyamebekyere catchment

Nyamebekyere is classified as low land-use intensity catchment and covers an area of 5.74 km^2. In the last 50 years, the forest was opened up for agricultural purposes, and from 1958-1960, a timber contractor (Owusu Amankwatia) was given a consignment in the forest reserve where he constructed the untarred road and the bridge in 1968 (Meijerink et al. 2003). The village is small and isolated and is not well connected to other villages and towns. Vehicles come to the village only on Fridays because of the Kunsu market. Firewood, fruits and other minor products are collected from the forest, but hunting and logging are prohibited. There is no fishing, as the river dries up almost immediately after a storm. There are three first-order streams that are located in the Forest Reserve: the Nyasi, the Anikokoo and the Aseka, with the latter two flowing very briefly after storms. The forest reserve has no cultural or religious value for the farmers in Nyamebekyere, and there is no sacred grove. However, there are various taboos and local customs for natural areas.

The Woramumu stream flows through a double culvert under a bridge of an untarred road to the Nyamebekyere village, into the Prabon and then the Nyasi further downstream. It may last from 5-48 hours after a rainstorm.

Table 3.2 Characteristics of the upland sub-catchments

Characteristic	Attakrom	Dunyankwanta	Nyamebekyere	Unit
Area of watershed	5.14	6.41	5.74	km^2
Watershed perimeter	12.46	11.61	11.78	km
Length of watershed	14.61	13.32	11.60	km
Average width	7.66	6.47	5.68	km
Stream length to Ofin	70.92	88.82	80.66	km
Average elevation	213.36	276.50	358.73	masl
Maximum elevation	243.84	320.04	411.48	masl
Minimum elevation	213.36	243.84	289.56	masl

3.2.2 Downstream Sites

To improve the understanding on interlinkages between stream physico-chemistry and macroinvertebrate communities, selected sites were included in this study. The following sections provide descriptions of each site.

Mankranso

The sampling point is at N 06°49.025′ and W 001°51.483′ on the Mankran River about 2 km from the Attakrom outlet. The town, Mankranso, is named after the river and is a center where the district headquarters of the Ahafo-Ano South District, community hospital, police station, and other public facilities that serve the entire district are located. On the outskirts of the town along the banks of the river, there is some farming (cocoa, oil palm, plantain, rice and cassava). There is also river fishing on both domestic and commercial bases. The main method of fishing is by hook and net during the rainy season, and it is illegal to use chemicals for fishing. During the dry season, mostly mudfish is caught. The smaller villages on the outskirts of the Mankranso burn charcoal for sale in the town.

Five boreholes provide water for the town at a cost of ¢100 (€0.01) per bucket. The money collected is used for repairs and maintenance. Piped water is also available for the community, and there is a community reservoir in case of shortages. The river water is used for washing, and although children normally swim and fish, the water is boiled before use for bathing, as there have been incidences of bilharzia. It is strictly forbidden to wash cars near the streams, as locals are aware that oil and car grease can contaminate the streams for downstream villages. The locals are considerate of any activities that would affect downstream users. Traditional taboos include forbidding menstruating women near or into the river, women near the river on Tuesdays, or any utensil that has been used on the fire (mostly cooking pots).

The Mankran River flows under the bridge that leads off the main Sunyani road to the Mankranso District area. Two large gutters drain from the town into the stream, but the sampling point was selected upstream of where the gutters enter the river. The main town Mankranso town ends about 50 m from the river. The stream flows for most of the year except for the dry season between February and the start of the rainy season.

Kunsu Mankran

The Kunsu Mankran site is located at N 06°49.359′ and W 001°53.893′, on the Mankrankuma River, which is approximately 6 km from the Duyankwanta outlet. The river flows through a large culvert opening under a bridge on the main Kunsu road that leads to the Nyasiso village about 3 km away. There are no villages immediately surrounding near this site.

Nyasiso village

The sampling point is located on the Prabon River at N 06°48.689′ and W 001° 55.197′, approximately 9 km downstream from the Woramumu stream outlet from the

Nyamebebekyere catchment. The Nyasiso village lies about 20 meters from the stream and has about 30 homes. There are many other smaller communities on the outskirts of the village. The bridge over the stream was built in 1935 and is on the main road from Kunsu that goes to other large villages close to the Ofin River – the Bonkwaso and the Abesua. Mixed crop farming is the major activity with small plantain, cassava, cocoyam, and maize farms, in addition to a few cocoa, oil palm and orange plantations. The trees are secondary forest, with trees depleted by logging. There is still one active logging company. There is no charcoal burning in the village. About 30% of the villagers own livestock – mostly chickens, goats and sheep, and only one person owns ducks. Friday is the Kunsu market day, when there is no farming and produce is taken to the market to be sold. No fishing is allowed in the stream when it is flowing, only when there is standing water. Lanterns, cooking pots and any other utensils that are used on a fire are not allowed anywhere near the streams, although torch lights are allowed. Menstrual women are not allowed near or in the streams.

The main source of water until 2004 was the stream, which was used for bathing, washing, cooking and other household uses. When the stream stopped flowing during the dry season, the locals dug holes in the stream beds to access the underground flow. A borehole was later constructed for which the villagers pay ¢2,000 (€0.19) per month per person. The villagers complain of skin worms after contact with the water. Mention was also made of guinea worms and bilharzia, which the villagers reported last occurred in the late 1990's.

In Nyasiso, the locals explain that since they can not afford fertilizers, there is little application on crops. According to them, there was some application many years ago but only as part of a demonstration project. Currently, few farmers use herbicides, based on advice given by the agricultural extension officers who come infrequently. The only other kind of support that has, up to the time of the survey, been given to the villagers is the provision of day-old chicks (52 chicks for each individual). The villagers are taught how to rear these until they are 3 months old when they are then sold.

The river flows through a single opening culvert under a bridge on the main untarred road that leads from the Kunsu town to Boatenkurom and connects to other smaller roads that network various villages throughout the area. The stream flows for most of the year except from February to the beginning of the major rainy season. During low flows, the stream channel is approximately 10% filled.

Afrensini

The Afrensini site is located at N 06°46.983´ and W 001°54.366´, on the Nyasi River and is approximately 10 km from the Nyamebekyere outlet. The river flows through a large culvert opening under a bridge on an untarred road off the main Kunsu-Mankranso road. There are no villages near this site. The river starts flowing at the start of the major rainy season and dries up after December, during the harmattan.

Borosase

The Borosase site is located at N 06°46.179´ and W 001°53.575´, downstream of the Mankrankuma River. The river flows through a large culvert opening under a bridge on an untarred road off the main Kunsu-Mankranso road. There are no villages located around this site. The river also flows for the most part of the year, with discharge at the start of the major rainy season until early December.

Akuapem

The sampling point is located at N 06°46.184´ and W 001°53.574´ about 0.5 km from the Akuapem village on the Mankrana River, with the Mankrankuma (from Dunyankwanta catchment) and the Mankran (from Attakrom) as its major sources. The Akuapem village has approximately 56 homes, with about 20 small hamlets comprising a few homes near the village. The nearest largest villages are the Ntabanu and Banchease. Most of the villagers originated from the Eastern Region of Ghana, and established the village during the 1939 earthquake. Mixed crop farming is the main activity, and some households own ducks, goats, chicken and sheep. Fishing is not a common activity. Agricultural extension officers from the district office infrequently visit and advise groups on planting, application of chemicals, etc.

The two boreholes in the village are the main source of drinking water, and cost ¢100 per bucket (€0.01). The river water is used for other domestic activities such as washing and bathing, although cases of skin disease and bloody urine have been reported. Market days are on Fridays, when villagers sell harvested produce at the Kunsu town. Tuesdays are considered as days of rest, when farming and women going near the rivers for fetching water, bathing or washing is forbidden. Libations are poured into the river on this day to celebrate special ceremonies for births, deaths, marriages, etc., which may have occurred during the course of the week.

During the dry season, the Mankrana River is about 20% of the channel is filled with water, and there are exposed tree roots in the sandy sloping banks. There are some cocoa and orange plantations in the vicinity of the sampling point. One major complaint of the farmers is that during the rainy season, for a period of 2 months when the river is completely flooded, access to the farms is restricted. Plans to build a bridge were halted by financial constraints. As an alternative, the farmers sometimes hire a car to access the farms from the other side of the river, but it is expensive. Eventually, most of the harvest is lost, as crops over-ripen and rot during this period.

Ntabanu

The sampling point is located at 06°46.179′ and W 001°53.575′, 1 km before the Mankrana River merges into the Ofin River, approximately 0.5 m from the Ntabanu village. The Ntabanu village is found at the end of the untarred Mile 19 road, which extends off the main Sunyani road. There are about 55 homes in the village, with 30-40 other smaller communities on the outskirts of the village. Akuapem is the only other larger village in the area. Mixed crop farming is the main activity, with some use of herbicides and fertilizers. Cocoa is the main crop that brings income, but crops such as cassava, plantain, and maize are planted between the cocoa plants for domestic use. There is some input from the agricultural extension officers, but their visits are irregular and they can register, advice and provide financial assistance to only those who are available. This alienates the other farmers who show disinterest in any information shared. Fishing in the river is mostly for home consumption and approximately 70% of the homes own only sheep, guinea fowl or chickens; goats are considered a taboo in the village. Hunting is not a common activity, not even the setting of traps. There is irregular logging by different companies at different periods, and charcoal production is by a few people for domestic use only.

There are no boreholes in the community, and the stream is used for all domestic purposes. There are plans by the district and the community to construct a borehole, as the villagers complain about blood in their urine and skin diseases in children. Tuesdays are rest days when farming is prohibited and libations are poured in the river. Menstruating women are not allowed near or into the river. There are no sanitary facilities for the villagers, although some individuals have constructed pits that may be used by others. There are plans to construct a communal pit, but currently most of the villagers go into the bushes.

Beposo

The sampling point is located at N 06°44.535´ and W 001°55.595´, 2 km from where the Mankrana River enters the Ofin River. The village near the Ofin River is called Nigeria and consists of about 20 homes. There is a large bridge that was built by the military to transport crops from other villages across the river. Mpasatia is the largest town approximately 10 km away, off the main highway from Kumasi to Adiambra. There are no schools in the surrounding villages, expect in two distant villages. Mixed crop farming is the main activity for domestic and commercial consumption. Common crops are cocoa, oil palm, plantain, cassava, cocoyam, and maize, and the use of fertilizers and herbicides is limited. Most villagers own livestock such as chickens and sheep. Goats are however forbidden, as it is a taboo against the river god.

There is only one borehole for the village 1.5 km away, which was established in June 2006. The river is used for all domestic activities including bathing, washing, cooking, drinking, etc. Fishing is done on a domestic scale, with the *Tilapia* sp. being common especially in the dry season. There are some health problems associated with the use of the water, mostly skin diseases and blood in urine, and in the dry season the water is boiled before use. Traditional taboos include ban of farming on Tuesdays, and no one is allowed to cross over the bridge with farm products until after 6 pm. Harvest is allowed on Fridays, but not any manual work such as weeding or planting. Women are not allowed near the river when menstruating, not even to cross the bridge. The only hospital/clinic is at Mpasatia, but one has to wait for a bike or car.

The Ofin River is perennial, and the stream fills about 1% of the flooding area during the dry season. During severe rainstorms, the river may flood the village, also affecting farms along the banks of the river.

4 LAND USE AND FARMING SYSTEMS

4.1 Introduction

Land-use dynamics result from the interaction between society and the environment, and methods available to assess its major drivers are usually based on both socio-economic and biophysical parameters (Lambin et al. 2001; Claessens et al. 2008). These assessments, which require measurable biophysical parameters (e.g., vegetation cover, crop types, nutrient inputs) and detailed socio-economic information (e.g., demography, market, institutions, technology), are beyond the scope of this study since extensive data sets are usually required for evaluation by land-use models (Agarwal et al. 2002; Robinson et al. 2007). For this study, the determination of the major driving forces of land-use (D in the DPCER conceptual framework) assumes that there are significant biophysical differences between the study catchments with varying degrees of land-use intensity, which will be reflected in the stream nutrient assessments ('P' and 'C' of the framework), since differences in vegetative cover, soil inputs, and related processes will influence the release of nutrients from soil into the aquatic system in different ways. Total stream nutrient loads and concentrations for each catchment stream are estimated in Chapter 5. Parameters such as nutrient sources, nutrient transport and pathways, or nutrient transformations from land to stream are not included in the evaluations.

Since agriculture is the main source of people's livelihood in developing countries and in many rural areas, farming systems are the major drivers of land-use. The opportunity to increase incomes and earn profits is the primary incentive for agricultural intensification, i.e., a more efficient use of production inputs using improved seed varieties, input of agrochemicals, more efficient use of labor, and better farm management (Dixon et al. 2001; Solano et al. 2001; Abdoulaye and Sanders 2005; Dar and Twomlow 2007). However, a farmer's perception of benefits and capacity for increased output is influenced by numerous socio-economic and cultural factors. The objective of this part of the study is to compare selected socio-economic variables that influence agricultural intensification in Ghana, assess the basic cropping systems, and to investigate the relationship that farmers have with the catchment water resources.

4.2 Methodology

A meeting was first arranged with the village chief and elders of each community to introduce the four members of the research team (which included three field assistants who also acted as translators and handled the protocol) before the field work was undertaken (i.e., water and biological sampling). The surveys were carried out in stages, with an initial qualitative exploratory appraisal for both upstream and downstream sites, followed by quantitative interviews of the communities only in the upland catchments, i.e., Attakrom, Duyankwanta and Nyamebekyere. The aim of the initial appraisal was to obtain a general description of the communities (presented in Chapter 2).

The questionnaire (Appendix 1) was pre-tested on two separate occasions (March and May 2006) in the upland catchments, with adjustments made to improve unclear questions and incorporate additional important factors. In the first pre-test, the author was assisted by three researchers from the Soil Research Institute, and in the second by two community teachers. For each catchment, a team of two teachers, who worked and lived in the assessed area and were well-known and respected in the community, also administered the questionnaires. They were selected based on their educational level and personal knowledge of the community. The second pre-test also served as a training session for these teachers. Each team had a lead person who was involved in other research duties (daily recording of the manual rainfall gauge). The actual survey was carried out in July-September 2006 during the minor dry season when farming activities had slowed down and the community teachers were on long holidays.

In selecting important socio-economic factors that contribute to increased agricultural activities in Ghana, different literature sources were consulted (DFID 2001; Drechsel and Zimmerman 2005; Kelly 2006; Oduro and Osei-Akoto 2008). Livelihood assets, as described by the Sustainable Livelihoods framework, for example, describes categories of properties that a farmer has that determines his livelihood (in this case, farming system) and influences his living standard (DFID 2001). These categories include (i) human capital, i.e., skills, knowledge, ability to work and health, (ii) social capital, i.e., informal networks and membership in formalized groups, (iii) natural capital, i.e., natural resources such as land, water, air quality, biodiversity, (iv) physical capital, i.e., infrastructure such as transport, shelter, water supply, energy, information, and (v) financial capital, i.e., available stocks and regular inflow of money.

For the study catchments, external influencing variables (i.e., biophysical, political, rural institutions) are generally similar, although structures such as access to markets and services (bank loans and farming advice) may vary. Based on the general literature, five broad categories were used to assess factors that contribute to the farmers' decision for agricultural intensification (services, household characteristics and wealth), demonstrate various forms agricultural activities (farming systems), and describe the interaction between the farmer and aquatic resources. These include:

- Access to services, i.e., markets and agricultural extension assistance
- Household characteristics, e.g., age, gender, education, occupation,
- Household wealth, i.e., income, housing type, livestock ownership, etc.,
- Farming and cropping systems, i.e., types of crops, use of fertilizers and pesticides, etc.,
- Relationship with water resources, i.e., stream use, source of potable water types and of sanitation, and water regulations.

Questions were both quantitative (to assess trends and patterns in the individual's behavior) and qualitative (to understand the reasons and understanding of the individual). Determination of the sample size of any study depends on how representative the sample size would be with regard to the total population under study. Through the pre-testing of the questionnaires and discussions with the village chief and teachers, an approximate estimate for the total number of households was established for each catchment, and 30% of this number was selected as a representative sample size (Dr. W. Laube, personal communication). Households were randomly selected, but within an arbitrary pre-determined income ranking (low, medium and high income levels) for representation (Phiri et al. 2004; Green et al. 2006), based on discussions with the chief and the teachers. Only the household heads were interviewed in their homes. Discussion of the results was supported by information from the VINVAL reports (Meijerink et al. 2003; Verzandvoort et al. 2005).

4.2.1 Data analysis

All statistical analyses were carried out in SPSS. Analyses included (i) simple descriptive summaries (frequencies and percentages) of the various variables assessed, (ii) one-way ANOVA to determine whether the means of selected variables between catchments were significantly different, with a post-hoc test to determine which means differed (equal variances not assumed) and (iii) binary logistic regression to determine the association between the dependent variable (fertilizer use), which is representative of increased nutrient input as land-use intensity increases, and selected influential independent variables.

4.3 Results and discussion

Almost all the crop balances in sub-Saharan Africa show a nutrient deficit, i.e., the difference between the quantities of plant nutrients applied and the quantities removed or lost, and there are now various programmes and policies put in place to encourage the use of fertilizers and soil management techniques (Shapiro and Sanders 1998; FAO 2004b; Fulginiti et al. 2004). The dependency on irregular and unreliable rainfall in sub-Saharan Africa, for example, is a major constraint that reduces the efficiency of fertilizers and therefore a farmer’s incentive to use fertilizers (FAO 2005). However, with favorable agro-ecological and infrastructural conditions, in addition to available input, credit and output marketing systems, smallholder farmers can be motivated to increase agricultural productivity and income (Nubukpo and Galiba 1999). The household’s resources that may support production and output are influenced by external variables (e.g., infrastructure, rural institutions and macroeconomic framework) and internal variables (e.g., individual’s or household heads’ age, gender and educational attainment) (Kelly 2006; Amanor and Pabi 2007). In the following sections, two categories are used to describe the household resources of each study catchment: (i) access to services that represent external variables, and (ii) internal factors such as the households’ characteristics and wealth. The characteristics of farming/cropping systems and the farmers’ relationship to water resources are also discussed, and contribute to the understanding of estimated nutrient loading into streams.

4.3.1 Services

One of the main challenges to increasing agricultural production in Africa is the smallholder farmers' access to agricultural services (marketing networks, research-extension-farmer linkages, input supply, strong institutional capacities, information, and other kinds of support) (Coulter et al. 1999; Sacerdoti 2005; Boateng 2006; Dar and Twomlow 2007). The participation of farmers in credit/input/output marketing arrangements for cash crops to promote food-crop productivity not only increases farmers' incomes. Farmers are also more likely to apply greater amounts of fertilizers on other crops (Jayne et al. 2004). The importance of this is seen in cases where the effectiveness of poverty reduction and food security programmes has been hampered by poor facilities, services and marketing arrangements (CSPR 2005).

Market access

Good access and proximity to markets is one major factor that influences and encourages agricultural development and inputs to crops (e.g., fertilizers) (Wiggins 2000; Oduro and Osei-Akoto 2008; Shilpi and Umali-Deininger 2008). Market access also refers to the output prices for the farmer, which reflects both physical access to the market and the costs of transport, as well as the prevailing market prices (a function of size of the market, population income and availability of competing supplies) (Wiggins 2000). Market proximity has a significant impact on the 'commercialization ratio' (i.e., the ratio of quantity sold to the quantity produced) of farming systems, as it provides demand-driven opportunities for cash crops (Oduro and Osei-Akoto 2008). A household that basically farms for subsistence reasons will be more likely to invest and increase production for commercial purposes if there are marketing opportunities.

Attakrom is located along the main tarred road between two major cities, Kumasi and Sunyani, and has relatively better access to commercial vehicles, which pass through the nearby main market at Kunsu or to other major markets in the vicinity. A major tarred road also passes through Dunyankwanta, giving it access to the Kunsu market (2 km away), or the main town Mankranso (4 km away). In Nyamebekyere, access is far more limited, with individuals either trekking or cycling (for those who have bicycles) to the major intersection (3 or 4 km walk), or have access to the commercial vehicles that come to the community only on Fridays to purchase goods. Due to transportation expenses and access to the market only once a week, subsistence farming is more common in Nyamebekyere as compared to the other two catchments where access to the market is easier.

Availability of advice from agricultural extension officers and of farm loans

Soil fertility management practices and agricultural intensification is also dependent on the appropriate extension services and knowledge transfer. Higher fertilizer acceptance has been found among farmers in agricultural associations and with more frequent extension-officer visits, with less impact by radio and TV advertisements (Drechsel and Zimmerman 2005), although farmers around cities are more likely than rural farmers to be exposed to mass media (Ghana Statistical Service 1999). Positive agricultural returns experienced by farmers who benefited from extension officers' advice is also an influential knowledge transfer due to personal contact and information exchange between farmers. The influence of social learning from friends and neighbors is important in the adoption of new techniques by a farmer, although this influence decreases the more experienced a farmer is (Conley and Udry 2001, 2005). A farmer, for example, is more likely to increase (or decrease) the use of fertilizer on new cash crops, such as pineapple, when someone he shares information with achieves higher than expected profits when using more (or less) fertilizer than he did; but the farmer is less influenced in the case of familiar maize-cassava technology.

The availability of advice from the agricultural extension officers (who make routine rounds at farms to advise farmers about pruning, planting and felling trees, supervise and supply new seedlings) and access to farm loans to farmers was investigated (Table 4.1Table 4.1). From the survey, Attakrom had more access to or took advantage of agricultural extension officers (25.6%) and farm loans (16.5%), as compared to Dunyankwanta (3.0%, 1.5%, respectively) and Nyamebekyere (1.5% and 0.0%, respectively). From the interviews, however, visits from the extension officers ranged from every few months to once a year, and not all farmers benefitted because the officers' visits were unpredictable (some farmers were on the fields when they came). In Ghana, although the involvement of farmers with extension services has long been promoted, there is still a poor linkage in the exchange of information (Boateng 2006). The extension staff-to-farmer ratio is estimated to be 1:1500, which means that extension workers cannot always meet the needs of farmers, and with the inadequate training of personnel, workers have little impact on agricultural development (Sraku-Lartey and Sam 2003; Duo and Bruening 2007).

Significant relationships have been found to exist between loan acquisition and agricultural inputs such as fertilizers, which is important as start-up capital for initial fertilizer, seed or pump purchases (Drechsel and Zimmerman 2005). An extra US $100 of credit, for example, received by an average farm household in Zambia, can increase output by between 2.6 and 4%, even with other inputs being constant (Deininger and Olinto 2000). For all the respondents who answered yes to loans in this study, loans were obtained from banks at an average 30% interest annually, with maximum loans of ¢1,000,000 (€ 92.6), repayable over a period of two years. In Ghana, however, credit facilities for agricultural ventures have decreased over the years. Credit loans to the agricultural sector have dropped from 25% in 1998 to 7% in 2006, and bank lending from 9.7% to 4.3% (Mustapha 2008).

Table 4.1 Respondents who benefit from assistance from agriculture extension officers and farm loans (%)

		Attakrom	Dunyankwanta	Nyamebekyere
Assistance		(N = 82)	(N = 67)	(N = 69)
	Yes	25.6	3.0	1.4
	No	74.4	97.0	98.6
Farm loans		(N = 79)	(N = 65)	(N = 70)
	Yes	16.5	1.5	0.0
	No	83.5	98.5	100.0

4.3.2 Household characteristics

In addition to environmental, institutional, and economic factors, basic household characteristics are important factors that affect a farmers' personal decision for agricultural intensification practices (Lukanu et al. 2004; Ruben 2005). Household characteristics include age, education, gender of the household head, marital status, household size, division of labor, and household food availability.

Age

The age of a person has been found to significantly influence preferences and decisions for innovative agricultural practices (Gockowski and Ndoumbé 2004; Marenya and Barrett 2007). According to the authors, when decision-makers grow older, their planning horizons shrink and incentives to invest in future productivity diminish. Although younger farmers may be less experienced, learning costs for adopting new practices are lower, the farmers are more likely to adopt innovations, and relatively healthier and stronger younger farmers are more likely to implement them than older farmers. In addition, early in the life of the farmer, earnings increase with increasing age as the farmer gains experience, but decreases as the individual gets older (Canagarajah et al. 2001).

The majority of respondents were between the ages of 30 and 59, in Attakrom (71.5%), Dunyankwanta (65.2%) and Nyamebekyere (67.1%) (Table 4.2). In Attakrom, the greatest proportion (28.6%) of the respondents was the 50-59 years age group, although an equally large proportion (25%) was in the age group 30-39 years old. In Dunyankwanta and Nyamebekyere, a greater proportion (30.4% and 27.1%, respectively) of the respondents was between 40 and 49 years, although in Nyamebekyere, there was a higher proportion of farmers in the 30-39 age group. Statistically, there was enough evidence to show that there were significant differences in the means of the age groups between the three catchments at $p<0.05$ (Table 4.3), especially between Attakrom and Nyamebekyere ($p=0.007$) (Table 4.4).

Table 4.2 Distribution of respondents by age (%)

Age (years)	Attakrom	Dunyankwanta	Nyamebekyere
	N = 84	N = 69	N = 70
<20	0.0	4.3	0.0
20 – 29	8.3	5.8	14.3
30 – 39	25.0	17.4	24.3
40 - 49	17.9	30.4	27.1
50 – 59	28.6	17.4	15.7
>60	10.7	24.6	7.1
Dont know	9.5	0.0	1.4

Table 4.3 One-way ANOVA for differences in the age distribution of respondents between catchments (significance at p<0.05)

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	17.827	2	8.914	4.919	**.008**
Within Groups	398.657	220	1.812		
Total	416.484	222			

Table 4.4 One-way ANOVA post hoc test for differences between catchments for age distribution of respondents

(I) Locality	(J) Locality	Mean Difference (I-J)	Std. Error	Sig.
Attakrom	Dunyankwanta	.12267	.22847	.932
	Nyamebekyere	.65476(*)	.21135	**.007**
Dunyankwanta	Attakrom	-.12267	.22847	.932
	Nyamebekyere	.53209(*)	.21961	.049
Nyamebekyere	Attakrom	-.65476(*)	.21135	**.007**
	Dunyankwanta	-.53209(*)	.21961	.049

** Mean difference is significant at the .05 level.*

Gender

Female-headed households are known to be poorer than male-headed households throughout sub-Saharan Africa, and the association between gender and wealth has been the focus of many studies (e.g., Quisembing et al. 1995; Phiri et al. 2004). Gender-linked practices have shown that men and women adopt agricultural technologies, such as new crop varieties and chemical fertilizers, at different rates; however, female-headed households have been found to be just as productive as their male counterparts (Deininger and Olinto 2000). Although the highest proportion of male respondents was in Attakrom (70.2%) and the highest proportion of females in Dunyankwanta (42.0%) (Table 4.5), there was not enough evidence to show statistical differences between the catchments in gender distribution at $p<0.05$ (Table 4.6).

Table 4.5 Distribution of respondents by gender (%)

Gender	Attakrom	Dunyankwanta	Nyamebekyere
	N = 84	N = 69	N = 70
Male	70.2	58.0	67.1
Female	29.8	42.0	32.9

Table 4.6 One-way ANOVA for differences in the gender of respondents between catchments (significance at $p<0.05$)

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.599	2	.299	1.322	.269
Within Groups	49.814	220	.226		
Total	50.413	222			

Occupation

The primary occupation for rural dwellers in Ghana is farming (Canagarajah et al. 2001); this is also the case in the three study catchments (Table 4.7). In each catchment, more than 85% of the respondents were farmers, with trading and livestock ownership as secondary major occupations. In Dunyankwanta and Nyamebekyere, a small proportion of respondents (11.6% and 7.1%, respectively) had primary occupations as traders and teachers, with farming as a secondary occupation. Secondary occupations, especially in trading and livestock ownership, were greatest in Nyamebekyere (68.8%) as compared to Dunyankwanta (34.8%) and Attakrom (6.0%). With Attakrom as a highly intensive land-use community, the main source of income is agriculture, which means that farmers are more likely to focus to only on farming. In Nyamebekyere, income is from both on-farm and non-farm activities, and remoteness does not discourage non-farm activities (Canagarajah et al. 2001). Other occupations for all catchments were grouped into the following three categories: (i) low-skilled self-employed, includes palm wine taper, basket weaver, and hunter, (ii) medium-skilled self-employed, includes carpenter, repairman, purchasing clerk, electrician, shoemaker, barber, hairdresser, corn-mill operator, and transport owner, and (iii) skilled employed, includes a pastor and a midwife.

The decision of farmers to diversify their assets, to have multiple income sources, and use assets and wealth for different activities is influenced by ‘push’ factors (risk reduction or responses to diminishing factor returns due to constraints, crises, or high transaction costs), and ‘pull’ factors (realization of strategic options between activities, such as specialization in skills or crop-livestock integration) (Barrett et al. 2001; Canagarajah et al. 2001). Non-farm activities have been defined as non-agricultural activities that include wage work (including wage work on farms) and self-employment in any non-agricultural activity, and that is significantly influenced by education, age of the individual, location, and regional characteristics (Canagarajah et al. 2001). Observations by Joliffe (2004) that households with higher education are more likely to work in non-farm activities than those with lower education are also confirmed by the higher education standards in Nyamebekyere (see next section: Education Level). Between 40% to 45% of the average household income was achieved by non-farm activities, which is becoming an increasingly important way out of poverty (Reardon 1997). Involvement in non-farm activities has been associated with lower poverty, and in some situations the type of employment is dependent on the incomes derived from agriculture (Newman and Canagarajah 2000; Oduro and Osei-Akoto 2008). Non-farm activities in African villages are usually first-stage activities that are a spin off from agricultural activities (FAO 1998), although some skill-intensive activities were observed in the catchment, e.g., carpentry and teaching.

Table 4.7 Distribution of primary and secondary occupations, and of types of secondary occupations (%)

Occupation	Type	Attakrom	Dunyankwanta	Nyamebekyere
		N = 83	N = 69	N = 70
Primary				
	Farmer	96.4	87.0	92.9
	Teacher	0.0	2.9	7.1
	Trader	0.0	8.7	0.0
	Other	3.6	1.4	0.0
Secondary		6.0	34.8	68.8
	Farmer	0.1	3.6	5.0
	Livestock owner	0.0	1.5	14.8
	Teacher	0.0	0.0	1.0
	Trader	0.1	0.8	17.8
	Other	0.2	2.5	8.9
	None	5.6	22.7	21.5

Educational level

Literacy and the level of formal education affect the kind of information people have access to and the range of opportunities at their disposal (UNEP 2008). Worldwide, the educational level of a population is important in determining land-use activities, since education provides more opportunities to increase income, determines the types of livelihoods found in a community, determines the ability of an individual for skilled labor, and also directly increases production or improves the allocation of resources to indirectly increase production (Welsh 1970; Psacharopoulos and Patrinos 2002; Yang and An 2002). Although studies have shown overall benefits of educating farmers, some authors have indicated that for developing countries, these benefits are seen mostly in Asia with little or no evidence of positive effects on productivity in Latin America and Africa (Phillips 1987; Deininger and Olinto 2000; Jollife 2004). The influence of education is rather seen on input use despite the market imperfections (Deininger et al. 2000), although in countries like Ghana, the returns to education are not as significant as in other African countries such as Uganda (Canagarajah et al. 2001). According to Jollife (2004), the fact that education affects behavior on the farm and farm productivity has been the focus of most studies, and non-farm benefits of education have been poorly assessed. Results from Jollife's (2004) study, show that in Ghana the value of education is found more in the impact on non-farm activities, and that education increased non-farm profit far more than on-farm.

The assessment of the educational level of the respondents in the three catchments (Table 4.8) shows a greater proportion of individuals with no or only primary education (90.1% of respondents) in Attakrom, and a greater proportion (67.8%) with more advanced education, i.e., from Middle School Leaver's Certificate (MSLC) to polytechnic and teacher training, in Nyamebekyere. This corresponds to the occupation results, where Nyamebekyere shows a greater proportion of respondents (70%) with secondary occupations, compared with a significantly smaller percentage (6%) in Attakrom. Individuals who are more educated than other members in the household are less likely to work strictly on the farm, more likely to work off the farm, and spend a larger proportion of their working hours in non-farm activities (Jollife 2004).

Table 4.8 Distribution of respondents by educational level (%)

Education	Attakrom	Dunyankwanta	Nyamebekyere
	N = 80	N = 68	N = 59
None	48.8	27.9	28.8
Primary	41.3	39.7	3.4
Polytech/Teacher Training	3.8	0.0	6.8
Junior Secondary School	6.3	13.2	25.4
Middle School Leavers Certificate	0.0	19.1	35.6

Migration

In rural livelihood frameworks, migration remittances form one of the three main sources of livelihood, including agriculture and local non-farm income. In Ghana, four types of migration have been defined, i.e., rural-rural, rural-urban, urban-urban, and urban-rural, with rural migrations further characterized into seasonal labor migration, long-term migration and return migration (Primavera 2005). Seasonal migration, a circular movement that involves periodic return to the area of origin, provides a means to diversify livelihoods and gain access to capital for investments at home. In northern Ghana, there is only one rainy season. Farmers seasonally migrate to the south as a survival strategy for bad harvest years and to improve the households' livelihood by providing food and financial capital from the south. Here, the incidence of seasonal migration is significantly higher in middle-income households than in poor or wealthier households (van der Geest 2005). Seasonal migration also refers to farmers who migrate seasonally to another village only for farming purposes. This phenomenon is seen in the northern region of Ghana where farmers migrate from neighboring towns and villages (Tamale, Damongo, Yendi, etc) to the Wuripe village once a year (Braimoh 2004). Wuripe becomes populated at the onset of the rainy season (June) when the farmers come to carry out intense farming, and leave at the beginning of the dry season when lack of water drives them back to the permanent homes. For the tilled areas in Wuripe, drastic land-cover changes were observed where woodland was converted to agricultural land, and influencing factors were found to be population size and distribution, marketing of produce, and technological evolution of the household.

In the study catchments, the comparison of the residency status showed that a greater proportion of respondents in Attakrom (50.6%) and Dunyankwanta (52.2%) had migrated into the catchments, as compared to Nyamebekyere (12.9%), mainly from the Ashanti Region (Table 4.9). Farming was the main reason given by respondents for moving to Attakrom and Dunyankwanta, with a small percentage (<5%) indicating other reasons such as trading, moving in with family members, and transfers (for those who were teachers). Compared to the other catchments, a relatively larger proportion of the respondents in Attakrom (21.7%) was non-resident, i.e., farmers who did not permanently reside in the catchment, but owned farms and stayed for short periods (seasonal farmers). The lower incidence of migrants to Nyamebekyere could be due to its relative isolation and distance from major roads and markets.

Table 4.9 Respondents who are residents, have migrated, or temporarily live in catchments (%)

Residency		Attakrom	Dunyankwanta	Nyamebekyere
		N = 83	N = 69	N = 70
Resident		27.8	47.8	85.7
Migrated		36.1	50.7	11.4
Location	Neighboring town	9.5	2.8	2.5
	Ashanti region	14.6	39.5	8.7
	Outside region	10.3	7.1	0.0
	Outside Ghana	1.7	1.4	0.0
Non-resident		36.1	1.4	2.9

4.3.3 Wealth

Poverty and social inequity remain the major constraints to sustainable development in Africa and are a major cause of environmental degradation. Poverty refers to more than the lack of access to financial resources and material resources, and includes lack of capabilities that allow access to income, health, education, empowerment and social inclusion, and human rights (UNEP 2008). One common measure of poverty is wealth, which influences a farmer's capacity to invest in the land or financially benefit from produce (Langyintuo and Mungoma 2006; Shilpi and Umali-Deininger 2008). Definitions of wealth groups and indicators are often arbitrary with categories frequently based on the researcher's definitions. Wealth ranking methods (i.e., participatory research methods in which community members define wealth criteria and classify themselves based on this) have been recommended as being more reliable in determining wealth groups of households (Phiri et al. 2004; Green et al. 2006).

Farm households have varying levels of different assets, each of which can potentially contribute to the wealth status of the household. Wealth indicators, comparable across villages, generally fall into the following categories: land distribution or land cultivated, physical assets (such as livestock, mechanical labor, radio set, bicycle, housing type, etc.), access to cash and credit through non-governmental organization or government programs, income generated from livelihoods (both on- and non-farm), and expenditure (food, farm inputs, labor, education) (Phiri et al. 2004; Green et al. 2006; Langyintuo and Mungoma 2006). From these categories, wealth levels for this study are assessed by internal and external income, housing status and type, livestock ownership and types of animals, property rights and number of fields.

Income categories

The overall monthly earned income of respondents show that a greater proportion of respondents in Nyamebekyere (65.7%) belong to the low income group (<¢400,000 or €37 per month) as compared to Dunyankwanta (56.1%) and Attakrom (48.6%) (Table 4.10). In Attakrom, the proportion of high income (> ¢1,000,000 or €74 per month) respondents was relatively larger than in the other two catchments. More than half of the community (54.2%) receives frequent unearned income as compared to Dunyankwanta (22.7%) and Nyamebekyere (15.7%), in the form of payments from family members within or outside the community, and in a few cases, pension payments. This translates into greater financial resources for respondents in the high land-intensity use catchment. Statistically, there was not enough evidence to show significant differences in income levels between the catchments at $p=0.106$. Differences were significant for external incomes at $p<0.05\%$ (Table 4.11) between Attakrom and Dunyankwanta ($p=0.001$) and between Attakrom and Nyamebekyere ($p=0.000$) (Table 4.12).

Table 4.10 Monthly earned income and unearned income (%) (* €1= ¢10.8)

Amount earned per month			Attakrom	Dunyankwanta	Nyamebekyere
		(¢,000)*	N = 72	N = 66	N = 70
Earned Income					
	Low	<400	48.6	56.1	65.7
	Medium	400 - 799	23.6	25.7	24.3
	High	> 800	27.8	18.2	10.0
Unearned Income	Yes		52.6	22.7	15.7
	No		47.4	77.3	84.3

Table 4.11 One-way ANOVA for differences between catchments for earned (Ea_Income) and unearned (UE_Income) incomes (significance at p<0.05)

		Sum of Squares	df	Mean Square	F	Sig.
Ea_Income	Between Groups	7.887	2	3.943	2.265	.106
	Within Groups	356.883	205	1.741		
	Total	364.769	207			
UE_Income	Between Groups	5.643	2	2.822	14.813	**.000**
	Within Groups	39.810	209	.190		
	Total	45.453	211			

Table 4.12 One-way ANOVA post hoc test for differences between catchments for unearned income

Dependent Variable: UE_Income

(I) Locality	(J) Locality	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
Attakrom	Dunyankwanta	.29904(*)	.07763	**.001**	.1114	.4866
	Nyamebekyere	.36917(*)	.07241	**.000**	.1941	.5442
Dunyankwanta	Attakrom	-.29904(*)	.07763	**.001**	-.4866	-.1114
	Nyamebekyere	.07013	.06798	.663	-.0943	.2346
Nyamebekyere	Attakrom	-.36917(*)	.07241	**.000**	-.5442	-.1941
	Dunyankwanta	-.07013	.06798	.663	-.2346	.0943

** Mean difference is significant at the 0.05 level.*

Housing

Since wealthier farmers are able to own and afford better facilities, the housing status and the quality of building material were used to assess the wealth level of the household. A greater proportion of the respondents lived with family members in a shared home in Attakrom (47.6%) and Nyamebekyere (44.9%). In Dunyankwanta (43.5%), the greatest

proportion of households owned their own homes (Table 4.13). In Nyamebekyere, there was an average distribution between those who owned, rented or lived in family homes.
The communities were distinctly different in the quality of material used to build the homes. In Attakrom, although mud was used by 60% of the respondents, a significant proportion (40%) could afford more expensive materials such as brick and cement. In contrast, only 13.4% and 11.6% in Dunyankwanta and Nyamebekyere, respectively, could afford such materials.

Table 4.13 Housing status and type of building material for home (%)

Parameter		Attakrom	Dunyankwanta	Nyamebekyere
		N = 72	N = 66	N = 70
Housing status				
	Own	35.4	43.5	27.5
	Rent	17.1	17.4	27.5
	Family/Shared	47.6	39.1	44.9
Type of housing				
	Mud	57.1	86.6	88.4
	Brick	29.9	11.9	-
	Cement	10.4	1.5	11.6
	Corrugated iron (Zinc)	2.6	-	-

Livestock ownership

In improving livelihoods, there is an increasing complexity in the integration of crops and livestock by smallholder farmers in response to factors such as population increase, declining soil fertility, climate change and unpredictable weather patterns (Kruska et al. 2003; Herrero et al. 2007). Several species of livestock have different purposes, e.g., the provision of food for the family, cash from product sales (e.g., milk, beef, and eggs), capital assets, provision of manure, fiber for clothes, etc. In some countries, draught animals such as oxen also contribute directly to the productivity of land (ploughing, manure) and can increase credit access by serving as collateral (Deininger and Olinto 2000).

Nyamebekyere had the highest percentage of respondents who owned livestock (77.1%) as compared to Attakrom (46.4%) and Dunyankwanta (37.7%) (Table 4.14), which gave enough evidence for statistical differences between catchments at $p<0.05$ (Table 4.15). Differences were significant between Attakrom and Nyamebekyere ($p=0.000$) and between

Dunyankwanta and Nyamebekyere (p=0.000) (Table 4.16). For all catchments, the order of livestock abundance was chickens>goats>sheep. Since subsistence farming is the major farming type in Nyamebekyere, meat supplements the protein component of diet and livestock is considered an asset and investment for the poorer farmers in Nyamebekyere, who belong to a relatively lower income category than those in the other two catchments.

Table 4.14 Livestock ownership and types of animals (%) (Types columns may add up to more than the total percentage, as different types of livestock are owned by individual farmers)

	Types	Attakrom	Dunyankwanta	Nyamebekyere
		N = 84	N = 69	N = 70
Yes		46.4	37.7	75.7
	Chickens	36.9	19.3	58.6
	Goats	21.4	4.4	37.1
	Pigs	-	1.8	1.4
	Sheep	13.1	3.5	18.6
	Other	7.7	-	2.9
No		53.6	62.3	24.3

Table 4.15 One-way ANOVA for differences in livestock ownership between catchments (groups) with significance at $p<0.05$

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	6.059	2	3.030	13.481	**.000**
Within Groups	49.439	220	.225		
Total	55.498	222			

Table 4.16 One-way ANOVA post hoc test for differences between catchments for livestock ownership

(Dependent Variable: Livest_own)

(I) Locality	(J) Locality	Mean Difference (I-J)	Std. Error	Sig.
Attakrom	Dunyankwanta	-.08747	.08031	.623
	Nyamebekyere	.30714(*)	.07451	**.000**
Dunyankwanta	Attakrom	.08747	.08031	.623
	Nyamebekyere	.39462(*)	.07752	**.000**
Nyamebekyere	Attakrom	-.30714(*)	.07451	**.000**
	Dunyankwanta	-.39462(*)	.07752	**.000**

** Mean difference is significant at the 0.05 level.*

Property rights

Property rights to resources such as land, water, and trees are important factors in the role of poverty reduction, resource management and environmental management linkages. They may constrain or facilitate sustainable use, protection or resource improving investments, as well as determine welfare of the households who depend on these resources (World Bank 2006). In the Ashanti Region, property rights are communal with land ownership by the 'Amakomhene' (chief) and administration by the village head or the 'Odikro'. The sharecropping system (produce is shared between the sharecropper and landowner at a ratio of 2:1) is more important to the farmers, although other types of land-tenure systems are available (Meijerink et al. 2003). The family land inheritance is free to use as desired except when leased, and in this case the chief has to be part of the agreement. In share tenancy, food crops are for the farmer and tree crops for the land owner; in rentals, the farmer compensates the land owner by an agreed measure. Food crops on stool lands are solely for the benefit of the farmer, but this is not as common due to unavailability of land. Renting of land is also available but there is no standard rent and costs range depending on the size of the field, the fields are to be used only for food crops.

According to the VINVAL study, more than 50% of the Attakrom community practices sharecropping, normally applicable to non-permanent crops. Currently, with the commercialization of food crops, cash payments are being demanded by landowners and have caused the intensification of agricultural activities by the sharecroppers to maximize benefits. Landowners also try to maximize benefits from the land and give out the land irrespective of its cropping history. In Dunyankwanta, 90% of the community own land through family inheritance, with 50-60% involved in land tenancy where farmers cultivate cocoa for the land owner and food crops for themselves. In Nyamebekyere, the 'taungya' system allows farmers to cultivate any area they wish as long as they replant young forest tree saplings in assigned areas within the catchment. The saplings are provided by the Forestry Department.

Number of fields per household

In Attakrom, a greater proportion of the population farmed on only one field (Table 4.17). In Dunyankwanta, there was an almost even spread of respondents who farmed between 1 and 3 fields, and in Nyamebekyere, a larger percentage of the households farmed on 2 fields. Fields in Attakrom were generally rented, in Dunyankwanta they were family lands, and in Nyamebekyere, there was an even distribution between family land, rentals and government-provided land.

In Nyamebekyere, the land is within the forest reserves, although the local farmers have been allowed to pursue subsistence farming by the government, and pay for this by planting secondary trees. The 'other' status refers to the situation where a farmer owns some of the land and rents it or is a laborer in another, a situation which is more common in Dunyankwanta and Nyamebekeyere. In all the catchments, field sizes were on average between 1-5 acres (0.405-2.023 hectares).

Table 4.17 Property rights, number of fields and size of fields (%)

Parameter		Attakrom	Dunyankwanta	Nyamebekyere
		N = 83	N = 62	N = 67
Land ownership				
	Family land	28.0	58.1	32.8
	Government	3.7	-	22.4
	Laborer	19.5	8.1	3.0
	Rent	42.7	8.1	34.3
	Other	6.1	25.8	25.8
Number of fields				
	1	52.4	28.4	24.3
	2	27.4	31.3	41.4
	3	15.5	29.9	25.7
	4	3.6	7.5	8.6
	>5	1.2	3.0	-
Size of fields (acres)*				
	1-5	62.9	71.6	59.9
	6-10	26.5	17.6	25.2
	11-15	5.3	4.7	6.8
	16-20	4.0	0.7	4.8
	21-25	0.7	5.4	1.4
	>25	0.7	-	2.0

** 1 acre = 0.405 hectares (or 0.004 km^2)*

4.3.4 Farming and cropping system

This section summarizes the responses of the interviewed farmers about factors that influence soil properties and may affect nutrient export from soils into the aquatic system, i.e., types of crops and fallow periods, fertilizer and pesticide use, and livestock ownership. For precise information on the actual differences in nutrient contents of the soil in the three catchments, detailed research would be required to analyze individual farmland soil properties and soil nutrient content. However, as the purpose of the research was to compare the differences in socio-economic characteristics and behavior of farmers that would contribute to overall nutrient input within each catchment, it is assumed that the differences in these activities would be reflected in different levels of Impact (measured as total nutrient loading in the streams), without the need to analyze farmland soils for definite quantities in nutrient levels.

Fallow and land preparation

Traditionally, long fallow periods were used to restore soil quality and yield levels, but with demographic pressure, the number of fallow years has been shortened such that fallowing alone is not sufficient to maintain soil fertility (Nubukpo and Galiba 1999). With the decreasing land availability and option for long fallow, Drechsel et al. (2005) presumed that soil management practices (e.g., fertilizer input) would intensify, since most farmers (80%) were aware of declining yields due to decreasing fallow periods. The authors, however, found no significant relationship between the length of fallow periods and farmers' soil fertility management practices, although there were a few incidences of fertilizer application, explained as either compensation for shortened fallow periods or more fertilizer accessibility in areas where fallow periods were shorter (close to the urban areas, e.g., the city of Kumasi).

From the interviews, post-harvest activities in the catchments were classified into one of four categories: (i) immediate replanting after harvesting mature crops on intercropped fields, (ii) replanting of crops, done at the same time of the year and mostly on intercropped fields, (iii) retaining only tree crops on fields after food crops were harvested, since trees had relatively longer life spans, and (iv) fallowing, where the entire field is left for a period depending on the history of its use. Only two farmers out of all respondents interviewed indicated that the land was returned to the owner after harvest. On fields that had only one crop, fallow periods ranged between 3 months to 3 years depending on the crop in Attakrom (27.6%) and in Dunyankwanta (9.0%) (Table 4.18). In Nyamebekyere, most respondents indicated that replanting was immediately after harvest, with no fallow periods. Most of the farmers in all the catchments practiced intercropping, which means that harvesting periods varies for different crops, and fallowing cannot be carried out on these fields. In addition to restoring soil fertility, re-growth of natural vegetation during fallow periods helps in the control of weeds (Styger and Fernandes 2006). Studies have shown that fallow periods of >3 years are more effective at weed control than periods of ≤3 years (Awanyo 2008). This is because the larger pool of tree seeds in soils leads to a greater recruitment of trees in the longer fallow periods, which shade out weeds and reduce weed seed production. As weed infestations increase with reduced fallow periods, many farmers use fire during land preparation to control weed growth. The slash-and-burn technique also provides nutrient-rich ashes, which are used on crops in the fields, and in some areas only on higher value crops in multiple-cropping fields (Drechsel and Zimmerman 2005). Mulching (keeping weed and crop residues on the field) is being promoted as an alternative method being more effective in controlling weeds, maintaining soil fertility and saving labor costs (Ekboir et al. 2002), but it is still not widespread in Ghana. Burning leaves the soil bare and recruitment of weed seeds is high, whereas with mulching, germination is suppressed.

In this study, land preparation was mainly by slash and burn, with planting carried out immediately after. In Attakrom, preparation included the felling of trees (3%), and the application of herbicides within approximately two weeks after burning. For fields that had multiple crops, weeding was continuously carried out under young plants or tree crops that remained on the land after harvest. For some of the tree crops (cocoa and orange), herbicides were applied once a year to control weeds. According to Awanyo (2008), although frequent weeding was effective in suppressing weeds, it was rather how careful the weeding was done that was more important. Due to the labor-intensive process of land preparation, i.e., clearing of vegetation and burning, some farmers mentioned that laborers were hired to clear the fields. Labor, one investment in the intensification of cultivation (the other being the application of nutrients), is related mainly to land clearing and weeding but not to any other farming input tasks (Drechsel and Zimmerman 2005), and requirements depend on the kind of vegetation that needs to be cleared (i.e., trees or grasses and broadleaf weeds).

Table 4.18 Post harvest and fallow (%)

Activity	Attakrom	Dunyankwanta	Nyamebekyere
	N = 76	N = 67	N = 62
Immediate replanting	61.8	19.4	98.6
Planting same time each year	7.9	37.3	0.0
Tree crops left on land	2.6	34.3	0.0
Fallow	27.6	9.0	1.4

Major crop types

In general, farmers growing commercial crops are more likely to invest in soil fertility improvement (e.g., fertilizers) as a means to improve returns from the harvest (Kelly 2006). In Ghana, agricultural production is typically of traditional export crops (cocoa and oil palm), traditional non-export subsistence crops (yam, plantain), and non-traditional export crops (fruits, vegetables and root crops). In most villages in Ghana, farmers do not specialize in specific crop types but rather produce a wide range of crops (Oduro and Osei-Akoto 2008). Compared to the past, declining trends have been observed in cocoa production with increased growth in oil palm (as an export crop) and more nutrient- and moisture-efficient crops (e.g., cassava) as subsistence and cash crops. The decline of cocoa productivity, due to the fact that landowners have no resources for replanting dying trees, has led to more interest in traditional crops that can be used as cash crops. These include tree crops such as citrus and oil palm, and recently rice crops (Meijerink et al. 2003). The general increase in sharecropping is also a response to the decline of cocoa productivity, as tenants provide extra labor and invest resources into the land.

For each catchment, the ranking of importance of different crops by the VINVAL project and the results of this research for the top ten crops (total percentage of farmlands on which the crops were grown) were compared (Table 4.19). Major cropping systems include (i) traditional food crops maize, cassava, plantain and cocoyam, (ii) newly emerging cash crops such as rice and vegetables (okra, pepper), and (iii) the tree crops cocoa, citrus and oil palm (Meijerink et al. 2003). The principal crops grown by the interviewed farmers (cultivated on 30-45% of the farms) were cassava, cocoa, and plantain. An additional crop was maize in Attakrom and Nyamebekyere, and cocoyam in Dunyankwanta. Although these were the most common crops, ranking in the VINVAL project showed different farmer preferences. For example, cocoa and maize were ranked as the most preferred crops in both Attakrom and Dunyankwanta due to its higher commercial value; however, cassava and plantain were the most grown crops (ranked 4th and 5th by the farmers). These crops serve beyond household subsistence requirements as cash crops and can be regularly harvested, in comparison to the seasonal cocoa. Cocoyam is a high cash earner in the lean seasons (Meijerink et al. 2003). On the other hand, in Nyamebekyere, preferences and common crops grown corresponded; plantain (84.4%) and cocoyam (76.2%) were the most dominant food crops, and ranked as the 1st and 2nd preferred crop, respectively, by the VINVAL project.

In most cases, mixed tree cropping was practiced, i.e., tree crops were grown together with a minimum of two or three food crops on the same field. The types of crops grown were similar within the three catchments, with the exception of pineapple, which was not found at any of the farms in Attakrom, and rice in Nyamebekyere.

In Ghana, there has been a rapid increase in pineapple production due to incentives such as the exemption from non-traditional crop export duty, a growing domestic market for pineapple juice processing companies, and it not being as labor intensive as other non-traditional crops (Takane 2004). Rice, a relatively new cash crop, requires a considerable investment in herbicides and labor, and was found on fewer farms in Attakrom (6.6%) and in Dunyankwanta (2.0%), with none observed in Nyamebekyere. On one rice field in Attakrom, for example, the farmer spent her entire day shooting birds with a hand-made sling, as other methods such as scarecrows (rags or clothes on sticks) did not work.

Table 4.19 Comparison of the importance of different crops for farmers between the VINVAL project (ranking; 1 highest, 6 lowest) (Meijerink et al. 2003) and research results (% total number of respondents that cultivate the crop).

Crop type	Attakrom		Dunyankwanta		Nyamebekyere	
	Study (%)	VINVAL	Study (%)	VINVAL	Study (%)	VINVAL
Cassava	42.4	4	47.3	3	40.8	3
Cocoa	35.8	1	43.9	1	38.8	6
Cocoyam	31.1	6	31.1	5	76.2	2
Maize	36.4	2	27.0	2	10.2	4
Oil palm	19.2	--	6.8	--	15.1	--
Okra	3.3	--	-	--	-	--
Orange	8.0	--	6.1	--	6.1	5
Pepper	2.7	--	9.5	--	28.6	--
Pineapple	-	--	4.7	--	13.6	--
Plantain	43.1	5	33.8	4	84.4	1
Rice	6.6	3	-	6	-	-
Yam	-	--	13.5	--	17.0	--

- food crop not mentioned by respondents   -- food crop grown but of lower ranking/percentage than 6

Manure use

Intensity of livestock rearing within a catchment can be an important contribution to soil nutrients depending on the amount of manure generated. Manure is an important source of nutrients, as it maintains and replenishes soil fertility for crop production, and has been an old technology in parts of Africa, where farmers practice mixed livestock and crop farming (Brouwer and Powell 1998; Lupwayi et al. 2000; Mando et al. 2005; Mkhabela 2006; Rufino et al. 2006). In Ghana, manure use is more common in the northern region, although its use is found in parts of the south-western region where commercial poultry farming is predominant (FAO 2005). It has shown success when applied to crops such as cowpea, and may be an important source of fertilizer throughout Ghana in the near future.

In the three study catchments, however, manure (poultry, sheep and goat manure) was not considered a useful resource by most of the communities and was rather discarded, except by a few farmers (<2% of all respondents). Manure collected from pens was usually dumped at a general dump site away from the community within the catchment (although not near the streams). Discussions with farmers indicated that agricultural extension officers had tried to educate them on the use of manure, but this had not been accepted by the farmers, although the reason why was unclear. The trend of low manure use corresponds with results for areas located near the study sites, where less than 5% of the farmers applied manure to fields (Drechsel and Zimmerman 2005). According to that study, the labor- and time-consuming collection and transport was not considered worthwhile by a majority of the farmers, as quantities were generally small and fields were far away from the compounds. Factors that negatively affect the farmers' decision to use manure include farm size, distance of fields to the homestead, proportion of cultivated land recently under fallow, labor and transport requirements for handing manure, lack of technical information on fertilizer value and management of manure, increased growth of weeds, and bad smell (Williams 1999; Mkhabela and Matereschera 2003; Abdoulaye and Sanders 2005). The collection of the manure and transport to the farm sites is considered a tedious process requiring the use of extra labor, with the perception of the returns not immediately apparent to the farmers (Abdoulaye and Sanders 2005; FAO 2005).

Pesticide use

Weeds compete with the crops for soil nutrients, and increased weed growth promotes diseases (insect attacks) and high humidity which, in Ghana, encourages the 'black pod' disease (Fosu et al. 2007). Although the assessment of toxic chemicals in streams was not part of this research, farmers' responses about pesticide use contributes to the understanding of the priorities of farmers in relation to investments in crops and land-use intensity. Attakrom had the highest use in pesticides (68.8%) followed by Dunyankwanta (43.5%), with minimal use in Nyamebekyere (2.9%) (Table 4.20). The most common reason for no use was that the farmer could not afford pesticides, although most farmers are aware of their benefits. Statistically, there were significant differences in pesticide use between the three catchments at $p<0.05$ (Table 4.21; Table 4.22).

Types of pesticides used in the catchments include the following;

(i) Herbicide – Condemn, Power, and Roundup (active ingredient glyphosate) belong to a group of broad spectrum herbicides usually used before planting, as part of the land preparation process. Atrazine is a selective herbicide, with active ingredient atrazine, used after planting to control broad leaf plants and grass.

(ii) Fungicide – Champion, Fungrian, Foko, and Kocide prevents fungal growth on crops. Champion and Kocide have the copper based active ingredients (copper hydroxide), and Foko and Fungrian are manganese-based.

(iii) Insecticide – Thionex for general control and Dursban (Chloropyrifos) usually for the prevention of termite infestation. Active ingredients include endosulfan. Although DDT has been banned, 3 of the farmers apparently still had access to it (or probably used DDT as a generic name for pesticides). In the national annual monitoring and assessment program for 2005, high values of DDT (0.4 mg L^{-1}) were, in a few cases, recorded in parts of the south-western basin systems, which is above the WHO guideline value of 0.001 mg L^{-1} (Ansa-Asare and Darko 2006). According to the report, these high values need to be assessed.

The most popular pesticides applied in the catchments were Atrazine, Kocide, and Roundup. Land preparation generally is done by manual weeding using cutlasses, and those who can afford it use Roundup approximately 3 weeks after weeding, before the planting season begins. Roundup is also used to clear the weeds under the tree crops, i.e., cocoa, orange and oil palm. Atrazine is applied on an average of 8 weeks after planting, and mainly to crops such as maize, cassava, plantain, cocoyam and rice. Kocide is usually applied on the tree crops cocoa and orange once a year, although some farmers applied it frequently to vegetables. One source of worry for cocoa farmers is the fungus *Phytophthora* which causes canker of the stem and in mummified dry pods, husks and roots (Fosu et al. 2007). Two types are found in Ghana – *P. palmivora* which is less destructive and lives in the flower cushions and *P. megakarya* which is more destructive and survives in the soil. Kocide is typically applied in May when the fungus appears.

Table 4.20 Pesticide use in the last 2 years (2004-2006), types used, and the reasons given by respondents who answered 'No' (%). (Types columns may add up to more than the total percentage as multiple types of pesticides was used by individual farmers)

Pesticide Use		Attakrom	Dunyankwanta	Nyamebekyere
		N = 79	N = 63	N = 69
Yes		70.9	44.4	2.9
Types	Atrazine	31.6	23.8	-
	Champion	2.6	6.3	-
	Condemn	5.0	7.9	1.5
	DDT	2.6	-	1.5
	Dursban	2.6	-	-
	Foko	3.8	-	-
	Fungrian	7.6	-	-
	Insecticide	2.6	-	-
	Kocide	21.6	4.8	1.5
	Power	5.0	-	-
	Roundup	34.2	7.9	-
	Thionex	1.3	6.3	-
No		29.1	55.6	97.1
Reasons	Cannot afford	27.6	48.9	95.6
	No need	1.5	6.7	1.5

Table 4.21 One-way ANOVA for differences in pesticide use between catchments (groups) (significance at $p<0.05$)

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	17.146	2	8.573	52.756	**.000**
Within Groups	33.801	208	.163		
Total	50.948	210			

Table 4.22 One-way ANOVA post hoc test for differences between catchments for pesticide use

Dependent Variable: Pesticide

(I) Locality	(J) Locality	Mean Difference (I-J)	Std. Error	Sig.
Attakrom	Dunyankwanta	-.26442(*)	.08141	**.004**
	Nyamebekyere	-.67988(*)	.05532	**.000**
Dunyankwanta	Attakrom	.26442(*)	.08141	**.004**
	Nyamebekyere	-.41546(*)	.06631	**.000**
Nyamebekyere	Attakrom	.67988(*)	.05532	**.000**
	Dunyankwanta	.41546(*)	.06631	**.000**

** Mean difference is significant at the 0.05 level.*

In Ghana, an estimated 87% of farmers use a wide range of chemicals as herbicides, fungicides and/or insecticides (Dinham 2003). As also observed in this study (Table 4.23), herbicides are the predominant pesticide type in Ghana. Herbicides are perceived to perform longer, be more effective over a wider area than manual weeding, and result in reduced time, cost and labor (Ntow et al. 2006). Pesticides are available in agricultural retail stores, and a few pesticide sellers measure out smaller quantities for sale to those who cannot afford the entire container. Information about pesticide application comes from pesticide sellers, agricultural extension officers, pesticide labels and other farmers. The amounts applied vary depending on the farmer, crop and application time, with applications either by knapsack (for those who can afford it) or spraying bottles. Some farmers randomly mixed the pesticides, with the understanding that this makes them more effective, especially when cheaper brands and smaller quantities are all that can be afforded. Although many farmers use chemical pesticides in Ghana, it is not used correctly since most have received no training in use and application, which affects making proper decisions on pesticide selection and leads to poor application and timing rates, and health risks (Ntow et al. 2006).

Table 4.23 Pesticide types used (%). Columns add up to more than total percentage since each respondent used more than one type of pesticide.

Pesticide	Name	Attakrom	Dunyankwanta	Nyamebekyere
Herbicide	Atrazine Condemn Power Roundup	75.8	15.9	1. 5
Fungicide	Champion Foko Fungrian Kocide	35.6	11.1	1.5
Insecticide	Dursban Thionex	3.9	6.3	0.0

Fertilizer use

In Ghana, fertilizer use has fluctuated over the past few decades. Under the agricultural policies of the 1970's and 1980's, major production incentives for increased input use existed for farmers and included fertilizers, improved seeds, and bank loans administered by public agencies. In the early 1980's, fertilizers was sold to farmers at about half the price agencies had to pay. From 1987 onwards, subsidies were gradually removed, ending completely in 1989. By 1999, there was a reduction of 48% of total fertilizer use. In 2008, the government re-introduced fertilizer subsidies of 40-50% for poor smallholder farmers. Although subsidized, incentives for purchasing and applying fertilizers are fundamentally the fertilizer yield response and input and output prices (Kelly 2006). Farmer knowledge and experience with fertilizers will affect the perception of the yield response and profitability, which is generally lower than that perceived by researchers and extension personnel. The incentives are also shaped by relative returns, such as profitability, as compared to other non-farm or health-related opportunities. These returns are influenced by different management practices by different farmers, changes in climate and soil quality, output prices that are usually volatile and can fluctuate from season to season, and even the variability in the prices of fertilizers in space and time. The use of fertilizers in Ghana varies according to the region, with the Upper regions being the largest consumer, due to the production of vegetables under irrigation during the dry season in the Upper East (FAO 2005). Maize accounts for 40% of fertilizer use on food crops.

For the study catchments, fertilizer use in 2004-2006 was higher in Attakrom (20.5% of respondents) than in Dunyankwanta (12.3%) and Nyamebekyere (0%) (Table 4.24), a phenomenon also observed by the VINVAL project (Meijerink et al. 2003). There is enough evidence to show significant differences in fertilizer use between catchments ($p<0.05$) (Table 4.25), which forms the basis for this study's hypothesis that nutrient levels, physico-chemistry and macroinvertebrate community dynamics varies significantly. Differences are significant between Attakrom and Nyamebekyere ($p=0.000$) and between Dunyankwanta and Nyamebekyere ($p=0.012$) (Table 4.26).

When asked about the reasons for their lack of fertilizer use, a greater proportion of farmers indicated that they could not afford fertilizers. However, financial capital is not the only reason that farmers do not purchase fertilizers. There are also no incentives for the farmers to risk investment in production, as fertilizer prices are unstable, market prices fluctuate and there may be other priorities such as health and children's education (Kelly 2006). Another main reason, which is supported by Drechsel and Zimmerman (2005), is the perception of farmers that there is no need for fertilizers, since they are used only for a short time in the shifting cultivation cycle. In the above study, a smaller percentage of farmers (18%) also indicated reduced food quality (e.g. of cassava), lack of information about fertilizer use (10%), increased weed growth (5%), and degradation of soil quality (2%). In Attakrom and Duyankwanta, NPK/15-15-15 was the most common fertilizer, followed by 'asasewura' (a premixed cocoa fertilizer), and ammonium sulphate. The formulation of Asasewura is 0-18-22 plus calcium, sulphur and magnesium, and has been significant in increasing cocoa yields (FAO 2005). All fertilizers used in Ghana are imported, with the most important group being the NPK compound fertilizers, followed by ammonium sulphate and muriate of potash (FAO 2005). Major importers of fertilizers are private companies (80%), some commercial farms, and the Agricultural Development Bank (ADB) that imports either for their clients or for their own use.

In the catchments, fertilizers were applied mostly to cocoa and maize, with a few applications (approximately 6%) to rice, orange, pepper and oil palm. Since cocoa and maize are cash crops, investment in fertilizers provides greater returns than for subsistence crops. One farmer, however, used fertilizer on all his crops, which included cassava, oil palm, cassava, pineapple, plantain, yam and cocoyam. Fertilizer application for cocoa is by broadcasting, i.e., granules are spread around in the beds of large plants. Fertilizers used on cocoa were Asasewura and NPK/15-15-15 that were applied to the plants once a year, usually at the onset of the rainy season in June. The fertilizer amounts applied varied per farmer, and responses ranged from 1 bag (50 kg) per 4 acres (1.6 hectares) to 2 bags per acre (0.4 hectares). Fertilizer application for maize is by spot/ring application, where granules are placed 5-30 cm away from the base or in a ring around the plant. Maize is usually planted between April and June, before or after the rains start, with harvesting 4-5 months later. NPK 15-15-15 is usually applied to maize 2 weeks after planting; ammonium sulphate was applied 6-8 weeks after planting. For other crops, applications for the tree crops oil palm and oranges, and for pepper and rice are once a year at the start of the rainy season.

The logistical regression analysis was applied to explain the use of fertilizer in the catchments. In addition to high correlation with pesticide use, other important variables are farm loans, access to agricultural extension officers, land status and residency, in order of decreasing significance (Table 4.27). The model explained 94.1% of the variability at $p<0.05$.

Table 4.24 Fertilizer use in the last 2 years (2004-2006), types used, and the reasons given by respondents who answered ‘No’ (%)

Fertilizer Use		Attakrom	Dunyankwanta	Nyamebekyere
		N = 83	N= 65	N = 70
Yes		20.5	12.3	0.0
Types	Asasewura	4.8	1.5	-
	7-7-7	1.2	-	-
	NPK/15-15-15	13.3	10.8	-
	NH_42SO_4	4.8	1.5	-
	NPK + Foliar	1.2	-	-
No		79.5	87.7	100.0
Reasons	Cannot afford	54.7	87.0	88.2
	Land fertile	43.8	13.0	11.8

Table 4.25 One-way ANOVA for differences in fertilizer use between catchments (significance at $p<0.05$)

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1.600	2	.800	8.374	**.000**
Within Groups	20.533	215	.096		
Total	22.133	217			

Table 4.26 One-way ANOVA post hoc test for differences between catchments for fertilizer use

Dependent Variable: Fertilizer

(I) Locality	(J) Locality	Mean Difference (I-J)	Std. Error	Sig.
Attakrom	Dunyankwanta	-.08174	.06060	.448
	Nyamebekyere	-.20482(*)	.04457	**.000**
Dunyankwanta	Attakrom	.08174	.06060	.448
	Nyamebekyere	-.12308(*)	.04107	**.012**
Nyamebekyere	Attakrom	.20482(*)	.04457	**.000**
	Dunyankwanta	.12308(*)	.04107	**.012**

** Mean difference is significant at the 0.05 level.*

Table 4.27 Logistic regression of association between fertilizer use and various parameters (Ea_Income = earned income, UE_Income = unearned income, Land_own = land ownership, Agric_Ext = agricultural extension officers, Farm_loan = access to farm loan, Livest_own = livestock ownership). df = degree of freedom; Sig = significance, at $p<0.05$.

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 1(a)	Gender	.824	1.133	.529	1	.467	2.280
	Age	-.775	.418	3.442	1	.064	.461
	Education	-.435	.283	2.358	1	.125	.647
	Ea_Income	.363	.322	1.275	1	.259	1.438
	UE_Income	.576	.873	.435	1	.510	1.778
	Migration	-1.630	.752	4.704	1	**.030**	.196
	Land_own	1.227	.554	4.897	1	**.027**	3.410
	Pesticide	3.252	1.173	7.691	1	**.006**	25.842
	Agric_Ext	2.696	1.081	6.218	1	**.013**	14.823
	Farm_loan	5.065	1.648	9.445	1	**.002**	158.407
	Livest_own	-1.108	.956	1.345	1	.246	.330
	Constant	-11.767	4.713	6.235	1	.013	.000

4.3.5 Water resources and sanitation

Water is an important environmental resource for development, linked to poverty, human welfare and health, and impacts household labor due to the efforts to obtain it (Madulu 2003). Potable water for all three catchments is obtained from boreholes, which have mechanized pumps provided by the government, with a few farmers depending on hand-drawn wells dug in the fields. Stream flow is seasonal in the catchments, and the availability of a reliable source of potable water in the village provides a measure of security and increased standard of living for the residents. The labor costs required for obtaining and transporting water is reduced, and the relative quality of groundwater compared to stream water ensures a healthier community. Overall, respondents were satisfied with the quality of water, which in their perception ranged from good to excellent. To maintain the running costs of the boreholes and repairs when there is a problem, communities in Attakrom and Nyamebekyere are charged a minimal fee for the use of the boreholes. These fees range from >¢1000 (€0.10) per year in Nyamebekyere to ¢100-¢500 (€0.01-€0.05) per use in Attakrom. In Dunyankwanta, there is no payment for water. Water is stored by households in containers or tanks and does not require any form of pretreatment before or during use. In circumstances when there is a temporary breakdown of the borehole pump, residents of the communities obtain water from other parts of the village, or nearby villages within the vicinity.

With regard to sanitation, refuse dumping and sewage were compared for each of the catchments. Refuse is usually dumped away from the living areas of the communities at a specified dump site, which is not located near any of the streams in both Attakrom and Nyamebekyere. In Dunyankwanta, farmers were aware of and complained of refuse being dumped near streams, which in their estimation leads to diseases and poor water quality; and that there was the need for stricter rules by the District Assembly to prevent this. All the communities have an established place of convenience – the pit latrine in Nyamebekyere, the KVIP in Dunyankwanta, and a range of facilities at Attakrom (KVIP, pit latrine, water closet). In Nyamebekyere and Dunyankwanta, all the facilities are public and use is free of charge. In Attakrom, there are a few private owned water closets and, although some of the public facilities are free, others charge a fee ranging between ¢100 and ¢500 per use, whilst others go to the bush as an alternative place of convenience.

With the exception of Nyamebekyere, due to the inconsistency of stream flows, most farmers in Attakrom and Dunyankwanta use the streams during the rainy season for a variety of purposes (Table 4.28), such as mixing the herbicides for spraying, washing, bathing, cooking, and drinking when on the fields. From discussions, approximately 20% of the respondents from Attakrom and Dunyankwanta, but none of the respondents from Nyamebekyere, were aware that activities of their communities could affect the quality of the streams and downstream communities. These farmers were aware that the applied chemicals could be washed into the streams, and a few farmers complained that at times fishing was done illegally with the use of chemicals (chemicals poured in the stream kill fish, which float up for easier retrieval). Most of the farmers were also aware of the implications of farming too close to the streams, since flooding periodically destroys the crops. Downstream sites , with intermittent stream flow, had boreholes constructed within the past few years by the government, but communities along sites on the Ofin River with perennial flow, depend mostly on the river for all domestic use. In most of the downstream sites, villagers complain of skin diseases and bloody urine, especially among the children who swim in the river.

In the three catchments, traditional regulatory measures still function as a method of controlling communities and their interaction with the environment, even though there is the general impression that traditional laws are slowly losing authority. Every week, one day is assigned a ‘no farming day’, dedicated to the earth gods - Tuesdays in Attakrom and Dunyankwanta, and Fridays in Nyamebekyere. No one is allowed to work on the farm (i.e., weeding or clearing) although some allowance is given for minimal harvesting. Menstrual women are forbidden to go near the streams until the end of their cycle, and on Tuesdays, women cannot cross any of the streams nor can any person collect water from the stream. Animals are not allowed near the streams, and fines are imposed on the owners of animals that are found free range during prohibited hours, i.e., between 6 a.m. and 3 p.m. daily. To protect the forests, most of the community members are forbidden to enter, with the exception of ‘authorized persons’. Offenders are sanctioned and have to pay a fine of usually rum and other drinks in addition to a ‘cleansing’ by the slaughter of animals.

Table 4.28 Stream use in the catchments (%)

Stream Use	Attakrom	Dunyankwanta	Nyamebekyere
	N = 79	N = 69	N = 67
Yes	75.9	60.9	3.0
No	24.1	39.1	97.0

4.4 Summary

The farming/cropping systems were evaluated for each catchment as a function of land-use intensification. Land preparation, as in most parts of sub-Saharan Africa, is by weeding, burning, and clearing. The crops types are comparable across catchments, with cassava, cocoa, plantain and maize being the major crops on 30-45% of the fields. Intercropping is common, either with other vegetable crops or tree crops such as cocoa, oil palm, and orange. The catchments are located within the same administrative district (Ahafo-Ano South District) and share similar cultural and institutional setups. However, a large proportion of the farmers in Attakrom benefited more from institutional facilities, i.e., access to agricultural extension officers and bank loans, than Dunyankwanta or Nyamebekyere, where none of the respondents benefited from these services. Market access and proximity were better for Attakrom and Dunyankwanta and limited for Nyamebekyere.

In Attakrom, a greater proportion of the respondents (28.6%) were between 50 and 59 years old, were exclusively farmers (96.4%) who on average had basic education (90.1%), and had an even distribution of earned and unearned income (from family members or pension schemes). Sharecropping (produce shared between the sharecropper and landowner at a ratio of 2:1) was the most common form of land arrangement in Attakrom, and the proportion of respondents who use pesticides (70.9%) and fertilizers (20.5%) were highest.

In Dunyankwanta, respondents were mostly 40-49 years old, were predominantly farmers (87%) although 34.8% had secondary occupations. Education was mainly basic (67.6%).

Compared to the other catchments, a larger percentage of the respondents (50.7%) had migrated into the catchment mostly for farming purposes. More than half the respondents were in the low earned income category (56.1%), and 22.7% with unearned income. Livestock ownership was the lowest compared to the other catchments (37.7%), and land arrangement was mainly by share tenancy, where farmers grow vegetables among tree crops that belong to the land owner. The proportion of respondents who use pesticides (44.4%) and fertilizers (12.3%) were comparatively lower than Attakrom.

In Nyamebekyere, the majority of respondents were 40-49 years old (27.1%). Of the three catchments, a greater proportion had secondary occupations (68.8%) in addition to farming (92.9%). Education was the highest of all catchments, with a larger proportion of the respondents having secondary level education (61.0%). Migration was the lowest (11.4%), and mainly due to teacher transfers. The number of respondents in the low earned income category was the highest (65.7%), and only 15% reported receiving any form of unearned income. A large proportion of the respondents owned livestock (77.1%), and land-use arrangements allowed the cultivation of requested areas as long as forest tree saplings were replanted. There was no fertilizer application in Nyamebekyere, and pesticide use was minimal (2.9%).

The most common fertilizer applied in the study was NPK/15-15-15, used mainly on the commercial crops cocoa and maize. Common herbicides were Atrazine, for maize, cassava, plantain, cocoyam and rice, and the fungicide Kocide, on cocoa. In addition to a high correlation to pesticide use, a logistic regression analysis showed that the major factors explaining use of fertilizer were access to credit, access to extension officers, migration and land ownership.

In the catchments, there is minimal dependence on stream water because of the intermittent flows, with boreholes providing potable water of good quality. In Attakrom and Dunyankwanta, farmers use water from the streams mainly when they are working on the fields, and there were occasional reports of fishing with chemicals. Most of the respondents were aware of the consequences to downstream users.

5 LAND USE AND STREAM NUTRIENTS

5.1 Introduction

Close coupling has been established between land-use and water quality, with surface runoff and erosion processes being major pathways for the transport of nutrients and sediments to streams (e.g., Chapman 1996; Carpenter et al. 1998; Moyaka et al. 2004). Freshwater quality limits have been set for users of water resources in Ghana (WRC 2003a), but there is currently no available information or standards established for nutrient loads. Literature on water quality in surface waters has focused mainly on physico-chemical monitoring for large drainage basins (WRC 2003b; c; d), or the assessment of specific water bodies (e.g., Biney 1987; Ansa-Asare 1992; Ansa-Asare and Asante 1998), some in mining areas (e.g., Danwka et al. 2005; Serfor-Armah et al. 2006). A few studies have estimated nutrient loads, although these were for sites along major rivers, and estimations represented total inputs from domestic, industrial, and agricultural sources (e.g., Karikari and Ansa-Asare 2006; Akrasi and Ansa-Asare 2008). Domestic sources, for example, were presumed to contribute to the observed loads of nitrates, phosphates and sulphates which increased downstream along the Birim River; and high manganese levels f in 84.2% of the samples indicated mining sources (Ansa-Asare and Asante 2000).

The objectives in this part of the study were to assess the pressure (P) and chemical state (C) of the DPCER framework. This chapter is divided into the following three main sections, (i) hydrology, (ii) physico-chemistry and (iii) nutrient load estimation of the streams draining the three upland catchments. In the hydrology section, total water yield is estimated, since nutrient load and yield are based on the magnitude of stream flow. Nutrient ion concentrations are compared to assess the differences in stream physico-chemistry, and the nutrient loads and yields for each catchment are calculated as a product of water yield and nutrient ion concentration. The overall objective of this part of the research is to depict the range, magnitude and differences in nutrient concentration and loads/yields between catchments with different land-use intensities. Leaching patterns and specific sources of nutrient loading, which require detailed soil data and runoff information, were not incorporated.

5.2 Methodology

5.2.1 Hydrology

A weather station installed in May 2003 in the Duyankwanta catchment at 6°52.568′ N and 1°55.411′ W (253 masl) by the VINVAL project, measured the following meteorological parameters for the three catchments – relative humidity, air temperature, wind speed, wind direction, rainfall, radiation and air pressure. The weather station was an *Eijkelkamp Co*. mini electronic meteorological station powered by a small solar panel, with an anemometer to record wind speed and direction, a tipping bucket rain gauge for rainfall monitoring, and sensors to measure solar radiation, air temperature and humidity. All parameters were recorded on an hourly basis and stored in the main unit memory of the station. The data was downloaded using HogWin software. Climatic data was also obtained from the only meteorological station in Kumasi at 6°43′ N and 1°36′ W (286.3 masl). In addition to the weather station, one manual rain gauge was installed at each of the catchments. The volume of precipitation was recorded at 0900 hours every morning, which was representative of the previous day's rainfall.

Stream level

Divers (Van Essen Instruments) installed in the streambed of each catchment outlet recorded water level changes in a datalogger. Measurements of date, time, water level and temperature were on an hourly basis. Two CTD-divers were installed at each catchment outlet, one upstream and one downstream, i.e., on either side of the W-weir (at Dunyankwanta), and the culverts at Nyamebekyere and Attakrom. Early in the monitoring process, one diver at the upstream end of Nyamebekyere was stolen, and that at the upstream end of Attakrom malfunctioned, leaving only one diver per site for Nyamebekyere and Attakrom. The diver type DI 240, which measures up to 5 m water column with a usable range of up to 4 m water and an accuracy of ±0.1% FS (full scale) and resolution of 0.1 cm, was installed at all points except downstream at Dunyankwanta. This was because a DI 240 was not available. Another diver type DI 241, which measures up to 10 m water column with a usable range of 9 m, accuracy of ±0.1% FS and resolution of 0.1 cm, was installed instead. Diver measurements of temperature range between -20°C and 80°C with an accuracy of ±0.1°C and resolution of 0.01°C. A Van Essen Baro-Diver DI250 was installed at Dunyankwanta to measure variations in air pressure in the three catchments (with the assumption that the variations within the 10-km area of the catchments were not significant). The diver's measuring range is up to 1.5 m with 0.3% FS accuracy and 0.1 cm resolution. The data from the divers were regularly downloaded with a LoggerDataManager software (LDM 3.0.2) when the streambed was dry.

Discharge and velocity were established for each catchment by a hydrographer (Mr. Mawuli) from the Ghana Meteorological Department. Instrumentation was checked, cleaned and downloaded at the start of the dry season. Since the quality of the stage-discharge relationship is important in determining the total discharge for the stream, and may be modified by growth of weeds, the area was regularly cleared, especially during the rainy season.

5.2.2 Physico-chemistry and nutrient ion concentration

For accurate estimations of total load, the frequency of nutrient ion concentrations would need to be estimated at least daily. Weekly sampling generally provides relatively precise load estimates (Johnes 2007). However, due to the more variable flows of the upland study streams, a more frequent sampling regime of every 48 hours was employed in order to capture a greater proportion of the flow. The total number of water quality samples (Table 5.1) and distribution of the sampling points along the stream level (Figure 5.1) are presented. The fewer number of 48-hour samples obtained for Nyamebekyere was due to the shorter discharge periods after a storm, typically lasting for an average of 24 hours.

Table 5.1 Number of water quality samples obtained during study period. (A = Attakrom, D = Dunyankwanta, N = Nyamebekyere)

	2005			2006							Sum
	Sep	Oct	Nov	May	Jun	Jul	Aug	Sep	Oct	Nov	
A	-	15	10	4	14	8	7	2	11	6	77
D	2	15	10	3	8	6	6	1	11	11	73
N	1	6	-	-	1	3	-	-	5	-	16

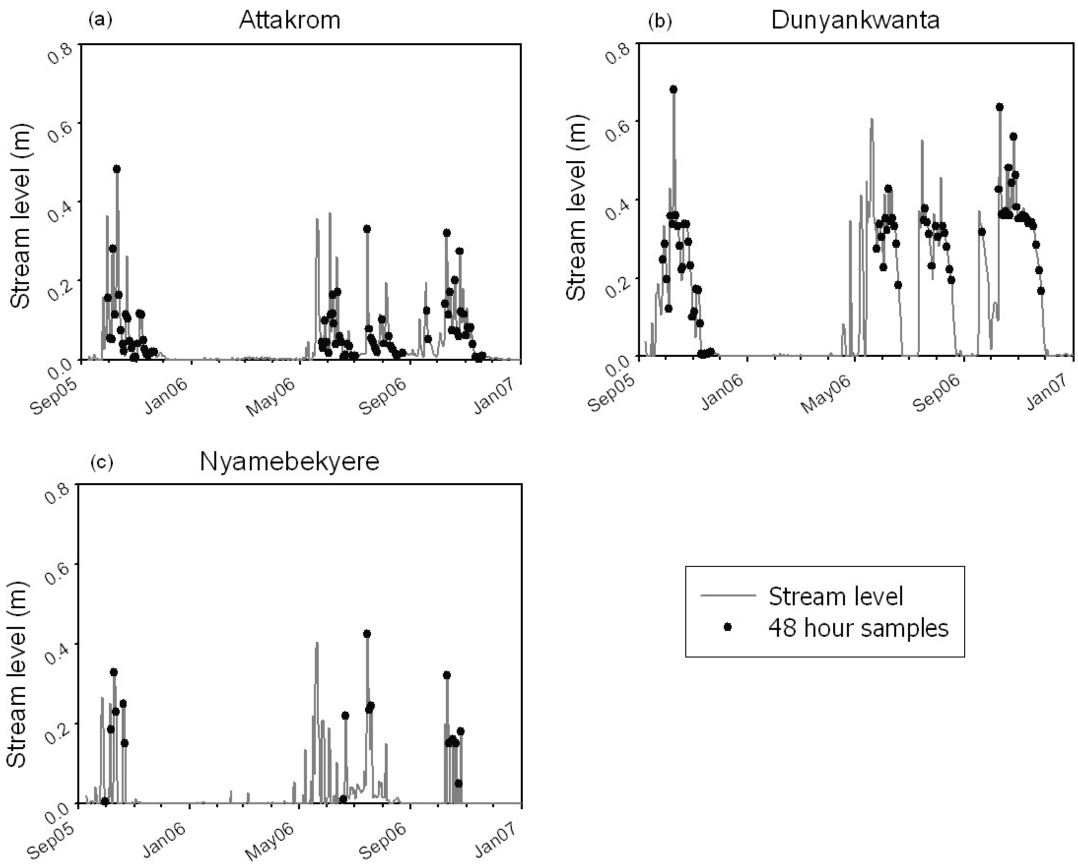


Figure 5.1 Stream level sampling points for Attakrom, Dunyankwanta and Nyamebekyere

Physico-chemistry

A Horiba U-10 water quality checker was used in the field to measure conductivity, DO, pH and temperature (Table 5.2). Although the meter included a turbidity option, there were difficulties in obtaining accurate readings as single measurements would fluctuate widely when the probe was immersed in the stream. As a result, turbidity values were not included in the analyses.

Calibration was done automatically by immersing the probe into the standard solutions supplied with the meter, with the calibration button pressed once for each of the parameters. Calibration was once a month during the sampling period.

Table 5.2 Measurements and specification of Horiba Digital U-10.

Parameter	Range	Repeatability
pH	0 – 14	±0.05
Conductivity (mS cm^{-1})	0 – 100	±1% of full scale
Dissolved Oxygen (mg/l)	0 – 19.9	±0.1 mg/l
Temperature (°C)	0 – 50	±0.3°C

Nutrient ion concentration

Manual grab samples were collected with 1 L polyethylene bottles approximately at the same time of the morning for each site, according to standard regulations for examination of water and wastewater (Eaton et al. 1995). Prior to collection, all bottles were thoroughly washed with de-ionized water. Sampling was done by wading out into the stream and facing the upstream flow, where water would be representative of the stream and not affected by activities that would stir up the substrate sediments. The bottles were rinsed with water from the streams and the bottle submerged under the surface of the stream to collect a sample. When filled, the lid was placed on the bottle before removal from the stream, and labeled with the site, date and time of collection. Samples were placed in coolers with ice packs to maintain low temperatures of about 4°C and transported within a couple of hours to the Soil Research Institute (SRI) laboratory of CSIR (Center for Scientific and Industrial Research), located in Kumasi. At the laboratory, samples were immediately placed in a refrigerator with a maximum temperature of 4°C until analysis, usually within 5 days of collection.

Concentration levels of calcium (Ca), magnesium (Mg), exchangeable potassium (K), exchangeable sodium (Na), nitrogen compounds (nitrate NO_3-N and ammonium NH_4-N), and ortho-phosphate (PO_4-P) were analyzed (Table 5.4) by the laboratory staff at SRI. Calibration curves were prepared for samples analyzed colometrically, and control standards were added to check for accuracy for each batch of analysis. Blank analyses were done to determine inferences from glassware, reagents or equipment. Samples were replicated at regular intervals (10%) to check for precision, and instruments were calibrated before analysis.

Table 5.4 Methodology and apparatus used for testing for each nutrient parameter

Parameter	Apparatus/Method	Reference
Ammonia nitrogen (NH_4-N)	Bertholot Colorimetric method	Eaton et al., 1995
Nitrate nitrogen (NO_3-N)	Colorimetric Determination method	Cataldo et al, 1975
Exchangeable potassium (K) Exchangeable sodium (Na)	Gallenkamp Flame Analyzer Model FGA-330	Eaton et al., 1995
Orthophosphate (PO_4-P)	Phosphorus-Molybdenium Blue method	Eaton et al., 1995
Calcium (Ca) Magnesium (Mg)	EDTA Titrimetric method	Eaton et al., 1995

5.3 Data Analysis

5.3.1 Hydrology

In order to accurately assess the nutrient yields from each catchment, it is important to estimate the stream discharge. Miscalculation of the discharge leads to errors in determining nutrient loads, as this is the function of the amount of water that leaves the catchment. To assess discharge as a proportion of total rainfall volume, the basic water balance of each catchment system was established by the mass balance equation (Equation 5.1) (Shahin 2002):

$$(I + P_e) = (O + DR) \pm \Delta SM \pm (GWP)_r + ET \tag{5.1}$$

Where: I = inflow to the system (e.g., irrigation), P_e = effective precipitation, O = outflow from the system, DR = drainage, ΔSM = change to soil moisture in storage, $(GWP)_r$ = groundwater discharge, and ET = evapotranspiration.

Inflow and Precipitation

In the absence of any irrigation to the catchment area, total inflow of water was limited to total precipitation estimated from the rain gauge measurements.

Outflow and Discharge

Due to the unavailability of groundwater discharge data, estimations of total discharge were based only on stream level changes at the outlets. Hourly values of total water pressure were downloaded from installed divers and corrected with hourly barometric diver measurements and standard pressure value of water (1.01972 cm) to give an accurate pressure reading of surface water discharge. A steady upward drift was observed in the average daily readings from January 2006 for Attakrom and March 2006 for Nyamebekyere (both installed by the VINVAL project in 2003), but not for Dunyankwanta (installed in July 2005). The drift was corrected using water level values obtained by periodic manual readings of the staff gauges at the outlets. Rating curves were established by plotting all discharge measurements against corresponding stage readings for the three catchments, and the trend line with the best fit was used to calculate discharge levels (m^3 s^{-1}) during stream flows (Shaw 1988) (Figure 5.2). Daily discharge values for 2005 and 2006 were then calculated in m^3 day^{-1} and totaled for annual runoff per catchment area.

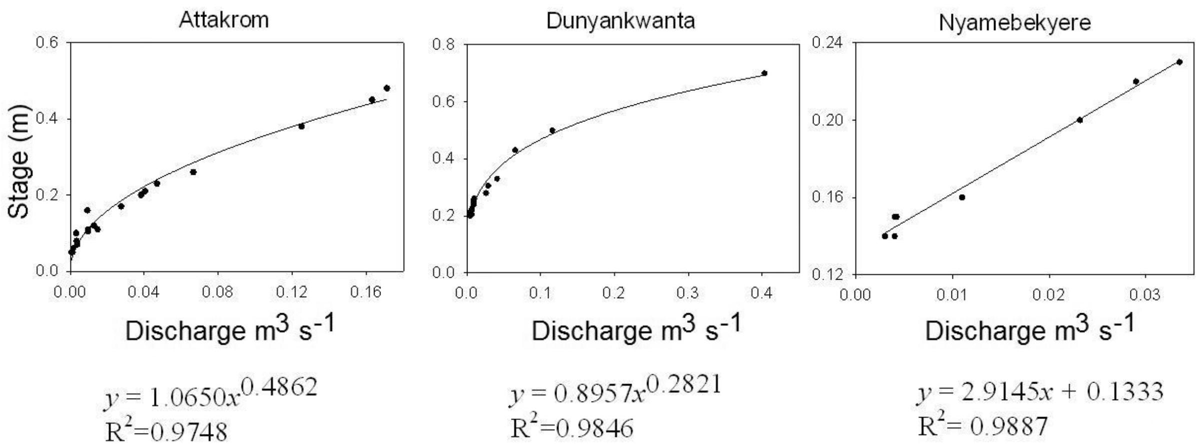


Figure 5.2 Rating curves and best fit trend lines for stream stage-discharge.

Soil water storage

In calculating the changes in soil water storage (ΔS), an estimate of the soil's ability to store water is required. The available water holding capacity of a soil is based on the difference between its upper limits, i.e., field capacity (water content of soil at equilibrium), and lower limits, i.e., permanent wilting point (when plants begin to wilt). Since soil storage capacity and the initial soil moisture were unknown for the catchments, a balancing routine was used to set the initial soil moisture at the beginning of each year to 0. This assumes that there are no changes in major seasonal patterns from one year to the other and annual soil moisture storage is 0 at the start of each year (Dr. C. Rodgers, personal communication).

Evapotranspiration

In hydrological studies, evapotranspiration is generally calculated as the amount of available water after discharge and soil storage changes; in physical meteorology, it is the combined process of both evaporation from soil and plant surfaces and transpiration through the stomata of the plant surfaces (Shahin 2002). Potential evapotranspiration is the rate at which water is removed from the soil surface by evapotranspiration if there is no restriction on the available water. Actual evapotranspiration is the actual amount for a specified crop at a designated time, corrected for the possible condition of dry soil.

To determine the evaporative capacity of the atmosphere for the study area, the FAO Penman-Monteith equation (Equation 5.2) was used to calculate ET_o, i.e., or the reference crop evapotranspiration. This equation estimates evaporation of a hypothetical crop with an assumed height of 0.12 m, a fixed surface resistance of 70 sm^{-1} and an albedo of 0.23, and is recommended as the standard method for best results and minimum possible errors (Allen et al. 1998).

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \tag{5.2}$$

Where: ET_o = reference evapotranspiration [mm day^{-1}], R_n = net radiation at the crop surface [MJ m^{-2} day^{-1}], G = soil heat flux density [MJ m^{-2} day^{-1}], T = mean daily air temperature (at 2 m) [°C], u_2 = wind speed at 2 m height [m s^{-1}], (e_s - e_a) = saturation vapor pressure deficit [kPa], Δ = slope vapor pressure curve [kPa°C^{-1}], and γ = psychrometric constant [kPa°C^{-1}]. ET_o values were calculated using an Excel spreadsheet.

Climatic parameters required for ET_o computation include solar radiation, air temperature, air humidity and wind speed, which were all obtained from the VINVAL weather station. Missing data due to infrequent downloading and malfunctioning sensors for rainfall and humidity in 2006, were estimated using data obtained from the installed barometer at Duyankwanta, correlations with the regional weather station data (Kumasi), or calculation procedures recommended by the FAO guidelines for missing or unreliable data (Allen et al. 1998).

Temperature

For missing air temperature values (12 March to 22 May 2005; 29 October 2005 to 15 September 2006) from the VINVAL weather station, a linear correlation with average daily temperature data from the weather station and the barometer installed in the same catchment showed a regression coefficient of R^2 = 0.7951 (Figure 5.3). The formula obtained was used to fill in for the missing data.

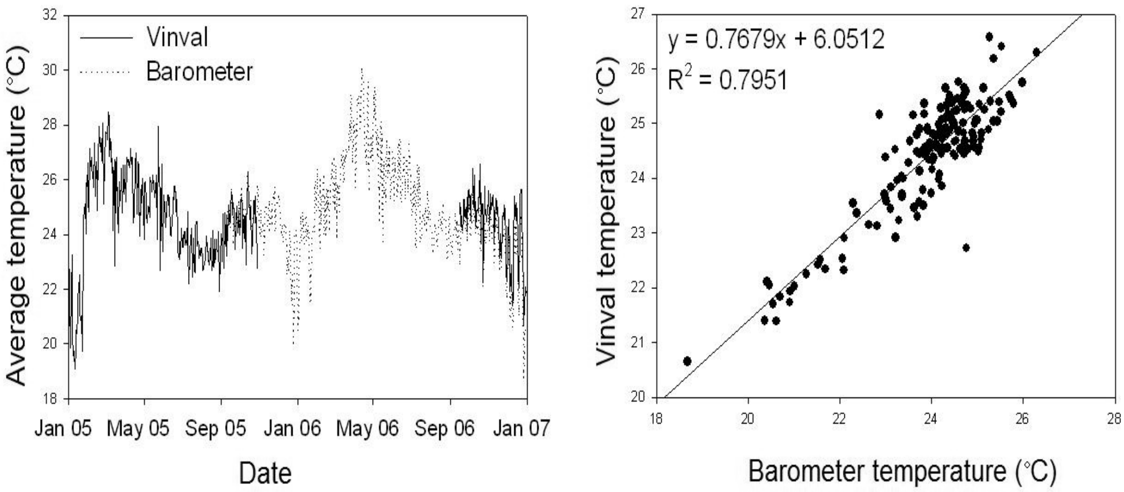


Figure 5.3 Graph and linear correlation between average temperature values obtained from the Barometer diver and VINVAL weather station.

Humidity

In estimating actual vapor pressure (Eaton et al. 1995), the FAO guidelines recommend using both maximum and minimum values of relative humidity (Equation 5.3).

$$e_a = \frac{e^o(T_{\min})\dfrac{RH_{\max}}{100} + e^o(T_{\max})\dfrac{RH_{\min}}{100}}{2} \tag{5.3}$$

Where: e_a = actual vapour pressure [kPa], e^o (T_{min}) = saturation vapour pressure at daily minimum temperature [kPa], e^o (T_{max}) = saturation vapour pressure at daily maximum temperature [kPa], RH_{max} = maximum relative humidity [%], and RH_{min} = minimum relative humidity [%]

The VINVAL weather station humidity sensors malfunctioned for most of 2006. The *RH* data of the meteorological department were substituted for the determination of ET_o for the catchments. Since the evaporative capacity of the atmosphere is estimated, variations due to vegetative cover is not reflected in the results obtained. In addition, since RH_{min} values for

July 2006 were missing for the Kumasi meteorological station, FAO's suggestion for the estimation of e_a when RH_{min} readings are uncertain (Equation 5.4), was applied.

$$e_a = e^o(T_{\min})\frac{RH_{\max}}{100} \tag{5.4}$$

Wind

FAO's recommendation is to use 2.0 m s^{-1} as the average wind speed for missing wind data. However, an average value of 0.5 m s^{-1} was used for the catchment areas, which is more representative of the wind speeds observed from available data from both VINVAL and Kumasi weather stations (Figure 5.4).

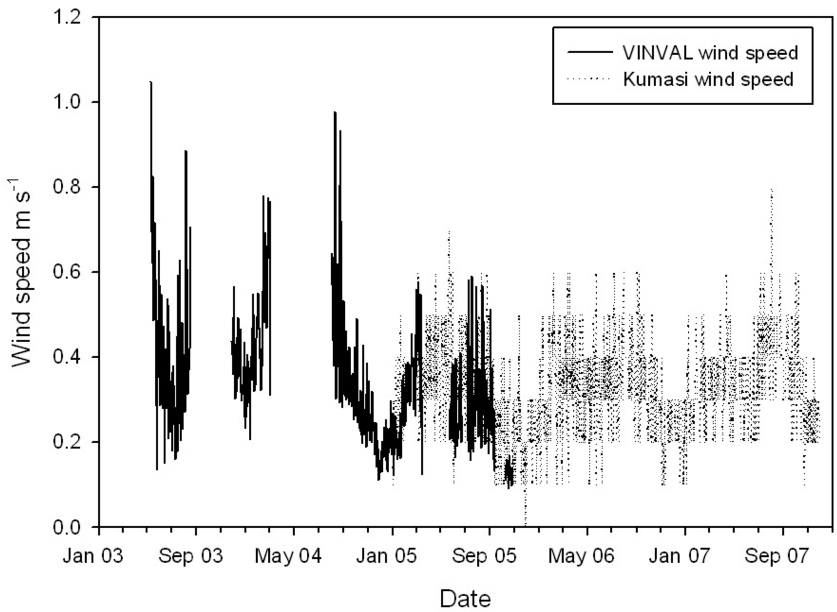


Figure 5.4 Average daily wind speeds (m s^{-1}) from Kumasi and VINVAL weather stations.

5.3.2 Stream chemistry

Box and whisker plots show the range of all measured concentrations for each catchment for the entire period; 50% of the data points lies within the box, with the middle horizontal line of the box representing the median value, whiskers showing the range of data, and circles showing the outliers.

Flow-weighted mean ion concentrations

To determine the overall average concentration of nutrient ions for a time period in order to enable comparisons between catchments, each sample's contribution with respect to discharge needs to be accurately estimated. The discharge volume for each sample varies from one measurement to another, and as such each sample has to be weighted differently when averages are calculated. Data on the measured concentration (*C_i*) are weighted by the sample-time window (*t_i*) and discharge at the time of sampling (*Q_i*). The flow weighted mean concentration (FWMC) represents the total load for the time period (month, season and year) divided by the total discharge for the time period (Equation 5.5).

$$FWMC = \frac{\sum_{1}^{n}(C_i \cdot t_i \cdot Q_i)}{\sum_{1}^{n}(t_i \cdot Q_i)} \tag{5.5}$$

5.3.3 Nutrient load estimation

Ideally, with continuous discharge and concentration data, the actual load of pollutants transported through the cross section of a river or stream during a time interval (Equation 5.6) is usually expressed as:

$$L = \int_{t_1}^{t_2} Q(t)C(t)dt \tag{5.6}$$

Where: L represents the load between time t_1 and t_2, *$Q(t)$* the stream flow at time *t*, and *$C(t)$* the chemical concentration at time *t*.

With *C* not provided as a continuous measurement (one sample approximately every 48 hours as compared to the hourly data available for stream flow), the annual nutrient load from the catchments was calculated by two different methods – the averaging or interpolation method and the ratio estimation method. The averaging method includes commonly used calculations shown below (Littlewood et al. 1998; Letcher et al. 2002; Li et al. 2003; Quilbé et al. 2006; Johnes 2007) (Equations 5.7 and 5.8).

(i) Average sample concentration times average sample discharge:

$$L_1 = n\left(\frac{1}{nd}\sum_{i=1}^{n} C_i\right)\left(\frac{1}{nd}\sum_{i=1}^{n} Q_i\right) = n \cdot \overline{C} \cdot \overline{Q} \tag{5.7}$$

Where: n is the total number of days for the period of load estimation, nd the number of days in the period that concentration data was measured, C_i is the sampled concentration on day i, and Q_i the average flow on day i.

(ii) Average concentration (Dann et al. 1986) or mean concentration times annual discharge

$$L_2 = \frac{\sum_{i=1}^{n} C_i}{nd} \cdot \mu_q \tag{5.8}$$

Where: μ_q is mean daily flow for the statistical period. The comparison of annual estimates obtained from Equations 5.7 and 5.8 yielded the same values, so only L_2 was used for comparison with the equation presented below.

(iii) Flow-weighted average sample concentration times average sample discharge (Equation 5.9):

$$L_{FW} = K \frac{\sum_{i=1}^{n} C_i Q_i}{\sum_{i=1}^{n} Q_i} \mu_q \tag{5.9}$$

The ratio estimator method includes the Beale's Ratio estimator (Beale 1962) as reported by Quilbé et al. (2006), which multiplies L_{FW} in Equation 5.9 by a ratio that accounts for the covariance between load and stream flow values (Equation 5.10). This method has shown the least biased estimates and inaccuracy in the comparison of estimation methods to the 'true load' (i.e., comparison of nutrient estimation of artificial reduced data to t hat of the full dataset), especially in cases where there is relatively sparse concentration data and an absence of strong correlation between concentration and flow data (Preston et al. 1989; Mukhopadhyay and Smith 2000; Letcher et al. 2002; Endreny and Hassett 2005; Quilbé et al. 2006; Johnes 2007).

A third method, the Regression Method, has worked well in other studies (Endreny and Hassett 2005; Johnes 2007). However, for this method, a linear correlation relationship must first be established between concentration and discharge levels for nutrients. In addition, a calibration period of at least 75 samples taken over a two-year period, with 50% during low flow and 50% during high flows, is needed to establish a reliable linear relationship (Richards 2000). Correlation values higher than a threshold value of 0.5 has been suggested for the coefficient of determination (r^2) before the regression method can be used, meaning that more than 50% of the variability of concentration should be explained by the stream flow (Quilbé et al. 2006). For this study, correlations between nutrients and discharge for the three catchments were all lower than the $r^2 = 0.5$ screening method suggested (Table 5.4). Since the regression method was not applicable, the Beale estimator, also a reliable method, was used for estimating nutrient loads. The annual mean estimates calculated by the averaging methods are presented in the results only for comparative purposes, with seasonal and monthly values based solely on the Beale's ratio method.

The Beale method weights the concentration values by adjusting the mean of daily loads (i.e., product of concentration and discharge on days when samples are taken) by a flow ratio (Equation 5.10). This ratio is obtained by dividing the average flow for the period by the average flow for the days on which samples were obtained. A bias correction factor is also included in the calculation to compensate for the effects of correlation between discharge and load. The ratio method assumes increase in concentration with increases in flow – a factor which is prominent in small streams and rivers where increased concentration occurs mostly during storm runoff.

$$L_{Beale's} = \overline{CQ} \cdot \frac{\mu_q}{\overline{Q}} \left(\frac{1 + \frac{1}{nd} \cdot \frac{S_{CQ}}{\overline{CQ} \cdot \overline{Q}}}{1 + \frac{1}{nd} \cdot \frac{S_{\overline{Q}}}{\overline{Q}^2}} \right) \tag{5.10}$$

The parameter S_{CQ} (Equation 5.11) is a modified covariance of the flow and load and is calculated by:

$$S_{CQ} = \frac{1}{nd - 1} \left(\sum_{i=1}^{n} C_i Q_i - nd\overline{Q}\overline{CQ} \right) \tag{5.11}$$

$S_{\overline{Q}}$ (Equation 5.12) represents a sample variance on the daily flows for sample size *nd* and is given by

$$S_{\overline{Q}} = \frac{1}{nd - 1} \left(\sum_{i=1}^{n} Q_i^2 - nd\overline{Q}^2 \right) \tag{5.12}$$

Data was processed to ensure consistency of units, and all concentration units were converted to milligrams per liter (mg L^{-1}) and discharge units expressed in m^3 day^{-1}. Unit conversions were performed throughout all load calculations to ensure that final loads were consistently reported in the standard units of kilograms per specified period, i.e., day, month, season and year.

Table 5.4 Correlation values (r^2) between nutrient concentrations and discharge

mg L^{-1}	Attakrom	Dunyankwanta	Nyamebekyere
Ca	0.10	0.02	0.03
K	0.07	0.07	0.01
Mg	0.05	0.02	0.00
Na	0.07	0.01	0.03
NH_4-N	0.01	0.00	0.00
NO_3-N	0.01	0.02	0.05
PO_4-P	0.00	0.06	0.13

Nutrient yield

In order to assess and compare the pollutant loads from the different catchments, which are different in size, the pollutant load per unit area, or pollutant yield, was also calculated (Equation 5.13). This yield normalizes the load of the monitored catchment area allowing for more relative comparisons to be made between different land-use intensities. Yield, Y (kg ha^{-1} yr^{-1}), was obtained by dividing the total pollutant load, L (kg) for a given time period by the catchment area A (ha).

$$Y = \frac{L}{A} \tag{5.13}$$

5.3.4 Statistical tests

Statistical tests were carried out only for detection of the differences in spatial trends and not for testing if these differences were significant enough to impact the aquatic system, although general comparisons are made to established WRC water quality standards for aquatic ecosystem health and domestic users. A significance level, or α-value, of 5% (0.05) was used for all comparisons, although it is important to note that significant differences are not always environmentally consequential. The null hypothesis (H_0) is that there are no differences in nutrient concentrations between catchments for different land-use intensities. H_0 is rejected when p values are less than or equal to the α-value ($p<0.05$), assuming that there are significant differences between the catchments. When $p>0.05$, it is assumed that there is not enough evidence to reject H_0. The smaller the p value, the less likely is H_0 to be true, and the stronger the evidence for rejection of the null hypothesis.

The Kolmogorov-Smirnov goodness-of-fit test was used to determine the normality in data distribution. The null hypothesis states that there is no difference between the data sets and a normally distributed one, and $p<0.05$ rejects normal distribution. For tests within individual catchments, data distribution was normal for some parameters and non-normal for others (Table 5.5). The test for data distribution for all catchments showed non-normal distribution ($p<0.05$) of all parameters except Mg, which means that overall, data were not normally distributed. Since water quality data are typically not normally distributed and usually have outliers, non-parametric tests have to be used (Helsel and Hirsch 2002). With the assumption of non-normality and a small sample size for Nyamebekyere (<20), non-parametric statistics were used to compare the differences in nutrient concentrations between catchments using SPSS.

The non-parametric analysis of variance, the Kruskall Wallis test, compares nutrient concentrations between catchments to determine if the values are identical (i.e., null hypothesis H_0) at significance level of 5%. When medians were significantly different, the non-parametric Mann-Whitney rank sum test was used to determine statistical pairwise differences between the medians to establish where, if any, these differences occurred.

Table 5.5 Kolmogorov-Smirnov (Z) normality test for nutrient samples, n = number of samples, Sig = significance. Non-normal distribution at $p<0.05$

Nutrient	Attakrom			Dunyankwanta			Nyamebekyere			All catchments		
	n	Z	Sig	n	Z	Sig	n	Z	Sig	N	Z	Sig
Ca	81	0.851	0.464	73	1.329	0.058	16	0.384	0.998	170	2.033	0.022
K	81	1.532	0.018	73	0.450	0.987	16	0.648	0.795	170	1.437	0.032
Mg	81	1.303	0.067	73	1.065	0.207	16	0.888	0.409	170	1.263	0.082
Na	81	1.016	0.253	73	1.795	0.003	16	1.632	0.010	170	2.089	0.000
NH_4-N	79	1.778	0.004	72	2.134	0.000	14	0.839	0.481	165	2.570	0.000
NO_3-N	79	1.560	0.015	72	2.507	0.000	14	0.682	0.741	165	2.638	0.000
PO_4-P	79	1.944	0.001	72	1.279	0.076	14	0.643	0.803	165	1.504	0.022

5.4 Results and Discussion

5.4.1 Annual dynamics

Hydrology

In the comparison and analysis of nutrient levels and yields for streams, the accuracy of stream-flow runoff has been determined to be the single most important factor (e.g., Li et al. 2003; Aulenbach and Hooper 2005; Johnes 2007). The precision of discharge measurements is, therefore, critical for the appropriate estimation of loads, especially for small ephemeral streams. Ideally, this accuracy should be supported by more efficient hydrological background studies, which have not been specifically established for the catchments in this study. However, inferences are drawn from or compared to various hydrological studies carried out by the GLOWA project, which have investigated issues such as rates of surface runoff and infiltration, the impact of climate variability on hydrology, and tree-water use and evapotranspiration rates within the Volta Basin (Ajayi 2004; Oguntunde 2004; Jung 2006). Although climatic data are available for 2005 and 2006, stream discharge readings for the three catchments began in the minor rainy season of September 2005. Without any detailed and long-term background hydrological data, an approximation of evapotranspiration for each catchment was calculated as total water volume input and output for only 2006 (Table 5.6), as data available for 2005 is partial. From September to December 2006, the diver datalogger for Nyamebekyere malfunctioned and measurements for this period were limited to periodic gauge readings.

For 2006, precipitation ranged between 1010.4 mm yr^{-1} (in Attakrom) and 1679.6 mm yr^{-1} (in Nyamebekyere), which indicates a large variability between catchments. Precise estimates of the volume of areal precipitation generally require measurements by rain gauges at several points within the catchment, since one gauge usually represents an area of 150 cm^2 (Shaw 1988) and can be a source of errors for larger scale estimations. In addition, the rain gauges were read by non-scientific staff, which could lead to instances of misreading or unrecorded events. However, in a study modeling the climate years 1936-1961 for the Volta Basin, results for the south-western parts showed an annual average precipitation value of 1800 mm, with a large range between 1340 mm and 2175 mm, similar to that estimated for the catchments (Oguntunde 2004).

Although discharge volumes varied between catchments, the percentage runoff was similar for Attakrom (2.3%) and Nyamebekyere (2.5%, but with missing data estimated by manual gauge readings), but much higher in Dunyankwanta (6.2%). Studies comparing rainfall-runoff percentages at plot levels in parts of the Volta Basin estimated a 5% runoff fraction for long runoff plots (2 m x 18 m), and higher discharge fractions of 33% for smaller plots (2m x 2m) (Ajayi 2004). In the Volta Basin, the average fraction of rainfall which becomes river discharge is estimated at 9%, although values range for different locations from 4.9% in the Black Volta, which lies adjacent to the catchment sites, to higher values of 13.5% in the more northern Oti due to its steeper terrains (Andreini et al. 2000). Despite the differences between catchments, the fraction of rainfall which became stream discharge in this study is comparable to the research of Andreini et al. (2000) and Ajayi (2004). The conversion of land from forested areas to agricultural lands often leads to significant increases in runoff volumes due to lower infiltration and evapotranspiration rates (Siriwardena et al. 2006; Li et al. 2007). The estimated lower discharge volumes in Nyamebekyere, although with the highest precipitation values, may therefore be indicative of higher evapotranspiration and infiltration typical of the greater vegetation cover of forested areas (Ajayi 2004; Oguntunde 2004).

To assess the effects of land-use intensity on soil properties in the catchments, soil compaction was assessed by evaluating soil bulk density, pore size class distribution and soil water retention parameters (Ungaro et al. 2004). Overall, the soils of the three catchments are dominated by loams (36%) followed by sandy loams, clays and clay loams (12% each). A positive trend was observed in bulk density average values with increasing land-use intensity, although the differences were not statistically significant. The positive trend in bulk density was correlated to an increase in microporosity (pore Ø< 7.5 µm) and a decrease in macroporosity (pore Ø>100 µm). Statistical differences were found in microporosity only between medium and high land-use intensity catchments, and in macroporosity between (i) low and high land-use intensity, and (ii) medium and high land-use intensity. A positive trend in soil water retention parameters was also observed with increasing land-use intensity, although differences were significant only between the low and high land-use intensity catchments. There are indications that increasing land-use intensity influences water retention properties. However, without detailed studies on how the vertical variability of the soils, hydraulic properties, dominant flow paths, etc. influence discharge rates, conclusive statements cannot be made about the changes in water yield as natural land is converted to agricultural land.

Rates of evapotranspiration can be measured and/or estimated from models or empirical approaches. Direct measurement approaches (e.g., using lysimeters) are difficult and time-consuming. In models, various parameters which interact to influence evapotranspiration are incorporated, i.e., weather (radiation, air temperature, humidity, wind speed), crop factors (crop type, variety and development stage), and environmental conditions (soil salinity, fertility, diseases, pests, poor soil management, ground cover, plant density and soil water content) (Oguntunde 2004). Meteorological data was rather used for this study, as it is also effective at estimating evapotranspiration with improved frequency and accuracy (Shahin 2002). Potential evapotranspiration values for the south-western parts of the Volta Basin, seen on evapotranspiration maps created by the Advection-Aridity (AA) model for 25-year data series (1936-1961) (Oguntunde 2004), were between 1340 and 1433 mm, and comparable to this study's estimated ET_o (1396.3). The AA model also shows ET_a values between 1297 and 1353 mm annually for the catchment areas ranges, which is higher than values estimated for Attakrom (987.5 mm), and lower than that of Nyamebekyere (1638.3 mm, a value that may be biased due to missing data). This could be due to the variations in surface albedo as a result of land-use intensity. Surface albedo is a major factor influencing the amount of water available for evapotranspiration depending on the type of vegetation, with as much as 1492 mm per annum for land-use comprised of mixed forest, mixed dry/irrigated crops, and crop/wood mosaic (Oguntunde 2004).

From the above discussions, precipitation values (although with high variation), discharge estimates (although Nyamebekyere with missing data) and calculated evapotranspiration rates using meteorological data, are similar to estimates obtained by other researchers within the study basin. With no supporting hydrological data on how land-use affects water dynamics from precipitation to surface runoff in small catchments, these estimates are adequate for the objectives of calculating nutrient load exports.

Table 5.6 Total precipitation (P), total discharge (Q), discharge as % precipitation, actual evapotranspiration (ETa), potential evapotranspiration (ET0) - 2006

Catchment	Total P (mm yr^{-1})	Total Q (mm yr^{-1})	Q as % P	Total ET_a (mm yr^{-1})	Total ET_0 (mm yr^{-1})
Attakrom	1010.4	22.9	2.3	987.5	
Dunyankwanta	1286.5	79.9	6.2	1206.6	1396.3
Nyamebekyere	1679.6	41.3*	2.5	1638.3	

** Total discharge may be underestimated with only manual gauge readings from Sep to Dec 2006*

Chemical State (C)

In order to assess the quality of the streams from the three catchments, measured values for physico-chemistry and nutrient ion concentrations (Appendix 5) are compared to the Raw Water Quality Criteria and Guidelines for Ghanaian freshwaters (WRC 2003a). These standards have been set for specific uses of freshwater in Ghana (such as domestic, recreational, industrial, agricultural, aquaculture, and for the protection of the aquatic environment) and establish the specific limits within which nutrient concentrations should be maintained, i.e., a Target Water Quality Range (TWQR) which is the range of ideal nutrient concentrations. This ideal range, or the 'No Effect Range', means that there are no adverse effects on the quality of water for a particular use or on aquatic ecosystem health. For the purpose of this study, the guidelines set for domestic water use (WRC 2003e), i.e., for washing, cooking, bathing, drinking, etc., and aquatic ecosystem health (WRC 2003f) are used (Table 5.7). For those parameters without set guidelines, references from other literature are used.

Table 5.7 Water quality parameters and TWQR (WRC 2003a)

Parameter	Aquatic ecosystem	Domestic water use
Conductivity μS cm-1	10 – 1,000**	0 – 700
Dissolved oxygen (mg L-1)	5 – 7**	-
pH	5% change*	6 – 9
Temperature	10% change*	-
Ca (mg L-1)	0 – 100	0 – 32
K (mg L^{-1})	-	0 – 50
Mg (mg L^{-1})	0 – 100	0 – 30
Na (mg L^{-1})	-	0 – 100
NH_4-N (mg L^{-1})	7	0 – 1
NO_3-N (mg L^{-1})	15% change	0 – 6
PO_4-P (mg L^{-1})	-	-

- No established standards since there is no direct toxicity (No literature standards were found for PO_4-P as it is usually a limiting nutrient);
**Percentage variation allowed compared to un-impacted background conditions;*
*** (Chapman 1996)*

Stream physico-chemistry

The range of values for physico-chemical values measured *in situ* (conductivity, dissolved oxygen, pH and temperature) shows that median values for conductivity and temperature were highest in Attakrom (Figure 5.6). Higher levels of conductivity in Attakrom (223 μS cm^{-1}) indicate higher concentrations of dissolved solids and major ions, as compared to the other two catchments. The average values of typical, unpolluted rivers is approximately 350 μS cm^{-1}, with no associated health risks, except for a 450 μS cm^{-1} taste threshold for domestic consumption (Ansa-Asare and Darko 2006; Karikari and Ansa-Asare 2006). Although readings were quite varied based on the outliers observed, median DO values, relatively lower in the medium land-use intensity catchment than the other catchments, were all below the acceptable range for aquatic ecosystems of 5-7 mg L^{-1}. Dissolved oxygen (DO) is influenced by temperature and biological activity. The time of sampling and levels of organic decomposition greatly influence DO readings. As the headwater streams of these catchments flow in response to storm events, DO readings during periods of lower velocity or in still waters may have recorded lower values based on higher levels of biological activity. The pH median values for all catchments fell within the acceptable range of 6-9. Health implications are not based on specific pH values, but it is associated with other aspects of water quality, such as presence of metal ions whose toxicity is influenced by pH levels (WRC 2003e). The pH of surface- and groundwater usually reflects their humic acids CO_2, CO_3^{2-} and HCO_3^- contents. Temperature values are important due to its effect on other physical phenomena such as rate of biochemical and chemical reactions in the water body, reduction in solubility of gases and amplifications of taste and odor (Olajire and Imeokparia 2001). In forested areas, canopies provide shade that maintains the low stream temperatures that are typical of these catchments, which was also observed in Nyamebekyere. Results of the Kruskal Wallis test indicate that there is enough evidence of differences between the catchments at a significance level of 5% (Table 5.8) for conductivity, dissolved oxygen, and temperature.

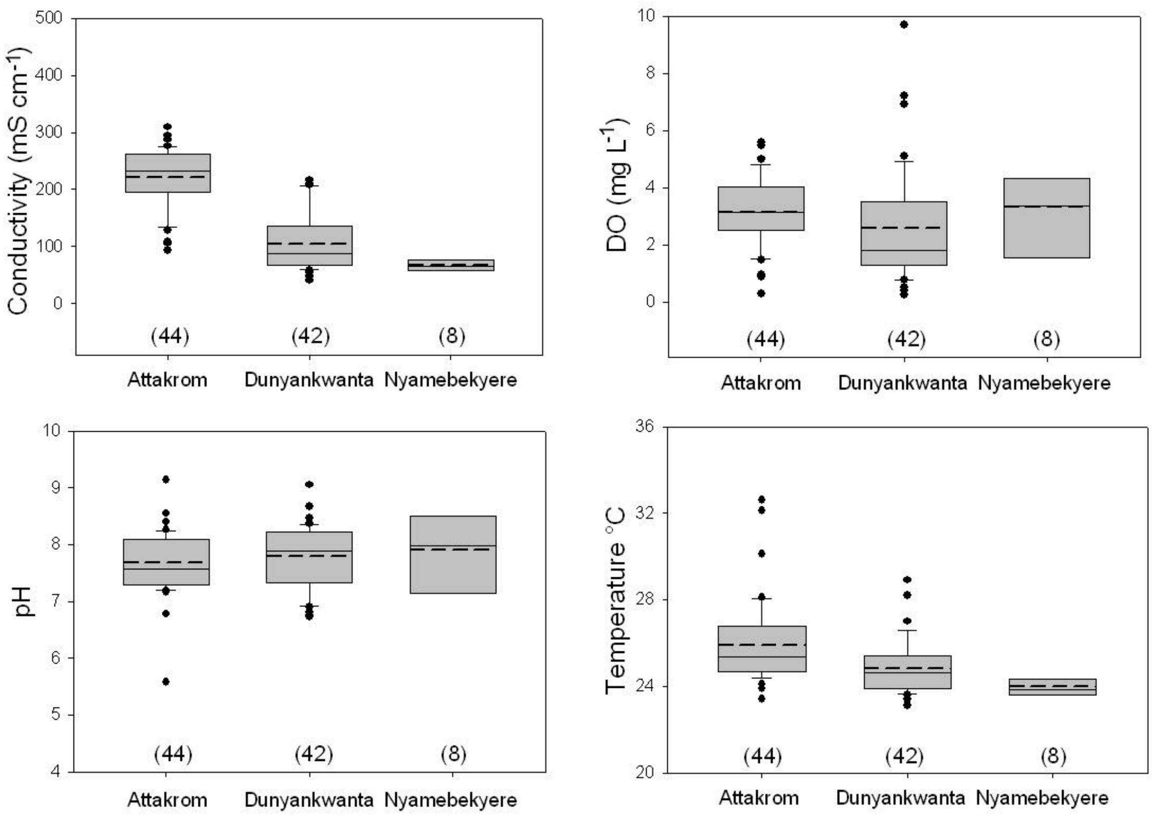


Figure 5.5 Box and whisker plots showing range of measurements for conductivity, DO, pH, and temperature (September 2005-December 2006). Dotted line represents the mean value, solid line represents the median value, and numbers at the bottom represent number of total samples.

Table 5.8 Kruskal Wallis test for differences in physical parameters between the catchments – Attakrom, Dunyankwanta and Nyamebekyere

	Conductivity	DO	pH	Temperature
Chi-Square	56.176	6.515	1.216	19.676
df	2	2	2	2
Asymp. Sig.	**.000**	**.038**	.544	**.000**

df = degrees of freedom; Asymp. Sig. = significance at $p<0.05$

Nutrient ion concentrations

Median values were highest at Attakrom and lowest at Nyamebekyere for all parameters with the exception of NH_4-N, NO_3-N and PO_4-P, where values did not vary much between catchments (Figure 5.6). Median nutrient concentrations for the three catchments were mostly within the TWQR specified for ideal conditions in Ghanaian waters. There are no strict Ca criteria for ecosystem health, although if the ratio of Ca to Mg is <1, investigations are required in order to protect shell organisms (Chapman 1996; WRC 2003f). For this study, the Ca:Mg ratio is >1, which is appropriate for shell organisms. Ca levels were within typical domestic use limits of 32 mg L^{-1} for all catchments, with levels at Nyamebekyere closer to the aquatic standards. It was within the domestic use limits for Dunyankwanta and Nyamebekyere but borderline for Attakrom. K values for all catchments were also well within the range for domestic health. Although higher than the typical values of 2-5 mg L^{-1} for natural waters, there are no known risks to ecosystem health. Mg levels at all the catchments fall within normal levels for both aquatic and human health. No health risks have been indicated for higher levels of Mg, although the taste threshold (70 mg L^{-1}) prevents ingestion at harmful concentrations (Chapman 1996; WRC 2003e). Na concentrations were well below TWQR values for human health, although values in Attakrom were higher than the other two catchments. Most of the values fell below the 20 mg L^{-1} standard set for drinking water although a few samples at Attakrom exceeded this level. For all the catchments, mean NH_4-N levels were well within the limits for aquatic health (chronic effects are above 15 mg L^{-1}), but slightly higher than standards set for human consumption, since some samples exceeded the threshold values. Although there are no immediate human health effects of levels of NH_4-N within the TWQR of 7.0

mg L^{-1} for aquatic ecosystems, taste and odor complaints may occur at concentrations above 1.5 mg L^{-1}. For NO_3-N levels, mean and median concentrations were comparable to the typical concentrations of natural surface waters (5 mg L^{-1}), although many of the outliers exceeded this for Attakrom and Dunyankwanta. High concentrations above 10.0 mg L^{-1} can be potentially toxic to human health, as excessive nitrate may result in infant cyanosis, also known as methemoglobinemia (which interferes with the oxygen carrying capacity of the blood) or 'blue baby syndrome', in children less than one year old (Carpenter et al. 1998; WRC 2003e). There are no significant health risks for older children or adults, and boiling water will not remove nitrate. Nitrate can also be toxic to livestock if reduced to nitrite, and levels of 40-100 mg L^{-1} in drinking water is considered risky. For PO_4-P, there are no established drinking water standards since it is not considered to be directly toxic to humans and animals, but can be toxic to aquatic life as a result of stimulated productivity and increased eutrophication (Carpenter et al. 1998).

Nutrient concentrations were flow weighted over time periods, i.e., adjusted to discharge levels at sampling time in order to normalize the concentration values for average discharge, for comparison at varying discharge levels. Concentrations differ between for Ca, Mg, Na and NO_3-N, with lower variations for K, NH_4-N and PO_4-P. Attakrom showed the highest flow-weighted concentrations, similar to the median values, with the exception of K and NH_4-N (highest in Dunyankwanta) and NO_3-N (highest in Nyamebekyere). The dominance in ionic composition for each catchment stream follows the order typical for natural freshwater systems in Ghana, i.e., Ca>Mg>Na (K) (Chapman 1996; WRC 2003f). Results of the Kruskal Wallis test show that at a significance level of 5% there are differences between catchments for all stream nutrient concentrations except NH_4-N and NO_3-N (Table 5.9). At $p<0.05$, the Mann Whitney test results (Table 5.10) show that the distinctions between Attakrom and Dunyankwanta are based on significant differences in the measured concentrations of the cations – Ca, Mg, Na and K. Between Attakrom and Nyamebekyere, differences are significant for all parameters except the nitrogen compounds; and between Dunyankwanta and Nyamebekyere, differences are significant for Ca, Mg, Na and PO_4-P.

Since water interacts with the soils before entering streams, nutrient concentrations can be influenced by the soil properties. The VINVAL project's soil characterization for the three study catchments (Ungaro et al. 2004) provides soil quality assessment in terms of percentage organic carbon. Results showed significant differences in the mean percentage organic carbon content of the topsoil. Dunyankwanta had the highest amount of organic carbon (3.14%) compared to Attakrom (2.24%) and Nyamebekyere (1.76%). In order to compare the soils, the authors based their comparisons on soil organic matter stratification, which is defined as a property at the soil surface divided by the same property at a lower depth. A high rate for organic carbon generally indicates relatively undisturbed soil. The authors found significant differences ($p<0.05$) between the three catchments, with Nyamebekyere having the lowest stratification ratio (0.50), followed by Attakrom (1.85), and the highest ratio in Dunyankwanta (3.04). With no observed correlations between the carbon levels and soil texture (silt + clay), the VINVAL report proposed that this could be due to the fact that storage of carbon in forest biomass results in lower levels in the soils of forests. The report also suggests that a higher proportion of plant residue in grassland vegetation is of root matter, which decomposes slowly and contributes more efficiently to soil humus formation than forest leaf litter. However, detailed information on the history and duration of cultivation, soil formation and organic carbon cycles are required to properly assess differences between catchments. In neighboring inland valley watersheds, a study investigating soil properties under different land uses showed that mean nitrogen contents was high, possibly due to the dense vegetative cover, litter fall and higher mineralization (Annan-Afful et al. 2005). Contrary to the VINVAL report, the study suggests that soils under permanent vegetation (such as primary forests) or cropping systems (cocoa farms) generally have a high organic carbon content. This means that these systems may be more effective in restoring soil organic matter than in systems where annual plants were grown. During the soil drying phases in the dry season, reduced forms of nitrogen, particularly NH_4^+, are nitrified to NO_3^- that may be lost by leaching during the rains. Phosphorus is low in these areas possibly due to P-fixing compounds in the soil. These studies confirm that natural background levels of soil nitrogen are generally high and phosphorus are low, which was observed for the catchments.

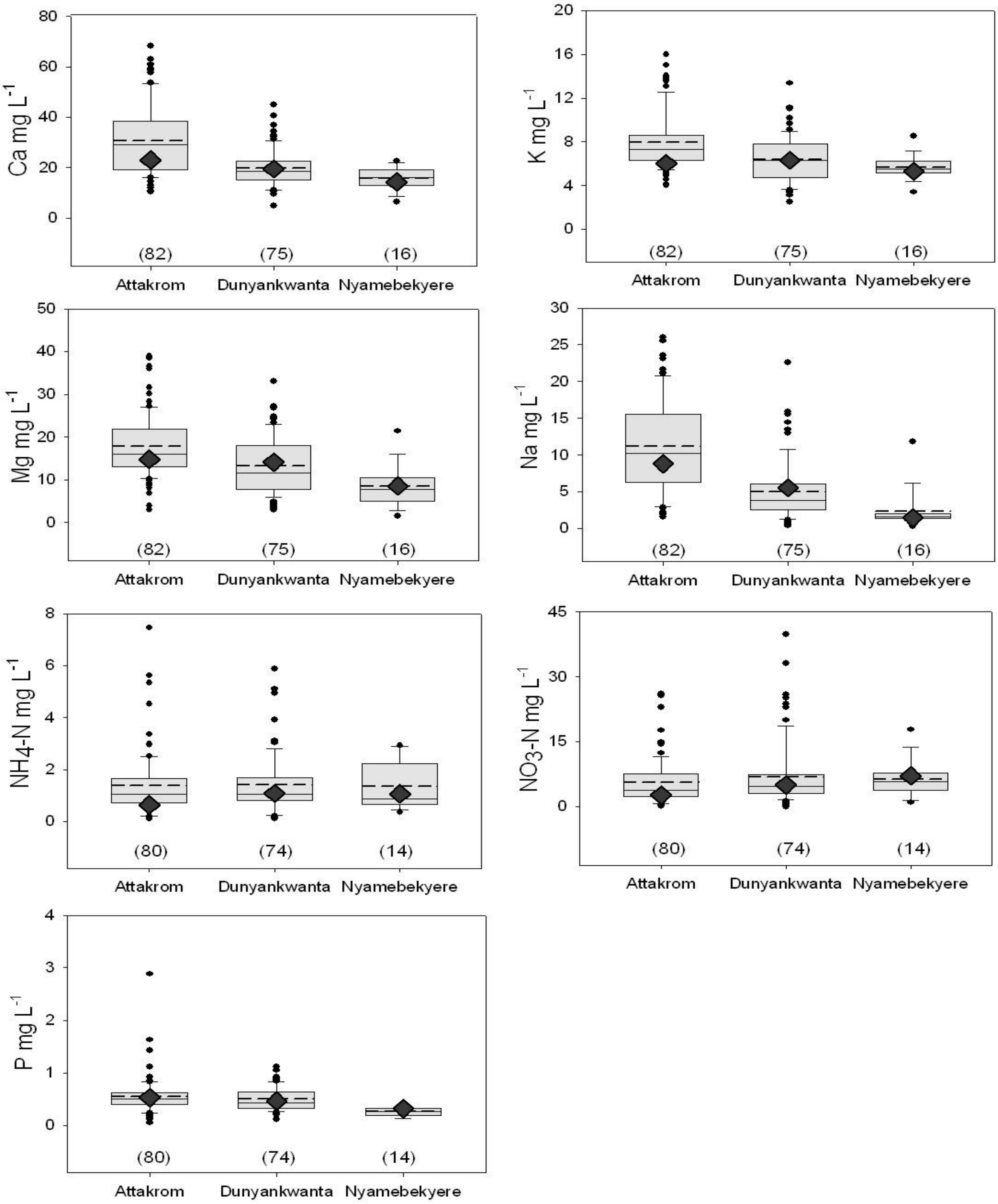


Figure 5.6 Nutrient concentrations ranges, flow-weighted means (diamond shape). Dotted line represents the mean value, solid line represents the median value, and numbers at the bottom are total number of samples.

Table 5.9 Kruskal Wallis Test for differences in nutrient parameters between the catchments - Attakrom, Dunyankwanta and Nyamebekyere.

	Ca	K	Mg	Na	NH_4-N	NO_3-N	PO_4-P
Chi-Square	38.922	20.333	31.233	57.173	.103	2.023	20.914
df	2	2	2	2	2	2	2
Asymp. Sig.	**.000**	**.000**	**.000**	**.000**	.950	.364	**.000**

df = degrees of freedom; Asymp. Sig. = significance at $p<0.05$

Table 5.10 Mann Whitney tests for differences in nutrient parameters between Attakrom, Dunyankwanta and Nyamebekyere (Sig. = significance at $p<0.05$)

a Grouping Variable: Catchment (Attakrom and Dunyankwanta)

	Ca	K	Mg	Na	NH_4-N	NO_3-N	PO_4-P
Mann-Whitney	1438.000	1976.000	1789.500	1202.000	2800.000	2559.000	2562.000
Wilcoxon	4139.000	4677.000	4490.500	3903.000	5960.000	5719.000	5190.000
Z	-5.500	-3.548	-4.224	-6.349	-.164	-1.062	-1.051
Sig. (2-tailed)	**.000**	**.000**	**.000**	**.000**	.870	.288	.293

b Grouping Variable: Catchment (Attakrom and Nyamebekyere)

	Ca	K	Mg	Na	NH_4-N	NO_3-N	PO_4-P
Mann-Whitney	172.500	217.500	141.500	69.500	535.000	448.000	146.500
Wilcoxon	308.500	353.500	277.500	205.500	640.000	3608.000	251.500
Z	-4.625	-4.185	-4.925	-5.624	-.193	-1.128	-4.368
Sig. (2-tailed)	**.000**	**.000**	**.000**	**.000**	.847	.259	**.000**

c Grouping Variable: Catchment (Dunyankwanta and Nyamebekyere)

	Ca	K	Mg	Na	NH_4-N	NO_3-N	PO_4-P
Mann-Whitney	396.500	455.500	325.000	200.000	475.500	441.500	147.000
Wilcoxon	532.500	591.500	461.000	336.000	580.500	3069.500	252.000
Z	-2.007	-1.373	-2.769	-4.103	-.333	-.731	-4.178
Sig. (2-tailed)	**.045**	.170	**.006**	**.000**	.739	.465	**.000**

Nutrient load (P)

The mean annual nutrient load was calculated for 2006, as discharge and nutrient measurements for 2005 were obtained from September and are therefore not representative of the entire year. The contribution of nutrient loads for this period, which represents the minor rainy season 2005 (September to December 2005), are assessed in the seasonal and monthly loads sections. In the absence of more frequent data, the accuracy of the loads estimated for the three catchments cannot be validated, especially as there are no available published data on loads from small catchments as a function of a predominant type of land-use. The comparison of load estimates to other countries have no real meaning, since hydrological dynamics, soil properties and pollutant transport processes depend on the characteristics of the catchment. However, since the purpose of this study was to compare catchments with similar hydro-morphological characteristics, the load estimates obtained are informative about the differences between the catchments based on their specific land-use intensities.

From the results, the magnitude of total load of each nutrient exported from the three catchments is in the order Dunyankwanta>Nyamebekyere>Attakrom (with the exception of PO_4-P where Attakrom values are higher than those for Nyamebekyere) (Table 5.11). Total annual nutrient loading from Dunyankwanta were higher than Attakrom and Nyamebekyere. As discussed earlier (Section 5.3.3), Beale's Ratio method is known to be relatively more accurate and unbiased in nutrient load estimation, as it weights the concentration values with discharge levels, and also provides a correction factor for the co-variance between concentration and load. However, in order to assess the degree of possible bias or inaccuracies that may result from the calculations, Quilbé *et al*. (2006) suggest the comparison of different averaging procedures. The load estimations, obtained using the equations for L_2, L_{FW} and $L_{Beale's}$ presented in Section 5.3.3, are therefore compared (Table 5.11). L_2 estimates, i.e., values from the averaging calculation method (un-weighted concentrations), are on average approximately 20% higher than Beale's Ratio estimator for the different nutrients, although Duyankwanta shows relatively less variation. The mean annual load of PO_4-P calculated for Nyamebekyere was lower than the Beale's estimate, indicating that averaging the sparsely available concentration data led to underestimations when there were low values with low flow levels, whereas the flow-weighted formulas adequately weighted the concentration with the flow. The Beale's method has performed well when tested in a number of catchments for the estimation of nutrients and sediment loads, however, it has been noted that the influence of the correction factor decreases as the number of samples increase (Webb et al. 2000; Johnes 2007). The flow-weighted estimates, i.e., L_{FW}, which is essentially minus the correction factor in the Beale's equation, confirms this as differences of less than 5% is observed for all nutrients at all sites. The performance of the correction factor is thus not clear when results are tested against full records. The sampling regime of every 48 hours, for this study, may have been frequent enough to reduce the bias between the concentration and flow that usually occurs with infrequent sampling; however, without any other background concentration or discharge information for verification, this can only be a tentative conclusion.

Table 5.11 Annual nutrient loads (kg yr^{-1}) for 2006 for the three catchments, calculated by Beale's Ratio estimator method; and the mean relative difference (%) of load estimates calculated by equations L2 (Equation 5.8) and LFW (Equation 5.9).

Nutrient	Attakrom			Dunyankwanta			Nyamebekyere		
	Beale	%L_2	%L_{FW}	Beale	%L_2	%L_{FW}	Beale	%L_2	%L_{FW}
Ca	2371.0	30.9	0.8	10669.1	7.9	3.7	3270.5	21.8	4.3
K	705.2	24.0	0.8	2681.2	10.9	3.7	1201.8	10.0	4.3
Mg	1887.0	16.4	0.8	6467.5	18.2	3.7	1905.7	20.5	4.3
Na	917.7	36.9	0.8	2327.9	21.9	3.7	361.7	45.0	4.3
NH_4-N	157.1	9.8	0.7	744.8	13.5	3.8	343.3	21.7	2.6
NO_3-N	681.7	17.8	0.7	3021.1	19.9	3.8	1048.9	41.6	2.6
PO_4-P	70.7	-0.5	0.7	195.8	22.8	3.8	84.6	-23.1	2.6
Avg		19.3	0.8		16.5	3.8		19.6	3.5

% L_{FW} values for Ca, K, Mg and Na are slightly different from values for NH_4-N, NO_3-N, and PO_4-P due to unequal number of samples (see Figure 5.6)

Total annual yields, which normalize the differences in loading due to catchment area, are higher in Dunyankwanta for all nutrients, higher yields in Nyamebekyere as compared to Attakrom for all nutrients except Na, and similar yields for Mg and PO_4-P in Nyamebekyere and Attakrom (Figure 5.7). Since nutrient concentrations were highest in Attakrom, it was expected that nutrient export from this catchment would be higher than from medium intensity and forested catchments. However, the results show the lowest loads in Attakrom. Since differences in runoff can greatly influence nutrient loading (Harmel et al. 2006), the low nutrient loading from the high intensity catchment could be a function of total discharge, as Attakrom has the lowest overall total discharge. This stresses the importance of accurately establishing hydrological dynamics for a catchment when assessing pollutant loading from various catchment types, since runoff generation processes and variations of hydrological sensitive areas (Storm et al., 1988) are important factors that drive the movement of nutrients.

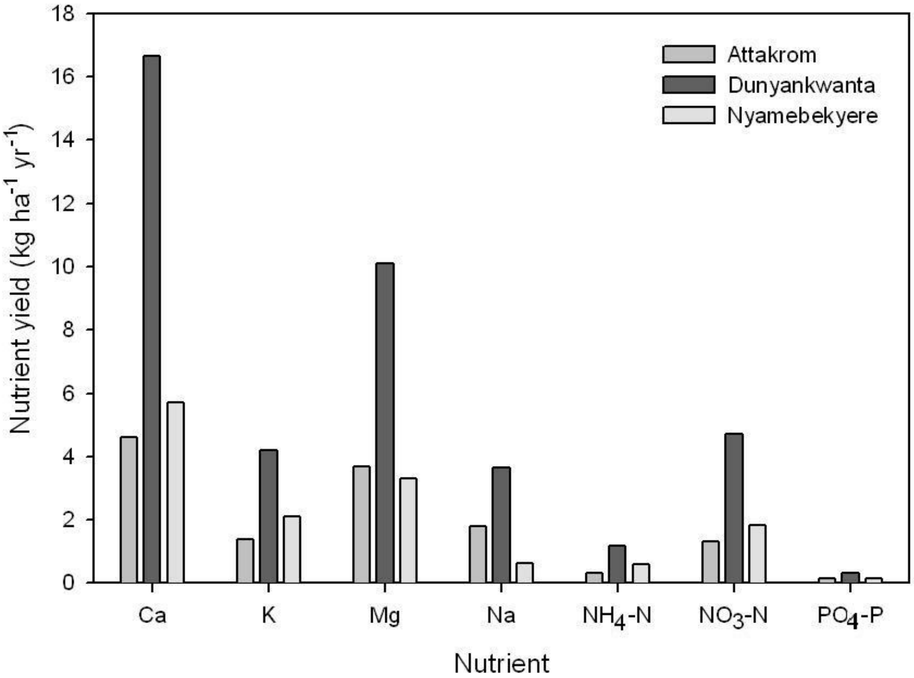


Figure 5.7 Annual nutrient yields (2006) calculated by Beale's Ratio estimator method

5.4.2 Temporal dynamics

Temporal and spatial variations in in-stream nutrient concentrations are usually influenced by the characteristic vegetative cover and hydrological processes governed by climate, soil properties and type of land-use activity (Gafur et al. 2003). The timing of applications of fertilizer, manure and litter influences these variations (Harmel et al. 2006), as correlations have been observed between increasing nitrogen application and annual dissolved nitrogen stream loads (Harmel et al. 2006). Depending on storm events, the clearing and burning of vegetation to prepare the field for planting can also influence variations in nutrient loading. The high temperatures on the soil surface cause the topsoil to become temporarily hydrophobic and lead to increases in overland flow frequency and intensity, with surface erosion and accompanying nutrient losses (Bagamsah 2005).

For this study, the average seasonal and monthly patterns can only be described with reference to the annual values since establishing definite temporal patterns requires long-term data. The importance of the above factors on in-stream nutrient dynamics is discussed in Chapter 7, where the interlinkages between the different components within the DPCER framework are presented. Nutrient concentrations of each sample are plotted against daily rainfall for each catchment (Appendices 2; 3; 4). Distinct patterns in nutrient concentrations during rainfall events were not observed, as the 48-hour sampling frequency could not capture the variations during and after an event. However, a number of higher measurements were obtained during periods of low rainfall in June and November for Attakrom and Dunyankwanta and in October during the minor rainy season for Nyamebekyere. In Nyamebekyere, concentrations of Ca, K and PO_4-P did not vary much throughout the study period.

Seasonal dynamics

Hydrology

Hydrographs for daily precipitation and discharge in the three catchments are presented (Figure 5.8a). In Nyamebekyere, the diver malfunctioned from September when the minor rainy season began and analysis for this period is based only on manual gauge readings obtained during nutrient sampling periods. The outlet streams all display one discharge peak during the minor rainy season in 2005, and three peaks in 2006 representing three major discharge periods: May-June, July-August, and September-November. Dunyankwanta shows the highest levels and most persistent stream flows, followed by Attakrom, and Nyamebekyere with the lowest and most fluctuating levels. In the major rainy season, overall discharge volume was higher but in the minor season, the percentage rainfall that was converted to runoff was higher. The average annual percentage of precipitation that left the catchment as surface runoff via the stream channels was about 4%, although it varied between 2% and 7% between years and catchments (Figure 5.8b). These values were estimated for the duration of each rainy season period to account for the time lags in runoff, and the results displayed for three separate periods. Relatively lower precipitation was observed for the minor rainy season of both years, although in 2006, there was a higher percentage of rainfall converted into stream flow as compared to the major rainy season of the same year.

Nutrient ion concentrations (C)

For all catchments, the flow-weighted mean concentrations differed between seasons, although less markedly in Nyamebekyere, especially for K, Na and PO_4-P (Figure 5.9). In Attakrom, concentrations were generally higher in the 2006 minor rainy season for all nutrients except PO_4-P, where one very high value (2.88 mg L^{-1}) was recorded at the start of the rainy season (possibly due to increased concentrations in the first flush of rainfall after the long dry season). In Dunyankwanta, higher values were in the 2006 major rainy season after the long dry season and the harmattan, with the exception of Ca and the nitrogen compounds. In Nyamebekyere, variations were generally minimal, except for Ca and NH_4-N that were higher in the 2006 minor rainy season, and NO_3-N, in the major.

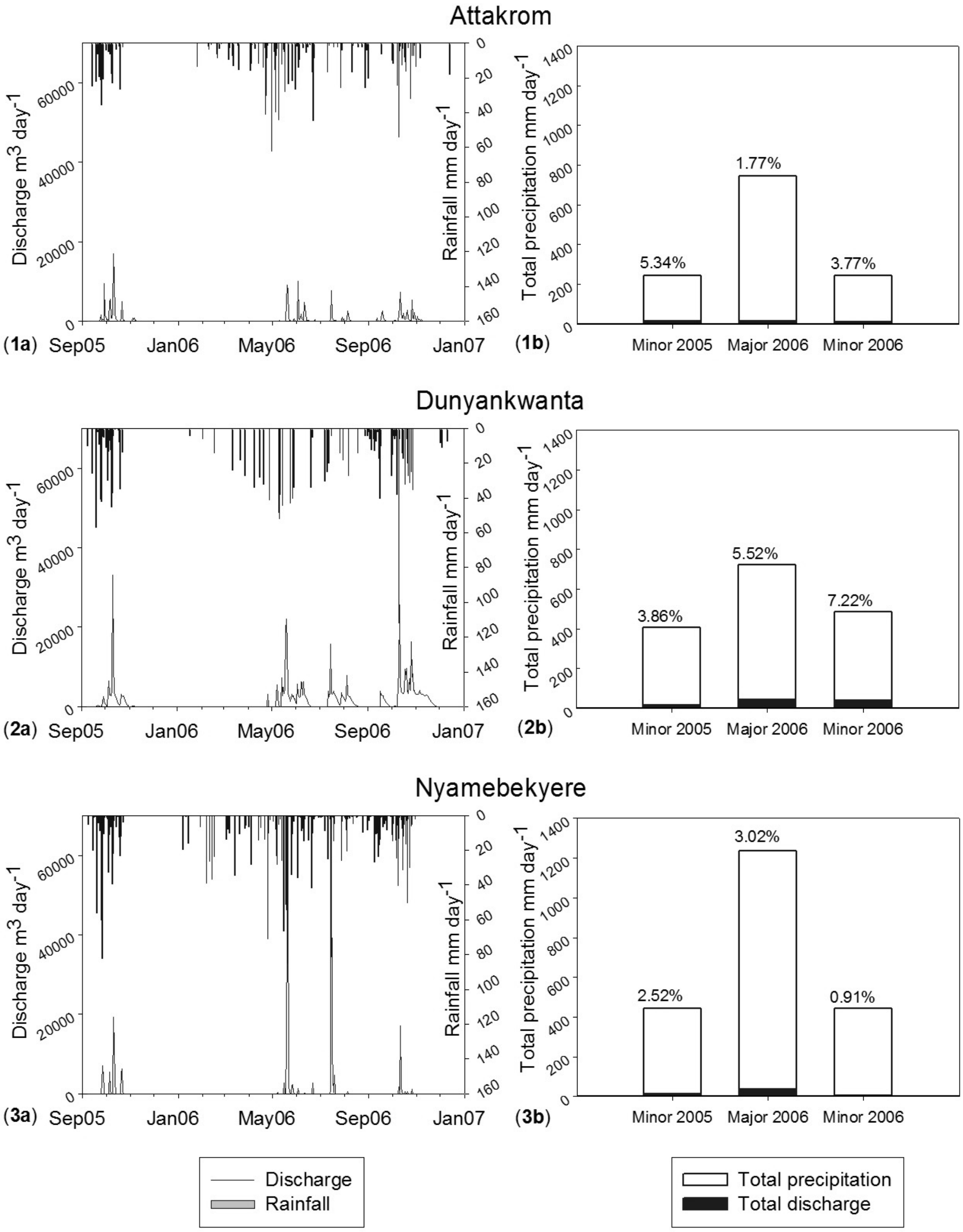


Figure 5.8 (a) Total discharge (m^3 day^{-1}) and total precipitation (mm day^{-1}), (b) total discharge (mm day^{-1}) as a proportion of total precipitation (mm day^{-1}), with discharge percentage indicated at the top of bars. (Minor = minor rainy season; Major = major rainy season). Nyamebekyere with manual stream level readings only, in Minor 2006.

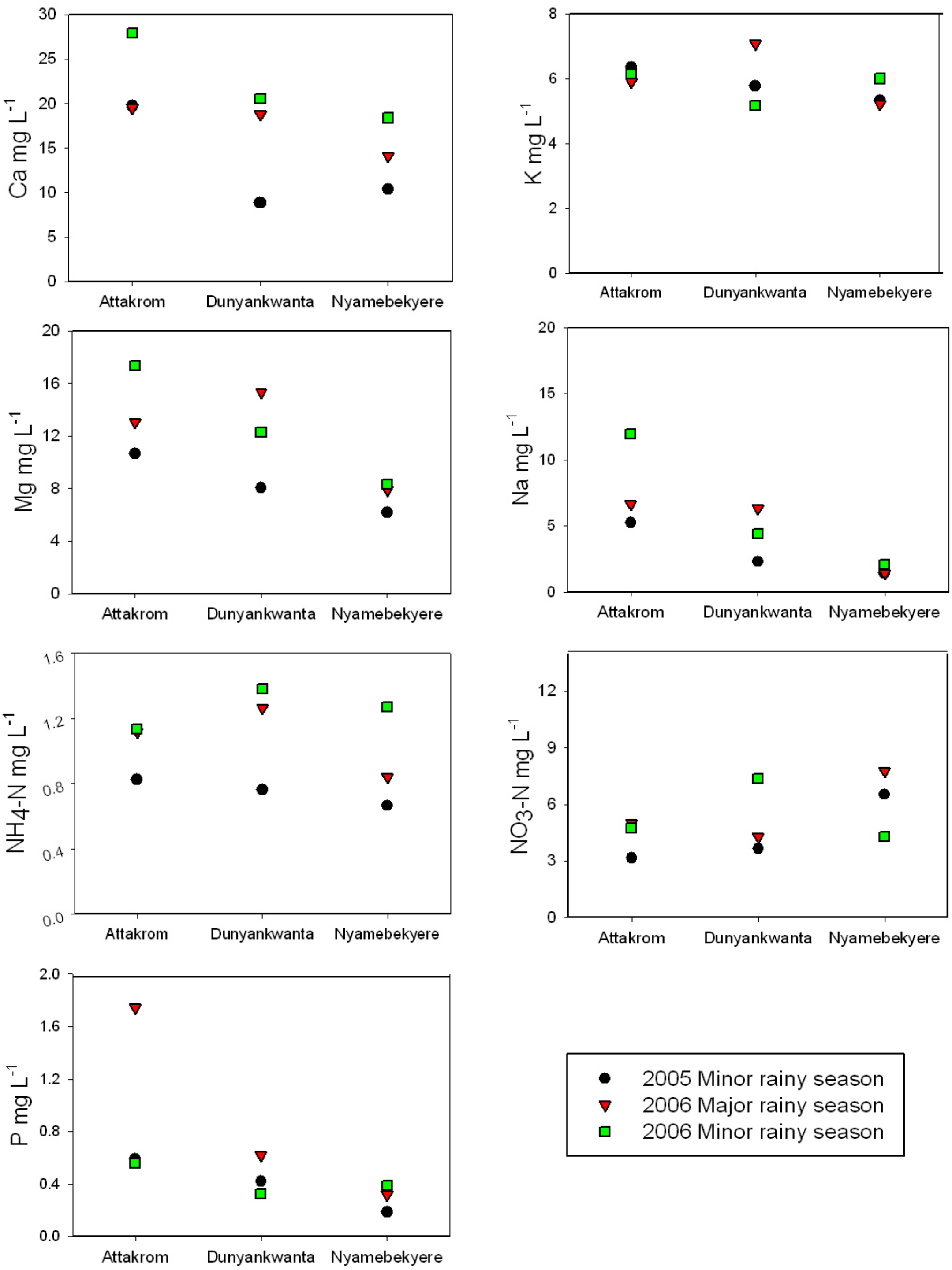


Figure 5.9 Flow-weighted mean for nutrient concentrations during the rainy season periods of 2005 and 2006.

Nutrient loads (P)

For all the catchments, higher total nutrient loads were estimated during the major rainy season of 2006 (Table 5.12). As the previous section shows that flow-weighted mean concentrations in the major rainy season of 2006 were not always higher than the other seasons, the high loads during this period were mostly due to the relatively larger volume of total discharge in this period. The annual nutrient outputs into streams will, therefore, be influenced by exports that occur during the major rainy season (between the months of May and July).

Total nutrient yield from each catchment is also dominated by the contributions from the major rainy season (Figure 5.10). Compared to the other catchments, Attakrom shows a comparatively regular seasonal yield for all nutrients for the duration of the study. In Dunyankwanta, nutrient yields are high in 2006 for all nutrients except Na, which was high only during the major rainy season. In Nyamebekyere, relatively higher yields were observed only during the major rainy season, with the exception of Mg and Na that maintained the same yields for the duration of the study. The consistent yields in Attakrom suggests that sources of nutrient input are constant throughout the year, as compared to Dunyankwanta, where inputs were increased in 2006, and to Nyamebekyere, where inputs dominate only during the major rainy season.

Table 5.12 Seasonal total loads (kg) of nutrients during the major (1) and minor (2) rainy seasons in 2005 and 2006 (computed by the Beale equation).

Nutrient	Attakrom			Dunyankwanta			Nyamebekyere		
	2002-2	2006-1	2006-2	2005-2	2006-1	2006-2	2005-2	2006-1	2006-2
Ca	33.9	40.6	20.6	42.4	133.8	81.0	9.7	65.6	8.5
K	1131.0	1263.7	732.5	893.5	6198.4	4849.5	457.3	4590.1	406.8
Mg	623.4	969.8	585.7	817.2	3368.1	3045.2	333.0	309.3	199.7
Na	305.8	492.2	281.2	234.7	1205.0	1118.5	72.6	61.2	47.4
NH_4-N	372.4	421.5	204.3	585.3	1264.8	1307.9	273.0	718.6	133.6
NO_3-N	46.0	83.5	46.8	77.5	385.7	350.5	34.3	437.5	30.2
PO_4-P	177.5	312.0	210.5	374.3	1150.0	1565.3	339.3	1036.3	99.9

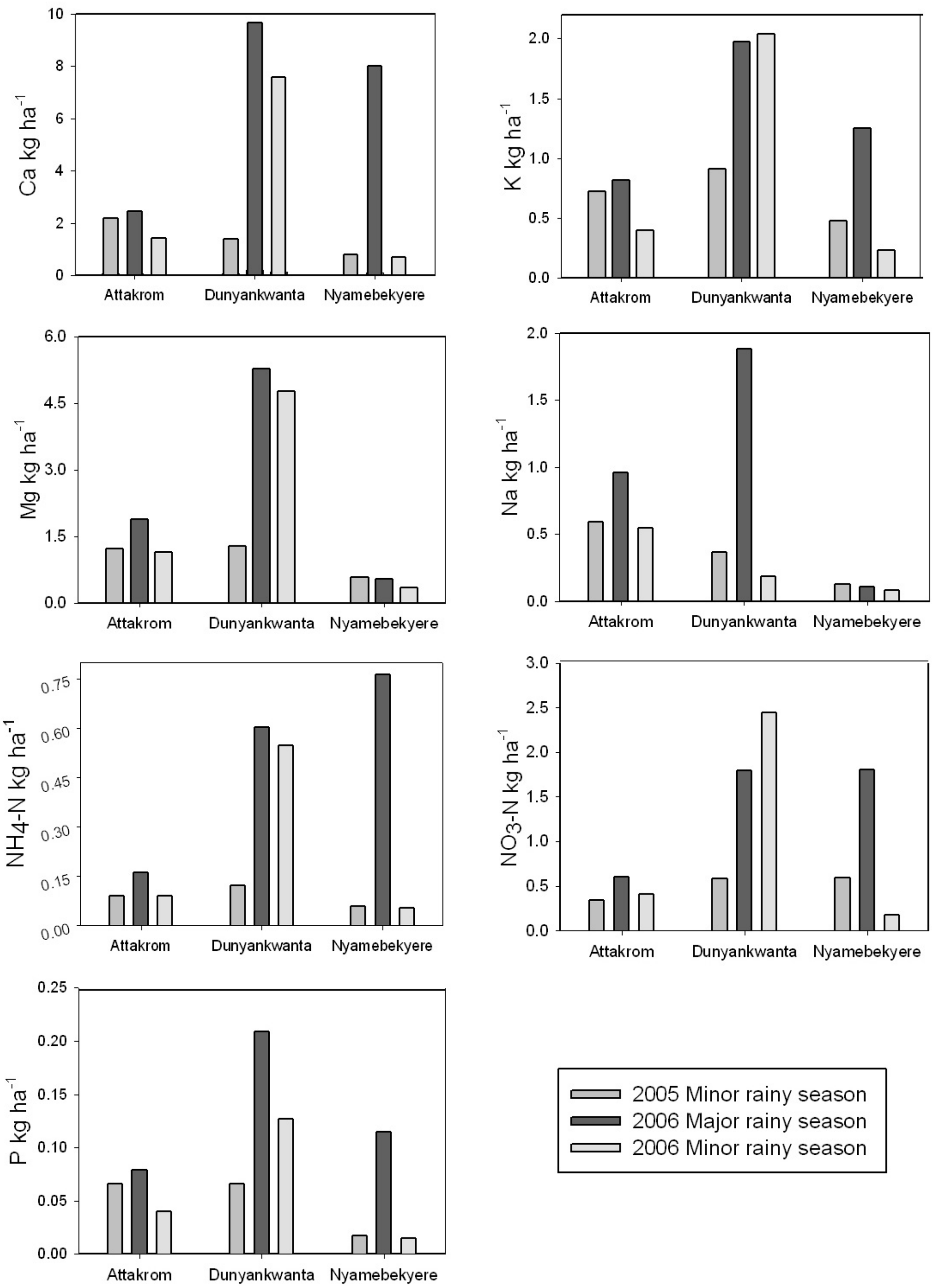


Figure 5.10 Total seasonal yield (kg ha^{-1}) from each catchment during the major and minor rainy seasons in 2005 and 2006 (computed with the Beale equation).

Monthly dynamics

Hydrology

Climate

The observed rainfall patterns follow the bi-modal annual rainfall frequency for the tropical belt, although the differences in precipitation (mm) at the three catchments may be indicative of the high spatial variability in precipitation in West Africa (Kunstmann and Jung 2003). Monthly precipitation values show that in 2005 the highest rainfall occurred in May and September, and for 2006 in May and October (Figure 5.11). The monthly in-stream temperatures (calculated monthly mean of hourly diver readings) for Attakrom showed higher variability throughout the year. Vegetative cover around the Attakrom stream is far less than the shaded streams of Dunyankwanta and Nyamebekyere. The in-stream temperature is, therefore, influenced by the atmospheric temperatures and is seen to follow the same patterns. The highest temperatures occur in May/June and the lowest, between November and February, during the harmattan period.

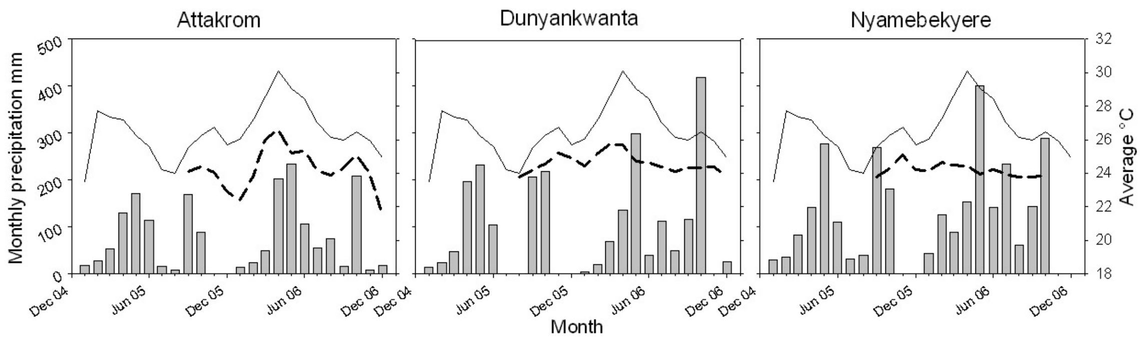


Figure 5.11 Climograph for 2005/2006, showing total monthly precipitation (bars), air temperatures (solid line), and stream temperatures (dotted line). Stream temperatures are averaged hourly diver reading from September 2005.

Discharge

Discharge varied throughout the year, with the highest discharges in May (2006) and in October (2005 and 2006), and no flows in the dry season months (December to April) and the transition month between the major and minor rainy season (September) (Figure 5.12). The monthly total discharge was lower and less variable for Attakrom as compared to the other catchments. Monthly discharge at Nyamebekyere was the most variable, with discharges occurring mostly in the months of September (2005), May, July and October (2006), which are periods of highest precipitation.

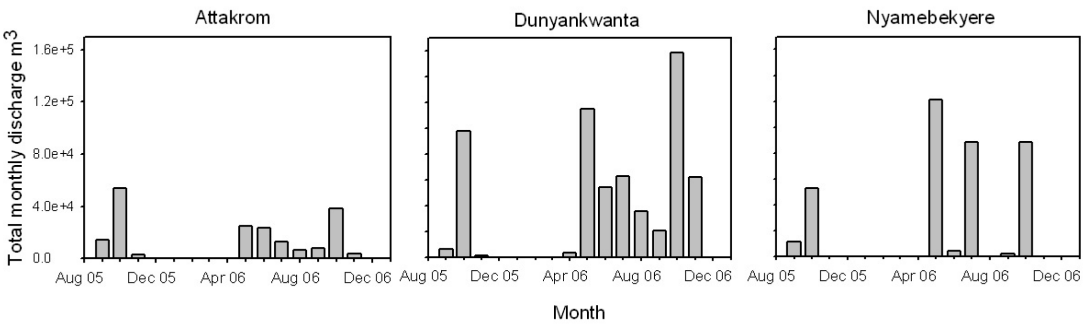


Figure 5.12 Total monthly discharges for the study catchments, September 2005-December 2006

Potential evapotranspiration

The monthly averages for weather variables (temperature, relative humidity, and sunshine hours) to calculate ET_0 (Table 5.14) showed minimum temperatures in December and January (17.2°C in December 2006) and maximum temperatures in April (39.1°C). The highest daily humidity were observed in October (RH = 95%) and lowest in December (44%). Although these values were estimated for the entire research area, differences in humidity values may exist for each catchment, especially for Nyamebekyere, where greater vegetative cover can lead to higher humidity. The daily maximum sunshine hours occurred in November and the minimum between August and September. The ET_0 estimates ranged from a minimum of 2.7 and maximum of 4.7 mm day^{-1}, with the lowest daily values observed from July to September and the highest in April. The percentage of rainfall that is returned as evapotranspiration in the Volta Basin has been estimated at more than 80% during the rainy season, with ET_0 values ranging from 4-7 mm day^{-1} (Oguntunde 2004). This corresponds to values obtained in this study, which follow the same patterns of low values in the rainy months of June to October and higher values between November and January during the dry season.

The monthly calculated ET_0 patterns were similar to patterns obtained for the Kumasi regional meteorological average ET_0 estimates (Figure 5.14) (Ghana Meteorological Services Department, personal communication), with calculated values slightly lower than the meteorological averages from January to September 2005 and higher from September 2005 to December 2006.

Table 5.14 Monthly minimum, maximum mean temperature, relative humidity, sunshine hours, and mean ET_0 for the study period (values in parentheses are standard deviations)

Month	Air temperature (°C)			Relative humidity (%)			Sunshine (hrs)	ET_0
	Min	Max	Mean	Min	Max	Mean		
Sep 05	21.1	29.9	25.5 (0.9)	64.2	90.5	77.4 (4.4)	3.8 (2.2)	3.29 (0.60)
Oct 05	20.6	31.9	26.3 (0.7)	63.0	91.6	77.3 (4.8)	6.9 (2.3)	4.05 (0.56)
Nov 05	20.5	32.9	26.7 (0.5)	58.1	89.7	73.9 (3.1)	7.0 (1.3)	3.92 (0.31)
Dec 05	18.7	32.7	25.7 (1.1)	55.5	91.5	73.5 (4.4)	6.0 (2.0)	3.50 (0.41)
Jan 06	18.4	33.7	26.1 (1.0)	52.9	91.3	72.1 (6.2)	6.3 (2.4)	3.70 (0.55)
Feb 06	20.2	34.3	27.2 (0.8)	54.7	89.9	72.3 (4.3)	6.5 (1.9)	4.09 (0.49)
Mar 06	20.4	36.7	28.6 (1.3)	56.5	88.1	72.3 (3.0)	6.3 (2.3)	4.43 (0.65)
Apr 06	21.1	39.1	30.1 (0.9)	57.8	87.4	72.6 (5.1)	6.7 (2.3)	4.82 (0.76)
May 06	21.1	37.0	29.0 (1.1)	62.8	91.0	76.9 (5.0)	6.6 (2.5)	4.08 (0.82)
Jun 06	21.5	35.4	28.5 (0.9)	64.0	92.1	78.1 (3.7)	5.9 (2.3)	4.42 (0.67)
Jul 06	21.3	32.7	27.0 (0.8)	-	92.6	-	3.8 (2.2)	3.01 (0.44)
Aug 06	20.8	31.4	26.1 (0.6)	68.5	93.5	81.0 (4.3)	3.2 (2.2)	3.23 (0.65)
Sep 06	20.7	31.2	26.0 (1.2)	69.6	92.6	81.1 (3.4)	3.1 (1.5)	3.22 (0.43)
Oct 06	21.3	31.6	26.5 (0.9)	64.0	95.4	79.7 (4.0)	5.7 (1.9)	3.75 (0.52)
Nov 06	19.3	32.5	25.9 (0.9)	50.6	93.9	72.2 (4.8)	7.2 (1.3)	3.83 (0.33)
Dec 06	17.2	32.6	24.9 (1.4)	43.9	92.6	68.3 (6.8)	5.9 (2.0)	3.37 (0.36)

- Data not available

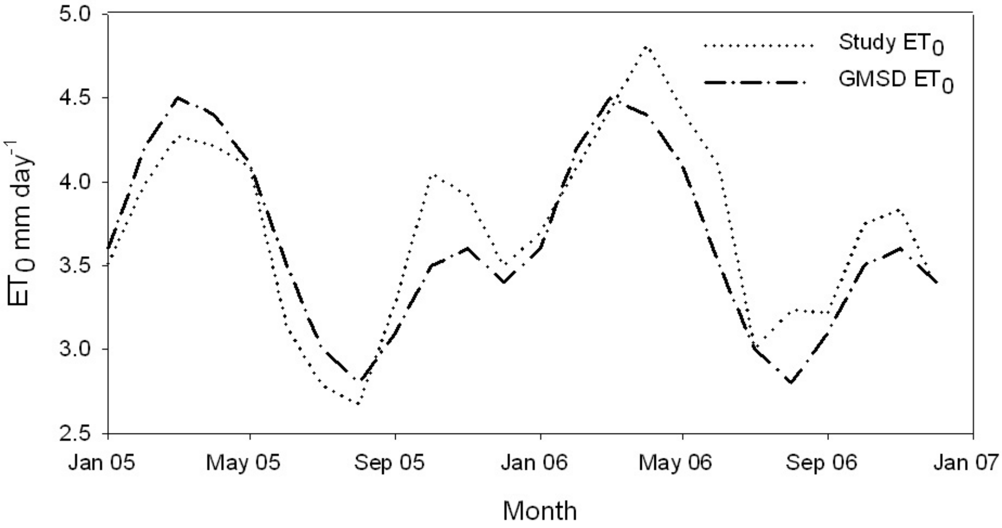


Figure 5.13 Calculated ET_0 and Ghana Meteorological Services Department (GMSD) averages for Kumasi

Nutrient ion concentrations and loads

Flow-weighted nutrient concentrations are compared across months for each catchment (Figure 5.14). In Attakrom, the highest measurements were in August for the cations, and in July for the nitrogen compounds. The high PO_4-P concentration measured in May could be an outlier, or since it occurred after the long dry harmattan season, could be due to increased concentrations in the first flush of surface runoff. In Dunyankwanta, flow-weighted concentrations varied throughout the year, with no particular observable patterns. In Nyamebekyere, monthly mean values were generally lower than for the other catchments, with minimal variations except for the nitrogen compounds – where NH_4-N was highest after periods of low flows and NO_3-N highest in June 2006. Conclusions cannot be made for monthly variations since longer periods of investigation are needed to eliminate the annual variations that may naturally occur.

For nutrient loads, the highest monthly nutrient loads and yields corresponded with months when discharge volumes were highest (Appendix 6). In Attakrom and Dunyankwanta, the highest loads were at the start of each rainy season (October and May), and in Nyamebekyere, with the bias of missing data between September and December 2006, in July 2006.

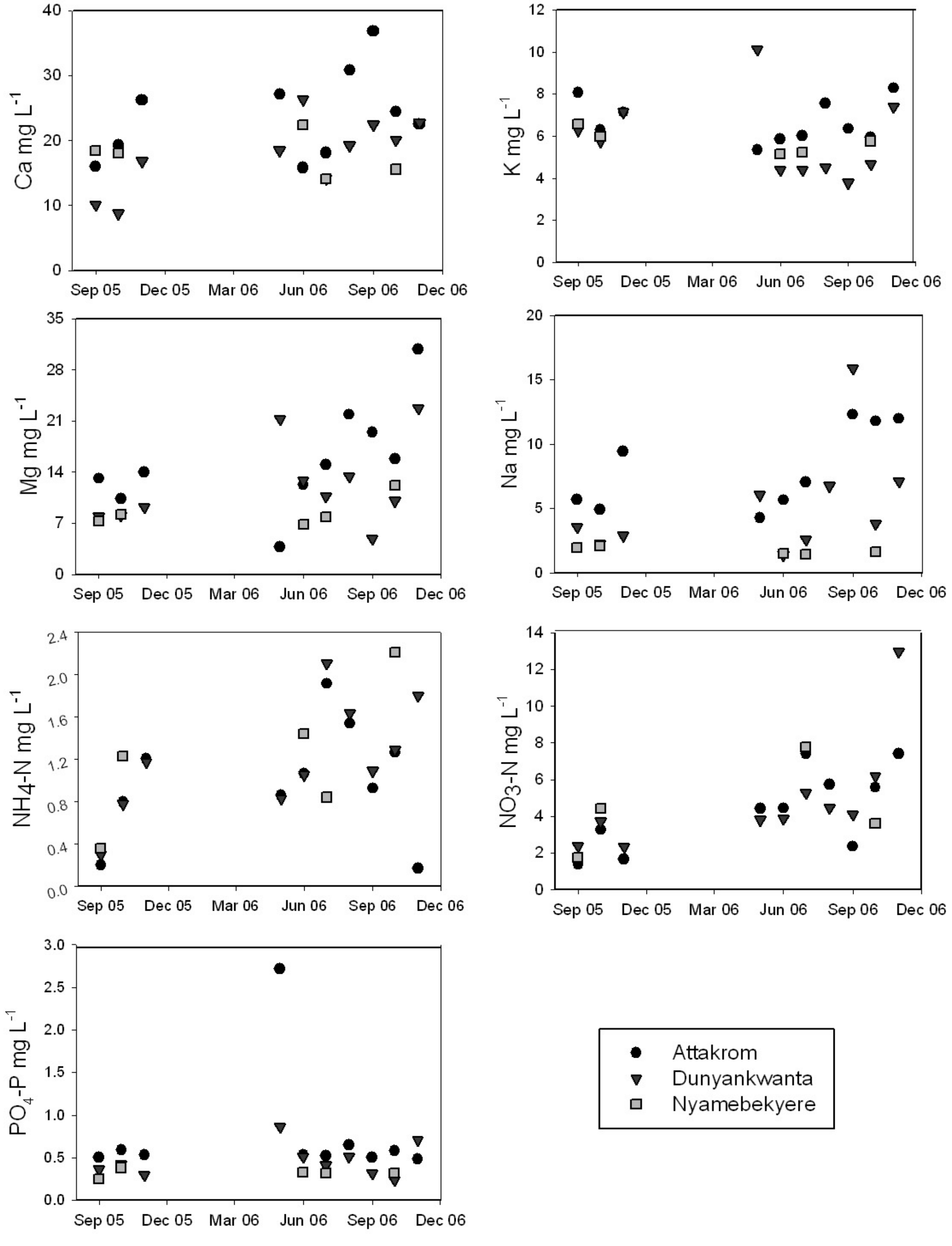


Figure 5.14 Flow-weighted means for monthly nutrient concentrations

5.5 Summary

The main objectives of the work presented in this chapter were to assess the *Pressure* and *Chemical state* of the streams draining the three research catchments within the DPCER framework. The previous chapter described the differences in land-use activities, with the expectation that the various activities observed would be reflected in the total nutrient loading (pressure) into the streams and physico-chemical dynamics (chemical state). In the absence of any historical data, the focus was to compare the differences between catchments without making final judgments about the state of the environment, although some general comparisons are made to overall water quality in Ghana.

Although located within the same geo-morphological basin, the hydrology between catchments significantly differed. As upland headwater streams, discharge events occurred during and immediately after storm events, with variations in levels and duration of flow depending on the catchment hydrology. Overall, rainfall followed the local bi-modal pattern, with highest discharge periods occurring in May and October, which are also periods of highest precipitation. The highest rainfall and most inconsistent discharge occurred in the forested catchment, and lowest rainfall and least variable discharge in the agricultural catchment. The average percentage of rainfall that left the catchment as discharge was 4%, comparable to studies carried out in the adjacent areas in the Volta Basin. However, the total volumes of discharge varied between catchments, with the highest rates of discharge in Dunyankwanta and the lowest in Attakrom.

Nutrient loading, an indicator for the quantity of nutrients exported from terrestrial sources into the stream was estimated by the Beale's ratio equation, a relatively unbiased method, which weights the concentration values with discharge levels and provides a correction factor for their covariance. The magnitude of total nutrient loads was in the order Dunyankwanta>Nyamebekyere>Attakrom for all parameters except Na where the Attakrom load values were higher than the Nyamebekyere. The higher nutrient loading in Dunyankwanta could be related to its higher discharge volumes. Most of the export occurred during the major rainy season (May to August) when discharge volumes were relatively higher, especially at the start of the season when accumulated nutrients over the dry season were flushed out with the first rains.

Stream physico-chemistry and nutrient ion concentrations, which measure the chemical state of the environment, are crucial to aquatic ecosystem and human health. Overall, the catchments fell well within the Ghana raw water quality guidelines for domestic use and aquatic ecosystem health. Between catchments, differences were significant for conductivity, dissolved oxygen and temperatures. Attakrom showed the highest conductivity levels indicating higher concentrations of dissolved solids and major ions; Nyamebekyere with highest DO and pH and lowest temperatures. For the nutrient ions, there were significant differences in the concentrations of Ca, K, Mg and Na between the catchments, including PO_4-P between Nyamebekyere and each of the other catchments. Flow-weighted concentrations, which normalize concentration values according to discharge volumes for each stream in order to compare catchments, were generally highest in Attakrom. Due to the short sampling period for the study, seasonal variations in physico-chemistry could not be established. However, the flow weighted nutrient concentrations were generally higher in the minor rainy season for Attakrom, in the major rainy for Dunyankwanta, with relatively little variation in Nyamebekyere. The lack of significant differences of NH_4-N and NO_3-N indicates that there are considerable sources of organic material from land sources for all three catchments, which needs to be investigated. However, based on the concentrations of the major cations, there are significant differences between the catchments.

6 AQUATIC MACROINVERTEBRATES AND STREAM PHYSICO-CHEMISTRY

6.1 Introduction

Changes in land-use, especially agriculture, that alter riparian corridors, extract water, and increase nutrient and sediment inputs, have the strongest impacts on aquatic invertebrate assemblages (Díaz et al. 2008). Chapter 5 presented the fact that there are varying magnitudes of nutrient loads and significant physico-chemical differences between the streams of the three investigated catchments as a function of increasing land-use. Macroinvertebrate responses are greatly influenced by local physico-chemical and habitat conditions (Richards et al. 1996; Richards et al. 1997; Sponseller et al. 2001). This chapter assesses the ecological state (E of the DPCER framework) in response to the chemical state (C), by linking the observed distribution of macroinvertebrate taxa to measured physico-chemical and nutrient variables. In Ghana, there are few documented studies on the taxonomy and traits of macroinvertebrates (e.g., Petr 1970; Hynes 1975a; b; Gordon 1995), and even fewer on the implications of increasing nutrients for macroinvertebrate taxa and community structure (Thorne and Williams 1997; Thorne et al. 2000). The Water Resource Institute has been developing the Chutter's Index (based on South Africa's macroinvertebrate indicator system) for national water quality assessments, however, there is still a large number of taxa whose tolerances are yet to be established (WRC 2003a).

Due to the scarcity of information on macroinvertebrate community structures in Ghana, especially for rural catchments, this part of the research initially examines taxa distribution as a function of stream physico-chemistry for a number of sites within the Ofin Basin. This includes the three upland study catchments and selected downstream locations. Since information is required only on how local stream physico-chemistry may influence the observed ecological states, a detailed evaluation of the drivers and pressures of the downstream sites was not required. A general summary of the socio-economic setting is, however, provided in Chapter 3. Based on the observations, macroinvertebrate community dynamics at the upland catchments are discussed in response to the measured chemical state.

6.2 Methodology

Periodic habitat assessments and monthly ecological and water quality surveys were carried out at the three upland catchment stream outlets (Attakrom, Dunyankwanta, and Nyamebekyere) and six selected downstream sites (see Table 3.1) for a 16-month period from September 2005 to December 2006. The lower stream sites were selected based on access to mid- and downstream locations along each of the streams that drained the selected upland catchments.

Three different activities were carried out based on methods adapted from the US EPA manual on rapid bioassessment protocols for use in streams and wadeable rivers (Barbour et al. 1999) to assess the physical, chemical and biological conditions of the stream. The watershed/habitat approach was used to classify the physical condition, water quality sampling to determine the chemical condition of the stream, and macro-invertebrate sampling to determine the biological condition.

6.2.1 Watershed/Habitat Approach

In addition to information obtained from the VINVAL Working Papers (Meijerink et al. 2003; Verzandvoort et al. 2005) on the upstream sampling points and catchment areas, a visual assessment of each sampling point was carried out (Appendix 7). The summary of the assessments include the appearance of the stream water, the width and depth of the stream channel, a description of activities within 200 m of the sampling site, type of weir, if present, and a general habitat assessment (Appendix 8).

6.2.2 Physico-Chemical Condition

Grab sampling and meter readings

Monthly manual grab samples of stream water were obtained and processed (see Chapter 5). A Horiba Digital Water Quality Checker Model U-10 was used in the field to measure conductivity, DO, pH, and temperature in situ on a monthly basis (see Table 5.2).

6.2.3 Biological Condition

Sampling Procedure

The biological survey method for multi-habitats (Barbour et al. 1999) was used to sample for aquatic invertebrates at each site during stream flow. A D-frame dip net with a frame area of 0.3 m^2 and net of mesh size 500 µm was swept through approximately 0.5 m of open water and swiftly inserted and withdrawn in areas of aquatic vegetation to obtain the organisms. A total of 20 jabs were made along a 100-m stretch located upstream from the access point of each site. Collected material after 10 jabs was rinsed with stream water and emptied into a pre-labeled plastic 1-liter container with a screw cap. A composite of all collected organisms at each sampling site was preserved as one large sample with 40% formaldehyde added to the container, which contained stream water, to a dilution of approximately 4-6% formalin. A few drops of Rose Bengal dye were also added to stain the organisms for easier sorting in the laboratory.

Analysis of samples

The obtained samples were transported to the Center for Africa Wetlands (CAW) laboratory, at the University of Ghana, for further processing. Samples were washed in a 500-µm mesh sieve with tap water to remove excess formalin, sediments and organic particles (inspected for organisms before discarding), and the organisms were spread out evenly in a flat, white pan marked into quarters with a grid. Organisms were picked out with forceps using a hand lens and then counted. In circumstances where the density of organisms was higher than 100, sub-sampling, where organism numbers within one grid were counted, were used to extrapolate for the total number. Identification was carried out with a hand lens or low power binocular microscope up to the family level of the Linnaeus binomial system of classification using macro-invertebrate identification keys (Needham and Needham 1962; Croft 1986).

6.2.4 Quality Assurance

In the field, samples were labeled to include the site and stream name, date and time of collection. After sampling, all nets and pans were rinsed thoroughly, examined, and all debris removed. In the laboratory, all samples were examined by another person to check identification and counts. After processing, all sieves, pans and trays in contact with the sample were rinsed and examined. All specimens were preserved for future reference. Identified samples were recorded in a logbook with label details.

6.3 Data Analyses

Data analyses was based on descriptive and non-parametric statistics, and was performed using the Plymouth Routines In Multivariate Ecological Research statistical software PRIMER version 6 (P_6) (Clarke and Gorley 2001). PRIMER is a collection of various statistical routines used in ecological and environmental studies. It was developed specifically for ecologists to analyze multivariate data that includes species or sample abundance (or biomass) together with associated physico-chemical data.

To meet the objectives of the study, standard univariate diversity options were used only to (i) describe the macroinvertebrate community; multivariate analyses included physico-chemical data to (ii) discriminate between sites based on biotic and abiotic variables, (iii) link the patterns of observed taxa distribution to abiotic variables, (iv) describe the pattern of occurrences of taxa across similarly grouped sites, and (v) determine 'disturbance' levels at each site.

6.3.1 Macroinvertebrate assemblage description

The DIVERSE option summarized the diversity indices, which included taxon number, total individuals, diversity, richness, and evenness. Diversity was represented by the Shannon diversity index (Equation 6.1) which incorporates richness (measure of the total number of taxa present per site) and evenness (measure of the degree of distribution among the different taxonomic groups):

$$H' = -\sum_i p_i (\log p_i) \tag{6.1}$$

Where: p_i is the proportion of the total count of the ith taxon.

The Simpson Diversity Index (Equation 6.2) incorporates a higher contribution of rare taxa to the community structure. Comparatively, the Shannon diversity index has a higher weighting system for common taxa with respect to their distribution within a community. The Shannon index is more sensitive to changes in dominant species, while the Simpson index is more sensitive to changes in rare species:

$$1-\lambda' = 1-\left\{\sum_i N_i\left(N_i-1\right)\right\}/\left\{N\left(N-1\right)\right\} \tag{6.2}$$

Where: $1\text{-}\lambda'$ is the evenness index, which has its largest value when all taxa have the same abundance, N is total sample size, and N_i is the number of individuals of taxa i.

Taxa richness by the Margalef's index (d) (Equation 6.3) is a measure of the number of taxa (S) present for a given number of individuals (N), in the equation:

$$d = (S-1)/\log N \tag{6.3}$$

Evenness was expressed by the Pielou's evenness index (Equation 6.4), where H'_{max} is the maximum possible diversity that would be achieved if all species were equally abundant $(=\log S)$:

$$J' = H'(observed)/H'_{\max} \tag{6.4}$$

As an additional measure, cumulative frequencies of 100% of taxa are plotted for each site, or K-dominance plots. Taxa are ranked in decreasing order of abundance and the values converted to percentage abundance, relative to the total number of individuals at the site. The number of pollution intolerant taxa Ephemeroptera, Trichoptera and Odonata, (the

ETO index) and numbers of pollution tolerant taxa, Chironomidae and Oligochaeta, were also quantified.

6.3.2 Site grouping based on macroinvertebrate assemblages

To compare similarities in macroinvertebrate assemblages between sites, similarity measures were calculated using the Bray Curtis coefficient following 4^{th} root transformation of raw data. Relative numbers were initially standardized to reflect the percentage of total abundance accounted for by each taxa. Graphical representation was by group-average hierarchical clustering (CLUSTER), which groups samples according to characteristically similar patterns in community abundance, and the nMDS (non-metric Multi Dimensional Scaling) ordination, which maps the relative distances of sites in 2-dimensions based on their similarities. Stress values in nMDS plots <0.05 indicate an excellent representation of data, <0.1 a good ordination with no misleading interpretation, and >0.2 not completely reliable especially in the upper half of the range (Clarke and Warwick 2001b).

6.3.3 Site grouping based on environmental variables

Principal Component Analysis (PCA) was performed separately for the environmental data obtained in-situ (pH, conductivity, dissolved oxygen and temperature) and the analyzed nutrient ion concentrations (Ca, K, Mg, Na, NH_4-N, NO_3-N, and PO_4-P), to obtain separate plots that illustrate the dissimilarities between sites based on Euclidian distance. Data were initially examined using the Draftsman plot, and skewed parameters appropriately transformed to reduce the strong contribution of outliers. Data were normalized (subtracting the mean and dividing by standard deviation for each variable) to change the differing unit scales of each environmental variable into dimensionless parameters for comparison before proceeding with the PCA.

6.3.4 Community structure and environmental variable linkages

For linking community analysis to environmental variables, the BIOENV procedure (Bray-Curtis similarity for biota and Euclidean distance for environmental variables) with

Spearman's rank correlation coefficient ρ were used to determine which of the measured physicochemical parameters significantly influenced the distribution of species among sites. The significance of the results (999 permutations) were compared to the null hypothesis of 'no agreement in multivariate pattern' ($\rho=0$) at significance level $p<5\%$.

From the BIOENV results, the environmental variables with the highest correlation was retained and LINKTREE described how biotic factors contributed to the grouping of assemblage samples. Sites were clustered at separate levels, with each cluster determined by the differences in values of influencing environmental variable/s. The significance of the divisions was tested by the similarity profile test (SIMPROF), to test the null hypothesis that specified divisions in the samples do not differ. The statistic π measures the departure of the real from the mean of simulated profiles with no further division when the test is not significant. From the sample groups identified in the LINKTREE clustering, the SIMPER analysis was used to identify the role of individual taxa that contributed >80% to the separation between two groups of samples or within a similar group.

6.3.5 Measurement of community stress

Based on observations that variability in impacted communities is greater than that of non-impacted sites (Warwick and Clarke 1993), relative dispersion within groups was assessed by the MVDISP option. This provides complementary information of variability within each group, with large numbers corresponding to greater within-group dispersion. In addition, the comparative Index of Multivariate Dispersion (IMD) contrasts the average rank of similarities among impacted samples with the average rank among non-impacted samples, such that IMD has a maximum value of +1 when all similarities among impacted samples are lower than any similarities among non-impacted samples (Clarke and Warwick 1994). The opposite (i.e., similarities among impacted samples are higher than non-impacted similarities) gives a minimum of -1 for IMD, and values near zero imply no difference between groups.

6.4 Results

6.4.1 Macroinvertebrate assemblage

From the 80 samples obtained from 11 sites over a period of 16 months, a total of 31 families (Figure 6.1; Appendix 9) from 17 orders (Figure 6.2; Appendix 10) were obtained. The total number of individuals per taxa for each site is presented (Appendix 11). The 5 most scarce macroinvertebrate families (Table 6.1) may represent temporary population of migratory adults, or wash off from a nearby location during a storm event.

Diversity indices (Appendix 12) with averages per site (Table 6.2) were also calculated. The highest average number of taxa (21) was observed at the midstream site H2, and the lowest numbers at the forested upland stream, L1. The highest average number of individuals was at the downstream site Ofin2, although the evenness (degree of individual distribution among taxa) and richness (measure of taxa for given number of individuals) indices were the lowest. H1 showed the highest values in richness, evenness and diversity indices. Overall, the mid- and downstream sites had higher taxa and individual numbers. The upstream sites had higher evenness and diversity indices, indicating an even spread of individuals per taxa despite the overall lower numbers.

The K-dominance plot (Figure 6.3a) summarizes the diversity indices graphically. The cumulative frequency of 100% of ranked taxa for all the sites show steeper slopes for H1, M3 and HM4, indicating higher evenness of individuals per taxa (i.e., lower dominance) and high taxa richness (fewer taxa per individuals). At the other extremity, with flatter curves, are the sites L3 and Ofin2, which display lower equitability (higher dominance of specific taxa) and lower taxa richness. The plot by stream level (Figure 6.3b) shows steeper slopes for the up- and midstream lower sites. The midstream sites show intermediate levels of evenness and richness, and the downstream sites display lower evenness and richness indicated by the flatter curves.

Based on the diversity summaries, the upstream sites show few individuals per taxa and relatively low numbers of taxa, but there is no dominance as each taxon is equally represented. The mid- and downstream sites have higher numbers of individuals for a relatively higher number of taxa. However, with the uneven spread of individuals per taxa there is greater dominance.

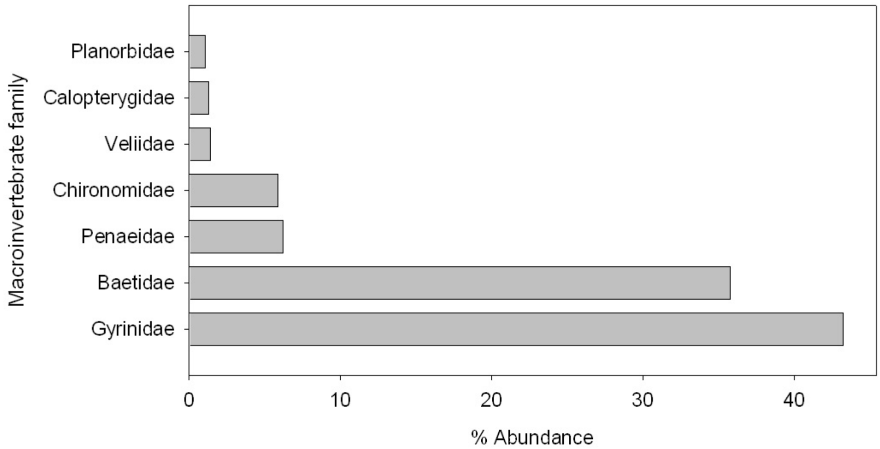


Figure 6.1 Percentage composition (>1%) of most abundant macroinvertebrate families

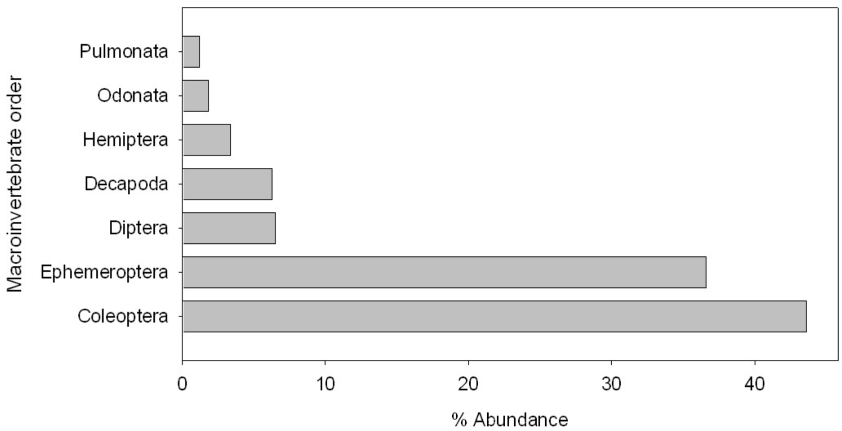


Figure 6.2 Percentage composition (1> %) of major macroinvertebrate orders

Table 6.1 Occurrences of most rare macroinvertebrate species

Order	Family	Site	Period
Odonata	Gomphidae	M2 & H1	Dec 2006
Trichoptera	Hydropsychidae	L1, M1	Sep 06, Oct 2006
Diptera	Syrphidae	M2	Jul 2006
Hemiptera	Hydrometridae	Ofin1	Nov 2006
Arhynchobdellida	Hirudinidae	H1	Oct 2006

Table 6.2 Average numbers of macroinvertebrate taxa (S), average numbers of individuals (N), Margalef's index of richness (d), Pielou's evenness index (J), Shannon index (H′) and Simpson's Diversity Index (1-λ).

Site	S	N	d	J'	H'	1-λ
H1	11	11.8	**4.06**	**0.82**	**1.97**	**0.89**
M1	6	16.5	1.78	0.81	1.45	0.74
L1	4	8.5	1.40	0.75	1.04	0.67
H2	**21**	169.7	3.90	0.36	1.11	0.42
M2	13	60.1	2.93	0.48	1.23	0.53
L2	17	28.2	4.79	0.45	1.28	0.54
M3	8	20.0	2.34	0.81	1.68	0.79
L3	6	46.0	1.31	0.30	0.55	0.23
HM4	16	54.2	3.76	0.63	1.76	0.78
Ofin1	12	64.0	2.64	0.25	0.62	0.24
Ofin2	12	**212.1**	2.05	0.19	0.47	0.18

Bold = highest values

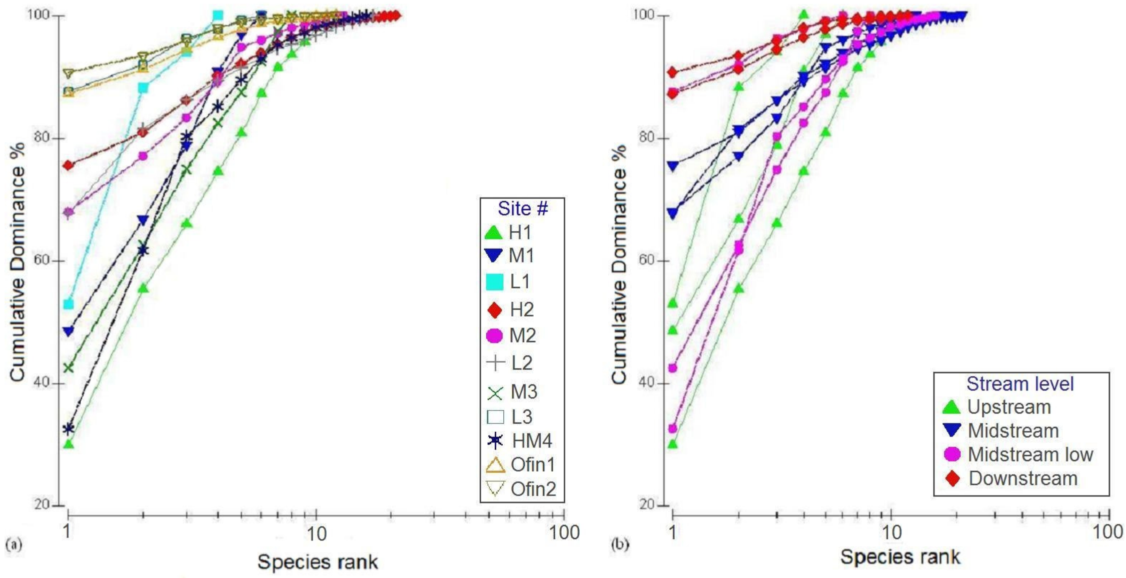


Figure 6.3 K-dominance plots for (a) each site and (b) stream level

Diagnostic Taxa

The midstream sites were observed to have the highest numbers of diagnostic taxa, and H2 the highest percentage of individuals (Table 6.3). Ephemeroptera, Trichoptera and Odonata are sensitive taxa and their numbers decline as the pollution gradient increases. Only two Trichoptera individuals (from the same family) were observed. The highest numbers of Ephemeroptera and Odonata (comprising of three families each) were observed at the midstream sites, with comparatively lower numbers downstream. The highest numbers of pollution tolerant taxa, Chironomidae and Oligochaeta, were also observed at the midstream sites, with lower numbers of chironomids downstream but no occurrences of oligochaetes. In summary, high numbers of both pollutant sensitive and tolerant taxa were observed at the midstream sites. Depending on the families that make up each of the diagnostic orders, a wide range of tolerance can be observed (Thorne and Williams 1997). According to the authors, diagnostic groups are rather more effective where pollution gradients are higher.

Table 6.3 Summary of diagnostic taxa: #I = number of individuals in each order; %T = percentage of total community of macroinvertebrates at each site; #F = number of families

Site	Ephemeroptera				Trichoptera		Odonata				Chironomid		Oligochaete	
	# I	%TI	# F	%TF	# I	%TI	# I	%TI	# F	%TF	# I	%TI	# I	%TI
H1	18	37.5	2	16.7	0	0.0	0	0.0	0	0.0	3	6.3	1	2.1
M1	0	0.0	0	0.00	1	2.9	0	0.0	0	0.0	4	11.8	0	0.0
L1	1	5.9	1	25.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
H2	1578	77.5	3	14.3	0	0.0	24	1.2	2	9.5	80	3.9	2	0.1
M2	451	68.0	2	13.3	0	0.0	37	5.6	2	13.3	61	9.2	6	0.9
L2	192	67.8	2	11.1	1	0.4	6	2.1	1	5.6	39	13.8	1	0.4
M3	17	42.5	1	12.5	0	0.0	2	5.0	1	12.5	3	7.5	0	0.0
L3	121	87.7	1	16.7	0	0.0	6	4.4	1	16.7	2	1.5	0	0.0
HM4	31	5.2	2	11.7	0	0.0	4	0.7	2	11.8	174	29.2	1	0.2
Ofin1	21	3.3	1	7.7	0	0.0	5	0.8	2	15.4	12	1.9	0	0.0
Ofin2	67	2.9	2	16.7	0	0.0	5	0.2	2	16.7	26	1.1	0	0.0

Other taxa

Although the distribution of other taxa was not an objective of this study, vertebrate taxa formed 17.9% of the total aquatic fauna sampled (see Tables 10.5; 10.6), with 88.2% belonging to fish groups and the rest to Anura (tadpoles). Some of the fish species were distinct enough to be identified to the genus level, i.e., *Barbus* (the most abundant), *Tilapia*, *Clarias* and *Hemichromis* spp. *Barbus* spp. was greatest at H2, HM4 and the Ofin River. Fish fry formed 40.9% of the vertebrate individuals and were highest at Ofin2. The distribution of the most abundant vertebrate taxa is presented in Figure 6.4.

Chordates are considered important in their contribution to describing ecosystem health. Fish have typically been used in various monitoring programs, although relatively few studies have investigated their relationship with macroinvertebrate distributions (Hering et al. 2006; Flinders et al. 2007) In general, fish mobility and longevity signify environmental influence on a much broader spatial scale than macroinvertebrates (Plafkin et al. 1989), and predictions of their responses to stressors are based on watershed area and land-use, whilst macroinvertebrate communities typically respond to lower-scale or site-specific stressors (Flinders et al. 2007). It was observed that these results are comparable to the macro-invertebrate distribution, in that the midstream site H2 shows the highest number of species. Further research is, however, needed before conclusive statements can be made.

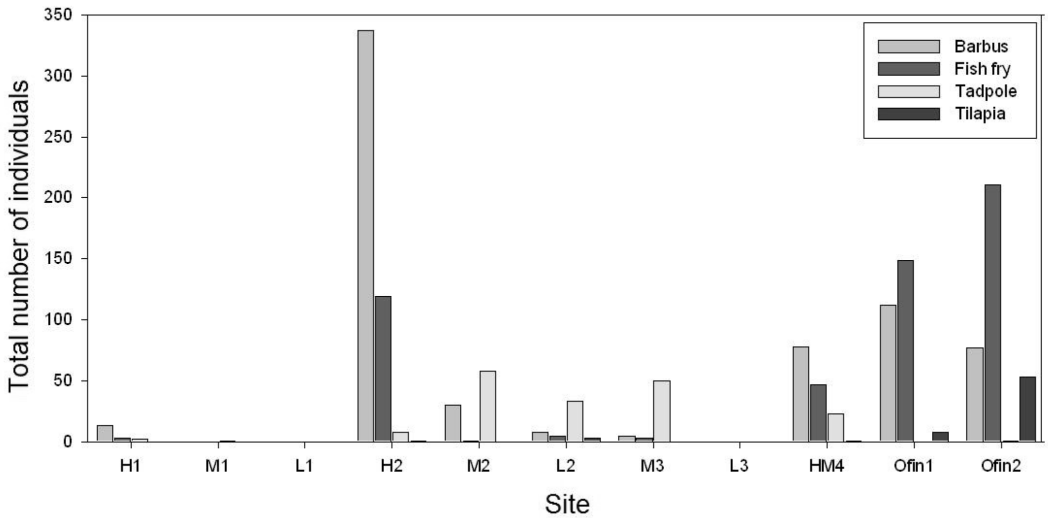


Figure 6.4 Distribution of vertebrates

6.4.2 Site grouping based on macroinvertebrate assemblage

For the multivariate analyses, all sampled macroinvertebrate taxa were retained for the similarity comparisons between sites. In general, macroinvertebrates (as most biological indicators) are temporally insensitive (Chapman 1996) and some studies have found that there is no significant correlation between rainfall and macroinvertebrate diversity (Tumwesigye et al. 2000; Besley and Chessman 2008). With no background data for the sites and the relatively short time frame of the study, the temporal patterns, if any, could not be assessed. The monthly samples were, therefore, averaged per site since information about the average community structure at each site is important for the objectives of the study.

The cluster analysis of the macroinvertebrate taxa for similarly occurring taxa shows that there are similarly occurring families (at Bray Curtis >60), with the two most dominant taxa being Gyrinidae (occurring with Planorbidae, Penaeidae and Chironomidae) and Gerridae (occurring with Caenidae, Ampullaridae and Oligochaeta) (Figure 6.5).

Based on the distribution of sites based on macroinvertebrate taxa, the cluster (Figure 6.6) and nMDS (Figure 6.7) analyses show a distinct separation of L1, with all other sites clumped tightly together. NMDS is based on similarity ranks, which assumes that all the study sites have taxa in common. Macroinvertebrate taxa occurring at L1 are also found at other sites (see Appendix 11). However, this extreme outlier could have been influenced by the relatively different organization of taxa in the community and the numbers present. With the exclusion of L1 from the analysis, mainly for the purpose of viewing the division of the other sites, H1 and M1 are observed to separate out individually from all sites at Bray-Curtis similarity of >60. The rest of the sites cluster into three separate groups, i.e., (i) the lower midstream sites of L3 and M3, (ii) the upper midstream sites of H2, M2, L2 and HM4, and (iii) the downstream Ofin sites, all (Figure 6.8). At Bray-Curtis <55, however, only the upland catchment sites L1 and M1 significantly separate out, with all other sites displaying similar macroinvertebrate taxa distribution.

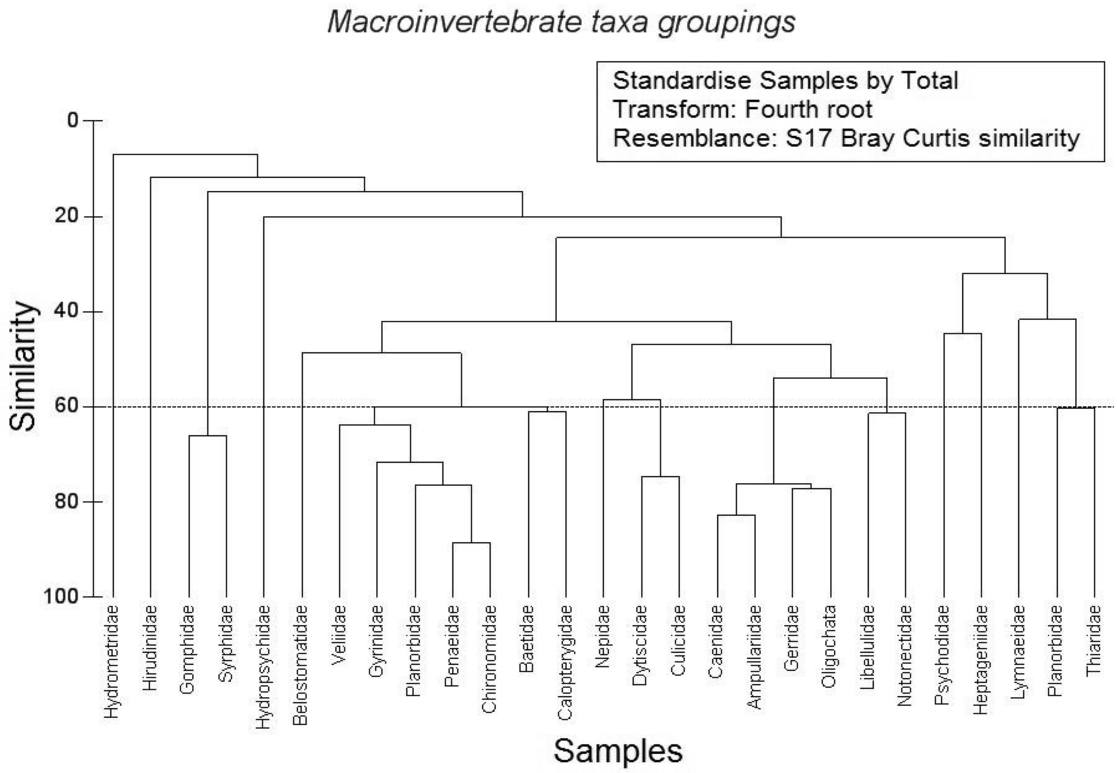


Figure 6.5 Macroinvertebrate taxa cluster analysis showing similarly occurring taxa at Bray Curtis similarity >60%.

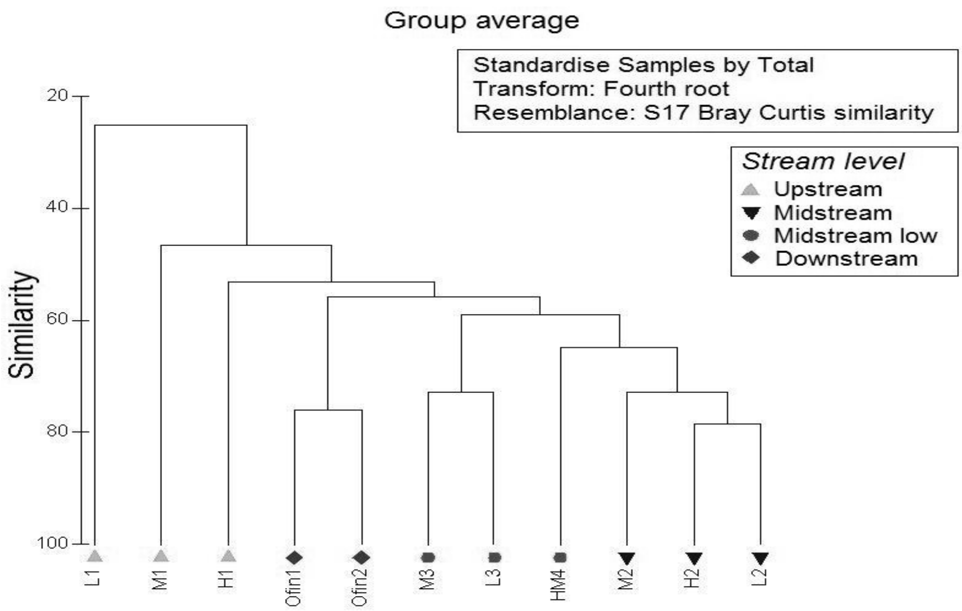


Figure 6.6 Cluster of all sites, using group-average clustering from Bray Curtis similarities on fourth-root transformed abundances.

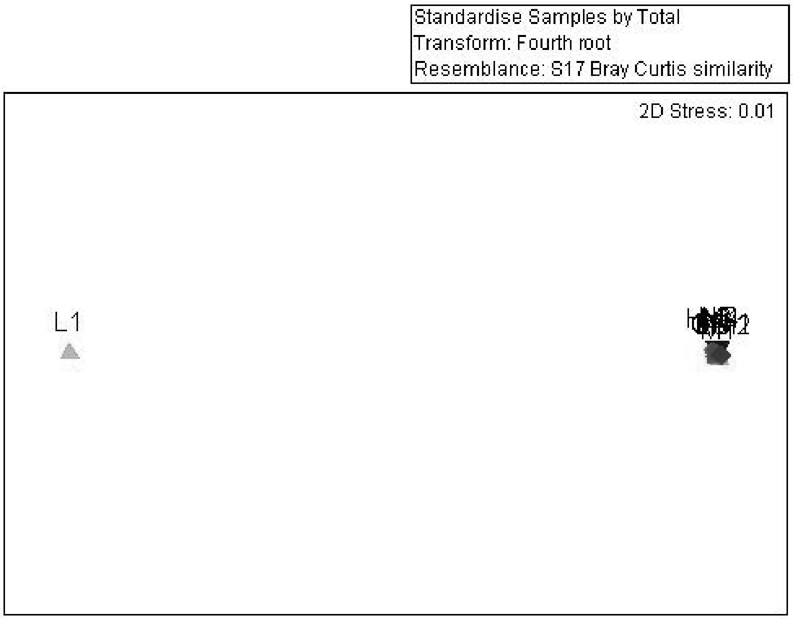


Figure 6.7 nMDS of all sites, using group-average clustering from Bray Curtis similarities on fourth-root transformed abundances (stress = 0.01). Site L1 (the forested low land-use intensity catchment) shows a distinct separation from all sites.

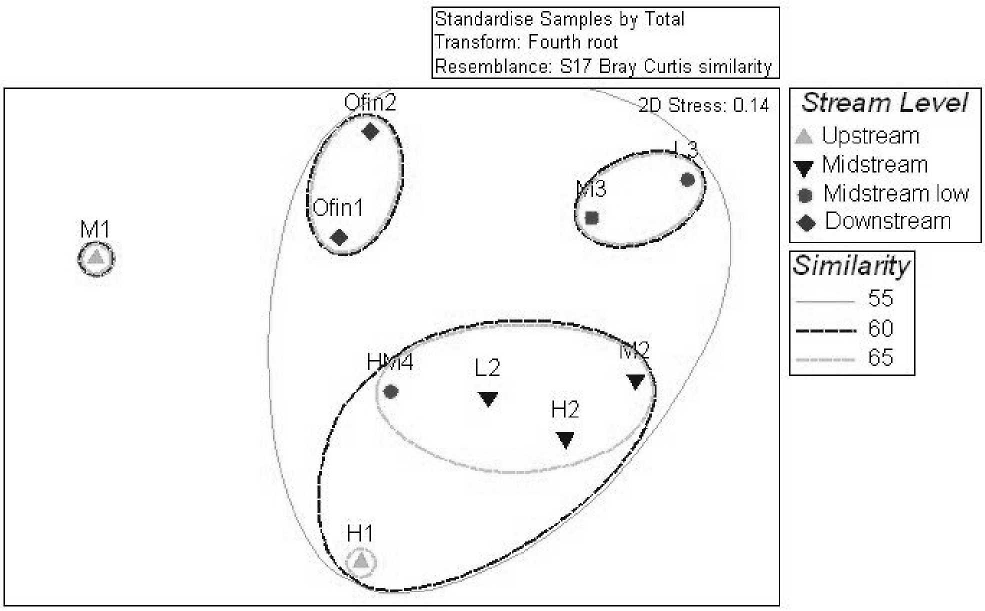


Figure 6.8 nMDS of all sites without Nyamebekyere (stress = 0.14)

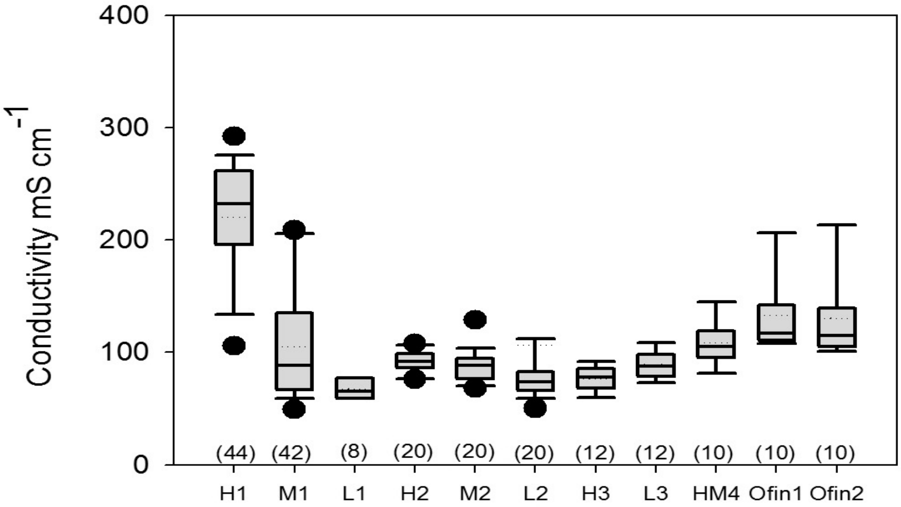
6.4.3 Site groupings based on environmental variables

Physico-chemistry

The mean and median values for physico-chemical data measured *in situ* (pH, conductivity, DO and temperature) were obtained for all sites (Figure 6.9a; Figure 6.9b; Appendix 13). The highest conductivity values were observed at H1. DO values showed high variations at all the sites and measured the lowest at M2. The highest median pH values and lowest temperature readings were observed at L1. With the exception of conductivity, physico-chemical parameters were highly variable during the research period, possibly due to seasonal changes. Physico-chemistry for all the sites was within the Target Water Quality Range (TWQR) set for domestic use and aquatic ecosystem health for Ghanaian rivers, except DO. Although some measurements extended into the acceptable range (especially in the downstream sites), the median DO concentrations were generally below the recommended 5-7 mg L^{-1} for aquatic ecosystem health. This may be the result of increased biological activity during low flow in the shallower upper- and midstream sites.

PCA Analysis

Eigenvalues in PCA represent the amount of variance explained by each axis. The PRIMER software presents these values as a percentage of the total variance. In deciding how many components to present, the rule of thumb is the '80% rule', where the first axes that explain 80% (cumulative) of the total variation is used. Other tools are available to select the number of axes (e.g., broken stick model), however, in many scientific publications the graphical output of PCA consists of the first two axes (Legendre and Legendre 1998). If these two axes explain a low percentage, then the information is considered unreliable and a further examination is required (Clarke and Warwick 1994). For this study, PCA yielded two principle components with eigenvalues >1 that explained 76.6% of the variance of data (Table 6.4). The PC1 axis, determined mainly by pH and temperature variables, accounted for 47.0% of the variance, and the PC2 axis (29.6%) was determined by dissolved oxygen (DO). Sites with increasing pH and decreasing temperature are plotted along the PC1 axis, and increasing DO along axis 2 (Figure 6.10).



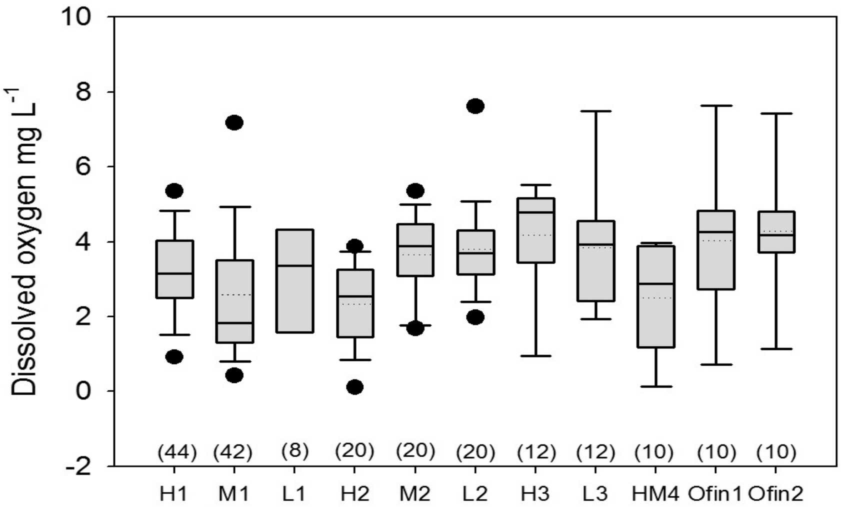
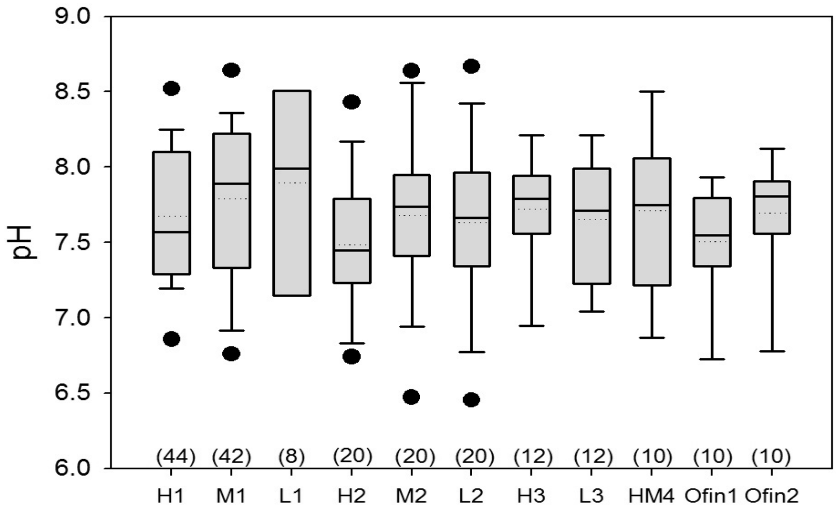


Figure 6.9a Box and whisker plots showing 5th and 95th percentiles of physico-chemical measurements. Dotted line represents the mean value; solid line represents the median value; in parenthesis is the total number of samples.



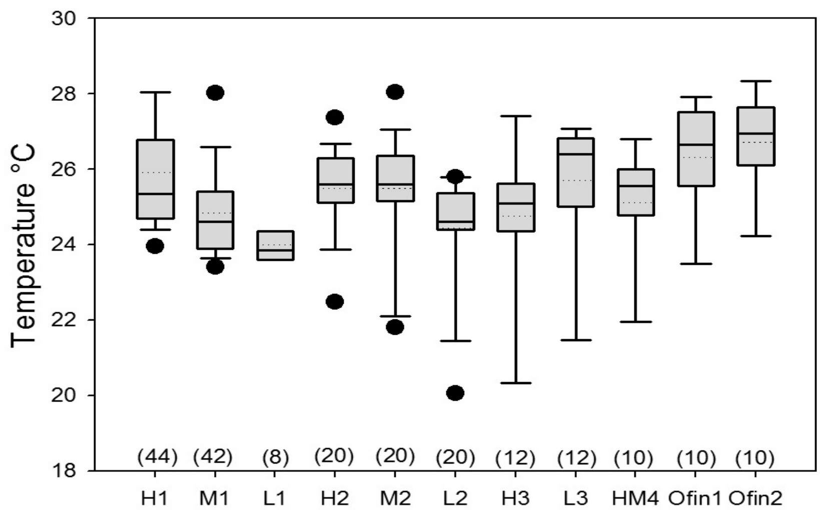


Figure 6.9b Box and whisker plots showing 5th and 95th percentiles of physico-chemical measurements. Dotted line represents the mean value; solid line represents the median value; in parenthesis is the total number of samples.

Table 6.4 Principal Component Analyses (PCA) of physico-chemical parameters (pH, conductivity, dissolved oxygen and temperature)

Eigenvalues

PC	Eigenvalues	%Variation	Cum.%Variation
1	1.88	47.0	47.0
2	1.18	29.6	76.6
3	0.534	13.4	90.0
4	0.401	10.0	100.0

Eigenvectors

(Coefficients in the linear combinations of variables making up PC's)

Variable	PC1	PC2	PC3	PC4
pH	0.574	0.265	0.653	0.418
Conductivity	-0.500	-0.451	0.723	-0.156
DO	-0.250	0.799	0.217	-0.502
Temperature	-0.598	0.297	-0.069	0.741

Principle Component Scores

Samples	SCORE1	SCORE2	SCORE3	SCORE4
H1 Attakrom	-1.75	-1.79	1.27	-0.745
M1 Dunyankwanta	1.87	-1.52	8.95E-2	0.863
L1 Nyamebekyere	2.56	0.311	0.499	-0.379
H2 Mankranso	-0.691	-1.18	-1.55	-4.14E-2
M2 Kunsu	4.05E-2	0.609	-6.11E-2	-2.89E-2
L2 Nyasi	0.677	0.196	-0.615	-0.852
M3 Borosase	0.464	1.37	0.171	-0.693
L3 Afrensini	-0.581	0.857	-0.244	0.493
HM4 Akuapem	0.174	-0.516	5.9E-2	0.468
Ofin1 Ntabanu	-1.79	0.589	-0.313	-3.27E-2
Ofin2 Beposo	-0.977	1.08	0.703	0.948

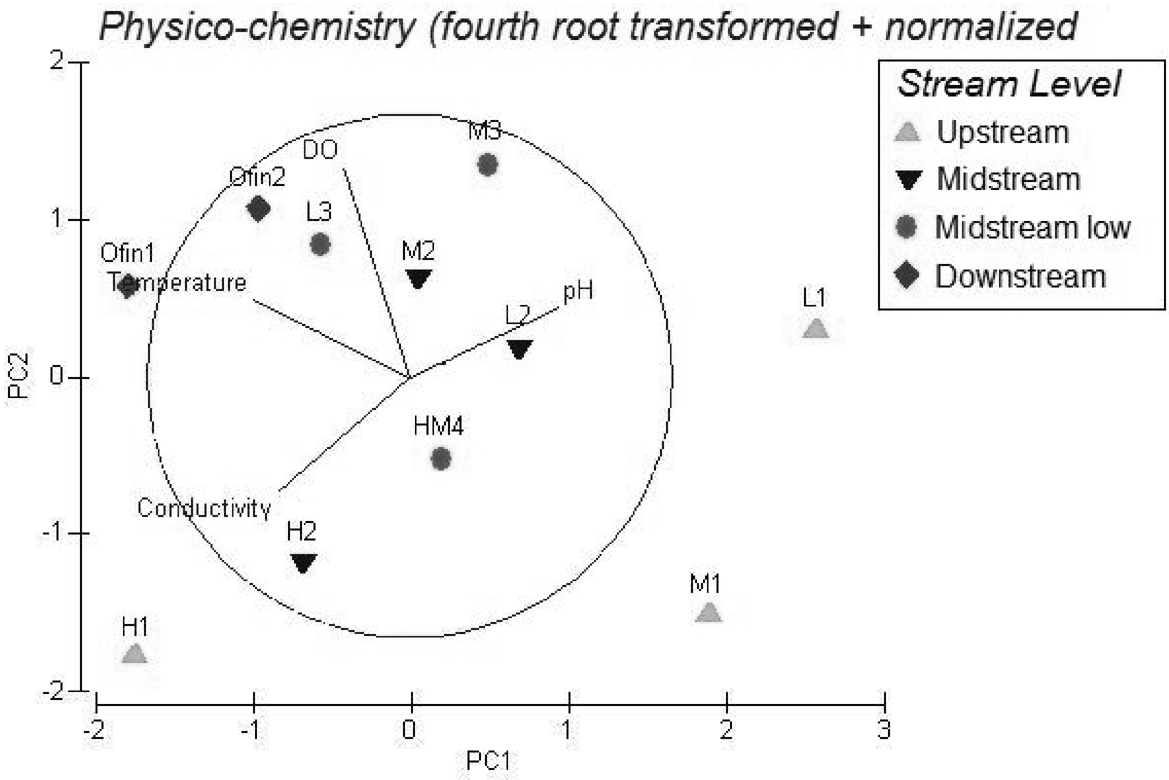


Figure 6.10 PCA ordination (pH, temperature, conductivity and dissolved oxygen)

Nutrient ions

The median nutrient ion concentrations for all sites (Figure 6.11a; Figure 6.11b) showed significant differences (Table 6.5) only for the cations (Ca, K, Mg and Na) and PO_4-P, but were generally within the Ghana Target Water Quality Range (TWQR) (see Table 5.8) established for domestic water use and aquatic ecosystem health. Ca and Mg nutrient levels were within the optimal ranges and the requirements of Ca:Mg ratio of >1 to protect shell organisms were also met. H1 showed the highest nutrient concentrations that were on the borderline limits for domestic use. K concentrations were within the TWQR limits, although higher variability was observed at the sites originating from the high land-use intensity catchment (i.e., H1, H2, and H3), with the highest median values measured downstream. Na measurements were the lowest at M1 and L1, and highest at the downstream sites. Median NH_4-N and NO_3-N concentrations were on the borderline of the TWQRs for all sites, and the upper range of measured values over the study period exceeded the TWQR limits. Median PO_4-P concentrations were highest at the high and medium land-use intensity upland catchments (H1 and M1) and similar for all the other sites.

Table 6.5 Kruskal Wallis test for differences in nutrient parameters for all sites. (Asymp. sig = not significant at p>0.05, df = degrees of freedom)

	Ca	K	Mg	Na	NH_4-N	NO_3-N	PO_4-P
Chi-Square	101.553	131.796	93.349	128.576	9.790	16.333	115.410
df	10	10	10	10	10	10	10
Asymp. Sig.	**.000**	**.000**	**.000**	**.000**	.459	.090	**.000**

PCA Analysis

PCA ordination of nutrient data resulted in principle components with eigenvalues >1 that explained 76.5% of the variance of nutrient data (Table 6.6). Of the total variance, the PC1 axis accounted for 55.6% and was influenced by Ca, Mg, and NO_3-N, and PC2 (21.0%) by Na and NH_4-N. Streams with higher nutrient ion concentrations are located towards the bottom right half of the plot (Figure 6.12). The upstream sites are considerably different from each other, but the midstream and lower midstream sites show similar nutrient measurements, respectively. H1, Ofin1 and Ofin2 show the highest nutrient loads in general, although the Ofin sites have higher concentrations of nitrogen products (NO_3-N and NH_4-N) and lower Ca, K and Mg as compared to H1.

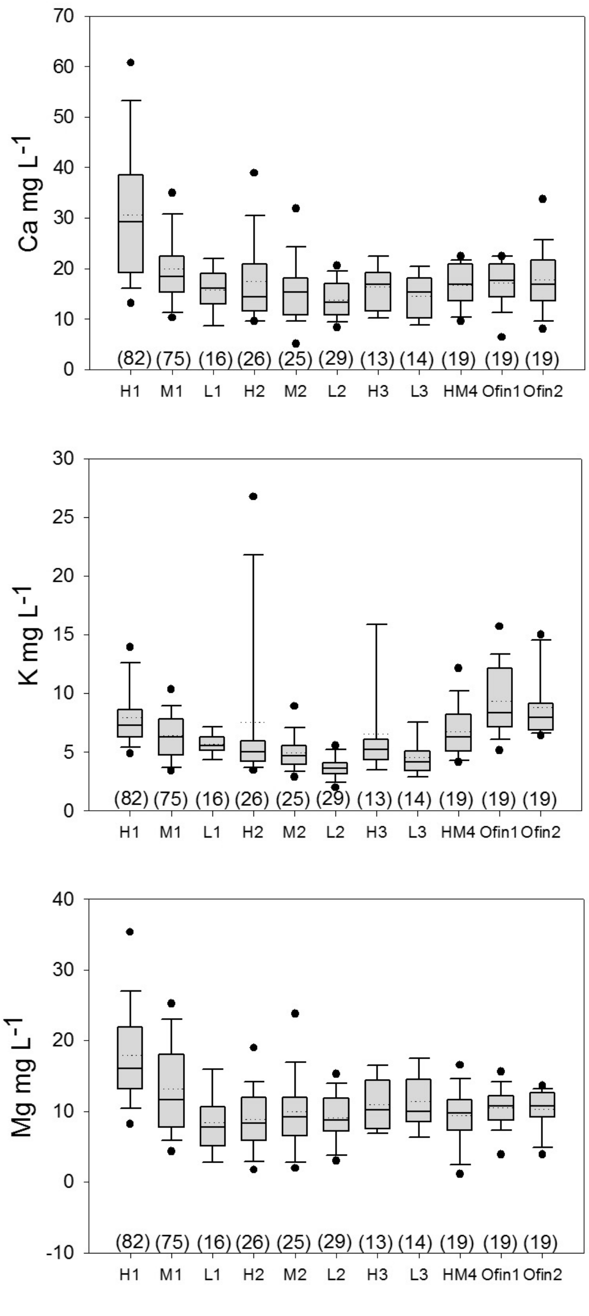


Figure 6.11a 5th and 95th percentiles of nutrient ion measurements. Dotted line represents the mean value; solid line represents the median value; bottom number in parenthesis is the total number of samples per site.

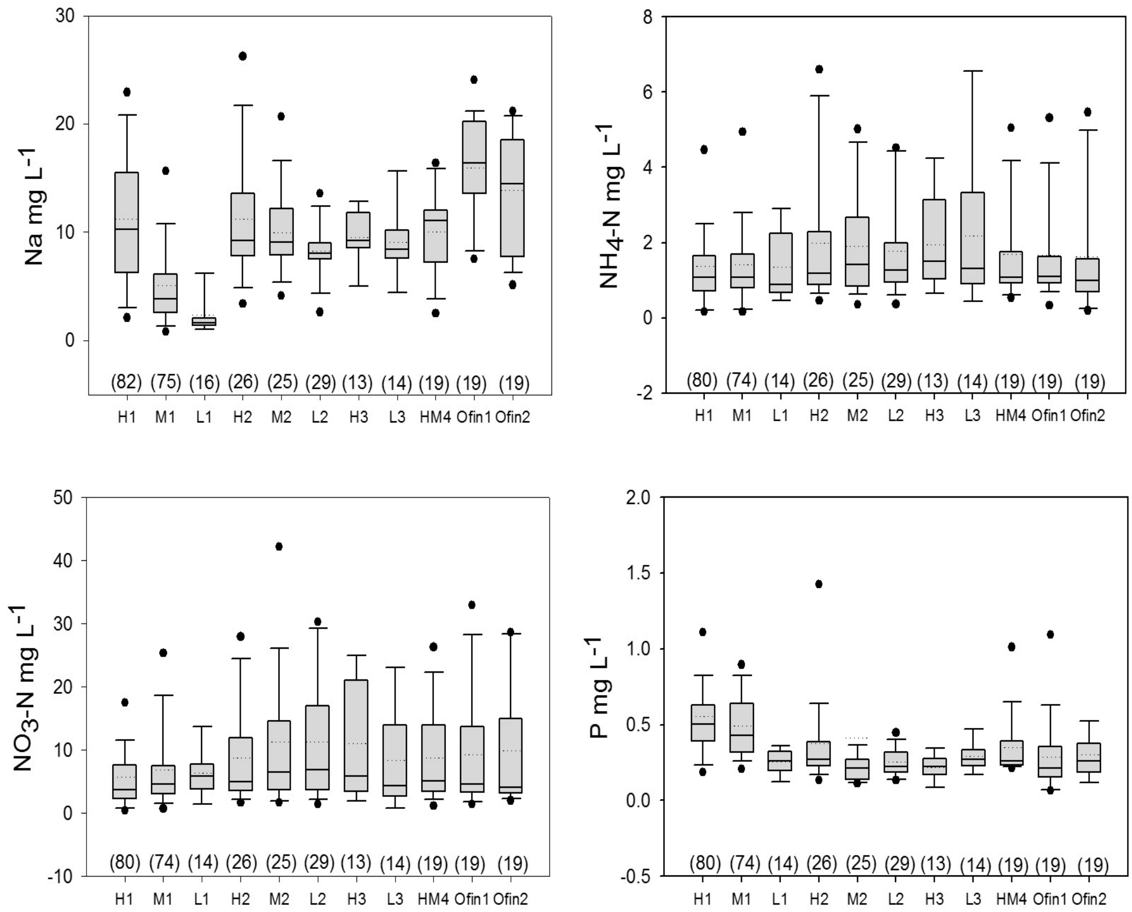


Figure 6.11b 5th and 95th percentiles of nutrient ion measurements. Dotted line represents the mean value; solid line represents the median value; bottom number in parenthesis is the total number of samples per site.

Table 6.6 Principal component analyses for nutrient parameters

Eigenvalues

PC	Eigenvalues	%Variation	Cum.%Variation
1	3.89	55.6	55.6
2	1.47	21.0	76.5
3	1.06	15.1	91.6
4	0.353	5.0	96.7
5	0.13	1.9	98.5

Eigenvectors

(Coefficients in the linear combinations of variables making up PC's)

Variable	PC1	PC2	PC3	PC4	PC5
Ca	0.464	-0.004	-0.252	-0.424	-0.048
K	0.393	0.081	0.525	-0.412	0.464
Mg	0.450	0.203	-0.332	-0.189	-0.111
Na	0.109	0.762	0.237	0.114	-0.529
NH4-N	-0.243	0.522	-0.559	-0.029	0.549
NO3-N	-0.439	-0.100	-0.143	-0.734	-0.380
PO4-P	0.406	-0.299	-0.403	0.251	-0.211

Principle Component Scores

Sample	SCORE1	SCORE2	SCORE3	SCORE4	SCORE5
Attakrom	4.45	5.9E-2	-1.3	-0.282	-0.327
Dunyankwanta	1.48	-1.47	-0.731	0.149	0.281
Nyamebekyere	-1.02	-2.92	0.745	-0.422	0.164
Mankranso	-2.64	3.57E-3	-0.597	-8.99E-2	-0.768
Kunsu	-1.92	0.736	-0.622	-0.582	4.86E-2
Nyasi	-0.921	-3.01E-2	0.296	0.829	-4.18E-2
Borosase	-1.17	1.15	-0.915	-0.638	0.556
Afrensini	-0.599	0.434	-0.76	1.25	0.269
Akuapem	9.58E-2	0.191	0.733	-0.105	-0.289
Ntabanu	0.912	1.25	1.57	-0.398	0.165
Beposo	1.33	0.587	1.59	0.29	-5.83E-2

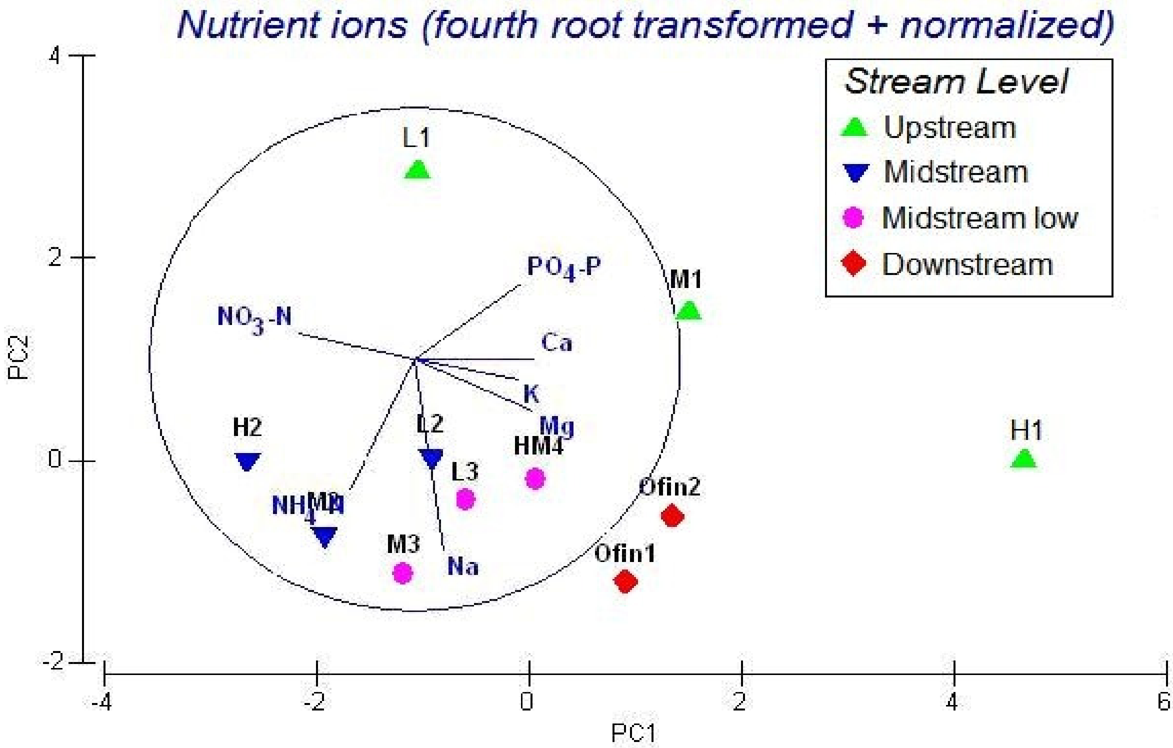


Figure 6.12 PCA ordination (nutrient ions)

6.4.4 Linking environmental factors to macroinvertebrate assemblage structure

The physico-chemical parameters (pH, DO, and temperature) and a combination of three nutrient variables (Mg, Na and NH_4-N) contributed most to the distribution of macroinvertebrate assemblages, as measured by the weighted Spearman rank correlation ρ_w (Table 6.7). The null hypothesis of the similarity profile test shows a division of sites up to level D, where further division is not significant at $\pi = 3.21$ at $p = 0.3\%$ (Table 6.8; Figure 6.13). Based on the six identified abiotic parameters that influenced the macroinvertebrate assemblages, division of sites were in the following categories:

- Group A: Composed of only L1, based on low values of temperature, NH_4-N, Na, and Mg, and high values of pH.
- Group B: Composed of only M1, based on higher Na and DO values, and lower pH
- Group C: Composed of H1, Ofin1 and Ofin2, based on higher Mg values
- Group D: Composed of all the midstream sites based on lower Mg and DO values

Table 6.7 Physico-chemical variables (conductivity, dissolved oxygen, pH, and temperature) and nutrient ions, showing best matches in bold (weighted Spearman rank correlation ρ_w)

Physico-chemistry			Nutrient ion concentration		
#	Correlation	Selection	#	Correlation	Selections
3	**0.440**	**pH, DO, temp**	**3**	**0.653**	**Mg, Na, NH_4-N**
4	0.392	pH, cond, DO, temp	1	0.627	Na
2	0.363	DO, temp	2	0.621	Na, NH_4-N
2	0.346	pH, DO	3	0.620	Na, NH_4-N, PO_4-P
3	0.341	cond, DO, temp	2	0.607	Mg, Na
3	0.282	pH, cond, DO,	4	0.602	Mg, Na, NH_4-N, PO_4-P
1	0.279	temp	4	0.600	Ca, Mg, Na, NO_3-N
2	0.273	pH, temp	3	0.582	Ca, Na, NO_3-N
2	0.268	cond, temp	5	0.576	Ca, Mg, Na, NH_4-N, PO_4-P
3	0.235	pH, cond, temp	4	0.567	K, Mg, Na, NH_4-N

Table 6.8 Site grouping to significant level based on most influential physicochemical and nutrient parameters. R = analysis of similarity between each group set, B% = absolute measure of group differences.

Level	π	Sig%	R	B	Parameters
A->(3),B	4.75	0.3	1	100	Temperature<23.9(>24.6)or pH>7.99(<7.89) or NH_4-N<0.887(>0.993) or Na<1.64(>3.8) or Mg<7.78(>8.27)
B->C,(2)	2.36	1.9	0.75	72.0	Na>8.04(<3.8) or DO>2.54(<1.83) or pH<7.81(>7.89)
C->(1,10,11), D	2.49	1.1	0.54	49.0	Mg>10.7(<10.2)
D->(4-6,9),(7,8)	3.21	0.3	0.79	39.0	Mg<9.72(>9.97) or DO<3.89(>3.94)
4-6,9	2.13	12.8*			

** Non-significant division after level D*

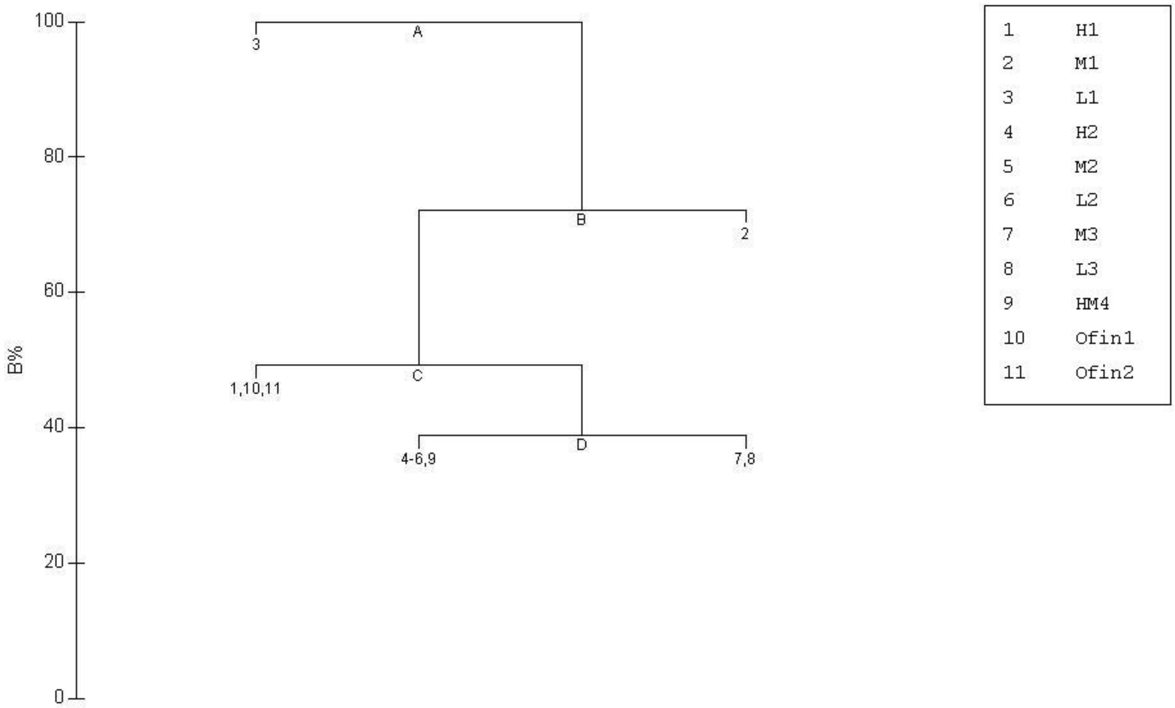


Figure 6.13 Site grouping based on most influential physicochemical and nutrient parameters. B% = absolute measure of group differences.

Contributing taxa

Based on the 4 distinctive grouping of sites identified in the LINKTREE analysis, 7 main macroinvertebrate taxa contributed to more than 50% of the dissimilarities observed between the groups (Table 6.9). The tolerance levels of these taxa describe the degree of organic pollution and are based on known standard sensitivities of each family (Thorne and Williams 1997; Mandaville 2002). The upland catchments of groups A and B, i.e., the forested and medium land-use intensity sites, respectively, were observed to have a smaller number of taxa as compared to the other groups. In group A, Psychodidae and Calopterigidae generally represent moderate levels of organic pollution, and in group B, Gyrinidae and Notonectidae are indicative of lower levels of pollution. For groups C and D, a relatively higher number of taxa and individuals were observed, although the distribution of individuals among taxa was uneven. In group C, the Gyrinidae and other taxa (Baetidae, and Veliidae), indicative of lower pollution levels, contributed the most to the dissimilarities, as compared to group D, where Baetidae and other associated taxa (e.g., Chironomidae, and Penaidae) are representative of relatively higher levels of pollution.

Table 6.9 Percentage contribution of macroinvertebrate taxa to >90% dissimilarity between groups. *Family index indicates pollution levels: 1-4 = good water quality, 5-6 = low pollution, 7-8 = moderate pollution, 9-10 = gross pollution (adapted from Thorne and Williams 1997; Mandaville 2002)

Taxa	Family Index	*C&B*	*C&A*	*B&A*	*C&D*	*B&D*	*A&D*
Baetidae	5	**16.30**	**14.45**	7.43	**12.97**	**15.13**	**13.01**
Psychodidae	8	-	**12.56**	**11.64**	-	-	**11.64**
Gyrinidae	4	**13.80**	**11.37**	10.34	**11.72**	**10.99**	4.30
Calopterygidae	6	-	**18.47**	**17.06**	6.25	5.04	**15.86**
Notonectidae	5	**16.92**	8.14	**15.49**	2.85	**15.08**	7.77
Planorbidae	7	9.04	2.04	8.10	5.85	8.92	4.46
Penaeidae	8	8.39	4.94	6.15	**12.54**	**10.98**	**12.03**
Chironomidae	8	**12.33**	10.24	**18.62**	**11.44**	9.26	10.31
Libellulidae	2	6.79	3.04	-	5.35	-	3.12
Veliidae	5	5.22	5.28	-	6.04	-	-
Gerridae	5	-	-	-	3.98	2.58	2.63
Belostomatidae	5	-	-	-	4.90	3.86	3.91
Caenidae	6	1.92	-	-	3.03	-	-
Ampullariidae	3	-	-	-	3.46	2.26	2.32
% Dissimilarity		**75.37**	**88.00**	**92.04**	**69.94**	**73.32**	**84.97**

(Bold – highest contribution to dissimilarity between sites)

6.4.5 Measurement of community stress

The principle of higher variability in stressed communities is based on research observations of marine communities where the habitat is more stable (Warwick and Clarke 1993; Clarke and Warwick 2001b). It is interesting to note, however, that its application in this study shows relatively higher variability at the upland catchment sites of L1 and M1. The relative dispersion results show that groups A and B > D > C (Table 6.10). Fewer individuals distributed among a few distinct taxa at these sites may be indicative of taxa more resilient to the erratic flow and locally distinctive physico-chemistry as indicated by the LINKTREE results. The high IMD value of +1 between groups A and B also indicates the highest dissimilarities between sites, and is based on their typical faunal and stream physico-chemical characteristics. For groups C and D, lower dispersion values suggest a comparatively lower variability in macroinvertebrate community structure within each group, and the IMD value of -0.018 (the closest value to 0) indicates higher similarities between the two groups as compared to the other groups.

Table 6.10 Relative dispersion and Index of Multivariate Dispersion (IMD)

Global Analysis		Pairwise Comparisons	
Factor value	Dispersion	Factor values	IMD
C	0.985	C, B	-0.367
D	1.003	C, A	-0.36
A	1.358	C, D	-0.018
B	1.36	B, A	1
		B, D	0.359
		A, D	0.359

6.5 Discussion

Based on the patterns of macroinvertebrate taxa distribution and stream physico-chemistry, significant ecological differences were found between the up-, mid- and downstream sites of the Ofin Basin. The results of the multimetric analyses suggest that the nutrient ions most influential on the distribution of macroinvertebrates are Mg, Na and NH_4-N. Ecological differences were significant between the three upland catchment streams, but not between the sites that occurred at the mid- and downstream locations, respectively. The high land-use intensity catchment, however, showed similarities to the downstream sites of the Ofin River, indicating comparable physico-chemistry and macroinvertebrate community structure possibly linked to increasing land-use activities.

Water quality at the upstream sites and the lower stream sites was within the Target Water Quality Range (TWQR) values set for domestic use and aquatic ecosystem health for freshwater in Ghana. The smaller streams of the upland catchments run through areas with more riparian vegetation as compared to the more exposed waters downstream, with shaded areas having lower in-stream temperatures, as seen in the low temperatures of the forested catchment (Kasangaki et al. 2008). As a result, median values for temperature were relatively higher at the mid- and downstream sites. Although the higher range of DO values was within the standard 5-7 mg L^{-1} for aquatic ecosystem health, median values for all the sites were mainly lower. DO values were relatively higher in the Ofin River sites, possibly influenced by the faster flowing nature (WRC 2003a), as compared to upstream sites which are shallower with lower velocities except after storms. The lower DO concentrations may also be due to the time of sampling. Sampling during low flows when there is increased biological activity, especially in shallow streams, may be a contributing factor.

In Ghana, streams and rivers are relatively well buffered and more or less neutral, with pH ranging between 6 and 8 (WRC 2003a). The high pH values observed for the low and medium land-use intensity sites further supports the assumption of measurements during increased biological activity in standing water, when the major pulse of discharge after a storm event subsides. Background values of 300 mS cm^{-1} have been indicated for Ghanaian waters, although average conductivity values downstream of the Ofin River have measured 107 mS cm^{-1} (Ansa-Asare and Darko 2006). The median conductivity values for most of the study sites were comparable, i.e., between 74 and 117 mS cm^{-1}. However, the higher values recorded at the upstream site of H1 (233 mS cm^{-1}) may be indicative of overall higher solute concentrations, confirmed by the high concentrations measured for Ca, Mg and PO_4-P. In Ghanaian rivers, a dominance of Na has been observed in water quality surveys (Larmie 1993; Ansa-Asare and Darko 2005), which in this study markedly increased with increasing land-use intensity and along the downstream gradient. With the exception of the higher levels of Ca and Mg observed for the lower stream sites, nutrient concentrations are comparable to the ranges observed for the Ofin River downstream locations in the report by Ansa-Asare and Darko (2006). Although there are inputs from a number of upland catchments to the mid- and downstream study sites, the source of nutrients cannot be explained by this research.

Various metric indices have been used to describe macroinvertebrate responses to environmental gradients, and commonly include measures of richness (total families and EPT richness), enumerations (total number of individuals), community diversity and similar indices, biotic indices (tolerance levels of taxa) and functional measures (division into trophic groups depending on the type of food and mode of acquisition). Recent topical studies have advocated the use of functional groups, i.e., the aggregation of species with similar biological traits (e.g., size, life cycle, reproduction, food, feeding habits, respiration and locomotion) for a more accurate representation of ecosystem functioning (e.g., Dolédec et al. 2006; Díaz et al. 2008). In an evaluation of metric systems for bioassessment of pollution gradients in three developing countries (Brazil, Ghana and Thailand), functional indices of feeding or trophic groups, i.e., type of food and mode of acquisition, failed to describe the environmental gradient and were not recommended for use in developing countries (Thorne and Williams 1997). Detailed local knowledge of the biology of species is required, as closely related species may display different modes of feeding. In addition, the transfer of functional group designations at higher taxonomic levels cannot be done with confidence for developing countries.

According to the evaluation by Thorne and Williams (1997), measures of richness, similarity and biotic indices of macroinvertebrates were observed to perform much better than enumerations, diversity indices and functional feeding measures. Increased diversity, based on measures of richness (measure of total number of taxa) and evenness (measure of degree of distribution among the different taxonomic groups) was typically associated with mild levels of pollution before the characteristic decline with increased organic pollution. Variations in diversity indices, however, can affect deductions about pollution gradients and are unsuitable when few taxa present at impacted sites are relatively even in their abundances (and result in higher diversity), or the rich fauna at an un-impacted site are dominated by few taxa (and result in lower diversity). This was also observed for this study, where diversity was higher at the upland medium (M1) and low (L1) land-use intensity catchment streams, although there were few individuals and few distinctive taxa. At the rest of the sites, although there was higher taxa abundance and richness, diversity was generally lower.

The pollution sensitive index EPT (Enteromorpha, Plecoptera, and Trichoptera), used in many environmental monitoring programs, also provides a general categorization of water quality. Plecoptera are usually found in cool clean streams of temperate regions, however, in the tropics, only one species has been found in the whole of West Africa (Durand and Lévêque 1981). The EPT index was, therefore, not applied in this study but an alternative pollutant sensitive index, numbers of ETO (Ephemeroptera, Trichoptera, and Odonata).

High numbers of both pollutant sensitive (Enteromorpha and Odonata) and tolerant taxa (Chironomidae) were observed at the mid- and downstream sites, but this can be attributed to the wide range of tolerances of families found within each of the diagnostic groups. The Baetidae and Caenidae, for example, indicate a fair level of pollution, but are comparatively the most tolerant of the Enteromorpha. High abundances of Ephemeroptera in temperate regions are indicative of more pristine areas, however, high numbers have been observed in agricultural and deforested areas in Uganda (Kasangaki et al. 2008), suggesting different regional tolerances. Due to the wide range of tolerances for the many species of Chironomidae, the high numbers observed in this study does not provide information on whether the taxa present are tolerant of fair levels of pollution. The general absence of the Trichoptera, generally found in a wide range of aquatic habitats but with greatest diversity in cool running waters with rocky bottoms, could also be explained by the muddy/clayey substrates of the sites (Prof. Gordon, personal communication). For these reasons, the diversity and pollution sensitive indices were not appropriate in describing stream nutrient categories as a function of increasing land-use activity.

Multivariate analyses of macroinvertebrate communities are recommended as being more efficient for describing responses to water quality than biotic indices (Cao et al. 1996; Thorne and Williams 1997). However, results may be influenced by natural variations in the assemblages, especially in sites where impacts are subtle (Fore et al. 1996; Besley et al. 2007). The lack of detailed knowledge of macroinvertebrate life cycles can also limit the interpretations of species absence. Significant differences have not been observed in dominant feeding groups as a result of rainfall or season (Tumwesigye et al. 2000) although seasonal variations in Ghana can result in high solutes (major ions) in the dry season and decrease in the rainy season due to dilution (Ansa-Asare and Darko 2005). In addition, there are no significant correlations between biotic indices and rainfall, although storms can influences overall numbers by its scouring effects (Besley and Chessman 2007). The study assumes that the external factors, i.e., climatic and seasonal patterns, influencing macroinvertebrate community dynamics are similar for all catchments. Although macroinvertebrates are temporally insensitive (Chapman 1996), the ephemeral nature and erratic flow regimes of the upland streams may disrupt colonization and inhibit development of macroinvertebrate communities. This can lead to the reduced, simplified fauna of headwater sites that result in a community in which a few species may be abundant (Mandaville 2002). At the forested low intensity land use site (L1), for example, stream flows lasted an average of 48 hours after a storm. At the other upland catchments, post storm flows lasted for four to five days with shallow pools forming after this period. Monthly samples were not always obtainable and sampling of shallow flows of a few centimeters was sometimes difficult with the pond net. In addition, during the dry season, flow in the stream channels of the downstream areas had withdrawn so significantly from the side vegetation that no biological fauna was obtained after sweeps, indicating some level of migration (James et al. 2008). Samples throughout the research period therefore varied for each site.

There is a wide range of environmental habitats that can influence macroinvertebrate communities, however, conductivity, NH_4-N, water temperature, and discharge have been observed to have the highest influence (Díaz et al. 2008). For this study, four categories of sites (Groups A to D) were identified based on biotic and major abiotic parameters (i.e., pH, DO, and temperature, and the nutrient ions Mg, Na and NH_4-N). Using macroinvertebrate taxa richness, discharge patterns, stream physico-chemistry, and general macroinvertebrate tolerance levels, each group is broadly described as follows:

- Group A (L1) – a highly variable community represented by a few individuals and few distinct taxa. Stream flow is highly sporadic and characterized by low temperatures and relatively lower nutrient levels. Known tolerance levels of the aquatic biota indicate moderate levels of organic pollution possibly due to the high litter fall and organic material found in forested areas.
- Group B (M1) – a variable community of few individuals and few taxa (although slightly more than for Group A). Stream flow is also sporadic but characterized by average levels of nutrient concentration. The tolerance levels of the aquatic biota indicate slight levels of organic pollution.
- Group C (H1 and Ofin1&2) – high individual abundance but few dominant taxa. Stream flow at H1 is sporadic as compared to the perennial nature of the Ofin sites. The concentrations of cations and orthophosphate are relatively higher than all the other groups. Based on tolerance levels, the aquatic biota indicates moderate levels of pollution.
- Group D (midstream sites) – highly diverse taxa and rich community. Stream flow is continuous during the rainy season. Nutrient concentrations are mainly average levels although magnesium ion concentrations are higher than other sites. Tolerance levels of the aquatic biota indicate slight levels of organic pollution.

Bio-assessments that assign pollution scores to habitats based on macroinvertebrate tolerance levels have been successful in many parts of the world. The application of biotic indices such as the British Monitoring Working Party (BMWP) and associated average score per taxon (ASPT) in Ghana, only worked well with a steep gradient of a priori classified polluted sites (Thorne and Williams 1997). The authors suggest that modifying sensitivities to the local conditions and adaptations to suit the local fauna will greatly enhance the performance of these indices in developing countries. For example, amphipods and isopods are indicative of intermediate levels of pollution in temperate zones but are largely replaced by freshwater prawns and crabs in the tropics (Thorne and Williams 1997). Since indices developed for European countries are more representative of temperate regions, an index based on the South African Chutters biotic index (Chutter 1972) is being developed for Ghana. Only a few indicators have been identified for 'very clean', 'polluted' and 'grossly polluted' waters, with a large number of Trichoptera, Coleoptera, Hemiptera and Diptera whose tolerance levels to pollution have not yet been established (WRC 2003a).

In assessments of the influence of land-use on stream physico-chemistry and biota, especially in comparisons of forests and agricultural catchments, some aquatic macroinvertebrate biotic indices widely used in temperate systems did not effectively differentiate categories in equatorial systems, or some results actually contrasted those observed in temperature systems (Kibichii et al. 2007; Kasangaki et al. 2008). Ephemeroptera, for example, normally found in more natural areas of temperate zones, seemed to be more pollution-tolerant and were rather better indicators of agriculturally impacted sites in the tropics, especially the Baetidae species (Kibichii et al. 2007). In this study, the Ephemeroptera were found at almost all the sites, with the exception of the less intensive land-use upland catchments of L1 (with only one occurrence) and M1. This verifies the observations by Kibichii et al. (2007). However, due to the varying sensitivities of taxa within the Ephemeroptera, there is the need to include family level resolutions, e.g., Caenidae, as indicators of agricultural areas.

Based on generally known tolerance levels of the observed macroinvertebrate taxa, the water quality of the studied streams indicate slight to moderate levels of pollution. However, in order to effectively distinguish between sites that lie in such an intermediate range or have similar water qualities, there is a need to improve the database to include appropriate region-specific sensitivities.

6.6 Summary

Due to the lack of information on macroinvertebrate responses to stream physico-chemistry and nutrient concentrations, a number of selected sites within the Ofin Basin were also assessed. Based on the general associations established by the PRIMER software between taxa distribution and stream chemistry, significant differences were found in the ecological states (E of the DPCER framework) between the three upland catchment streams. The results show low faunal richness at the upland medium and low land-use intensity catchments, but higher taxa richness at the high land-use intensity site and the rest of the mid and downstream sites, indicating greater similarity among these sites.

Univariate methods were generally not effective at describing ecosystem health, especially due to the wide range of tolerances of diagnostic taxa and the high abundances of the pollutant-sensitive taxa Enteromorpha at all the sites. The multivariate analyses, however, presented more information as to how measured environmental parameters may be influential in the distribution of macroinvertebrate communities. Based on the most influential abiotic parameters on distribution, i.e., physico-chemical variables (pH, DO and temperature), nutrient ions Mg, Na and NH_4-N, and generally known biotic indices, four significant groups were defined: (i) Group A (the low land intensity site), a highly variable habitat of few individuals and few distinct taxa, which are indicative of moderate levels of pollution, (ii) Group B (medium land use intensity site), a variable community of few individuals and few taxa, indicative of relatively lower levels of pollution, (iii) Group C (high land-use intensity site and downstream Ofin sites), with high individual abundance but few taxa that are indicative of low to moderate levels of pollution, and (iv) Group D (midstream sites), rich habitat with taxa representative of relatively low levels of pollution.

Multivariate analyses was useful differentiating between ecological states of the streams, and showed significant differences at the three upland catchments based on their chemical states. However, further research to improve taxonomic descriptions of local taxa will enable more appropriate classification systems that can effectively describe various categories of stream health and influences of land-use activities.

7 DPCER SYNTHESIS

7.1 Interlinkages

Despite the various knowledge gaps about the specific biophysical processes that transport nutrients from land to streams in small upland catchments in Ghana, the logical sequence of events using the DPCER framework illustrates the significant variations that occur as land-use activities intensify. The catchments were categorized by the VINVAL project based on the percentage of natural to agricultural lands. The results showed that increasing fertilizer use with agricultural intensification, the basis for higher levels of in-stream nutrients in this study, was influenced mainly by access to credit and institutional facilities that provide support to farmers. Fertilizer use, generally, was minimal but there were significant differences in various socio-economic factors (e.g., age, education, external income, pesticide use, livestock ownership, proximity to markets, access to facilities, migration, etc.) between catchments that could influence a farmer's incentive to increase agricultural output. Total nutrient loads/yields varied between catchments and were determined mainly by stream discharge volumes, or water yield. Although the hydrographs showed different patterns of flow, the percentage runoff from total precipitation was similar between catchments., and comparable to the estimated 5% runoff observed within the Volta basin. Nutrient ion concentrations co-related with land-use intensity (i.e., increasing concentration with increasing intensity) and showed significant differences between catchments, with the exception of nitrogenous compounds. Water quality evaluation based on the Ghana Target Water Quality Ranges (TWQRs) for domestic use and aquatic ecosystem health requirements showed that nutrient concentrations were mainly within limits. The ecological state, described by macroinvertebrate taxa distribution in response to abiotic parameters, indicates habitats of slight to moderate levels of disturbance; however, further research is needed to develop local taxonomic descriptions to effectively describe stream health. The upland catchments are significantly different from each other, compared to the mid- and downstream sites. The direct causes, sources, and transport rates of nutrients into streams still require further research, but for the purposes of this study, increasing stream nutrient ion concentrations were observed to positively correlate with increasing land-use intensity.

The aim of the DPCER framework in this study was mainly to establish a basic environmental descriptive cause-effect model, since an understanding of the links between land-use and in-stream nutrient concentration/loads in Ghana is currently limited. The inclusion of a comparative catchment component reduced the influence of natural variability and provided valuable information about how the cause-effect relationship changed with increasing land-use intensity. The measured values for the selected indicators represent a quality or state of each element within the framework. These values were compared to standards available from literature sources and compared across catchments to evaluate each parameter changed with intensification. Assumptions were made that (i) estimated nutrient loads and measured ion concentrations reflected agricultural activities, although there may be other unmeasured or minor inputs from domestic, wild animal or atmospheric sources, for example, and (ii) factors such as soil properties, nutrient transport mechanisms, in-stream nutrient dynamics, etc., are similar, although land-cover differences could influence nutrient ion behavior and transport in various ways. Different models have been suggested that link the flow of information in a balanced way to account for the uncertainties within each element and the interlinkages (Rekolainen et al. 2003). For this study, however, the detailed and extensive datasets required to run models were not available. Simple mathematical tools proved adequate to measure and compare each of the defined DPCER elements. Despite the above assumptions, the performance of indicators clearly illustrates significant differences that generally follow the gradient of land-use intensity. Generalizations and assumptions to explain the complexity of human-environment interactions has been one of the main criticisms of the traditional DPSIR method, on which the DPCER is based. However, the latter's conceptual structure has still been useful for establishing environmental cause-effect relationships for policy-supporting research, and when needed, as was done for this study, innovations can be included to expand its applicability (e.g., Scheren et al. 2000; Scheren et al. 2004).

In the selection of indicators, the scale of investigation is important for defining the boundary of impacts (e.g., local or national impacts) or the scale of driving forces and responses that can influence a system (e.g., how global agreements impact local markets). Applications of the traditional DPSIR framework are usually large scale, mainly for national or regional water systems that have different dominant types of land-use activities and a variety of impacts (e.g., Borja et al. 2006; Jago-on et al. 2009). For this reason, there have been criticisms that driving forces are usually defined by the prevailing external parameters, whereas socio-economic drivers at the household level that affect its characteristics and choices are rarely assessed, even though these are critical to the decision-making process of land use (Svarstad et al. 2008). The assessment of small upland catchments in this study provided a suitable platform to assess how the cause-effect system operates, with added advantages of evaluating household level parameters and providing more accurate hydrological estimates than would have been obtained for larger systems.

7.1.1 Drivers of land-use intensification

Factors driving a farmer's decision to manage soil fertility towards increased productivity have been the focus of regional studies (e.g., Barbier 1998; Omamo et al. 2002; Place et al. 2003; Giller et al. 2006). Agricultural intensification in sub-Saharan Africa has been described as either labor-led or capital-led or a combination of both (Aune and Bariono 2008). Labor-led intensification requires more use of labor per unit of land for preparation, weeding, manure application and harvesting, while capital-led intensification implies more use of inputs such as fertilizers, pesticides, and agricultural equipment. In assessing the factors influencing increased production in the southwestern parts of Ghana, Drechsel et al. (2005) found weak links between agricultural intensification and increased inputs, as farmers were predisposed mostly to low external inputs with minimal investments. In most cases, farmers preferred fallow periods for as long as possible, with slash-and-burn techniques providing the required nutrients. Farmers were more likely to look for land in remote areas (extensification) or invest in off-farm activities (income diversification) where land is scarce, population pressure was increased and fallow periods reduced, than invest into increased productivity per unit area of land. This phenomenon is supported by long-term projections of bioeconomic models that illustrate that intensification per hectare is more expensive for the farmer than the fallow system, due to the poor economic conditions of farmers in sub-Saharan Africa (Barbier 1998). The tendency for increased nutrient input was found only among a few rich rural farmers with high-value crops and urban farmers with closer proximity to the city markets, indicating that decisions for investment are largely determined by market access and financial returns (Drechsel and Zimmerman 2005; Kelly 2006). Studies explaining the adoption of agricultural innovations for hybrid cocoa in Ghana, for example, also show that the support small-scale farmers obtain via their social networks, which provide resources such as cooperative labor and network information, was more relevant than the advantages of the large farm size of large-scale farmers, who benefited more by access to bank loans (Boahene et al. 1999). Contacts with extension officers and the availability of hired labor had positive effects on the adoption of innovations, in addition to the indirect benefits of social status, i.e., farmers with higher social status are more likely to obtain a bank loan.

One assumption for this study is that increased stream nutrient ion concentrations and loads due to increasing land-use intensity are the result of increased fertilizer use. Estimated rates of fertilizer application in Ghana are low, and are only up by 20% of the farmers in the high intensity land-use catchment. Factors explaining fertilizer use were mainly access to credit, access to agricultural extension services, migration and land ownership (i.e., property rights). In addition, farmers who used pesticides were more likely to apply fertilizers. This corresponds to the above discussions as well as results of other studies (e.g., Erenstein 2006; Kelly 2006; Oduro and Osei-Akoto 2008) that increasing fertilizer use or the adoption of new agricultural techniques are not significantly influenced by access to land, income levels, and education, but rather by factors that influence incentives and associated costs (i.e., profits), such as agricultural extension support services, access to informal or formal credit systems, and proximity to markets.

The suitability of each catchment for agriculture is a significant determinant of the drivers of land-use intensity. Compared to the other catchments, Nyamebekyere for example, has poorer access and less proximity to the markets. It's location in a national forest reserve restricted farming options and strongly influenced farmers' choices, with farming mostly for subsistence. The diversity of livelihoods was highest in Nyamebekyere, where there is minimal settler farming, and most of the respondents are long-term residents. The proximity of Attakrom and Dunyankwanta to markets had a significant impact on the prevailing agricultural practices, and both catchment communities had the same access to extension services and bank loans; however, farming in Attakrom was observed to be more orientated towards cash crops. Respondents in Attakrom were characterized by their (i) lack of secondary livelihoods, (ii) low educational standards, (iii) low livestock ownership, and (iv) high percentage of external income compared to the other catchments. The first three characteristics are important factors in occupation and wealth diversification, which are strategic options for reducing risk factors associated with diminishing returns or high costs (Barrett et al. 2001).

Land-use intensity in the study catchments was assessed by comparing the relative proportion of cultivated to natural lands (including fallowed fields) (Meijerink et al. 2003; Verzandvoort et al. 2005). The results show that there is minimal fertilizer application in the catchments and extensification/labor led intensification is still the main strategy for increasing agricultural productivity. With the subsidization of fertilizers, the local conditions that influence a farmers' decision to invest in fertilizers can, however, eventually change (Lambin and Geist 2001).

7.1.2 Pressure – nutrient loading

Total nutrient yield for the catchments did not follow the trend of land-use, but was in the order Dunyankwanta>Nyamebekyere>Attakrom for all nutrients except sodium, where loads/yields in Attakrom were higher than in Nyamebekyere. The magnitude of nutrient loads/yields correlated with total water yield, as nutrient dynamics are closely linked to the hydrology of a catchment or basin (Lewis Jr. et al. 1999; Poor and McDonnel 2007). Long-term studies required to establish the catchment hydrology as a function of geology, soil, and land-use (Shrestha et al. 2008) were not available for this study. However, the measured annual water yield for each catchment was used to calculate nutrient loads and yields.

Hydrology

The water yield of a stream draining any given catchment is an important determinant of the exported total nutrient loads/yields. In the tropics, evapotranspiration and surface infiltration are the main factors that influence the flow regime (Brown et al. 2005).

Diminishing tropical forests, as a result of deforestation and conversion to other land-use types affect the catchment water balance (Calder 1998; Bruijnzeel 2004). The detailed data needed to determine evapotranspiration, i.e., weather, crop factors and environmental conditions, were beyond the scope of work of this study based on the specific objectives and research boundaries presented. Potential evapotranspiration (ET_0) was estimated by the FAO Penman-Monteith equation and actual evapotranspiration (ET_a) by simple calculations of the difference between annual ET_0 and stream water yield. The total annual water yield varied between catchments and was highest in Dunyankwanta (79.9 mm yr^{-1}), followed by Nyamebekyere (52.5 mm yr^{-1}) and Attakrom (16.4 mm yr^{-1}). Although there were missing stream-flow data between September and December 2006 for Nyamebekyere, the estimated percentage runoff (2.3%) was similar to that of Attakrom (2.7%), and both were lower than estimated for Dunyankwanta (6.2%). Despite these variations, the fraction of rainfall that becomes stream discharge is comparable to the estimated 4.9-5.0% runoff fraction in studies carried out in the Volta Basin (Andreini et al. 2000; Ajayi 2004).

Field studies involving the use of two catchments with similar characteristics (in terms of slope, aspect, soils, area, climate and vegetation located adjacent to or in close proximity to each other) have been effective at describing the changes in the magnitude of water yield resulting from changes in vegetation (Brown et al. 2005). One catchment usually serves as a control as the other is subjected to various types of 'treatment' involving some change in vegetation, e.g., afforestation, re-growth, deforestation, or conversion. Experimental studies are available that assess how the conversion of forests and natural vegetation to agricultural land impacts water yields in small upland catchments in the region. In Benin, for example, the reduced activity of macrofauna (mainly earthworms) in cultivated soils reduced the soil macroporosity and resulted in lower infiltration capacity and higher surface runoff (Giertz and Diekkrüger 2003; Giertz et al. 2005).

Increasing land-use intensity is generally associated with soils of higher bulk density, lower macroporosity and higher microporosity (Ungaro et al. 2004). Water retention properties are significantly influenced by increasing land-use intensity, as air entry pressures are higher and available water content, i.e., the difference between water content at field capacity (-100 cm) and water content at wilting point (-15000 cm), lower.

According to an evaluation of the study catchments by Ungaro et al. (2004), there was no evident effect on the slope of the water retention curves with increasing land-use intensity. Hydrological characteristics in Nyamebekyere were typical of forested areas, i.e., higher rainfall, low percentage runoff and more erratic stream flow (Giertz and Diekkrüger 2003; Brown et al. 2005). With a higher proportion of agricultural land in Attakrom than in Dunyankwanta, it was expected that percentage runoff and water yield would be higher. However, the opposite was observed, with hydrographs showing higher flood peaks, higher base flow, and longer discharge periods in Dunyankwanta. Although there are indications that water retention properties are influenced, more information is required on the dominant flow paths in order to predict changes in water yield as natural land is converted to agricultural land

Another study comparing West African headwater sub-catchments with different land-use types established that the observed differences in hydrographs were mainly due to variations in land cover/vegetation type and bas-fond (an area typologically composed of sandy soil at the border and more clayey soil in the central part) coverage (Giertz and Diekkrüger 2003). As cultivated areas increase, lower infiltration results in higher surface runoff and, depending on history of cultivation, soil erosion can also reduce soil thickness and lower the water storage capacity of the soil. Variations in surface runoff are also due to the variability of the rain, the amount and intensity of the event, as well as to the changing water content and infiltration capacity of the soil (Giertz et al. 2005). As the rainy season begins, the sandy soils of the bas-fond become gradually saturated with the flow generated on the hillslopes, and by the high rainy season, the bas-fond is saturated. The clayey part in the central part has lower permeability but higher water storage capacity, and contributes to the base flow between rainfall events. At the end of the rainy season, higher peaks can be observed even after small rainfall events. The high base flow of one catchment may, therefore, be attributed to a larger bas-fond area. In the study catchments, although there are two rainy seasons annually, three discharge periods were observed with the second major peak occurring towards the end of the major rainy season when there were fewer storm events. However, since hydrological parameters were not evaluated in this study, factors influencing the observed differences will need to be confirmed by further research.

Nutrient loads/yields

There are generally three sources of errors in estimating pollutant load that contribute to the overall uncertainties in nutrient load approximation: (i) knowledge uncertainty when selecting the appropriate techniques or estimation method, (ii) stochastic uncertainty, i.e., deviation of the concentrations from established means, and (iii) measurement uncertainty, i.e., unrepresentative sampling and errors in calibration, data gaps, poor sampling techniques, etc. (Etchells et al. 2005). In the absence of recommended estimation methods for nutrient loading in upland stream systems in Ghana, the application of the Beale's ratio estimator as an appropriate method was justified based on the literature review. The lack of historical hydrologic and concentration data was a constraint in quantifying the uncertainties of the estimated loads and deviations from established means. Admittedly, general assumptions of nutrient behavior during non-sampling periods may be a source of error. However, the Beale's ratio method includes a correction factor to compensate for the effects of correlation between discharge and nutrient load, and has yielded the least biased estimates especially when concentration and flow data are sparse (Mukhopadhyay and Smith 2000; Quilbé et al. 2006; Johnes 2007).

Although discharges in the study catchments are intermittent with stream flows only after storm events and for limited periods thereafter, the nutrient load estimation methods used are based on assumptions for perennial flow. The hypotheses of time and space variability suitable for describing the study site behavior and the pollutant processes linked to catchment hydrology can be effectively incorporated only in suitable water quality models that can simulate flash flood events (e.g., Chu et al. 2008). For these flash flood models, sampling is appropriately done by automated water samplers that are triggered by the rising hydrographs following storm events and provide representative samples of nutrient concentrations during surface runoff. However, there are logistical difficulties in accurately estimating loads of intermittent streams based on observational studies alone. More accurate and frequent sampling requires costly equipment and technology which are also at risk from theft and vandalism. For this study, grab sampling was carried out at the same time of the day every 48 hours, irrespective of the timing of storm events, and may occur at different positions along the hydrograph. However, the Beale's ratio method weights the concentration values by adjusting the mean of the daily loads by a flow ratio (average flow for the period divided by days on which samples were obtained). The comparison of nutrient loads calculated by the Beale's ratio method and flow-weighted means (similar to the Beale's method minus the correction factor) show minimal differences, indicating that sampling may have been frequent enough for the estimation of nutrient loads.

In general, small catchments show high variability in nutrient loads due to the differences in the driving forces of population pressure and farming activities, and hydrological variations that determine the dynamics of surface runoff (EEA 2005). For this study, annual nutrient estimates from the catchments (in order of lowest to highest yields - Attakrom, Nyamebekyere and Dunyankwanta) were 1.3, 1.8 and 4.7 kg NO_3-N ha^{-1}, 0.3, 0.6 and 1.16 kg NH_4-N ha^{-1}, and 0.09, 0.15 and 0.3 kg PO_4-P ha^{-1} for dissolved phosphates. These values are compared to estimates of nutrient losses established for undisturbed catchments (described as <5 individuals km^{-2}, 80% natural vegetative cover, and below 2.5 kg ha^{-1} yr^{-1} anthropogenic nitrogen deposition) for a broad range of catchment areas, elevations, and vegetations types, from the American tropics to the Gambia River (Africa) (Lewis Jr. et al. 1999). According to the authors, annual nutrient losses averaged 2.4 kg NO_3-N ha^{-1} and 0.39 kg NH_4-N ha^{-1}, values which are comparable to the ranges calculated for the study catchments. These background yields were predicted on the basis of general environmental variables such as drainage area, elevation and amount of runoff. However, with increasing land-use intensity, diffuse sources can be increasingly influenced by anthropogenic inputs. Increasing nutrient loads with increasing land-use intensity have been observed in the nutrient contribution into the Baltic and North seas in Europe, for example, where sparsely populated catchments (less than 35 inhabitants km^{-2}) with a low percentage of agricultural land (<15%) yield total loads of 3-4 kg N $ha^{-1}$and 0.12-0.17 kg P ha^{-1}, and medium (44-110 inhabitants km^{-2}) to intensive agricultural catchments, 10 to 15 kg N ha^{-1} and up to 1.0 kg P ha^{-1}; although P sources are usually dominated by point sources (EEA 2005).

For Ghana, total nutrient loads have been estimated for a few large river systems such as the Densu River that feeds the Weija reservoir, an important water supply for the western part of the city Accra (Karikari and Ansa-Asare 2006), and the Pra Basin located in the southwestern region, also important for water supply (Akrasi and Ansa-Asare 2008). The estimated nutrient loads calculated by these studies are however representative of *total* loads from domestic, agricultural and industrial activities. In addition, the loads are calculated by different methods and the results are presented in different units, i.e., kg day^{-1} for the entire basin. For the Densu River, for example, simple load estimations using mean discharge levels for 30 years and monthly sampled concentration data resulted in values of 15.4-371 kg NO_3-N day^{-1}, 16.6-521 kg NH_4-N day^{-1}, and 11.3-181 kg PO_4-P day^{-1} estimated for the entire basin. The Densu is known to be one of the most polluted basins in Ghana (Ansah-Asare et al. 2005). The conversion of estimates obtained in this study into the same units, is presented only for comparative purposes: 1.8-8.2 kg NO_3-N day^{-1}, 0.4-2.0 kg NH_4-N day^{-1}, and 0.2-0.5 kg PO_4-P day^{-1} for the upland catchments. For the Pra Basin, regression analyses were developed to establish the relationship between dependent variables (suspended sediment yields and nutrient export coefficient, i.e., total nutrient load divided by catchment area), and independent variables (runoff and catchment area). The regression equation was used to estimate suspended sediment or nutrient yield at any cross-section in the Pra drainage basin, using known mean annual runoff and catchment area data. Based on the model, 797 tonnes of nitrates nitrogen and 3 kilo tonnes for ortho-phosphorus phosphate are transported into the sea from the basin on an annual basis.

Although agricultural activities have been established as a main contributor to nutrients in streams, soil nutrient balances in the sub-Saharan region have shown that inadequate application of inorganic fertilizer and continuous harvesting of nutrient-depleted soils have rather resulted in net negative balances. In 2000, for example, values in Ghana were -35 kg N ha^{-1}, -4 kg P ha^{-1} and -20 kg K ha^{-1} (Stoorvogel and Smaling 1990; FAO 2003). The general impression is that since soil nutrients are low, and fertilizer use is below the recommended application rates for optimal productivity, the contribution via leaching and runoff to the eutrophication of aquatic systems is negligible. Studies quantifying agricultural nutrients have focused more on nutrient flows out of farmlands via harvested crops (Bationo et al. 1998; Briggs and Twomlow 2002; Grote et al. 2005). In West African cities, for example, 64 to 88% of the total inflow of food is from rural agricultural areas, and up to 80% of the discarded organic material in a city like Kumasi is neither treated nor recovered as a resource (Belevi 2002; Drechsel et al. 2007). When required, the quantification of nutrients lost via leaching, denitrification or erosion is usually estimated by functional transfers found in literature, since high investments and long research periods are necessary for such environmental monitoring. NUTMON (NUTrient MONitoring), a budgeting method that analyzes the environmental and financial sustainability of tropical farming systems (Smaling and Fresco 1993; de Jager et al. 1998a), measures output parameters such as harvested crops and residue outputs (partial or total loss of nutrients based on type of residue management by farmers, e.g., by burning or use as building material). Nutrient losses by natural processes are, however, estimated by multiple regressions, which have been found to correlate positively with rainfall, soil fertility class and total application of fertilizer and manure (e.g. De Jager et al. 1998b; van den Bosch et al. 1998; FAO 2003). Some authors argue that transfer-function estimations are higher for tropical systems in comparison to similar rates in high-input agriculture in temperate regions. This has contributed to the overestimation of nutrient losses and exaggerated soil deficiencies for the sub-Saharan region (de Ridder et al. 2004; Færge and Magid 2004; Vanlauwe and Giller 2006). The final VINVAL reports on agricultural nutrient flows and ecosystem nutrient balances for each of the study catchments will provide an invaluable source of information for comparative evaluations of the terrestrial nutrient losses in this study.

7.1.3 Chemical state – physico-chemistry and nutrient ion concentrations

Stream physico-chemistry and nutrient ion concentrations for the catchment streams were below limits established for domestic water and aquatic ecosystem health in Ghanaian freshwaters. For the purposes of this study, only major cations and dissolved forms of inorganic nitrogen and phosphorus in the streams were estimated, although the proportion of particulate forms from land is also important as erosion is a major mechanism of nutrient loss. Dissolved forms are biologically available and more important in eutrophication assessments. There were significant differences between catchments regarding increasing levels of Ca, K, Mg, Na and PO_4-P with increasing land-use intensity. Although the magnitude of total stream nutrient load (i.e., total load, kg yr^{-1}) was lowest in Attakrom, nutrient concentrations (i.e., in mg L^{-1}) were the highest, as was expected. Catchment differences in concentrations of nitrate and ammonia were statistically insignificant. Annual median concentrations were below nitrate limits established for domestic water use (i.e., 0-6 mg L^{-1}), but were low in Attakrom (3.7 mg L^{-1}) and relatively higher in Nyamebekyere (5.9 mg L^{-1}).

Tropical forests have higher concentrations of nitrogen than temperate forests due to higher concentrations in leaf litter (Oladoye et al. 2008). The amount of precipitation also influences both nitrogen deposition and fixation rates, and the rate at which it is released through decomposition. In Nyamebekyere, high in-stream nitrate concentrations could be influenced by the high organic contents in soils and the leaf litter usually found in semi-deciduous forests, which serve as a nutrient store and slowly release nitrogen, phosphorus, sulphur and potassium. Periodic surface runoff with storm events may flush the nutrients such that concentrations in the intermittent stream flow will be high during the few hours of flow. These values can also reflect higher mineralization and nitrification rates in forest soils, or a relative change in the proportion of the organic and inorganic N forms leached from the soil, rather than an absolute increase in total N leached (Chapman and Edwards 1999).

Differences in PO_4-P concentrations were not significant between the high and medium land-use intensity catchments, but were significant for each of these catchments and Nyamebekyere. Median concentrations were 0.50 mg L^{-1} (Attakrom), 0.43 mg L^{-1} (Dunyankwanta) and 0.26 mg L^{-1} (Nyamebekyere). These values are similar to the range for lower-order streams of the neighboring Mankran sub-catchment (0.07-0.75 mg L^{-1}) (Oppong et al. 2006). In downstream areas of rivers in the same region, the range of concentrations was slightly lower (0.00-0.35 mg L^{-1}), although higher for River Densu (0.66 mg L^{-1}), which is known to be polluted (Ansah-Asare and Darko 2006). The soils of the semi-deciduous forest zone of Ghana are known to be moderately acid and very low in plant available phosphorus (Owusu-Bennoah et al. 2000). Organic phosphate generally comprises 30-70% of the phosphate in mineral soils and since only soluble dihydrogen phosphates are absorbed by plants, there is little leaching of phosphates from the soil

(Banerji 1993). Phosphorus is tightly bound by soil particles (FAO 2003) and the amount lost to surface waters increases mainly with additional anthropogenic inputs (Carpenter et al. 1998).

Calcium and magnesium were the major cations in the streams, as these are the dominant base ions in soils and the most likely cations to be leached (Owusu-Bennoah et al. 2000; Lehmann and Schroth 2003). All soils contain very small amounts of exchangeable potassium especially in the sub-soils, and potassium is usually leached in smaller quantities even when there is fertilizer application. These cations are taken up by plant roots, re-circulated to the surface via plant residues and released when organic matter is mineralized. In West Africa, the combined concentrations of calcium and magnesium have been found to show a close association with nitrate fluxes, an indication of the role of nitrate in the control of the amounts leached (Lehmann and Schroth 2003). In this study, calcium and magnesium values were much higher in Attakrom, although nitrate values were similar across catchments.

Environmental monitoring involves measurements of concentrations in the water column that vary spatially and change rapidly. Diurnal variations could obviously not be assessed with the sampling protocol, although sampling at the same time of the day for all sites minimized the inaccuracies that could be introduced by these variations. Seasonal variations could not be clearly defined for this study, as long-term data for determining the inter-annual variations are usually required to establish definitive patterns. The frequent measurements showed, however, that nutrient ion concentrations were generally higher in June and November for Attakrom and Dunyankwanta, and in October, for some nutrients, in Nyamebekyere. For the flow-weighted means, variations were observed between the rainy seasons depending on the nutrient parameter. In Attakrom, for example, mean seasonal concentrations were higher in the 2006 minor rainy season for the cations, but were similar to concentrations in the major rainy season for nitrogen compounds indicating little change between seasons. In Dunyankwanta, higher mean values were observed in the 2006 major rainy season for all nutrients, except for calcium, and mean concentrations of nitrogen compounds were higher in the 2006 minor season indicating an increase between September and November.

From the interviews, it was established that a small percentage of farmers in Attakrom (20.5%) and Dunyankwanta (12.3%) used fertilizers. Applications were mainly on cocoa and maize crops, since investments in cash crops are profit-driven. For the mature cocoa trees (in addition to a few incidences of fertilizer applications to orange and oil palm plantations), the required annual treatments were carried out in June. For maize, fertilizer applications are at different stages of plant growth, i.e., between 4 and 8 weeks. Maize is generally planted in April/May just before or just after the start of the major rainy season. The most common fertilizers used were NPK/15-15-15, ammonium sulphate and asasewura (NPK/0-18-22, plus calcium, sulphur and magnesium). In Attakrom and Dunyankwanta, increased concentrations of Ca, Mg, K and NH_4-N nutrient ions (components of the fertilizers used) were observed in June, the time when fertilizers are applied. However, this relationship will have to be validated by further research. There may be other contributing land-use factors such as land preparation, which involves weeding and burning of vegetation and is carried out in April, a few weeks before the expected start of the rainy season. During slash-and-burn and depending on the intensity of the fires, between 25 and 80% of all Ca, K and P found in the slashed vegetation is released as smoke, and the nutrients remaining in the ash are vulnerable to removal by leaching (Critchley and Bruijnzeel 1996). High temperatures cause the topsoil to become temporarily hydrophobic, and depending on the timing of storm events, the ash left on the topsoil may be washed off with the first rains (Bagamsah 2005). An excess of exchangeable base cations over the cation exchange capacity, for example, has been observed at the beginning of the rainy season when organic litter accumulated during the dry season decomposes and large amounts of base cations are released (Owusu-Bennoah et al. 2000).

Agricultural activities are assumed to be the main source of nutrients exported to streams in this study. However, nutrient contributions from atmospheric deposition and leaf litter are also important. The dust-laden winds of the harmattan period between November and March are known to have large amounts of Ca and K (Wilke et al. 1984; Orange 1993; Harris 1998). In Ghana, the amount of dust deposition varies yearly, but higher deposition values in the north (16 g m^{-2}) have been observed compared to the south (5 g m^{-2}) (Awadzi and Breuning-Madsen 2007). Direct deposition into small streams is negligible, but the amounts deposited on land and vegetation can be a significant source of nutrients in surface runoff. Litterfall is an essential process in nutrient cycling in forests, and transfers organic matter and mineral elements from the vegetation to the soil surface (Vituosek et al. 1986). Leaf litter in a *Leucaena leucocephala* plantation in Nigeria, for example, accounted for 61% of the nutrients returned to the forest floor, with high concentrations of nutrients in the order N > P > Mg >Ca > K > Na (Oladoye et al. 2008).

7.1.4 Ecological state

Due to the poor database on the influence of the chemical state of streams on macroinvertebrate taxa distribution, especially within rural catchments of Ghana, stream physico-chemistry and macroinvertebrate taxa distribution were assessed for selected sites within the Ofin Basin. Based on the fundamental observations, tentative suggestions were made about the impacts of land-use on the ecological health of the streams.

Overall, the measured nutrient ion concentrations for all sites were within the Ghana Target Water Quality Range (TWQR) for domestic use and aquatic ecosystem health (WRC 2003a; 2003b). Water quality at the downstream sites vary throughout the year and is more suitable for drinking during the rainy season than in the dry season, when some form of pre-treatment is required. Most of the village communities depend on boreholes for potable water, however, a few downstream communities completely rely on streams for their water supply.

Based on the most influential nutrient ions, i.e., Mg, Na and NH_4-N, significant groupings occurred at the lower stream levels, i.e., sites that occurred mid- and downstream formed separate groups. However, the assessment of macroinvertebrate taxa distribution showed significant differences in both abiotic and biotic parameters between each of the upstream sites as predicted by the hypothesis. The mid- and downstream sites show more similarity in habitat conditions and community structure than between the upstream sites, which suggests that the upland catchments may be considerably influenced by the hydrology and catchment attributes. It is also interesting to note that the high land-use intensity upland catchment, with high macroinvertebrate richness, was most similar to the downstream sites.

Species richness and evenness have been identified as key metrics in ecosystem ecology, as they describe ecosystem properties such as biological productivity, habitat heterogeneity, habitat complexity and disturbance (Pielou 1975; Ward and Tockner 2001). Various theories have postulated the relationship between biodiversity and community stress, which affects population structure and resource availability. The most commonly applied is the Intermediate Disturbance Hypothesis (Connell 1978), which predicts biodiversity to be highest with moderate disturbance and to decrease at each end of the spectrum. In other words, with low or high disturbance, diversity decreases due to competitive exclusion by dominant species or survival of tolerant species, respectively, as has been observed in some tropical studies (e.g., Kibichii et al. 2007; Kasangaki et al. 2008). However, as recommended by Thorne and Williams (1997), diversity indices were found to be inappropriate for this study since the few occurring taxa with equal numbers resulted in higher diversity indices.

Most of the research on macroinvertebrate communities has been in temperate conditions, and the differences between tropical and temperate catchments limit the application of available knowledge to tropical macroinvertebrates (Ometo et al. 2000). Observed responses could be the product of combined natural and human interferences (Hodkinson and Jackson 2005), due to the fact that biological impairments can be underestimated by indicators based on richness (Cao and Hawkins 2005), or that variations in distribution and abundance may be related to additional factors not considered in a study (Mandaville 2002). In comparing sites in the same basin, it is assumed that many of these variations between catchments would be minimized to provide accurate representation. Although discharge is one important factor determining macroinvertebrate distribution (Díaz et al. 2008), it is important to note that intermittent stream flow upstream resulted in significant differences in macroinvertebrate community composition, but was not significant at the midstream sites, which also had irregular flows (although less erratic than the upstream sites).

The study shows that there are significant differences between the upland catchments based on the distinct stream physico-chemistry. Four distinct categories of habitats were identified, which were described mainly by the taxa richness, generally known tolerances of macroinvertebrates and characteristic stream physico-chemistry. However, conclusive statements describing the ecological state can not be made at this stage. For example, it was expected that taxa found at the Nyamebekyere site, a low land-use intensity catchment with relatively lower cation levels, would be inhabited by more pollutant sensitive taxa. However, the tolerances of the occurring taxa (Psychodidae and Calopterygidae) rather indicate high levels of pollution (Thorne and Williams 1997; WRC 2003). This could be due to the higher litter-fall found in forested catchments and flash flood phenomena, which resulted in higher concentrations of nitrogen compounds. Currently, there are several projects such as the Darwin Initiative (SWIMMER, University of Liverpool and Centre of African Wetlands, University of Ghana) underway to develop the macroinvertebrate database for the local region.

7.2 Integrated research challenges

Research programs that interlink across various disciplines to integrate diverse expertise and knowledge for a common purpose have become increasingly important in academic studies (Rodgers 2006). However, there are major difficulties faced in relating the independent boundaries for each discipline to each other, especially in areas such as conceptual frameworks, terminology and experimental approaches (Hannah et al. 2004). There is usually a tendency towards a multidisciplinary approach, which is based on traditional disciplines without integration, rather than towards an interdisciplinary approach where there is synergy of disciplines. One major insight from this research is that in the assessment of different parameters from different disciplines, it is critical to establish from the onset the position or standpoint of the research. This determines the perspective of the research and even the presentation of results. Maintaining a neutral outlook when assessing the conditions in unfamiliar disciplines, e.g., the evaluation of socio-economic parameters and influences on farming systems by a natural scientist, can be difficult when a reference point is not established at the beginning of the research.

Although the selected conceptual framework has been criticized for its narrow linear views, effective assessments can only be made with clearly defined objectives that address specific issues. It is necessary to focus only on information that enables the question to be assessed efficiently, even with the threat of loss of information. For example, coliforms, pesticides and sediment loads were not assessed in this study, although these parameters would have elaborated on the influence of land use on water quality in general. In addition, information that did not provide valuable contextual information or data necessary for each analysis was not considered. From the interviews, most communities complained of skin diseases and bilharzia, especially in children. Since parasitic components were not an objective of the study, this information was not incorporated, although public health issues are critical for effective water resource management.

Environmental monitoring is imperative to effective environmental decision-making. However, the interpretation of results from monitoring programs can be strongly influenced by the quality of data gathered. The DPCER framework provided a simple conceptual guideline for the assessment of specific elements and was effective in keeping to the objectives of the study. The assessment of each element was guided by specific definitions proposed by the conceptual framework and analyses methods were determined by the data available. With the cost and time restrictions of this study, it was difficult to assess each element in detail. Limitations in data quantity (number of samples taken spatially and temporally) and quality (time and location of sampling event), and associated uncertainties in results do not always allow absolute conclusions. However, the outcomes of the assessment and transparency about limitations form a useful basis for the evaluation of strategic policy options, and for the identification of areas requiring further research.

8 CONCLUSIONS AND RECOMMENDATIONS

With national programs being put in place to increase agricultural productivity for rural farmers in Ghana, the main objective of this integrated study was to understand how increasing land-use intensity influences in-stream nutrients and how this impacts on water quality. The study proved that for small upland catchment streams, there are significant differences in chemical and ecological states as land-use and associated nutrient inputs increase. Although fertilizer use is generally minimal and water quality remains within the Ghanaian Target Water Quality Range (TWQR) for domestic use and aquatic ecosystem health, anthropogenic influences are already evident. This signifies important environmental/social implications for developing national policy responses in integrated water quality management schemes.

Due to the lack of data on nutrient inputs and process-based mechanisms of nutrient transport as a function of specific land-use types in Ghana, integrated approaches in evaluating impacts on human and aquatic ecosystem health have been limited. The DPCER conceptual framework, based on the traditional DPSIR model, proved to be an adequate guideline in the assessment of the different facets that interlink agricultural intensification and human/ecological health in small upland catchments. To minimize the contribution of natural climatic variations and unmeasured biophysical processes, especially in data-poor areas, this study used a comparative catchment component, i.e., the comparison of similar or neighboring catchments, using simple mathematical tools. Since water yield was observed to have a major influence on in-stream nutrient loads/yields in each catchment and is a parameter that is also affected by the conversion of natural to agricultural lands, this study recommends the incorporation of a hydrological element to create a Driving forces-Hydrology-Pressure-Chemical state-Ecological state-Response (DHPCER) framework.

8.1.1 Driving forces

Increasing fertilizer use in small upland catchments in the southwestern region of Ghana is mainly driven by access to credit and institutional facilities, in addition to property rights and resident status. The access to facilities as an influencing factor is an advantage when educating and proposing/offering management techniques, since this enables contact with farmers who use agrochemicals. From the study, only an estimated 20% of the respondents applied fertilizer and this was generally to cash crops. This means that land-use intensification is rather defined by labor input and extensification, and fertilizer inputs are mainly profit driven. To further assess the relationship between land-use and nutrient export, there is the need for research to establish how farmers' activities influence soil nutrients and the pathways of nutrient export into the aquatic systems.

8.1.2 Pressure - nutrient loads/yields

The Beale's ratio method provided satisfactory estimates of nutrient loading. The magnitude of nutrient loads/yields did not follow the land-use gradient. Dunyankwanta had the highest nutrient loads which were 3-fold the amounts calculated for the other two catchments. Based on literature review, yields are within ranges estimated for undisturbed systems, which indicates the export of background levels of nutrients for all catchments.

Measured stream flow was assumed to represent all surface and subsurface contributions. The hydrographs show variations in levels and duration of flow for each catchment, indicating different hydrologic conditions possibly influenced by differences in the degree of land-use intensity. Nyamebekyere displayed the typical characteristics of forested catchments (erratic flow and low percentage runoff), but the variations in flow between Attakrom (lowest water yield) and Dunyankwanta (highest water yield) needs detailed assessments of soil properties and vegetation type to establish whether observed differences are due to land-use intensity. Since the magnitude of nutrient loads/yields is determined by water yield and is impacted by increasing land-use intensity, this study recommends incorporating a hydrological element, which would enrich the integrated cause-effect assessment. This proposition is suggested only for comparative studies between catchments with similar characteristics (i.e., slope, aspect, soils, area, climate, vegetation, and located adjacent or in close proximity to each other), as changes in water yield are location specific, and accurate assessments require one catchment to serve as a control/natural system.

8.1.3 Chemical state

Despite minimal fertilizer use, there are significant differences between upland catchments in physico-chemistry (dissolved oxygen, pH, and temperature) and in-stream nutrient ion concentrations (Ca, K, Mg, Na, and PO_4-P), which suggests increasing impacts of expanding agricultural land on in-stream nutrients. The physico-chemistry and nutrient concentrations are, however, within the TWQRs established for domestic water use and aquatic ecosystem health. The insignificant differences between catchments for nitrogen compounds may be indicative of background organic sources. This further supports the nutrient load results which indicate that the catchment streams are still natural systems.

It is suggested that for future integrated assessments of land-use intensification, water quality parameters such as pesticide components and sediment loss as a function of land-use be incorporated. In this study, pesticide use, for example, was extensive (70.9% of farmers in Attakrom as compared to 44.4% in Dunyankwanta and 2.9% in Nyamebekyere), and the impacts on the quality of water for domestic use and on aquatic biota are also very critical, especially for downstream users.

8.1.4 Ecological state

Due to the paucity of local information on macroinvertebrate community response to stream physico-chemistry, the study evaluated a number of sites in addition to the three upland study catchments. The results show that taxa distribution is influenced mainly by magnesium, sodium and ammonia nutrient ions, and that there are significant ecological differences between the upstream sites. Hydrological dynamics may play a major role in the observations, and the similarities between the high land-use intensity and downstream sites indicate similar biotic and abiotic conditions.

Multivariate analyses were useful in identifying significantly different categories of habitats at the upstream sites, with indications of slight to moderate levels of pollution. However, without a reliable local macroinvertebrate database, conclusive statements describing the ecological state of the habitats cannot be made. Further research is, therefore, needed to improve local taxonomic descriptions to enable more appropriate classification systems, especially to land-use, stream conditions and community changes.

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10 APPENDICES

Appendix 1:

Land Use and Farming Practices Questionnaire

Confidentiality of respondent views is assured.

Date	Date data entered
Locality	Data entered by
Interviewer	Data check by

******To interviewers, please continue any answers on blank page facing opposite the question asked******

Background Information of Respondent

1) Name ____
2) Sex ☐ Male ☐ Female
3) Age ☐ < 20 years ☐ 20-29 ☐ 30-39 ☐ 40-49
☐50-59 ☐ > 60 ☐ Don't know
4) a) Marital Status ☐ Single ☐ Married ☐ Divorced ☐Widowed
b) Number of wives ☐ 1 ☐ 2 ☐ 3 ☐≥ 4
c) Total Dependents Adults (≥18 years) ________ Children (< 18 years) _______
5) Level of Education ☐ None ☐ Primary ☐ Secondary
☐ Polytechnic/Teacher Training ☐ Other ________________
6) Religion ☐ None ☐ Christian ☐ Muslim ☐Traditional
☐Other
7) Occupation Primary ______________________________________
Secondary _____________________________________
Tertiary ______________________________________
8) *Estimated* total monthly income (*Cedis*) for the household (from all occupations)
☐ < 400,000 ☐ 400 – 599,000 ☐ 600 – 799,000
☐ 800 – 1,000,000 ☐ >1,000,000 ☐ Other ________________
9) Are there any external sources of income? ☐Yes ☐ No
If *yes*, where from (e.g. income from family members outside community, pensions, remittances)? ____
____
10) a) How frequent is this contribution received?
☐Weekly ☐ Monthly ☐ Irregularly

b) Approximately how much is this contribution per month (Cedis), as indicated above?

☐ < 99,999 ☐ 100,000 – 199,999 ☐ 200,000 – 299,999

☐ 300,000 – 399,999 ☐ 400,000 – 499,999 ☐ >500,000

11) Wealth level

a) Housing status

☐ Own ☐ Rent ☐ Shared ☐ Family

☐Other ____________

b) Housing kind

☐ Mud ☐ Brick ☐ Cement ☐ Zinc

☐Other ____________

c) Property

☐ Bicycle ☐ Car ☐ Television ☐ Wheelbarrow

☐Radio ☐ Agricultural equipment ☐Pump ☐Other

12) a) Residency

☐ Non-resident (*lives in another town*) ☐ Resident

☐ Local (*moved from another town*) _______ years

b) If migrated, where did you move from?

☐ Neighbouring village/town ☐ Within Ashanti Region

☐ Outside Ashanti Region ☐Outside Ghana

☐ Other _____

c) Why did you move away?____

d) What was the purpose for moving to this community? __________________________

Knowledge of the Environment

13) In the table below, select resources other than *farmed products*, which are obtained from the environment.

a) Who collects these resources?

[1] Men [2] Women [3] Children [4] All

b) What are these resources used for?

[1] Domestic [2] Sale [3] Other [4] Both

c) What periods of the year are these resources obtained

(‘*Inf*’ refers to infrequent periods)

d) What kind of effects do you think these activities may have on the environment?

[1] Positive [2] Negative [3] Don’t know

	(a) Resources	*b) Collector*				*c) Use*				*d) Period of Activity*													*e)Effects*		
		1	2	3	4	1	2	3	4	J	F	M	A	M	J	J	A	S	O	N	D	Inf	1	2	3
1	Wild animals																								
2	Snail																								
3	Fish																								
4	Crab																								
5	Firewood																								
6	Palm thatches																								
7	Bamboo																								
8	Medicinal herbs																								
9	Fruits																								
10	Mushrooms																								
11	Honey																								
12	Palm wine																								
13	Water																								
14	Charcoal																								
15	Fufu stick																								
16	'Akpeteshie'																								
17																									
18																									

14) a) Is there hunting in the community?

☐Yes ☐ No ☐ Don't know

b) If yes, approximately how many hunters do you think live in this community?

☐ <10 ☐ 11- 20 ☐ 21 - 30 ☐ 31- 40 ☐ >41

15) What energy sources are usually used in the preparation of food?

☐Firewood ☐ Charcoal ☐ Other_______________

16) a) Is there any fishing in surrounding streams/river?

☐Yes ☐ No

a) Are there any regulations to protect fish and other aquatic fauna?

☐Yes ☐ No

b) If *yes*, what kind is it?

☐ Official ☐ Local ☐ Self imposed

Explain

____

15) a) Is there any logging around the community?

☐Yes ☐ No ☐Don't know

b) If *yes*, do the loggers have concession?

☐ Yes ☐ No ☐Don't know

c) How many of these loggers are from this community?

☐ None ☐ <5 ☐ 5 – 15 ☐ 16 - 25 ☐ >25

d) How many members of the community work for the registered loggers?

☐ None ☐ <5 ☐ 5 – 15 ☐ 16 - 25 ☐ >25

e) How many loggers do you think work without a concession?

☐ None ☐ <5 ☐ 5 – 15 ☐ 16 - 25 ☐ >25

18) Charcoal production

a) Is there any charcoal production in this community?

☐Yes ☐ No ☐Don't know

b) If *yes*, what is the charcoal used for?

☐Domestic ☐ Sale (small scale) ☐ Sale (large scale) ☐ Both

c) Do you think there are any effects of charcoal production on the community or in the forest?

☐Yes ☐ No ☐Don't know

If *yes*, please explain. ____

19) Bush fires

a) Are (uncontrolled) bush fires common?

☐Yes ☐ No ☐Don't know

If no, go to 19) e).

b) If yes, about how many cases are reported in a year?

☐ <5 ☐ 6-9 ☐ 10 - 14 ☐ >15

c) How are these bush fires caused? ______________________________________

d) What is done to those who cause these bush fires?

____

e) Is it forbidden to create bush fires?

☐Yes ☐ No ☐Don't know

f) Are there any methods to prevent bush fires?

☐Yes ☐ No ☐Don't know

g) If *yes*, can you give a brief description of it? ________________________________

____

____

Farming and Land Cover Change

20) How many fields do you farm on?

☐ 1 ☐2 ☐ 3 ☐ 4 ☐ >5

21) Do you own any of these fields?

☐All ☐ None ☐ Some

If not all, what is the status?

☐Labourer ☐Family land ☐ Rent ☐ Other___________

22) For the following questions, please answer in table below.

a) What is the size of each field? (Compare to size of football field if not sure of acreage)

b) What is the type of soil for each field?

c) How many types of crops are grown on each field? (Use crop list on right side)

No	*a) Size*	*b) Type of soil*	*c) Type of crops*
1			
2			
3			
4			
5			
6			
7			

23) Farming calendar

(a) Refer to crop list

(b) Indicate whether it is [1] Mono-cropping or [2] Intercropping

(c) Please tick appropriate months

(d) Indicate period after planting (e.g. two months, one year, etc)

(a) Crop type	(c) Planting	(d) Seeding period												(e) Harvest
		J	F	M	A	M	J	J	A	S	O	N	D	

Type of crop	
1	Avocado Pear
2	Bananas
3	Beans/Peas
4	Cassava
5	Cocoa
6	Coconut
7	Cocoyam
8	Coffee
9	Cola nut
10	Cotton
11	Cowpea
12	Egg plant/Garden egg
13	Groundnut/Peanut
14	Leafy vegetables
15	Maize
16	Mango
17	Okra
18	Oil Palm
19	Onion
20	Oranges
21	Pawpaw
22	Pepper
23	Pineapple
24	Plantain
25	Rice
26	Rubber
27	Sorghum/Millet
28	Sugar Cane
29	Sweet Potatoes
30	Tobacco
31	Wood
32	Yam
33	Other fruits
34	Other grain
35	Other vegetables
36	Other

24) How is land prepared for farming? ____

____

25) Is the land prepared the same for various crops?

☐Yes ☐ No

26) If *no*, what different methods are there?

(a) ________________________________

(b) ________________________________

(c) ________________________________

27) What happens to land after harvest and for how long?

____

Are fallow times the same for various fields/crops?

☐Yes ☐ No

(a) If *yes*, what is the average fallow period and when?

____x

(b) If *no*, briefly explain

____

28) Has there been any fertiliser application in the last 2 years?

☐Yes ☐ No

If *no*, why? ☐Can not afford

☐ Land is fertile enough ☐ Other __________

Go to question *33*.

If *yes*, please fill in table for fertiliser applications (*For b, and e, refer to list below)*

(a) Crop type/s	*(b) Fertiliser type*	*(c) Time and frequency of application per cropping cycle*	*(d) Quantity per application*	*(e) Application*

(b) Fertiliser type:
[1] NPK/15-15-15
[2] Foliar (Harvest-more, Algua)
[3] Ammonium sulphate
[4] 7-7-7 Compound
[5] Manure
[6] Other/s ________________________________

(e) Application:
[1] Spraying (knapsack)
[2] Broadcasting
[3] Spot/Ring application
[4]Other/s___________________________________

29) Have you observed any effects of fertiliser application on the crops?

☐Yes ☐ No

If *yes*, explain ______________________________

30) On the land? \

☐Yes ☐ No

If *yes*, explain ______________________________

31) On the stream/river?

☐Yes ☐ No

If *yes*, explain ______________________________

32) Is there any application of pesticides/herbicides/fungicides in the past 2 years?

☐Yes ☐ No

If *no*, why?

☐Can not afford ☐ No need ☐ Other ______________

Go to question 37

If *yes*, please fill in table for applications (*For b, refer to list on right hand*)

(a) Crop	(b) Type	(c) Time and frequency of application per cropping cycle	(d) Quantity per application

#	(b) Pesticide/herbicide/ fungicide		
1	Dursban		Others
2	Thionex	12	
3	Kocide	13	
4	Foko	14	
5	Champion	15	
6	Fungrian		
7	Roundup		
8	Glycel		
9	Condemn		
10	Power		
11	Atrazine		

33) Have you observed any effects of pesticide application on the crops?

☐Yes ☐ No

If *yes*, explain ______________________________

34) On the land?

☐Yes ☐ No

If *yes*, explain ______________________________

35) On the stream/river?

☐Yes ☐ No

If *yes*, explain ____

36) Have you noticed any changes in the soil or land cover within your life time?

☐ Yes ☐ No

If *yes*,

Change observed (positive or negative)	*Observed or assumed cause of change*

37) Eroasion on fields

a) Have you observed any erosion on the fields?

☐ Yes ☐ No

b) If yes, which fields was it observed on (including farmed crops)? ______________________

____

c) When was this observed?

☐ Last 6 months ☐ Last 12 months ☐ >Last 12 months

d) What do you think is the cause? ____

e) Did you change the fallow periods for these fields?

☐ Yes ☐ No

38) a) Have you observed any changes to water runoff from fields into streams?

☐ Yes ☐ No

b) If yes, which fields was it observed on (including farmed crops)? ______________________

____

c) When was this observed?

☐ Last 6 months ☐ Last 12 months ☐ >Last 12 months

d) If *yes*, what do you think is the cause? ______________________________________

e) Did you change the fallow periods for these fields? ☐ Yes

☐ No

39) a) Do you get support from Agriculture Extension officers?

☐ Yes ☐ No

If yes, what specifically do they come to do? ______________________________________

b) How often do they come?

☐ Weekly ☐ Monthly ☐ > Once a year ☐ < Once a year

c) When was the last time they came? ____

d) Do you follow their advice?

☐ Yes ☐ No

Give reasons for your answer ____

40) Do you get a fixed price for your produce?

☐ Yes ☐ No

41) Do you belong to a Farmers Co-operative?

☐ Yes ☐ No

42) a) Have you received any loan for farming activities?

☐ Yes ☐ No

b) If yes, where was it obtained from?

☐ Bank ☐ Money lender ☐ Other ______________________

c) What kind of loan? ____

d) How much was it? ____

e) What is the interest rate? ____

Water Quality

43) Does your community use any of the surrounding streams?

☐ Yes ☐ No

If *yes*, what for? ____

____

44) If *no*, what other freshwater resources does the community depend on? (e.g. for drinking, irrigation, watering livestock, etc) (*tick as many as applicable*)

☐ Rainwater ☐ Borehole ☐ Well ☐ Pipe water ☐ Other _______

45) Have you noticed any changes in the streams within your life time (including water quality)?

☐ Yes ☐ No

If *yes*,

Type of change	*When change started*	*Perceived cause of change*

46) a) Are any farms close to the stream?

☐ Yes ☐ No

b) If *yes*, how close to the stream/river?

☐ By stream ☐ Near stream (500 m) ☐ Some distance (<500m)

47) What do you think about farming along the banks of the stream? ___________________________

____

48) Are the streams protected in anyway? (i.e. grass buffer zone, etc)

☐Yes ☐ No ☐ Don't know

49) Do you think there are any activities in this community that can affect the quality of the streams and affect those communities which live down the stream?

☐Yes ☐ No ☐ Don't know

If *yes*, what are they? ____

Livestock

50) Do you own any livestock?

☐Yes ☐ No

If no, go to question 54.

If *yes*,

	How many?	Where kept?	Where watered?	Where/how fed?
Draught animals, (horse, donkey)				
Cattle (cows)				
Sheep				
Goats				
Pigs				
Chicken				
Other poultry *				
Other livestock**				

* ________________________ ** ________________________

51) Is any of the livestock allowed to water/graze/feed by the streams?

☐Yes ☐ No

If *yes*, how frequently?

☐ >Once a day ☐ Daily ☐ ~ 3 x weekly ☐ Infrequent

52) Are there any regulations about watering/grazing livestock by the streams?

☐Yes ☐ No

If *yes*, is it adhered to?

☐Yes ☐ No

If *no*, what is done ____

53) Is any of the manure recycled for fertiliser use?

☐Yes ☐ No

If *yes*, please explain ____

If *no*, what happens to the manure? ______________________________________

54) Are you aware of any regulations in keeping livestock in the community?

☐Yes ☐ No

If *yes*, what are they? ____

Regulatory Measures

55) Responsibility

Area	*Who is in charge of the area?*	*What is their responsibility?*	*Do you think others should be in charge of the area?*
Streams			
Land/Fields			
Forest areas			

56) Rules

Area	*Traditional rules*	*Punitive measures*
Streams		
Land/Fields		
Forest areas		

Public Health and Sanitation

57) Water availability

a) What is your major source of drinking water?

☐ Pipe ☐ Borehole ☐ Well ☐ Stream ☐ Other _______

b) How would you rate quality of drinking water available?

☐ Poor ☐ Good ☐ Excellent

c) Do you have to pay for your water?

☐Yes ☐ No

If *yes*, how much?

☐<¢100 ☐¢100 - ¢499 ☐ ¢500 - ¢999 ☐ >¢1000

☐ *per use* ☐ *per month* ☐ *per year*

d) How do you store water in your compound? ______________________________

e) Is this stored water treated in any way?

☐Yes ☐ No

If *yes*, how ____

58) Access to water

a) Do you sometimes have problems with access to drinking water?

☐Yes ☐ No

If *yes*, when? ____

b) Where is your alternative source of drinking water?

☐ None ☐ In village ☐ In vicinity ☐ In another village

☐ Other ______________________

60) Refuse disposal

a) Where do you dump your refuse? ______________________________

b) Are you aware of any refuse being dumped into/near water in your community?

☐Yes ☐ No

c) Do you think this is a problem?

☐Yes ☐ No ☐ Don't know

d) Do you think there will be an impact?

☐Yes ☐ No

e) Why? ____

f) What should be done about this if it's a problem in the community? ____________

____

61) Are you aware of any disease(s) transmitted through drinking water or bathing in the stream?

☐Yes ☐ No ☐Don't know

If *yes*, what type/s is it? ______________________________________

62) What types of diseases are common in this community?____________________

____

63) Is there a place of convenience?

☐Yes ☐ No

a) If *yes*, which type?

☐KVIP ☐ Pit latrine ☐ Water closet ☐Other __________

b) Is it private or public owned?

☐Public ☐ Private

c) How much do you pay (¢) if public owned?

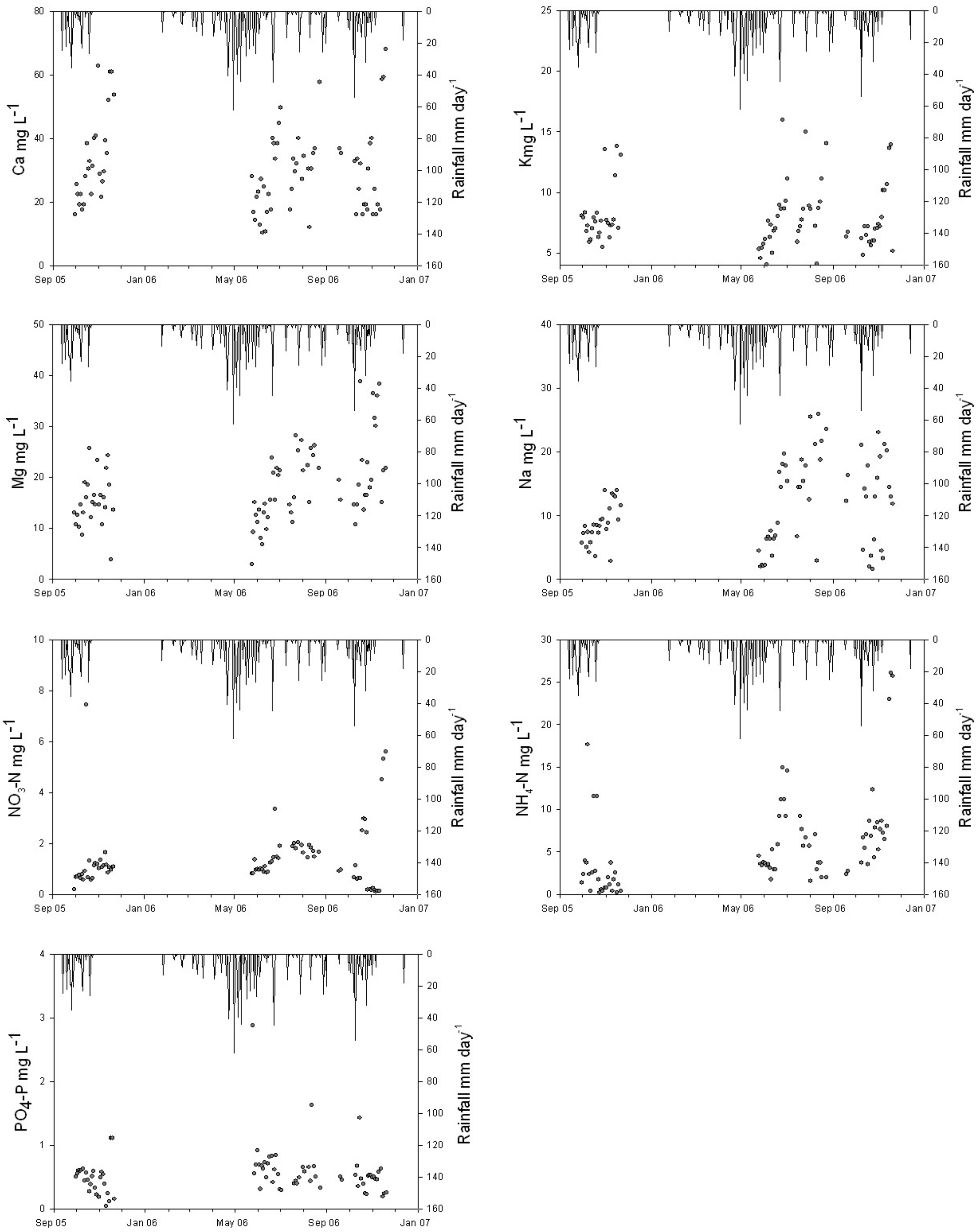
☐ *per use* ☐ *per month* ☐ *per year* ☐ Free ☐<¢99

☐¢100 - ¢199 ☐ ¢200 - ¢499 ☐ ¢500 - ¢999 ☐ >¢1000

d) If *no*, where do you use as a place of convenience? ______________________

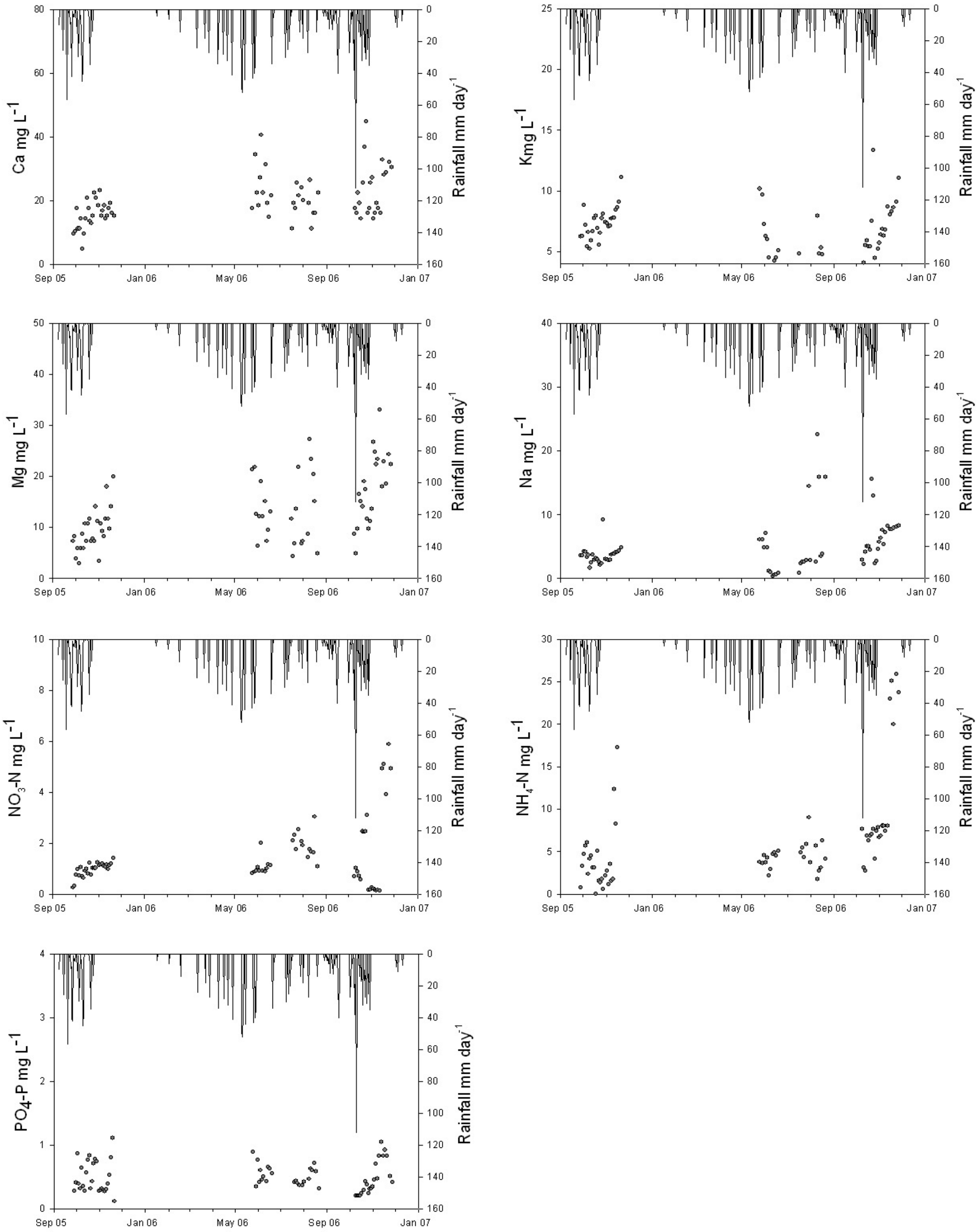
Appendix 2

Daily nutrient concentration (mg L^{-1}) and daily precipitation (mm day-^{1}) for Attakrom catchment

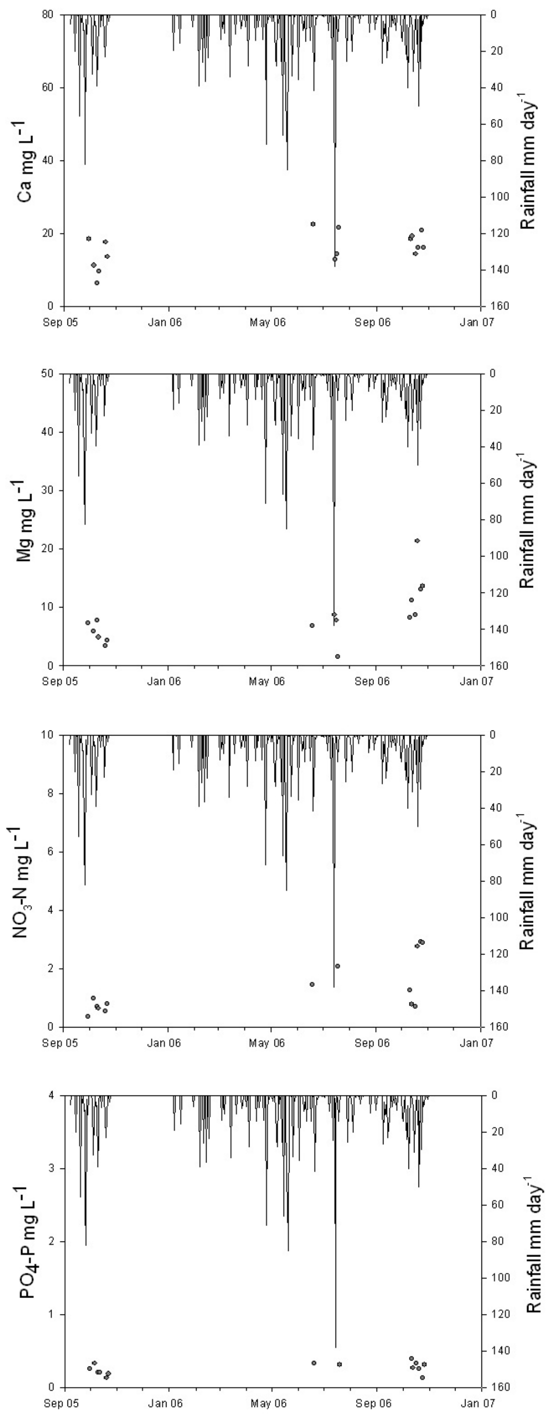


Appendix 3

Daily nutrient concentration (mg L^{-1}) and daily precipitation (mm day^{-1}) in Dunyankwanta



Appendix 4
Daily nutrient concentration (mg L^{-1}) and daily precipitation (mm day^{-1}) in Nyamebekyere



Appendix 5
Summary of physico-chemical parameters – median, minimum – maximum range, and means (standard deviation)

Parameter		**Attakrom**	**Dunyankwanta**	**Nyamebekyere**
pH	Median	7.57	7.89	8.03
	Range	5.57 – 9.14	6.73 – 9.05	6.88 – 8.81
	Mean	7.67 ± 0.57	7.79 ± 0.55	7.95 ± 0.74
Conductivity (µS cm^{-1})	Median	233	89	67
	Range	93 – 309	40 – 216	58 – 87
	Mean	221 ± 53	105 ± 52	70 ± 10
Stream temperature (°C)	Median	25.35	24.60	23.60
	Range	23.40 – 32.60	23.10 – 28.90	23.40 – 25.00
	Mean	25.92 ± 1.95	24.85 ± 1.27	23.93 ± 0.56
Ammonium (mg L^{-1})	Median	1.08	1.06	0.89
	Range	0.11 – 7.45	0.13 – 5.88	0.36 – 2.91
	Mean	1.38±1.23	1.41 ± 1.19	1.34 ± 0.92
Calcium (mg L^{-1})	Median	29.66	18.44	16.03
	Range	10.42 – 68.14	4.81 – 44.89	6.41 – 22.44
	Mean	30.60± 13.42	19.91 ± 7.38	15.83 ± 4.45
Dissolved oxygen (mg L^{-1})	Median	3.14	1.83	4.16
	Range	0.29 – 5.59	0.27 – 9.70	0.62 – 7.60
	Mean	3.16 ± 1.22	2.58 ± 1.96	3.47 ± 2.36
Magnesium (mg L^{-1})	Median	16.04	11.67	7.78
	Range	2.92 - 38.90	2.92 – 33.06	1.46 – 21.39
	Mean	17.90 ± 7.29	13.20 ± 6.72	8.42 ± 4.76
Sodium (mg L^{-1})	Median	9.43	3.80	1.64
	Range	1.59 – 25.99	0.39 – 22.62	0.29 – 11.84
	Mean	11.19 ± 6.42	4.99 ± 4.05	2.34 ± 2.63
Potassium (mg L^{-1})	Median	7.26	6.29	5.52
	Range	4.02 – 15.97	2.52 – 13.36	3.39 – 8.52
	Mean	7.94 ± 2.57	6.14 ± 2.32	5.68 ± 1.07
Nitrate (mg L^{-1})	Median	3.73	4.71	5.88
	Range	0.20 – 26.08	0.59 – 39.80	0.98 – 17.84
	Mean	5.72 ± 5.37	7.09 ± 7.50	6.36 ± 4.17
Phosphate (mg L^{-1})	Median	0.50	0.43	0.26
	Range	0.04 – 2.88	0.11 – 1.11	0.13 – 0.39
	Mean	0.56 ± 0.37	0.50 ± 0.22	0.26 ± 0.08

Appendix 6

Total monthly nutrient load (kg) for nutrients from each catchment for the study period (computed with the Beale equation)

Attakrom	**Ca**	**K**	**Mg**	**Na**	**NH_4-N**	**NO_3-N**	**PO_4-P**
Oct-05	1015441.2	331663.1	547928.0	260493.9	42162.0	172934.7	31424.7
Nov-05	83186.3	22612.7	44490.0	30186.9	3848.7	5266.9	1700.6
May-06	423201.6	133179.6	318486.7	60572.0	30166.6	88123.5	24304.9
Jun-06	343820.7	126536.5	265221.2	123092.8	22996.5	95473.8	11561.7
Jul-06	312964.1	91550.5	245749.0	147717.5	20636.4	70693.7	6005.5
Aug-06	211666.0	53471.9	153282.9	141396.2	11562.5	33633.8	4807.9
Sep-06	299270.1	52250.5	154222.5	105104.5	7612.2	19684.7	4039.0
Oct-06	774392.0	217529.1	603399.2	290241.9	55575.3	235776.5	23234.4
Nov-06	71683.3	32452.6	125209.1	37886.3	750.9	29696.9	1829.5

Dunyankwanta	**Ca**	**K**	**Mg**	**Na**	**NH_4-N**	**NO_3-N**	**PO_4-P**
Oct-05	819229.2	541806.4	760701.8	212938.4	73712.5	354872.1	39832.2
Nov-05	14514.6	6149.6	7975.9	2486.8	1013.2	2034.1	258.9
May-06	3045449.4	1019666.9	2127927.4	643357.6	100166.7	449420.1	67740.7
Jun-06	1351328.2	237251.9	655304.7	85403.1	56981.8	199232.6	27831.6
Jul-06	1301050.3	189717.3	490862.8	316508.0	130374.8	363331.6	24917.9
Aug-06	687821.0	173951.5	554550.2	326360.3	61418.7	131603.8	18718.7
Oct-06	3086887.9	776463.7	1552197.5	628667.2	225976.0	785068.3	37750.0
Nov-06	1324704.2	437292.9	1383350.5	424513.7	91666.5	729389.3	41802.2

Nyamebekyere	**Ca**	**K**	**Mg**	**Na**	**NH_4-N**	**NO_3-N**	**PO_4-P**
Oct-05	454428.6	271273.9	330236.0	72176.9	34126.2	337166.9	9666.4
Jun-06	99585.4	22764.4	30201.1	6619.7	6390.9	79168.3	1441.3
Jul-06	1886813.7	295376.0	127158.0	25174.2	182461.7	432183.9	27337.8
Oct-06	406807.1	133622.5	199679.4	47354.9	30235.2	99871.7	8505.3

Appendix 7
Intensive Stream Biosurvey Form

		Notes
A. General Characteristics		
1	Sampling point description	Distinctive color, appearance or smell of stream water
2	Width stream channel	Estimation of the width of the streambed covered by water from bank to bank
3	Stream depth	Average estimate of stream depth
4	Local Land Use	Activities present within 1/4 mile up-stream of and adjacent to the site
5	Established weir type	Type of weir at sampling sites
B. Habitat Assessment		
1	Shelter	The type of shelter (e.g., rocks, branches, debris) available for fish, insects, and snails
2	Pool substrate	Type of bottom substrate (e.g. mud, sand, gravel, or mixed)
3	Pool variability	Types of pools found in stream (e.g. large-shallow, large-deep, small-shallow, and small-deep) which may be formed during periods of low flow
4	Sediment deposition	Occurrence of deposited sediments in stream channel which creates changing stream bottom
5	Channel sinuosity	The meandering of a stream, whether winding with variety of habitats or straight with unvarying velocity
6	Channel flow status	Percent of the existing channel that is filled with water
7	Bank protection	Presence of natural vegetation that covers the stream bank reducing erosion.
8	Condition of banks	Erosion potential and status of stream bank, i.e. slope of bank, unvegetated banks, exposed tree roots
9	Riparian zone	Width of natural vegetation from the edge of the stream bank that is a buffer zone and controls erosion.

Adapted from USEPA, 2005

Appendix 8
Stream habitat survey summary

Site	Stream description	Channel width (m)	Stream depth (m)	200-m radius	Stream substrate	Shelter type	Pools	Channel flow	Bank slope	Bank erosion
Attakrom	Shallow flow	0.5-3.0	0.2-1.0	Maize farms, tall grasses	Sandy with small stones	Bank foliage, debris	Few and isolated	70% of channel to flooding	Little slope, flat	None
Dunyankwanta	Reddish brown water after storms	1.5	0.4-1.2	Mixed crops, natural foliage	Sandy, with underlying clay	Bamboo plant roots, natural foliage	Only one observed	40% of channel to flooding	Sharp slope, >50º	None
Nyamebekyere	Shallow flow	2	0.5	Forest trees, natural foliage	Sandy, small stones, clayey	Tree roots, leaf litter, natural foliage	Few and isolated	50% of channel to flooding	Flat	None
Mankranso	Turbid after storms, cloudy with silt or organic matter	5.0-3.0	1.0-3.0	Mainly tall grasses	Sand with gravels	Submerged grasses	Few large shallow	50% of channel to flooding	Slight slope	None
Kunsu	Muddy, silted water after storms, brownish from decaying vegetation	5.0-15.0	0.5-1.5	Small trees, brush	Clay	Hanging bank foliage	None	40 % - 80%	Sharp slope, >50º	None

Site	Stream description	Channel width (m)	Stream depth (m)	200-m radius	Stream substrate	Shelter type	Pools	Channel flow	Bank slope	Bank erosion
Nyasiso	Turbid after storms, cloudy with silt or organic matter	7.0	0.5-2.0	Few fields	Natural foliage	Submerged and hanging bank foliage	Few large, many small	10% of channel to flooding	Little slope	None
Borosase	Turbid after storms, cloudy with silt or organic matter	6.0 - 100.0	0.5-7.0	Farm fields, secondary forests	Fine silt, muddy	Tree roots, hanging foliage, debris	None	20% - 80%	Sloping, >45º	Some
Afrensini	Clear, fast flowing water	5.0 – 10.0	0.5-1.0	Small trees, brush	Stony, gravelly	Tree roots, hanging foliage	None	20% - 80%	Sloping, >40º	None
Akuapem	Milky brown water, perennial	5.0 – 10.0		Small trees, brush	Muddy	Tree roots, hanging foliage	None	20% of channel to flooding	Sloping, >40º	None
Ntabanu	Natural milky brown color, perennial	15.0-45.0	0.5-6.0	Farms, secondary forests	Muddy	Tree roots, hanging foliage	None	10% - 30%	Sloping >45º	Some
Beposo	Water color varies throughout year, perennial	7.0-1000.0	1.0-8.0	Farms, trees, brush	Sandy with gravel, small stones	Tree roots and hanging foliage	None	1% of channel to flooding	Sloping <25º	Some

Appendix 9
Sampled macroinvertebrate taxa, with number of individuals and percentage abundance per Family

Family	Order	Total #	% Abundance
Macroinvertebrates			
Gyrinidae	Coleoptera	2957	43.21
Baetidae	Ephemeroptera	2444	35.78
Penaeidae	Decapoda	427	6.25
Chironomidae	Diptera	404	5.92
Veliidae	Hemiptera	96	1.41
Calopterygidae	Odonata	89	1.30
Planorbidae	Pulmonata	73	1.07
Caenidae	Ephemeroptera	50	0.73
Belostomatidae	Hemiptera	49	0.72
Gerridae	Hemiptera	43	0.63
Notonectidae	Hemiptera	36	0.53
Libellulidae	Odonata	36	0.53
Dytiscidae	Coleoptera	28	0.41
Psychodidae	Diptera	24	0.35
Ampullariidae	Architaenioglossa	20	0.29
Culicidae	Diptera	14	0.20
Oligochaeta	Oligochaeta	11	0.16
Lymnaeidae	Pulmonata	9	0.13
Planorbidae	Basommatophora	8	0.12
Thiaridae	Mesogastropoda	4	0.06
Nepidae	Hemiptera	4	0.06
Heptageniidae	Ephemeroptera	3	0.04
Gomphidae	Odonata	2	0.03
Hydropsychidae	Trichoptera	2	0.03
Syrphidae	Diptera	1	0.01
Hydrometridae	Hemiptera	1	0.01
Hirudinidae	Arhynchobdellida	1	0.01
Subtotal individuals		**6836**	**82.06**
Other taxa			
Cyprinidae	Cypriniformes	1247	83.52
Anura	Anura	176	11.79
Cichlidae	Perciformes	68	4.55
Claridae	Siluriformes	2	0.13
Subtotal individuals		**1493**	**17.94**
TOTAL		**8329**	**100.00**

Appendix 10
Sampled macroinvertebrate taxa, with number of Family, number of individuals, and percentage composition per Order.

Order	# Families	# Individuals	% Composition
Macroinvertebrates			
Coleoptera	2	2979	43.62
Ephemeroptera	3	2497	36.56
Diptera	4	443	6.49
Decapoda	1	427	6.25
Hemiptera	6	229	3.35
Odonata	3	127	1.86
Pulmonata	2	82	1.20
Architaenioglossa	1	20	0.29
Oligochaeta	1	11	0.16
Basommatophora	1	8	0.12
Mesogastropoda	1	4	0.06
Trichoptera	1	2	0.03
Arhynchobdellida	1	1	0.01
Subtotal	*27*	*6830*	*100.00*
Other orders			
Cypriniformes	1	709	47.49
Unknown fish fry	-	538	36.06
Anura	1	176	11.79
Perciformes	1	68	4.55
Siluriformes	1	2	0.13
Subtotal	*4*	*1493*	*100.00*

Appendix 11
Total macroinvertebrate numbers sampled per site. A=Attakrom, B=Dunyankwanta, C=Nyamebekyere, D=Mankranso, E=Kunsu, F=Nyasi, G=Borosase, H=Afrensini, I=Akuapem, J=Ntabanu, K=Beposo.

Family	Numbers	A	B	C	D	E	F	G	H	I	J	K
Ampullariidae	20	5	0	0	5	8	2	0	0	0	0	0
Anura	176	2	1	0	8	58	33	50	0	23	0	1
Baetidae	2444	14	0	1	1537	449	191	17	121	29	21	64
Belostomatidae	49	0	0	0	37	4	0	2	0	3	0	3
Caenidae	50	4	0	0	40	2	1	0	0	0	0	3
Calopterygidae	89	0	0	9	24	36	6	2	6	3	1	2
Chironomidae	404	3	4	0	80	61	39	3	2	174	12	26
Cichlidae	68	0	0	0	1	1	4	0	0	1	8	53
Claridae	2	1	0	0	0	0	0	0	0	0	1	0
Culicidae	14	0	0	0	4	0	2	0	0	7	1	0
Cyprinidae	1247	16	0	0	456	31	13	8	0	174	261	288
Dytiscidae	28	0	0	0	3	2	2	0	0	21	0	0
Gerridae	43	2	0	0	28	4	2	0	0	5	1	1
Gomphidae	2	0	0	0	0	1	0	0	0	1	0	0
Gyrinidae	2951	12	16	0	110	7	13	1	6	111	558	2117
Heptageniidae	3	0	0	0	1	0	0	0	0	2	0	0
Hirudinidae	1	1	0	0	0	0	0	0	0	0	0	0
Hydrometridae	1	0	0	0	0	0	0	0	0	0	1	0
Hydropsychidae	2	0	1	0	0	0	1	0	0	0	0	0
Libellulidae	36	3	1	0	20	0	5	0	0	0	4	3
Lymnaeidae	9	0	0	0	1	0	0	0	0	0	0	8
Nepidae	4	0	0	0	0	0	1	0	0	1	1	1
Notonectidae	36	1	4	1	2	0	1	0	0	26	1	0
Oligochaeta	11	1	0	0	2	6	1	0	0	1	0	0
Penaeidae	427	0	2	0	109	40	9	5	2	194	9	57
Planorbidae	73	1	6	0	6	41	4	8	1	1	5	0
Planorbidae	8	0	0	0	7	0	1	0	0	0	0	0
Psychodidae	24	0	0	6	13	0	0	0	0	5	0	0
Syrphidae	1	0	0	0	0	1	0	0	0	0	0	0
Thiaridae	4	0	0	0	4	0	0	0	0	0	0	0
Veliidae	96	1	0	0	3	1	2	2	0	13	26	48

Appendix 12

Total number of macroinvertebrate taxa (S), total number of individuals (N), Margalef's index of richness (d), Pielou's evenness index J), Shannon index (H′) and Simpson's Diversity Index (1-λ). A=Attakrom, B=Dunyankwanta, C=Nyamebekyere, D=Mankranso, E=Kunsu, F=Nyasi, G=Borosase, H=Afrensini, I=Akuapem, J=Ntabanu, K=Beposo.

	S	N	d	J'	H'	1-λ
A0905	6	20	1.67	0.83	1.5	0.76
A1005	4	9	1.37	0.88	1.21	0.75
A0606	2	4	0.72	0.81	0.56	0.5
A0806	7	23	1.91	0.76	1.48	0.74
A1006	6	11	2.09	0.93	1.67	0.87
B0905	5	28	1.2	0.74	1.2	0.63
B1006	4	7	1.54	0.83	1.15	0.71
C0905	1	9	0	0	0	0
C1006	3	8	0.96	0.67	0.74	0.46
D0905	9	164	1.57	0.54	1.19	0.54
D1005	7	52	1.52	0.5	0.98	0.43
D1105	9	160	1.58	0.57	1.26	0.65
D1205	10	217	1.67	0.62	1.42	0.7
D0506	8	41	1.88	0.8	1.65	0.78
D0606	9	454	1.31	0.26	0.57	0.27
D0706	8	130	1.44	0.38	0.8	0.35
D0806	12	196	2.08	0.49	1.22	0.6
D0906	4	14	1.14	0.89	1.24	0.74
D1006	6	147	1	0.46	0.82	0.4
D1106	5	153	0.8	0.59	0.94	0.51
D1206	7	773	0.9	0.12	0.23	0.08
E0905	4	11	1.25	0.75	1.03	0.6
E1005	7	175	1.16	0.39	0.77	0.34
E1105	7	48	1.55	0.75	1.45	0.72
E1205	10	40	2.44	0.86	1.98	0.86
E0506	7	175	1.16	0.39	0.77	0.34
E0606	4	18	1.04	0.99	1.37	0.78
E0706	6	131	1.03	0.38	0.68	0.33
E0806	1	19	0	0	0	0
E0906	8	40	1.9	0.89	1.85	0.84
E1006	3	12	0.8	0.87	0.96	0.62
E1106	6	42	1.34	0.8	1.43	0.74
E1206	5	42	1.07	0.86	1.38	0.74
F0905	5	6	2.23	0.97	1.56	0.93
F1005	5	12	1.61	0.77	1.23	0.67
F1205	10	33	2.57	0.79	1.81	0.8
F0606	7	182	1.15	0.32	0.61	0.26
F0706	6	18	1.73	0.77	1.38	0.73
F0806	5	12	1.61	0.77	1.23	0.67
F0906	5	38	1.1	0.51	0.82	0.41
F1006	4	6	1.67	0.9	1.24	0.8
F1106	6	18	1.73	0.84	1.51	0.78
F1206	3	8	0.96	0.89	0.97	0.68
G0606	9	49	2.06	0.86	1.89	0.84
G1006	5	49	1.03	0.54	0.86	0.44
H0905	3	124	0.41	0.15	0.16	0.06
H1006	3	9	0.91	0.77	0.85	0.56
H1206	3	5	1.24	0.86	0.95	0.7
I0905	4	10	1.3	0.92	1.28	0.78
I1205	7	241	1.09	0.6	1.17	0.65
I0106	9	45	2.1	0.78	1.71	0.77
I0206	6	42	1.34	0.83	1.5	0.74
I0506	7	215	1.12	0.46	0.89	0.4
I0606	7	58	1.48	0.76	1.48	0.74
I0706	4	13	1.17	0.83	1.16	0.68
I0806	5	30	1.18	0.64	1.04	0.56
I1006	5	49	1.03	0.62	1	0.59
I1106	7	27	1.82	0.67	1.31	0.66
I1206	3	65	0.48	0.56	0.62	0.38
J1005	2	11	0.42	0.99	0.69	0.55
J0106	6	19	1.7	0.75	1.34	0.66
J0206	5	469	0.65	0.14	0.22	0.09
J0506	3	112	0.42	0.16	0.18	0.07
J0606	4	22	0.97	0.48	0.66	0.33
J0706	4	15	1.11	0.52	0.72	0.37
J0806	3	22	0.65	0.55	0.6	0.33
J1006	5	75	0.93	0.54	0.88	0.41
J1106	8	100	1.52	0.36	0.76	0.31
J1206	4	66	0.72	0.32	0.44	0.2
K1005	3	12	0.8	0.81	0.89	0.59
K1205	7	198	1.13	0.46	0.9	0.42
K0106	2	901	0.15	0.01	0.01	0
K0206	2	897	0.15	0.03	0.02	0.01
K0506	7	192	1.14	0.22	0.43	0.17
K0606	5	31	1.16	0.58	0.93	0.5
K0706	6	36	1.4	0.77	1.38	0.68
K0806	4	21	0.99	0.87	1.21	0.71
K1006	4	62	0.73	0.9	1.25	0.71
K1106	10	50	2.3	0.69	1.58	0.68
K1206	6	275	0.89	0.51	0.91	0.47

Appendix 13
Summary of stream physico-chemistry and nutrient ion concentrations. Median, range (minimum and maximum), and mean (standard deviation)

Parameter		**H2**	**M2**	**L1**	**M3**	**L3**	**HM4**	**Ofin1**	**Ofin2**
pH	Median	7.45	7.74	7.67	7.79	7.71	7.75	7.55	7.81
	Range	6.74-8.43	6.45-8.64	6.44-8.68	6.90-8.23	7.03-8.22	6.77-8.65	6.61-7.97	6.49-8.14
	Mean	7.49±0.44	7.68±0.51	7.63±0.54	7.72±0.37	7.65±0.41	7.71±0.53	7.51±0.39	7.69±0.43
Conductivity	Median	92	88	74	78	88	105	117	115
(μS cm^{-1})	Range	76-108	68-130	50-720	59-92	73-109	80-147	107-210	100-219
	Mean	92±9.3	88±14.5	107±145	77±10.3	89±11.6	109±20.1	133±34.7	130±39.2
Temperature	Median	25.6	25.6	24.6	25.1	26.4	25.6	26.7	27.0
(ºC)	Range	22.4-27.4	21.8-28.1	20.0-25.8	19.9-27.6	21.1-27.1	21.5-27.1	23.0-28.0	23.5-28.4
	Mean	25.5±1.08	25.5±1.49	24.4±1.45	24.8±1.96	25.7±1.79	25.1±1.51	26.3±1.45	26.7±1.30
Ammonium	Median	1.18	1.41	1.26	1.51	1.32	1.08	1.09	0.99
(mg L^{-1})	Range	0.30-6.72	0.23-5.02	0.25-4.52	0.66-4.25	0.28-8.87	0.53-5.05	0.33-5.31	0.19-5.46
	Mean	1.98±1.80	1.91±1.48	1.77±1.34	1.95±1.28	2.18±2.25	1.70±1.32	1.67±1.37	1.62±1.60
Calcium	Median	14.43	15.23	13.23	16.83	15.23	16.83	17.64	16.83
(mg L^{-1})	Range	9.62-47.29	3.21-34.47	8.02-20.84	9.62-22.44	8.82-20.84	9.62-22.44	6.41-22.44	8.02-33.67
	Mean	17.52±8.34	15.52±6.32	13.82±3.74	16.34±4.25	14.49±4.24	16.75±4.16	17.09±4.16	17.85±6.27
DO	Median	2.54	3.89	3.70	4.78	3.94	2.87	4.27	4.18
(mg L^{-1})	Range	0.08-3.88	1.67-5.37	1.95-7.74	0.76-5.54	1.89-7.80	0.11-3.99	0.01-8.70	0.09-8.30

Parameter		H2	M2	L1	M3	L3	HM4	Ofin1	Ofin2
	Mean	2.34±1.09	3.65±1.05	3.81±1.24	4.17±1.48	3.85±1.73	2.51±1.43	4.04±2.04	4.28±1.83
Magnesium	Median	8.27	9.24	8.75	10.21	9.97	9.72	10.70	10.70
(mg L^{-1})	Range	0.49-19.45	1.94-26.45	2.82-15.56	6.81-17.50	5.35-17.50	1.09-16.53	3.89-15.56	3.89-13.61
	Mean	8.80±4.42	9.91±5.28	9.10±3.34	10.96±3.58	11.39±3.93	9.37±3.84	10.52±2.75	10.31±2.76
Sodium	Median	9.24	9.05	8.04	9.24	8.42	11.07	16.36	14.44
(mg L^{-1})	Range	2.79-29.36	3.75-21.66	1.73-13.72	4.19-12.99	3.99-19.25	2.50-16.36	7.51-24.06	5.10-21.18
	Mean	11.20±5.79	9.95±4.12	8.23±2.68	9.50±2.47	9.09±3.69	9.99±3.84	15.95±4.72	13.86±5.22
Potassium	Median	5.03	4.70	3.58	5.23	4.16	6.29	8.33	7.94
(mg L^{-1})	Range	3.39-28.56	2.71-9.29	1.94-5.66	3.39-17.18	2.81-7.84	4.16-12.10	5.13-15.68	6.39-15.00
	Mean	7.56±6.77	4.94±1.47	3.69±0.94	6.52±4.13	4.51±1.51	6.74±2.18	9.34±2.85	8.83±2.70
Nitrate	Median	4.90	6.47	6.86	5.88	4.31	5.10	4.55	4.12
(mg L^{-1})	Range	1.18-30.59	1.57-48.63	1.18-30.39	1.96-26.08	0.01-24.12	1.18-26.27	1.37-32.94	1.96-28.63
	Mean	8.80±7.85	11.26±11.12	11.26±9.61	11.00±8.95	8.32±7.85	8.76±7.61	9.23±9.31	9.87±9.34
Phosphate	Median	0.27	0.21	0.22	0.22	0.27	0.26	0.21	0.26
(mg L^{-1})	Range	0.12-2.07	0.11-0.52	0.13-0.45	0.07-0.35	0.13-0.52	0.21-1.01	0.07-1.09	0.07-0.87
	Mean	0.38±0.36	0.23±0.10	0.25±0.09	0.22±0.08	0.29±0.10	0.35±0.20	0.29±0.24	0.30±0.18

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In God there is Ultimate Glory…