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ASSESSMENT of LAND COVER CHANGES and HYDROLOGIC RESPONSE of TAMNE RIVER BASIN

by

Henry N. N. Bulley ©

A Graduate Thesis Submitted in Partial Fulfilment of the Requirements for the Degree of Master of Science in Forestry

**Faculty of Forestry
Lakehead University
Ontario, Canada.**

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ABSTRACT

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Northeastern Ghana, West Africa, is characterised by a high population growth rate and adverse climatic conditions, e.g., a long dry season followed by a short-duration but intense rainfall pattern. Land degradation in this part of the country has caused farmers to extend their agricultural activities into marginal lands including flood plains. The consequence is an increase in flood damage to cropland, livestock, infrastructure and human lives. In this study, the nature of vegetation change in the Tamne River Basin was assessed by integrating remote sensing and geographic information systems (GIS). Inter-annual variation in rainfall and streamflow were assessed using statistical hypothesis testing. Gumbel Extreme Value distribution was used to estimate peak flow magnitudes for selected return periods. Field observations and interviews with farmers provided first hand information about the farming systems in the Tamne River Basin. There was no significant change inter-annual variation in rainfall and hydrologic response and the estimated 100 year peak flow was 59.9 m^3/s. Less than one percent of the total area in Tamne River Basin changed between 1975 and 1991. The distribution of the potential land cover changes confirmed the assertion that, farming systems constitute a primary cause of land degradation in the Upper East Region. The potential land cover changes have little or no effect on the hydrologic response in the Tamne River Basin. The study also provided a broad framework for detailed watershed analysis at the basin and sub-basin level, including the monitoring of land use change and distributed hydrologic modelling. In addition, the study highlighted some of the problems related to incomplete and outdated environmental information, and their implications on the effective integration of remote sensing and GIS for resource management and policy formulation in Ghana. Suggestions have been made for: integration of 'expert systems' into GIS and image processing in Ghana; quantitative accuracy assessment for the potential land cover changes; and, event-based hydrologic modelling for sub-catchments in the Tamne River Basin.

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CONTENTS

LIST OF TABLES

LIST OF FIGURES

Figure Page

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Henry N. N. Bulley

DEDICATION

I wish to dedicate this report to the loving memory of my deceased sister, late Sarah Adorkor Bulley, who passed away in April 1995 in far away Ghana, while I was in Canada pursuing my graduate studies.

1.0. INTRODUCTION

Population pressure in most semi-arid parts of the tropics including Ghana have led to a variety of demands on land and water resources. Such increased demands and attendant land use options have intensified land and water management conflicts, and thus, increasing the complexity of watershed analysis and management (Green, 1992). Land use and land cover are often used synonymously, however these are two different concepts. Land use refers to all human activities that are intimately related to the land (Clawson and Stewart, 1965). Land cover, on the other hand, refers to vegetation, water, soils and artificial construction covering the land surface (Burley, 1961). An assessment of the nature of land cover or land use changes, as well as the hydrologic response of a watershed (or river basin) is not only useful but also vital for effective watershed management.

This study addresses some issues related to land cover change and the resulting hydrologic response of the Tamne River Basin. The specific areas covered include: the magnitude and direction of land cover change; the nature and recurrence of flood producing peak flows; and inter-annual variations rainfall and streamflow. Although dry season water shortage is also a problem in northern Ghana, emphasis in the study was placed on flood potential of streamflow. Another important feature of the study was to demonstrate the usefulness of integrated image processing and geographic information systems (GIS) in assessing land cover change dynamics and to provide a land cover change map.

Most of Ghana's 238,500 km^2 of land is savanna (56%) and closed forest (35%) (Hall and Swaine, 1981). Generally, the forests extend to the south and the savannas occur in the northern parts of country. The threat of land degradation and desertification to the northeastern part of Ghana, i.e., Upper East Region, have prompted several conservation efforts, especially during 1945 to 1960 and after 1990 (Department of Geography and Resource Development (Department of Geography), 1992). The Tamne River Basin is representative of the nature of land degradation, water problems and population pressure in the northeastern part of Ghana.

The central problem in the northeastern part of Ghana is that of land degradation i.e., incipient desertification (Dodoo, 1975). Land degradation here is due mainly to poor land use practices (e.g., short fallow periods for shifting cultivation, use of fire for hunting and land preparation, and overgrazing by livestock). These land use practices interact within a fragile environment of dynamic natural ecosystems and complex socio-economic processes. Climate variability further exacerbates the problems of land and water management in the Upper East Region (Dodoo, 1975).

Pressure on arable land, frequent drought and the eradication of disease vectors, e.g., the tse-tse fly *(Trypanosoma sp.)*, has led some farmers to cultivate crops in river valleys. The consequences of high population growth rate and short duration but intense rainfall pattern of northeast Ghana is an increase in flood damage to cropland, livestock, infrastructure and human lives. Recent development efforts by governmental and non-governmental agencies are aimed at mitigating the threat of desertification. These agencies facilitate socio-economic growth in rural areas through increase in road networks, agricultural extension services, agroforestry programmes, and small scale irrigation projects. The benefits of these efforts can be eroded in a single or series of flood events.

Growing demand on land and water resources in Ghana, make temporal and spatial variations in water supply the critical issues of water conservation strategies in Ghana (Sam and Ayibotele, 1989). Long term quality data on land cover or land use, streamflow and rainfall, are rarely available in most tropical regions. The integration of GIS and image processing of remotely sensed data can greatly aid watershed analysis and management, especially in detecting changes in the land cover or land use dynamics of a river basin.

Knowledge of change in land cover is, however, uninformative unless it is linked to its impact on resources. An assessment of change should therefore include, as much as possible, the impact of the change (Green *et al.*,1994). Flood recurrence or flood risk information will not only help the hydrologists and engineers engaged in irrigation projects, but also foresters, agriculturalists and other resource managers in developing or implementing sustainable management strategies. An example of the management strategies in Ghana is the National Environmental Action Plan (Environmental Protection Council (EPC), 1991).

This study have been based on the presumption that observed trends in hydrologic response of the Tamne River Basin were influenced by land use and land cover changes in the catchment area. According to Lull and Sopper (1969) land cover changes resulting from land use and/or natural phenomena have obvious consequences on the hydrologic response of a watershed, the degree of which is influenced by the degree of change. The objectives of the study were:

1. To assess land cover changes in the Tamne River Basin by integrating image processing and geographic information systems,
2. To assess trends in hydrologic response and peak flows in the Tamne River Basin,
3. To evaluate any possible relationships between land cover change and hydrologic response in the Tamne River Basin.

2.0. REVIEW OF BACKGROUND INFORMATION

A review of literature related to the scope of the study is presented in this chapter. This includes: land degradation in the Tamne River Basin, land use and land cover change detection, integration of image processing and GIS, use of remote sensing and GIS in Ghana, and catchment hydrologic response.

2.1. LAND DEGRADATION IN TAMNE RIVER BASIN

The focus here is on some of the causes and forms of land degradation in the Upper East Region of Ghana with particular reference to the Tamne River Basin. The nature of land degradation discussed here is common to other parts of the country, except for the fact that, the extent of degradation is higher in this region.

2.1.1. Causes of land degradation

Farming systems - The farming systems in and around the basin constitute a major cause of the increase in environmental degradation (Brookman-Amissah, 1986; IFAD, 1990; Quansah, 1990; Department of Geography, 1992). Land degradation here is primarily due to a reduction in the length of fallow period from fifteen years to about three years (Department of Geography, 1992). This can be compared to the ideal situation of between twenty five and thirty years (Dickson and Benneh, 1988). Other causes of degradation include extension of cultivated area with its associated shortage of farm manure, increase in number of livestock holding and bush burning. Chemical fertilizers are adopted with inadequate understanding of the risk involved in their application. This practice, together with poor agricultural infrastructure result in a vicious cycle of land degradation in an already fragile environment and collapse of the farming system (Department of Geography, 1992).

Bush fires - Bush burning as a socio-cultural practice have persisted in and around the basin due to customary practices, traditional institutions and beliefs founded on bush burning and the use of fire in other forms. The negative influence of these socio-cultural practices is that they encourage the younger generation to burn and destroy trees without remorse (Korem, 1985). The environmental effects of controlled and uncontrolled fires include losses of vegetation, food crops, human settlements, wildlife and soil nutrients. Beside this, the intense heat from the fires facilitate 'hard pan' (crusted earth) formation thereby increasing the rate and volume of runoff and subsequent soil erosion (Dodoo, 1975).

Roads - The rehabilitation of roads, mainly through regravelling, in the basin have also led to large-scale excavation works. The practice where topsoils are left heaped up in small 'mountains' is responsible for most barren and erosion-prone stretches of land, as well as, the siltation of streams, dugouts and dams.

Energy supply - Fuelwood constitute an important source of energy for most household cooking and some commercial activities such as brewing of local beverages (e.g. pito), baking and food processing by local restaurants in most parts of the country (Overseas Development Administration (ODA), 1992). Poles from trees are commonly used in the construction of farm shelters, kraals (i.e., cattle pens), compound houses and the newly evolving suburban housing units in small towns including Garu, Bugri and Manga. With the rapid increase in population, the demand for fuelwood and poles is on the rise. The result is the commercialization of wood supply and indiscriminate destruction of existing trees around settlements as well as trees on fallow lands. In the absence of appropriate alternative energy sources, the destruction of trees in this fragile environment is likely to reach critical levels (Department of Geography, 1992).

Land tenure - The land tenure system in the Upper East Region is a complicated one in which the land is vested in the chiefs, religious heads (Tengdana) and family heads, who are all operating under separate and sometimes inter-related circumstances. The impact of land tenure on the environment is mainly due to the insecurity of tenure. This insecurity discourages the 'peasant' farmers from adopting long term conservation measures in the light of increasing exploitation of the land (Quansah, 1990).

Desiccation - There have been accounts of drought during the periods of 1975 to 1977 and 1981 to 1983 (Ofori-Sarpong, 1985 and 1986). However, drought and subsequent desiccation are considered to be minor causes of land degradation in the Upper East Region (Department of Geography, 1992). In spite of this, the impact of drought on the people can be critical, considering the fact that the Upper East Region in general has the greatest desertification hazard (UNSO, 1986).

As can be seen from the foregoing discussion, population pressure constitutes a major driving force behind all the afore-mentioned factors of land degradation. The nature of the population in and around the Tamne Basin is discussed in chapter three.

2.1.2. Forms of land degradation

Land degradation in the Tamne basin can be observed in the following forms: vegetation disappearance (deforestation); eroded soils; reduced fertility; reduced bio-diversity, pollution, and excessive sedimentation (FAO and UNEP, 1983). According to the Department of Geography (1992), most of the above forms of land degradation are laterally distributed alongside the road network in the Upper East Region. There is also a decrease in the extent of degradation as one moves away from human settlements. Those forms of land degradation that are relevant to the study are reviewed under the following headings.

Deforestation - A typical climax forest condition in and around the Tamne River Basin is that dominated by trees and shrubs (Rose-Innes, 1964). Relics of this condition are seen in sacred groves which are reminders of the bio-diversity of plants (and animals) that once prevailed in the basin area and in this region. As early as the 1960's, Rose-Innes (1964) observed that the sacred groves only represent sub-climax conditions and that there was no undisturbed vegetation in the Upper East Region.

Two stages of deforestation can be identified here, namely, the selective clearing stage and the grass indicator stage. The selective clearing is a common practice where some 'economical' tress are left on the farms, e.g. Shea butter tree *(Butyrospermum paradoxom)*, dawadawa tree *(Parkia clappertoniana)*, and baobab tree (*Adansonia digitata)*. Increasing demand for poles and fuelwood has threatened the existence of this practice. In Nyorogu, near Bawku, a very low density of such economic trees (i.e., one tree per 100 metre strip) were observed on a closely cultivated area (Musah, 1988). The spatial patterns of land use and land cover in the Upper East Region has not changed much between 1969 and 1979. Between 1979 and 1989, the area under cultivation in the region increased by 33 percent while the fallow areas decreased by 38 percent as given in Table 1 (IFAD, 1990). The grass indicator stage is characterized by the evasion

Table 1. Estimates of Land use and land cover between 1979 and 1989 for Upper East Region

Land use/land cover	1979 (x 1000 ha)	1989 (x 1000 ha)
Cultivated	223	300
Fallow	205	128
Plantation	5	5
Uncultivated - (shrub, tree and grass savanna)	382	382
Wet bottom lands	51	51
others	18	18
Total	884	884

(Source: IFAD, 1990)

of aromatic (bitter or coarse) grasses and forbs e.g. *Thelepogon elegans, Elyonurus probeguinii* and *Cymbopogon schoenanthus* (Department of Geography, 1992).

Eroded soils - Accounts of soil erosion in the Tamne basin are given by Adu (1972). The main agents of the erosion process can be identified as high intensity rainfall, surface runoff, high population densities, uneven population distribution and shortened fallow periods of farming systems. Sheet and gully erosion, which remove surface and subsurface soils, are the major forms of erosion in this area. According to Adu (1972) removal of the 'A' and 'B' horizon are rich in nutrients, tend to expose the 'C' horizons thereby decreasing the fertility of the soil. Halm and Asiama (1984) estimated that the rate of soil loss from fields in the Manga-Bawku are in the range of 0.1 tons per hectare per year (for grass/legume combination) to 2.2 tons per hectare per year (for bare soil). Musah (1988) also observed an average of six gullies per 100 metres distance with length, width and depths of 13, 2.0 and 0.5-8.4 metres respectively. According to the Department of Geography (1992), soil erosion in the region have shown a worsening trend over the past twenty-two years.

2.2. DETECTION OF LAND USE AND LAND COVER CHANGES

Land degradation is often manifested in land cover changes. The need for reliable and efficient mechanisms for mapping land use and land cover changes have been acknowledged by resource managers, analysts and planners (e.g., Jensen, 1986; EPC , 1992; Green *et al.*,1994; Fisher, 1995). Aerial photography have long been used by resource managers to assess the direction and magnitude of change in land use and land cover (Estes *et al.*, 1982). The advent of digital airborne and space borne data, as well as advancements in computer software and hardware have increased the number of techniques available for change detection (Green *et al.*, 1994). Lo and Shipman (1990) used sequential aerial photographs in a GIS to assess the impact of urban development on the environment. Landsat thematic mapper (TM) and other remotely sensed data have also been used to assess forest decline due to pollution (Vogelmann and Rock, 1988) and insect damage (Leckie *et al.*, 1988). Landsat multispectral scanner (MSS) and TM data were used to assess land cover change at the urban-rural fringe (Jensen and Toll, 1982; Adeniyi 1985) and to differentiate crop types and monitor crops over time (Odenweller and Johnson 1084; Wagner, 1992). Mishra *et al.*, (1994) also used data from Systèmme Probatoire la Observation de Terre (SPOT) and the Indian Remote Sensing Satellite (IRS-IB) to quantify forest and natural resource depletion in India.

2.2.1. Nature of change detection

The rate of change in land parameters vary greatly by category and location e.g. residential development on the agriculture lands in the rural-urban fringe occur at a much faster rate than the regeneration of clear cut land to forest (Estes *et al.*, 1982). Hence the variation in rate of change must be assessed carefully from both a functional and geographical perspective to provide appropriately stratified units amenable to the systematic extraction of land use and land cover change (Estes *et al.*, 1982). A basic assumption in digital change detection is that a pixel will have different brightness values on two dates if the land use change from one land cover type to the other (Jensen, 1986).

According to Jensen (1986), a change detection method should be based on a sensor system that has systematic periods between overflights, records imagery of the same geographic area at the same time of the day to minimize diurnal sun angle effect, maintains same scale and look-angle geometry, reduces relief displacement, and, records reflected radiant flux in consistent and useful spectral regions. Satisfying these conditions enable the analysis of spectral and temporal characteristics of digital imagery or aerial photographs to obtain change statistics and produce land use and land cover change maps. Green *et al.* (1994) characterized land use and land cover change detection techniques as those that make the detection of change possible, measure the extent and magnitude of change, update maps or GIS overlays; and, estimate the impact of change on environmental and economic conditions.

The present trend in change detection and monitoring are based primarily on map-to-map and image-to-image comparison (Green *et al.,* 1994). The overall goals of change detection and monitoring (Estes *et al.,* 1982; Jensen, 1986; Green *et al.,* 1994) are:

i. to compare spatial representation of two points in time by controlling all variances caused by differences in variables that are not of interest to the analyst and resource manager,

ii. to measure the extent and direction of change caused by differences in variables that are of interest to the analyst, resource manager or planner.

2.3. REMOTE SENSING AND GEOGRAPHIC INFORMATION SYSTEMS

2.3.1. Integration of Remote Sensing and GIS for the detection of land cover changes.

Effective integration of remote sensing and GIS can decrease the cost of gathering resource information and increase the detail of such information (Green, 1992). Verbyla (1990) has observed that a useful approach in land use and land cover change detection is to incorporate classified digital imagery and ground verification into a GIS. The flexible design of GIS also gives the analyst the ability to simulate the impact of land use and land cover changes (Green, 1992).

On the other hand, GIS layers can be incorporated into the processing of digital imagery to increase the accuracy of the classification. Westmoreland and Stow (1992) have indicated that optimum uses of ancillary data to facilitate digital image analysis invariably require an understanding of these data in the context of a particular application and how the data will contribute to the interpretation process. Generally, integrating GIS and image processing requires the first level capabilities identified by Ehlers *et al.* (1989), i.e. the ability to:

- overlay GIS directly on image data;
- move results of image processing into a GIS or GIS analysis into the image processing software; and,
- assess information in a GIS to facilitate the image processing task.

Various researchers have used integrated image processing and GIS to assess deforestation (eg. Sader and Joyce 1988; Lukede *et al.*, 1990; Sader, 1995). Strong correlations were reported between land clearing and proximity to roads, as well as, population and land clearing patterns (Sader and Joyce, 1988; Ludeke *et al.*, 1990; Southgate and Basterrechea, 1992). Sader *et al.* (1991) observed that estimates of vegetation growth and land use conversion trends are rarely reported. According to Sader (1995) this is because most remote sensing and GIS analysis of forest change only emphasize forest clearing.

The effectiveness of integrated GIS and image analysis can be enhanced by Expert Systems i.e computer programs that stimulate the reasoning of a human expert within a specific problem domain. The expert systems have been used to improve information extracted from remotely sensed images by automated merging of spatial ancillary data with the spectral data (e.g., Ripple and Ulshoefer 1987; Moller-Jensen 1990; Gyamfi-Aidoo 1991).

2.3.2. Error sources and accumulation

There is concern that the introduction of digital imagery has led to a false sense of accuracy (Thapa and Bossler, 1992). For example, Lunetta *et al.*(1991) indicated that performing spatial data analysis with data of unknown accuracy or incompatible error usually result in inaccurate products and subsequent misguided decisions by resource managers and planners.

The process of integrating remotely sensed data into a GIS includes data acquisition, processing, analysis, conversion, error assessment and final presentation (Lunetta *et al.,* 1991). The potential sources of error which may enter at various stages of processing are shown in Figure 1. The error may be transferred from one process stage to the other unknown to the analyst until it is manifested in the final product. According to Lunetta *et al.* (1991), this error may accumulate throughout the process in an additive or multiplicative fashion, and individual process errors may be overshadowed by other errors that are of greater magnitude. The amount of error entering the

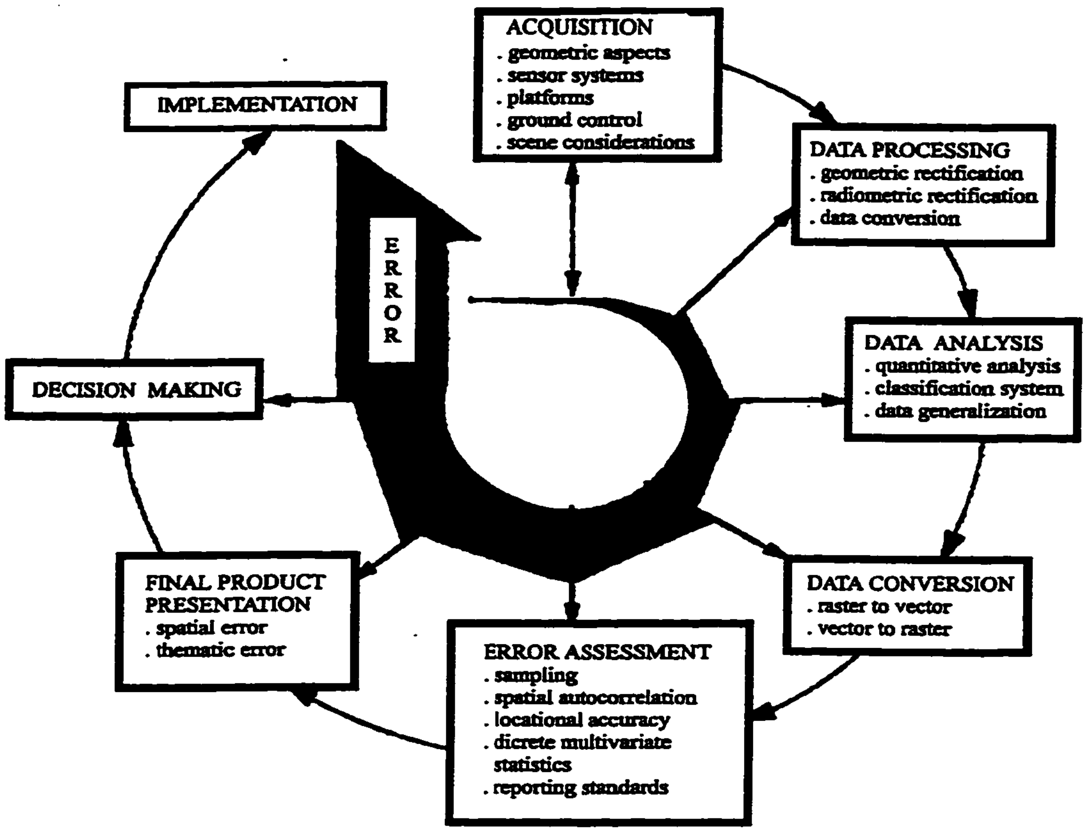


Figure 1. Error accumulation in a typical remote sensing processing flow.

(Source: Lunetta *et al.*, 1991).

system at each stage of the process may be estimated theoretically using the law of propagation of errors (Drummond, 1990). However, error assessment is usually only feasible at the end of the analysis (Lunetta *et al.*, 1991).

Remotely sensed data is considered as a primary source of data for GIS, whereas data extracted from maps, charts, graphs etc. constitute secondary data sources (Thapa and Burtch, 1990). Error associated with secondary data sources (Thapa and Burtch, 1990) include:

- error due to plotting control
- error due to compilation
- error introduced in drawing
- error due to map generalization
- error due to map reproduction
- error due to colour registration
- error due to deformation of map paper from shrinkage
- error due to uncertainty in definition of features
- error due to feature exaggeration
- error due to digitizing or scanning

2.3.3. State of Remote Sensing and GIS application in Ghana

The study pertains to an area in Ghana where the use of remote sensing and GIS is at the developmental stages. This section focuses on some of the issues related to efforts at integrating these technologies into resource management and planning in Ghana. The use of remotely sensed data in natural resource management in Ghana dates back to the 1960's. In particular, Adu (1969) used aerial photographs to produce soils, vegetation, land use and drainage maps for the Upper East Region. Also, Landsat MSS and ancillary data were used to produce land use map for the Upper East Region (IFAD, 1990). Other uses of remote sensing in the country include the forest inventory in the forest zone of Ghana (Agurgo, 1992).

In 1986, the EPC explored the use of GIS technology for resource management and planning in the country. For example, GIS was used in assessing land degradation in northern Ghana (Gyamfi-Aidoo, 1987) and pollution control in Obuasi near Kumasi (Danso, 1992). Since then, there have been a series of Remote Sensing/GIS workshops under the Ghana Environmental and Resource Monitoring Project (GERMP) and the National Environmental Action Plan (EPC, 1992). An important component of these workshops is that, the benefits of integrating remote sensing and GIS technologies to provide timely and cost effective data for resource management in Ghana have been acknowledged by both researchers and the user community (EPC, 1992). This is important because the lack of effective monitoring systems in the country have allowed gradual changes in the environment.to continue unnoticed until they become catastrophic. In most cases, the problem is not so much of the availability of resource information, but rather its accessibility (Gyamfi-Aidoo, 1987).

As part of the ongoing efforts to address the resource database problem, the Remote Sensing Application Unit in the University of Ghana is engaged in producing digital database for research, evaluation and monitoring of land and water resources in the Country (Agyepong, 1992). In addition to this, the Planning Division of the Forestry Department is mapping out the extent of forest clearing in the Forest zones located mainly in Southern Ghana (Agurgo, 1992). The Institute of Renewable Natural Resources at the University of Science and Technology in Ghana, has engaged in remote sensing workshops and acquired image analysis capacity to carry out land inventory task and to incorporate remote sensing and GIS into the academic programs (Runesson, pers. Comm.) The adoption of GIS and remote sensing technologies in Ghana, will therefore play an important role in resource management in the near future.

2.4. CATCHMENT HYDROLOGIC RESPONSE

Knowledge of changes in land cover or land use alone is not sufficient unless it is linked to the impact on the environmental processes. Therefore the role of land use or cover in catchment hydrologic response, and, techniques used in predicting this response are reviewed briefly in this section. The hydrologic response of catchment areas to rainfall depends on an interplay between climatic, geological and land use or land cover variables (Bruijnzeel, 1993). This hydrologic response is usually manifested in streamflow.

2.4.1. Sources of streamflow

Streamflow in a catchment is derived from surface flow and baseflow. Surface flow or direct runoff is the water that collects in a channel in direct response to precipitation while baseflow sustains streamflow during interstorm periods, especially in the dry seasons (Satterlund and Adams, 1992). Surface flow collects in the stream channel as channel interception and overland flow. Since Hewlett (1961a) proposed the *variable source area concept* of catchment hydrologic response to rainfall, various studies have been carried out to validate this concept (Satterlund and Adams, 1992). The *variable source area concept* states that, a portion of the catchment actively generates runoff in response to precipitation. This portion of the catchment changes, i.e., it expands during rainstorm and shrinks after the end of the storm. In semi-arid areas, Hortonian surface runoff are generated more frequently and in greater amounts near the channel due to reduced chances of infiltration near the channel (Lane *et al.*, 1978; Yair *et al.*, 1980).

Generally, runoff response of a catchment varies in recognizable patterns with seasons as shown in Figure 2. Various catchment responses to precipitation also occur over long periods of time During droughts, only a small portion of the precipitation appears as streamflow since most of the precipitation go to replenish depleted retention storage. In times of excessive precipitation, portions of the watershed that seldom contribute to streamflow become active contributors of runoff.

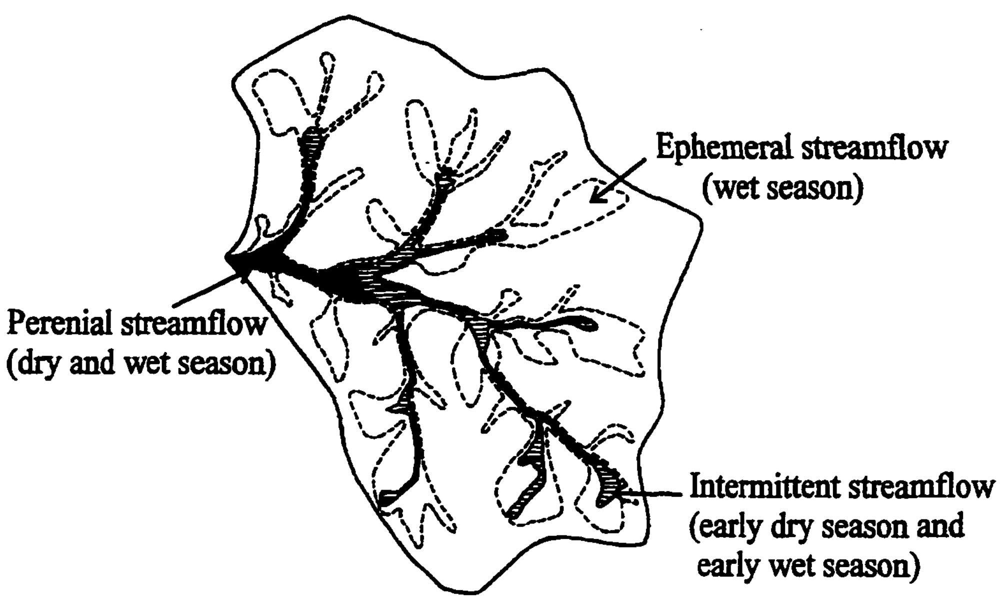


Figure 2. Pattern of seasonal variation in source areas of runoff generation. (Modified from Satterlund and Adams, 1992).

2.4.2. Land cover and flood damage

Floods occur when streamflow exceeds river or channel capacity resulting in overbank flow (Satterlund and Adams, 1992). Floods are also envisaged as a damaging flow of water that results from overtopping of the banks of creeks and rivers after extreme rainstorms (Hewlett and Doss, 1984). In particular, floods are generated by storms that occur towards the end of the rainy season when the soils have been soaked up thoroughly by antecedent moisture (Mooley and Parthasarathy, 1983). The sources of flood waters are the many small tributaries above the flood plain.

Damages in the small tributaries, or source areas, usually occur as field erosion, road washouts, and sedimentation that affect farming and other land use activities. Large rainstorms of long duration may have little on-site impact on the source areas, but can cause considerable damage around creeks and rivers downstream. Storm damage in these areas is usually due to the energy of flowing water.

It is important to note that the impact of land cover change, especially vegetation, on catchment hydrologic response have been a subject of much controversy among researchers. Some researchers have indicated that decrease in vegetative cover will lead to high peak flows and floods, widespread erosion, and long term stream dry up (e.g. Hewlett, 1970; Noteboom, 1987; Smiett, 1987; Satterlund and Adams, 1992; Fujieda *et al.*, 1993). Other researchers have suggested that removal of vegetative cover is important for increase in streamflow during the dry season and that the floods do occur even in the absence of land use disturbances (e.g. Hamilton, 1983; Bruijnzeel, 1986 and 1992; Bartaya, 1989; Pereira, 1989). However, this view is unpopular among conservationists and resource managers who are mainly concerned about long term impact of vegetation removal.

Since the magnitude of catchment response to precipitation is strongly influenced by its soil moisture status, increases in soil moisture levels due vegetation removal can result in more vigorous runoff (Ward, 1984). Vegetation clearing and soil exposure in land preparation are usually assigned an important role in flood water production in most commonly used hydrological methods, e.g. the United States Soil Conservation Service (SCS) runoff curve number method assigns curve numbers for predicting surface flow on the basis of six forest hydrologic conditions (SCS, 1964).

Peak flows at the basin outlet are responsive to land use activities like land clearing. Increases in source area peak flows may however have less significant effect on downstream floods (Hewlett, 1982a; Hewlett and Doss, 1984; Bruijnzeel, 1993). A description of effect of vegetation removal on the *variable source area* will help explain the different responses of streamflow peaks and volumes. After the vegetation is cleared, the stored water seeps downstream and tends to maintain a wider zone of wet soil along the stream channel than would have happened if the vegetation were left undisturbed and evapotranspiration losses were high. The wetter and wider source area yields larger flow volumes of both subsurface surface flow and baseflow than would be the case under vegetation. For a given rainstorm, the wider source area on cleared land generates more surface flow than the narrower source area under vegetation or forest cover (Satterlund and Adams, 1992).

Peak flows are largely a channel phenomenon and originate mainly from surface channels and storm period extensions. Channel extensions often occur in cleared areas since old rills and gullies are reactivated and new ones are formed. As the gullies deliver small but rapid flows during a rainstorm, these waters pile on top of the rising subsurface flow arriving from the wetted areas. It is therefore the change from subsurface flow to overland flow, that releases strong and increased peak flows during a heavy rainstorm which result in a quick rise in the storm hydrograph (Hewlett and Doss, 1984; Bruijnzeel, 1990; Malmer, 1993; Bruijnzeel, 1993). Although attempts at routing flood peaks from source areas through river systems in the tropics are promising, the effects of land use on such peaks still require extensive research work (Bruijnzeel, 1993).

The erosivity of surface flow (i.e. its ability to cause erosion) is another component that is of much concern to watershed managers. The increase in erosivity of surface flow in the source areas is strongly affected by local discharges, but not directly related to the volume of flood waters moving downstream. This is because floods consists of additive volumes from many different tributaries which may be subjected to different land use activities that vary in time and space (Hewlett and Doss, 1984).

<u>Savanna zones</u> - Since the study area is located in a savanna vegetation zone, the particular case of savannas is reviewed briefly. Savanna areas are characterized by highly variable precipitation and moisture deficiency for most part of the year. Despite the relatively low flows of this region, floods can be a major problem. Surface flow increases due to deforestation in these areas are less

consistent than in high closed forests but during the wet years high increases in runoff are likely (Satterlund and Adams, 1993). Most flows in savanna areas are derived from surface runoff. A combination of long dry seasons, highly inflammable fuel (dead vegetation), non-wettable soils, increasing land use and intense wet season make the flood hazard of savanna areas particularly great (Anderson, 1976). Especially in agricultural areas where bare soil is exposed, the threat of erosion from high intensity rainfall cannot be overemphasized.

2.4.3. Catchment modelling techniques

The models used in simulating watershed hydrologic response are generally classified as material and formal or mathematical (Ponce,. 1989). Material models include the use of physical representation of the prototype e.g. rainfall simulators and experimental watersheds. Ponce (1989) indicated that material models are usually limited in applicability and quite expensive. Mathematical models are usually preferred for catchment modelling because they are readily available, highly flexible, and comparatively inexpensive. Generally, mathematical models can be grouped into deterministic, conceptual, parametric and probabilistic models.

Probabilistic models are based on the law of chance and probability and are opposite in meaning to deterministic models (Ponce, 1989). The inherent randomness of most hydrologic processes require a probabilistic approach to the analysis of such processes (Bedient and Huber, 1992). There are two types of probabilistic models, namely, stochastic and statistical methods. Stochastic methods are used in the synthetic generation of hydrologic time series like daily streamflow, based on their random components e.g. Monte Carlo simulations (Yevjevich, 1972; Bras and Rodriguez-Iturbe, 1985). Statistical methods depend on measured data in predicting the behaviour or recurrence of such hydrologic phenomena as streamflow and floods (Ponce 1989). The flood frequency analysis used in this study is a typical statistical method.

Present trends in watershed analysis indicate an increasing use of deterministic and parametric models to evaluate various aspects of streamflow, erosion, canopy interception and evapotranspiration (e.g., Burges and Wigmosta, 1990; McCarthy *et al.*, 1992; Band *et al.*, 1993; Kowen *et al.*, 1993). Statistical models are still useful in hydrologic analysis (e.g., Branson and Owen, 1970; Alley and Burns, 1982; Fujieda *et al.*, 1993). Ponce (1989) noted that frequency analysis is very useful in estimating the recurrence of floods of given magnitudes. Hjalmarson and Thomas (1989) cautioned, however, that flood frequency relations for streams in dry areas are difficult to estimate due mainly to the extreme temporal and spatial variability of floods, many years of no streamflow records, and short periods of systematic annual peaks. Ponce (1989) also mentioned that fitting three parameter distributions to data from short record periods may imply an upper limit that may be lower than the actual limit of the flood magnitude.

The concept of return period is very important to flood frequency relations. An annual maximum event has a return period or recurrence interval of T years if its magnitude is equalled or exceeded once on the average every T years (Bedient and Huber, 1992). The reciprocal of T is the exceedence probability of an event i.e., the probability that the event is equalled or exceeded in any one year. Bedient and Huber (1992) have indicated however that return periods need not be limited to years, e.g., a 6-month rainfall has the probability of 1/6 of being equalled or exceeded in any one month.

3.0. STUDY AREA

3.1. LOCATION AND CLIMATE

The Tamne River Basin is located in the Bawku East district of the Upper East Region of Ghana as shown in Figure 3. It covers an area of 886 square kilometres and occupies about seventy percent of the Bawku East district including the district capital Bawku and some major towns like Garu and Manga. The basin lies within latitudes 10° 45' N and 11° 11' N and longitude 0° 25' W and 0° (i.e., the prime meridian).

The climate of the area comprise a single wet season from April to October and a distinct dry season. The Harmattan, a strong dry wind from the Sahara desert in the north, influences area during the dry season. In the wet season, the Monsoon (warm and humid air masses from the Atlantic Ocean) influences the area from the south. The onset of the dry season, followed the wet season, is dependent on the 'Inter-Tropical Discontinuity' that separates the Harmattan from the Monsoon. The average annual precipitation is estimated at 1100 mm (Dankwa, 1974). The wet season is characterized by short duration rainfall (i.e., two to three hours) and rainfall intensities of at least 200 mm per hour are common (Walker, 1962; Adu, 1969). The rainfall pattern show high inter-annual variability in time of onset and duration of rain (Ofori-Sarpong, 1986). In addition, seasonal flooding and waterlogging are common features of the peak period of the wet season, i.e., around August and September (Dodoo, 1975).

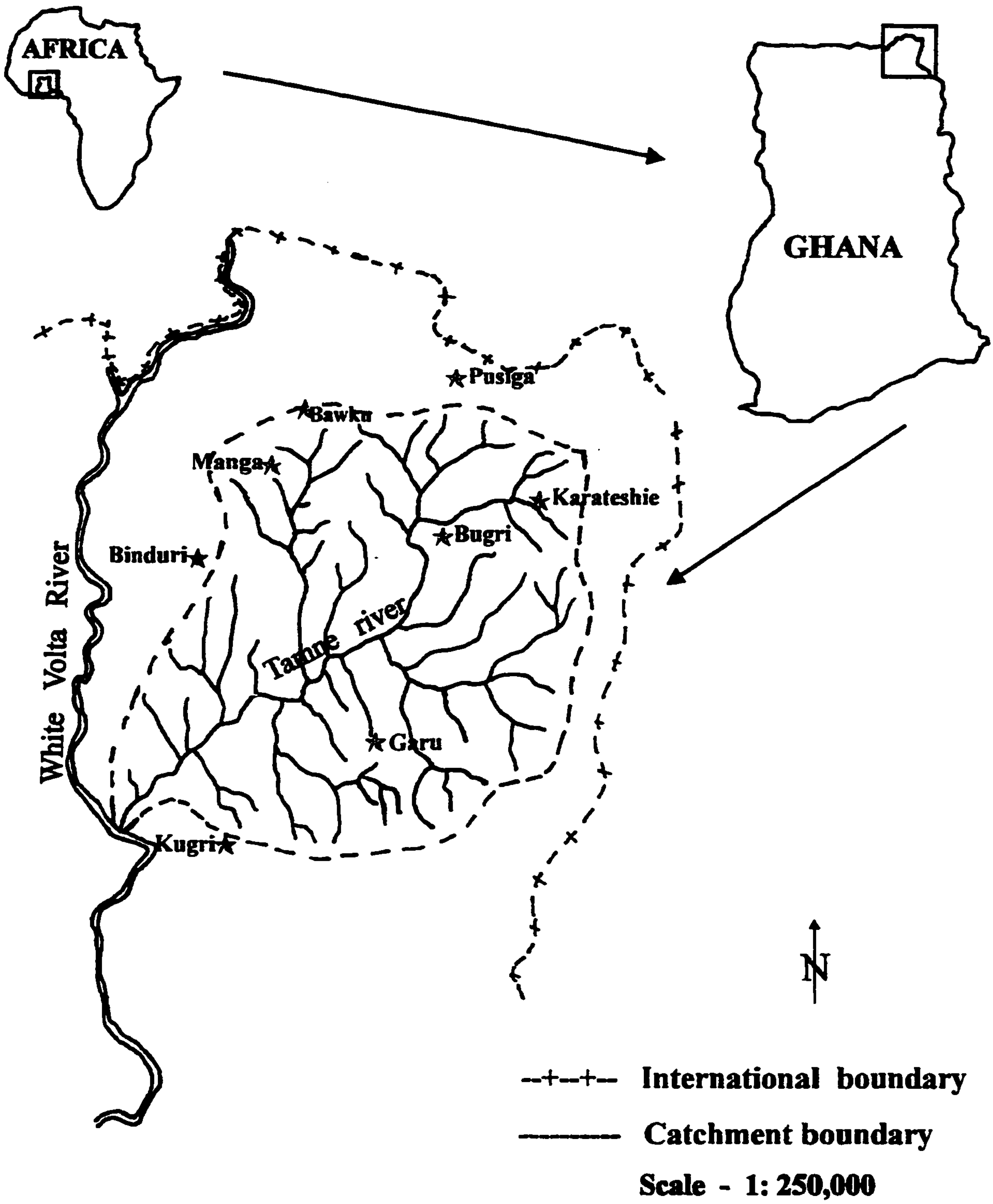


Figure 3. Study area of Tamne River Basin in the Upper East Region of Ghana

3.2. GEOLOGY AND SOILS

A complete description of the geology and soils in the area is given by Adu (1969). The soils here were developed over granitic Birrimian rocks, Voltaic rocks and old alluvial rocks of mixed and recent origin (Adu, 1969). Savanna ochrosols, savanna oxysols, and ground water laterites constitute the main soil groups in the area. The soils are poor in organic matter and they are often impervious to rainfall infiltration. Leaching removes soil nutrients while high evapotranspiration rates promote the formation of 'hard pans' (crusted earth) on the soil surface.

Despite the gently undulating terrain of the basin, the soils here are susceptible to sheet and gully erosion which result from improper land use practices, low water holding capacity of the soils and occasional torrential rainfall (Department of Geography, 1992). Stream bank erosion is also common along the main channel and tributaries. The increase in stream bank erosion is not due to changes in base level of the river or streams, but to changes in climate and vegetation which result in runoff increases.

3.3 VEGETATION AND LAND USE

The Tamne River Basin is located within two vegetation zones, namely, Sudan savanna that lies to the extreme north including Bawku, and the degraded form of Guinea savanna which extends below Garu. The Sudan savanna is characterized by very short and widely scattered 'dwarfish' trees (Dickson and Benneh, 1972). The Guinea savanna is also characterized by medium to tall grasses and a higher density of trees. Some of the dominant trees found here include Baobab

(*Adansonia digitata*), Shea butter (*Butyrospermum paradoxom*), Acacia (*Acacia sp.), Lophira sp.*, *Anogeiesus sp.* and *Bombax combretum* (Asamoah, 1992). There are also exotic tree species that were introduced by the Ministry of Forestry, e.g. Teak (*Tectona grandis*), Neem (*Azardirachta indica*) and Cassia (*Cassia siamea*).

The land use in the Tamne Basin is predominantly subsistent agriculture. Most of the area is representative of compound farming i.e., farming around homesteads and annual cropping in a permanent agriculture as shown in Figure 4 (Dickson and Benneh, 1972; Dodoo, 1975). The major farming systems are shown in Figure 5, but, the farming systems that are relevant to the study are now explained. Mixed farming, i.e., an integration of compound farming with livestock, is the most common farming system in the basin. Lowland and upland bush fallow system comprise the cultivation of staples like peanuts (groundnuts), guinea corn and millet, through rain fed land rotation. The farms are located in lowland and upland areas at distances of about one to six kilometres from the compound farms. The flood system involves the use of seasonally flooded areas for swamp rice during the wet season and vegetables in the dry season, provided the ground is still sufficiently moist. The system involves the use of simple water control measures such as small handmade ditches and gutters (Department of Geography, 1992).

The livestock systems are characterized by the rearing of poultry, goat, sheep, and cattle. However, cattle dominate pure livestock systems here and the Bawku East has the highest concentrations of cattle in the country. During the wet (or cropping) season, the cattle are held in kraals to avoid damage to crops. In the dry season, the cattle are allowed to graze freely in the

Figure 4. A homestead on a compound farm.

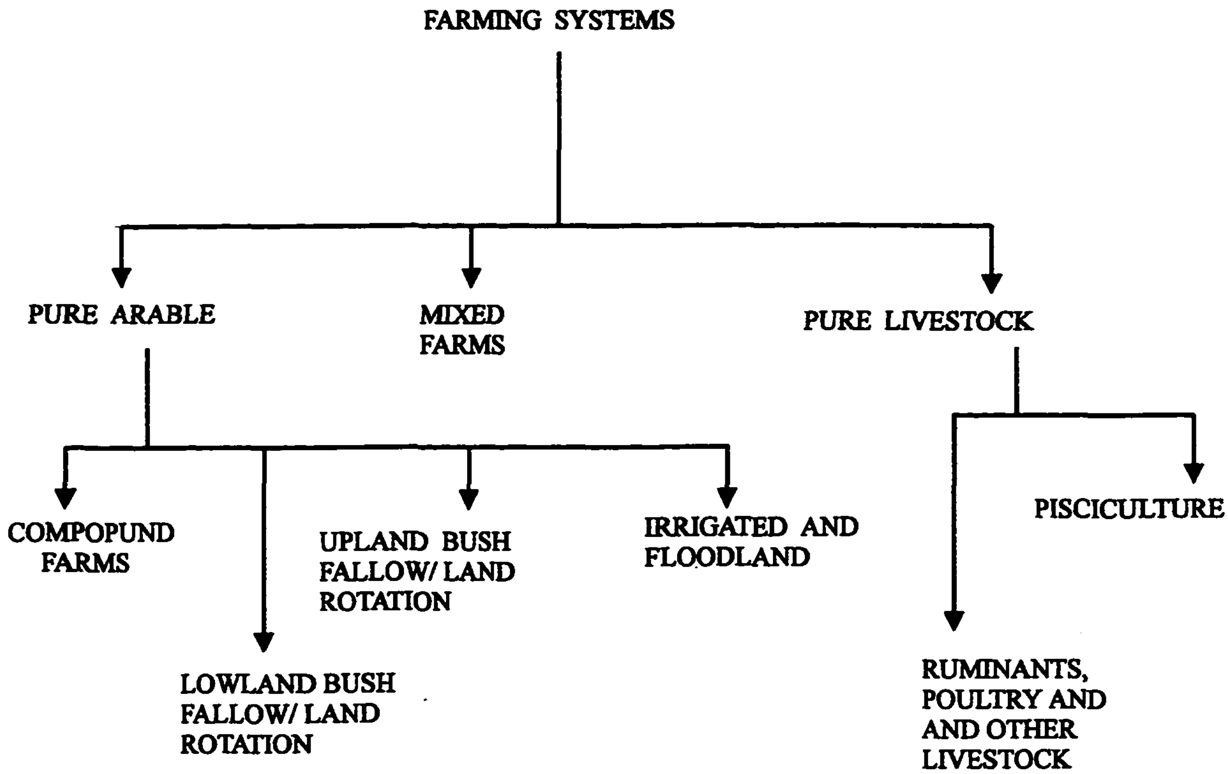


Figure 5. Schematic representation of farming systems in Upper East Region of Ghana. (Source: Department of Geography, 1992)

bush and harvested fields. Overstocking is common because the quantity of the cattle are regarded as status symbol and this practice constitute a major threat of overgrazing.

With regards to water supply, simple irrigation systems involving dams and dugouts were constructed in the 1950's and 1960's but most of them are presently in a state of disrepair (IFAD, 1990). Five dams and dugouts in the Tamne basin, including Bugri and Tarinyanga have been marked for rehabilitation (CARDS and GAS, 1994). Another dam to serve five communities is underway for the Kugur branch of the Bawku East Small Scale Farmers Association.

3.4. POPULATION

The nature of population dynamics in the Tamne River Basin is reflected in the population reports for the Bawku East District (Statistical Service, 1984). The population of the Bawku East district is predominantly rural (i.e., 79.2%) and a growing urban centre of Bawku (i.e, 20.8%). In addition, the population in the district is characterized by a consistent increase since 1960. The 1970 to 1984 growth rate for Bawku East district is estimated at 2.6% and that of Bawku alone is 3.6%. The 1984 population estimate for the Bawku East district was 196,412, and this implies that the population may reach 372349 in 1996. The Bawku East district has one of the highest population densities in the Upper East Region and the 1984 estimate is about 160 people per square kilometre. The consequence of the high population growth rate and population density is that of increased land pressure and environmental degradation in this predominantly rural and agricultural area.

4.0. METHODOLOGY

4.1. FIELD WORK

Field work in the Tamne River Basin was done during the wet season (i.e., June through August) of 1994. Although the satellite images used in the study were dry season images, the field work could not be done during this period due to the overall academic schedule. Before visiting the basin, agricultural and research officers who have worked or have research interest in the area, were contacted to put the study within the context of the realities of research work in northern Ghana. The choice of sites for such visits was based on accessibility and the advice of extension staff and researchers within and outside the basin.

A motorcycle was used to traverse the area. Some towns and villages visited were Bawku, Manga, Kaadi (near Binduri), Kugur, Bugri and Garu, as well as the main watercourse of the Tamne river. The field trip was carried out to: (a) observe the state of the Tamne river and its tributaries, vegetation, land use, erosion, flooding and waterlogging problems; and (b) collect exploratory data on the farming characteristics in the basin.

4.2. DATA SOURCES

The data sets used for the study were obtained from the following sources. Soils, vegetation/land use and elevation maps (1:250,000 scale) by Adu (1969) were obtained from the Soil Research

Institute of the Council for Scientific and Industrial Research (CSIR), Ghana. A 1959 drainage map (1:250,000 scale) of the White Volta catchment was obtained from the Water Resource Research Institute of the CSIR, Ghana. Topographic maps (1:50,000 scale) covering the Upper East Region were obtained from Survey Department in Accra, Ghana. Rainfall data, from 1960 to 1994 were obtained from the Accra and Bolgatanga offices of the Meteorological Services Department, Ghana. Water discharge data were obtained from the Architectural and Engineering services Corporation (Hydro Division), Ghana.

Landsat 1991 Thematic Mapper (TM) satellite image was obtained from EOSAT, Maryland, USA. Also, 1975 Landsat Multispectral Scanner satellite image (MSS) was obtained from the EROS Data Centre, South Dakota, USA. The choice of dates for the digital imagery was based mainly on the availability of cloud free images and at least, a ten-year interval. Aerial photographs were not used in the study because the latest photographs were taken in the 1960's and early 1970's. Some exploratory information on farming characteristics were also collected during field work.

4.3. HYDROLOGIC ANALYSIS

4.3.1. Data pre-processing

Rainfall data - Daily mean rainfall depth records available from three gauging stations within the Tamne River Basin, i.e., Bawku, Garu, and Manga were initially scrutinized for their quality. The records for Bawku showed serious gaps that rendered them unsuitable for further analysis. The records for the Garu station also contained a big gap between 1965 and 1976, however, the bulk of the data between 1977 and 1993 was useful. Also, rainfall data for the Manga station were almost complete for the record period of 1960 to 1993, with a few gaps that were not considered as very serious.

Additional data were obtained from Binduri and Kugri which lie immediately outside the study area. However, these data sets also contained some gaps. The Thiessen polygons method was used to estimate monthly average rainfall for the Tamne River Basin. Graphical and comparison of means methods were used to evaluate any differences in the average rainfall for the Tamne River Basin and that of the Manga station as shown in Appendix I. There was no significant difference between the means of the two data sets. The rainfall records from Manga station were then chosen to approximate the rainfall conditions in the Tamne watershed. Considering the fact that the study area is a large watershed, rainfall here is likely to vary both in time and in space (Ponce, 1989). However, this approximation was appropriate given the availability and quality of rainfall records for the stations in and around the Tame watershed.

Water discharge data - Initial evaluation of daily mean discharge records for the quality of data showed gaps, especially, from 1977 to 1979 and 1981 to 1989. Despite these gaps the data were preprocessed for further analysis (Appendix II), because, it was not possible to get complete data from adjacent catchments. Monthly and annual (i.e., calender year) mean water discharges were computed from hydrologic year records. The hydrologic year in Ghana are March to February. Peak discharges (peak flows) for the calender years of the record period were also identified and the peak flows for 1966 to 1976 were selected for flood frequency analysis (i.e., the use of statistical distributions to estimate the recurrence of flood or peak flows of certain magnitude).

4.3.2. Rainfall - streamflow relations

Monthly variation in mean rainfall depth, monthly mean discharge and mean temperature were plotted for the study area to provide a general description of the hydro-climatological condition in the area. The months of July, August, September were found to be the wettest months. The mean discharges were therefore categorized into wet season flows (i.e., mean discharge for the wettest months) and annual mean discharge (i.e., mean water discharge for the calender year). Simple test of hypothesis were done for peak flows, wet season flows and annual mean discharge to determine whether the values for 1980 to 1993 belong to the population based on the mean and standard deviation of the flows from 1966 to 1976. The periods prior to and after 1976 were chosen because the satellite images used in the study were from 1975 and 1991 respectively.

Hypothesis testing - Natural phenomena like runoff and peak flows are not normally distributed, but their logarithms are (Ponce, 1989). The peak flow (x) records were transformed into lognormal values, i.e., $y = \ln x$. A normal probability plot of y and recurrence year produced a fairly normal distribution. A normal distribution was then assumed for the transformation of peak flows. The parameters of the normal distribution of a population are mean (μ) and standard deviation (σ). The normal variate, z, is normally distributed with zero mean and a unit standard deviation. For the population of peak flows,

$$y = \mu + z\sigma$$

where z is also the frequency factor of the normal distribution.

At 95 % confidence limit, $z = 1.96$. For a population of y values from 1966 to 1976, $\mu = 3.24$ and $\sigma = 0.31$, the upper confidence limit of the y is given as:

$$y = 3.24 + 1.96\,(0.31)$$

$$y = 3.85$$

The number of years that peak flows were above the mean value and the number of years that the peak flows were below the mean were computed for 1966 to 1976 and 1980 to 1993 respectively. The computed numbers, together with scatter plots, see Appendix III (c), were assessed for any indications of changes in pattern. To confirm the changes, the means of the two groups of data were compared as follows.

For lognormal of peak flows from 1966 to 1976,

number of flows $(n_1) = 11$; mean $(\bar{x}_{11}) = 3.24$; degrees of freedom (df) = 10

$$\Sigma X = 116.27,$$

$$(\Sigma X)^2 \div n_1 = (35.60)^2 \div 11 = 115.21,$$

$$\Sigma x = \Sigma X - (\Sigma X)^2 \div n_1 = 1.06$$

For lognormal of peak flows from 1980 to 1993,

number of flows $(n_2) = 5$; mean $(\bar{x}_4) = 3.35$; degrees of freedom (df) = 4

$$\Sigma X^2 = 45.16,$$

$$(\Sigma X)^2 \div n_2 = (16.50)^2 \div 5 = 54.43,$$

$$\Sigma x = \Sigma X^2 - (\Sigma X)^2 \div n_2 = 0.39$$

The pooled variance was $S^2 = (1.06 + 0.39) \div (10 + 4)$

i.e., $S^2 = 0.10$

Comparing means,

$$t = \frac{(\bar{x}_{11} - \bar{x}_5)}{\sqrt{S^2\left(\frac{(n_1 + n_2)}{(n_1 \times n_2)}\right)}}$$

i.e., $t = (-3.30 + -3.24) \div 0.19 = -0.32$

The whole procedure for hypothesis testing was repeated for wet season flows, annual mean water discharge and annual mean rainfall. Peak rainfall was not used here because of the high variability in the intensity and distribution of rainfall in semi-arid climates in the tropics.

4.3.3. Flood frequency analysis

Selection of data series - Annual maxima series (Table 2) comprising only one extreme value per year for the period 1966 to 1976 were used for the frequency analysis. When dealing with return periods of at least 10 years, annual maxima series is preferred to the annual exceedence series which considers all extreme values above a certain threshold (Ponce, 1989). Besides this, the annual maxima series ensures that extreme values are independently distributed (Bedient and Huber, 1992).

Table 2. Annual maximum series for Garu station

Year	Month of recurrence	Peak flow (m3/s)
1966	Sept.	15.18
1967	Aug.	21.35
1968	Aug.	26.36
1969	Sept.	24.15
1970	Sept.	33.78
1971	Sept.	49.24
1972	Sept.	23.98
1973	Aug.	20.93
1974	Oct.	18.12
1975	July	33.78
1976	Oct.	27.38

Plotting positions. Gringorten plotting position formula (Gringorten, 1963) was used to compute the return periods and associated probabilities. Also, the annual maxima series were ranked in descending order and their respective probability and return periods were calculated.

Flood frequency estimates - Some of the common cumulative density functions that are applied to floods or peak flows are; Normal, Lognormal, Three parameter lognormal (3LN), Gamma (Pearson type three), Log gamma (Log Pearson type three or LP3) and Generalized extreme value or Gumble extreme value type one (GEV). The normal, lognormal and gamma distributions are two-parameter distributions, while 3LN, LP3 and GEV are three parameter distributions. Generally, three parameter distributions yield better flood estimates than do the two parameter estimates (Ponce, 1989). This is because three parameter distributions account for the skew factor that is usually associated with hydrologic processes like streamflow hydrograph.

Consolidated Frequency Analysis (CFA) was used to do an initial analysis of the annual maximum series (Appendix IV). The methods usually employed in curve fitting include graphical, least square, moments, and maximum likelihood. The CFA employs the maximum likelihood method in which parameters of the distribution are selected in order to maximise the joint probabilities of the distribution (Ponce, 1989). After assessing the statistics of the CFA analysis, LP3 was rejected as a possible candidate for fitting of the annual maximum series. This was because the skew coefficient of 1.4 was higher than the acceptable value of 0.5. Although 3LN distribution had lower skew coefficient than GEV distribution, the latter was used to fit the Gringorten plotting positions for annual maxima series. This was because GEV has worldwide application (Ponce, 1989, Bedient and Huber, 1992) and Ghana in particular (Allotey, in litt., 24 Jan 1996; CARDS and GAS, 1994).

Maximum likelihood is difficult to compute, therefore moments method was used with GEV distribution to confirm the results produced by the CFA analysis. Although the maximum likelihood method is more effective than moments method, the latter is the most commonly used curve fitting method (Ponce, 1989; Bedient and Huber, 1992). The cumulative density function

(CDF) or probability of non-exceedence of GEV is,

$$F(x) = e^{-e^{-y}}$$

The probability of exceedance is the possibility that a particular event will be exceeded or overtaken at any particular recurrence interval. The complementary probability to F(x), i.e., the probability of exceedence, is usually employed in flood frequency analysis. Mean ($\bar{x}$) and standard deviation (s) were calculated from the annual maxima series. The standard deviation was calculated using "n" as the divisor instead of "n - 1" (Lattenmaier and Burges, 1982).

Following an approach outlined by Ponce (1989) and considering the modifications to GEV distribution by Lattenmaier and Burges (1982), estimates of flood frequency for the selected return periods and associated probabilities were derived. A Gumbel (reduced) variate (y) was calculated as follows:

$$y = -\ln\left[\ln\left(\frac{T}{(T-1)}\right)\right]$$

where T and ln are return period and lognormal respectively. Flood discharge (x) for each Gumbel variate was calculated using the formula proposed by Lattenmaier and Burges (1982), i.e., for

$$\bar{y}_n = 0.5772 \text{ and } \sigma_n = 1.2825,$$

$$x = \bar{x} + (0.78y - 0.45)s$$

where $\bar{y}_n$ and σ_n are mean and standard deviations of the Gumbel reduced variate respectively.

4.4. LAND COVER CHANGE ANALYSIS

The land cover change analysis was undertaken by integrating image processing and GIS technologies. The image processing was done with ERDAS image processing software by Earth Resource Data Analysis Systems (ERDAS) Incorporated. Arc/Info software, Environmental Systems Research Incorporated (ESRI), was used to create GIS coverages and for map creation. Both softwares were used in UNIX and PC environments. A flow chart of the approach used in the land cover change analysis is shown in Figure 6.

4.4.1. Data pre-processing

GIS coverages - Six coverages were created using the capabilities of PC Arc/Info software (ESRI, 1992). These coverages namely, stream, roads, vegetation/land use, elevation, location and clip coverage, were later used to improve the classification of the satellite images. All the coverages were digitized from the 1:250,000 maps. A residual mean square error (RMS) of 0.001 inches was maintained throughout digitizing process, to reduce any chances of digitizing errors. The digitized coverages were edited, topology was established and attribute data were then added to the various coverages. The final coverages were later transformed to fit the Transverse Mercator imperial coordinate system currently in use in Ghana. A transformation accuracy of 99.56 feet (i.e., 30.05 metres) at map scale was considered acceptable for the study.

Landsat satellite data - The Landsat MSS and TM images are shown in figures 7 and 8 respectively. The seven original channels of the TM image were reduced to five channels by eliminating unwanted channels, i.e., one and six. Channels four and seven were offset by 61

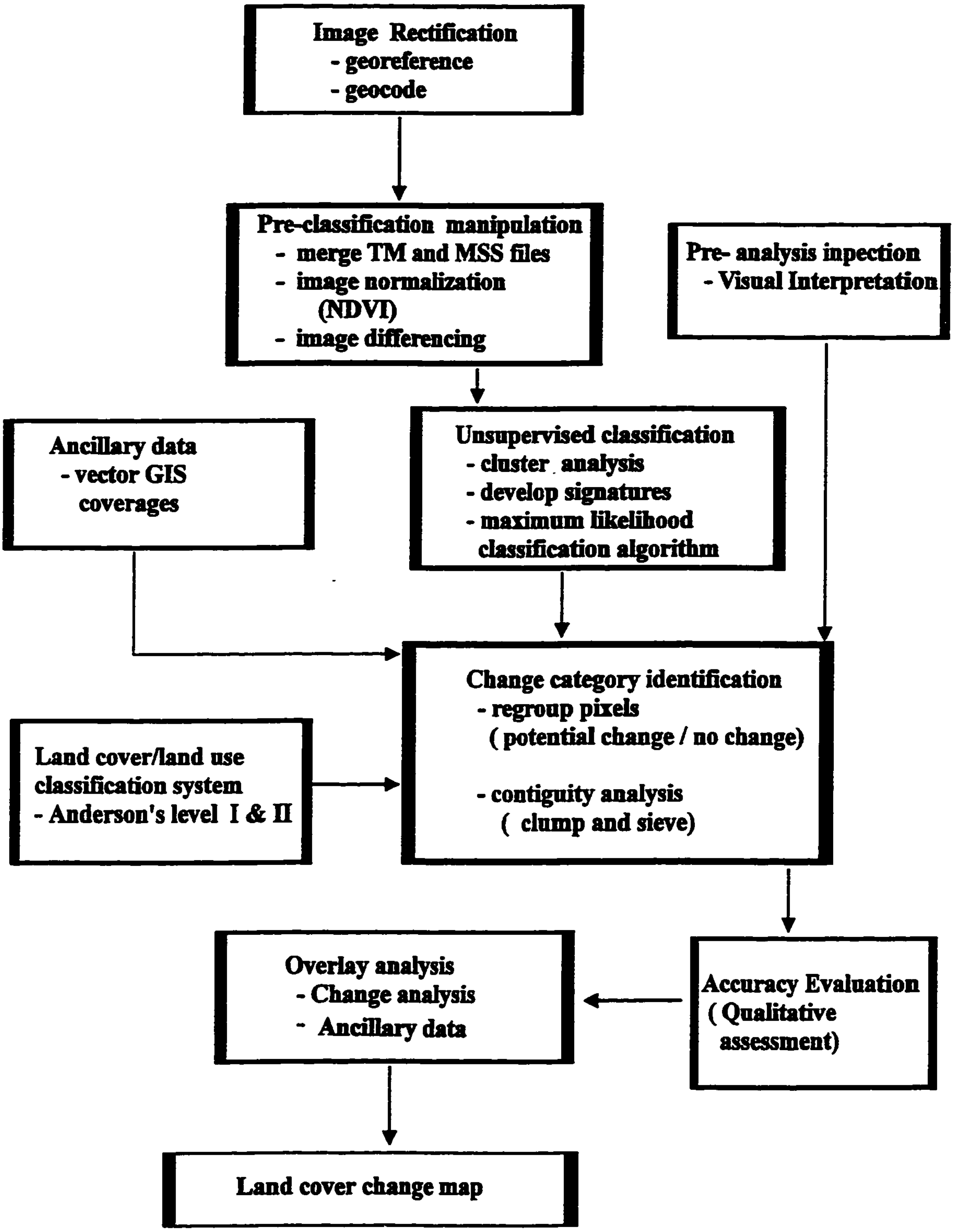


Figure 6. Flow chart of land cover change analysis for Tamne River Basin

pixels by the data vendor. These offsets were fixed by use of *subset* procedures in ERDAS. The 1991 TM scene of Northeastern Ghana was georeferenced to the Transverse Mercator coordinate system by image to map registration. Four topographic maps (1:50,000 scale) were used for the registration. Fifty-eight ground control points (gcps') that were visible on the TM scene, were selected from the maps. Thirty three gcps were deleted during the transformation process in order to yield an RMS tolerance of one pixel. A first order transformation (i.e., a linear least square regression) was used to delete the 33 gcps. The remaining gcps were used to generate a transformation coefficient matrix file. Care was taken to ensure that the gcps' were evenly distributed over the scene area. The matrix file was then used to resample the TM image through a cubic convolution. The spatial resolution of the TM data was changed from 30 metres to 50 metres.

The 1975 MSS satellite image was rectified i.e, geocoded, to the 1991 TM image. Two scenes of the 1975 data for the area were used. The relevant sections of the scenes were clipped out for further processing. Thirty gcps' were selected for both MSS and TM images. Ten of the gcps were deleted during a first order transformation to yield an RMS tolerance of one pixel. The remaining points were used to generate a transformation co-efficient matrix file. The matrix file was later used to geocode the MSS scene to the TM scene. The spatial resolution of the MSS data was changed from 80 metres to 50 metres.

The two satellite images were then checked for their accuracy by comparing selected coordinates to those obtained from the topographic sheets. The TM image showed good agreement with the

Figure 7. Landsat Multispectral Scanner (MSS) of Tamne River Basin, taken in 1975.

False colour Composite (Bands 4, 2, 1)

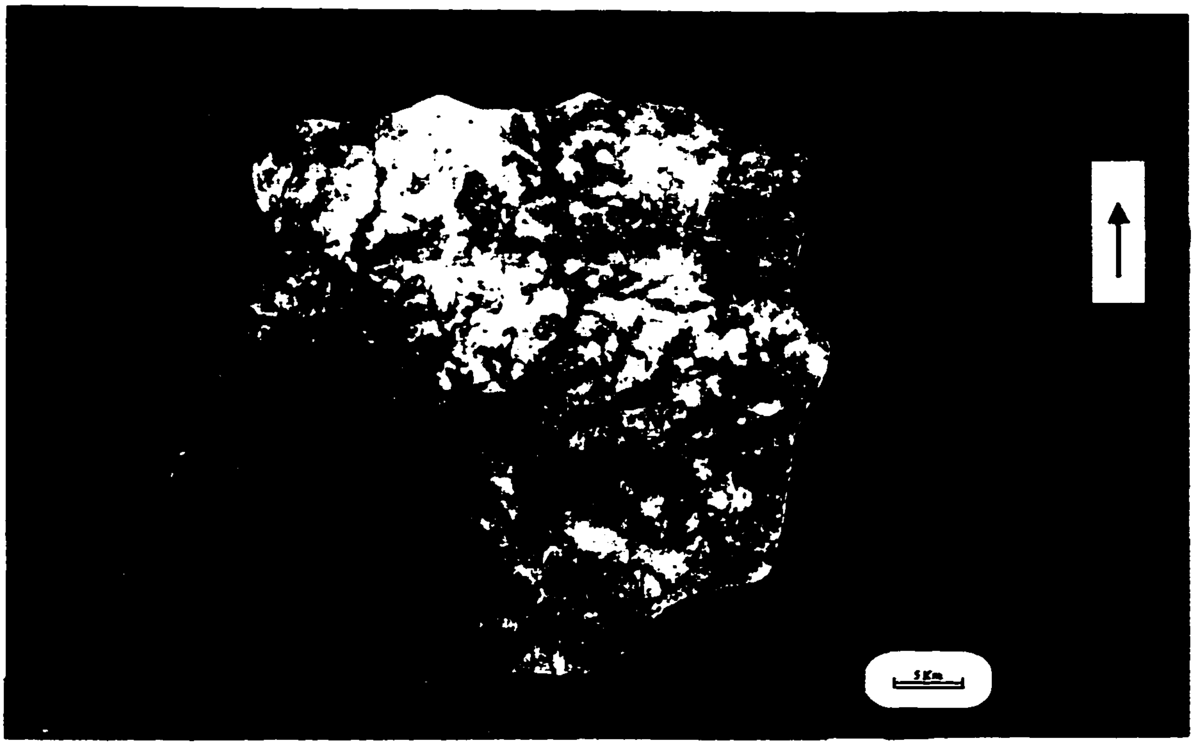


Figure 8. Landsat TM satellite image of Tamne river Basin, taken in 1991.

False colour composite (Bands 4, 3, 2)

topographic map while the MSS showed a slight shift, but this shift was less than one pixel. To reduce the processing time, the area of the Tamne River Basin was then clipped out from both TM and MSS rectified images using the converted clip polygon file. A new nine channel image file, that comprised four channels from the MSS (i.e., bands one to four) and five channels from the TM (i.e., bands five to nine), was created for further analysis.

Vegetation indices, i.e., normalised difference vegetation index (NDVI), were calculated for both the MSS and TM bands of the nine channel image file as follows:

$$NDVI(_{(MSS)} = (X4 - X2) \div (X4 + X2)$$

$$NDVI_{(TM)} = (X7 - X6) \div (X7 + X6)$$

where X is the channel or band.

The NDVI's were used to normalize the two images i.e., to reduce variations due to sun angle, atmospheric and soil moisture conditions (Jensen 1986; Eckhardt *et al.*, 1990; Hall *et al.*, 1991; Jensen *et al.*, 1995). The normalised MSS and TM image files were used in the following change detection algorithms.

4.4.2 Change detection algorithms

The selection of an appropriate change detection algorithm is based on the analysis of the cultural and biophysical characteristic of the target area; the availability of the multiple-date imagery; the precision with which the multiple date imageries are registered; and, the flexibility of the change detection algorithm alternatives (Estes *et al.*, 1982; Jensen, 1986). Some commonly used change detection algorithms are: image differencing; image ratioing; classification comparison; and, comparison of preprocessed imagery (Jensen, 1986).

Classification comparison (and comparison of preprocessed imagery) involves either post classification comparison or spectral/temporal change detection (Estes *et al.*, 1982; Jensen 1986). Post classification comparison was not used in the study because of some problems associated with this method. These problems are (a) the need for extremely accurate classification of the individual images since any errors may be compounded, and (b) urban and suburban heterogeneity in spectral response introduces mixed pixels, i.e., too much changes are consistently identified (Royal *et al.*, 1980; Jensen 1986; Jensen *et al.*, 1993; Green *et al.*, 1994).

The spectral/temporal change detection involve a single classification of multiple date data set using standard pattern recognition techniques (Weisemiller, 1977; Estes *et al.*, 1982; Jensen, 1986). Either Supervised classification or unsupervised classification are used to extract thematic information from the digital data (Jensen, 1986). In either case, 'changed' and 'unchanged' classes will have significantly different statistics. Supervised classification was considered unsuitable for the study because of insufficient ground truth information. Although the spectral/temporal change detection algorithm is attractive because of the single classification required, it can be complex, often involving too many classes and redundant bands (Estes *et al.*, 1982; Jensen, 1986).

Image differencing of the preprocessed satellite images, was combined with spectral/temporal classification in the study. Image differencing involved the substraction of digital imagery of the 1991 Landsat TM image from 1975 Landsat MSS image. The formula used to difference the normalised images is as follows:

$$\Delta X_{ijk} = BV_{ijk\,(75)} - BV_{ijk\,(91)} + 255$$

where, ΔX_{ijk} = change in pixel value

$BV_{ijk\,(75)}$ = brightness value for normalized 1975 Landsat MSS image

$BV_{ijk\,(91)}$ = brightness value for normalized 1991 Landsat TM image

$I = 1 \ldots$ number of line

$j = 1 \ldots$ number of column

k = a single band (i.e., NDVI).

According to Jensen (1986), 8-bit images can result in difference values between -255 and 255. The constant (i.e, 255) was therefore used to transform the any negative difference values to positive values. The result was a 'differenced' distribution of brightness values, with an almost Gaussian nature, for each band of the images used. The pixels of no change in brightness values are centred around the mean and the pixels of change are found in the tails of histogram (Estes et al., 1982; Jensen 1986). A critical element in the use of this algorithm is in deciding where to place the threshold boundaries between change and no change pixels displayed in the histogram (Estes *et al.,* 1982; Jensen 1986). Usually, a standard deviation from the mean is selected and tested empirically to determine if the changes were monitored accurately (Jensen, 1986). The use of maximum and minimum brightness values as thresholds in the study, yielded more realistic change pixels.

An unsupervised classification was then performed on the 'differenced image' file. In an iterative cluster analysis, Erdas *Isodata* module was used to group the pixels into 130 clusters. The signatures that were developed in the cluster analysis were then used in a maximum likelihood statistical classifier to assign pixels into meaningful spectral classes based on their common spectral characteristics i.e, band means and covariance matrices (Jensen, 1986). The unsupervised classification was repeated for the nine channel file. (the combined MSS and TM image file). The two output files of the classification process were used to identify the areas of potential land cover change. Pixels in classified 'differenced image' file were regrouped (i.e., recoded) into two classes, namely, 'potential change' and 'no change'. The land cover/land use classification system (Anderson *et al.*, 1976) and ancillary data i.e, the GIS coverages, were used to increase the precision of the recoding process.

Spatial enhancement was done using a majority filter to get rid of 'orphan' pixels in the 'potential change - no change' file. This was followed by contiguity analysis (i.e., Erdas clump and sieve routine) to allow vegetation removal of at least 21 hectares to remain, as shown on the map in Appendix V. Thematic maps, topographic maps, landscape photographs of the study area were used to evaluate the accuracy of the classification process. Insufficient ground truth information necessitated a qualitative assessment of the accuracy of the change detection analysis.

The 'potential change'-'no change' GIS file was then superimposed on raster files of the GIS coverages (i.e., stream buffer, vegetation, soil and roads) to assess any possible relationships between the potential land cover change areas and land degradation, as well as hydrologic response in the Tamne River Basin. The file produced above were converted into Arc/Info coverages using the *Gridpoly* command tool of Arc/Info. Topology was established for the resultant coverage with the *build* command tool. Attribute data and additional information required for map creation were added in tables and the text editor. Arc/Info macro language (AML) for the final map creation was written in the text editor (Appendix V). The AML was then used to create a plot file.

4.5. FARMING CHARACTERISTICS

Twenty farmers in the Tamne watershed area were interviewed using structured questionaries (Appendix VI). The farmers were selected randomly from eight towns and villages (Table 3). The low number of farmers from Barboaka, Kugrago, Tansia and Tempane respectively, was because the farmers involved were interviewed outside their home towns. With the help of extension workers in the area, exploratory data were collected on the farming characteristics of the Tamne River Basin. Information on flooding or waterlogging, farmland management, and livestock holdings, were analysed. Results of the analysis are presented in Chapter five.

Table 3. Selection of Farmers for interviews in the Tamne River Basin.

Town (or village)	Number of farmers
Bugri	2
Garu	5
Kugri	6
Kugur	4
Manga	7
Others*	4

* Others include a farmer from Baboaka, Kugrago, Tansia and Tempane respectively.

5.0. RESULTS

In this chapter, results of the hydrological analyses, land cover change analysis and observations of some farming characteristics are presented and explained in the following sections.

5.1. HYDROLOGIC ANALYSIS

5.1.1. Rainfall - streamflow relations

Monthly variation in mean rainfall, streamflow and temperature are shown in Table 4 and, Figures 9 and 10. Mean rainfall depth reached its highest values around July and September when the temperatures were low. Around the same period the runoff depth also reached peak values. This coincided with the peak period of a monomodal rainfall pattern that is typical of the Upper East Region of Ghana. The months of July, August and September were therefore considered as the wettest months in the Tamne watershed.

Inter-annual variations in peak flows are shown in Table 5 and Figure 11. The peak flows were found to be log-normally distributed, therefore, the lognormal values (i.e, y) of peak flow were used. Prior to 1976, the mean and standard deviation of y were 3.24 and 0.31 m^3/s respectively. The values of y (in m^3/s) for 1980, 1990, 1991, 1992 and 1993 were 3.11, 3.09, 3.83, 3.16 and 3.31 respectively. These y values were lower than the upper confidence limit (i.e., y_z) of 3.85 m^3/s. The calculation of the upper limit is explained on page 37. It was therefore reasonable to

Table 4. Monthly variations in rainfall and temperature for Tamne River Basin, and runoff for Garu station

	Mean rainfall (mm)	Mean temperature (°C)	Mean water discharge (m^3/s)	Runoff depth (mm)
January	0.36	26.72	0.01	0.07
February	1.61	29.04	0.01	0.06
March	15.02	31.70	0.00	0.00
April	36.76	32.04	0.03	0.17
May	91.43	30.38	0.55	3.34
June	108.22	28.27	0.75	4.62
July	166.08	27.00	3.09	18.95
August	213.20	26.39	6.70	41.05
September	160.50	26.66	8.00	49.04
October	53.31	28.39	1.48	9.06
November	6.90	28.07	0.22	1.32
December	1.97	26.65	0.10	0.60

assume that the y values from 1980 to 1993 belong to the population based on y values prior to 1976.

Before 1976, the number of y values above and below the mean were five and six respectively. After 1976, the number of y above and below the mean were one and four respectively. These results and scatter plots, indicate that there was a possible change, i.e., a decrease, in pattern of peak flows [Appendix III (e)].

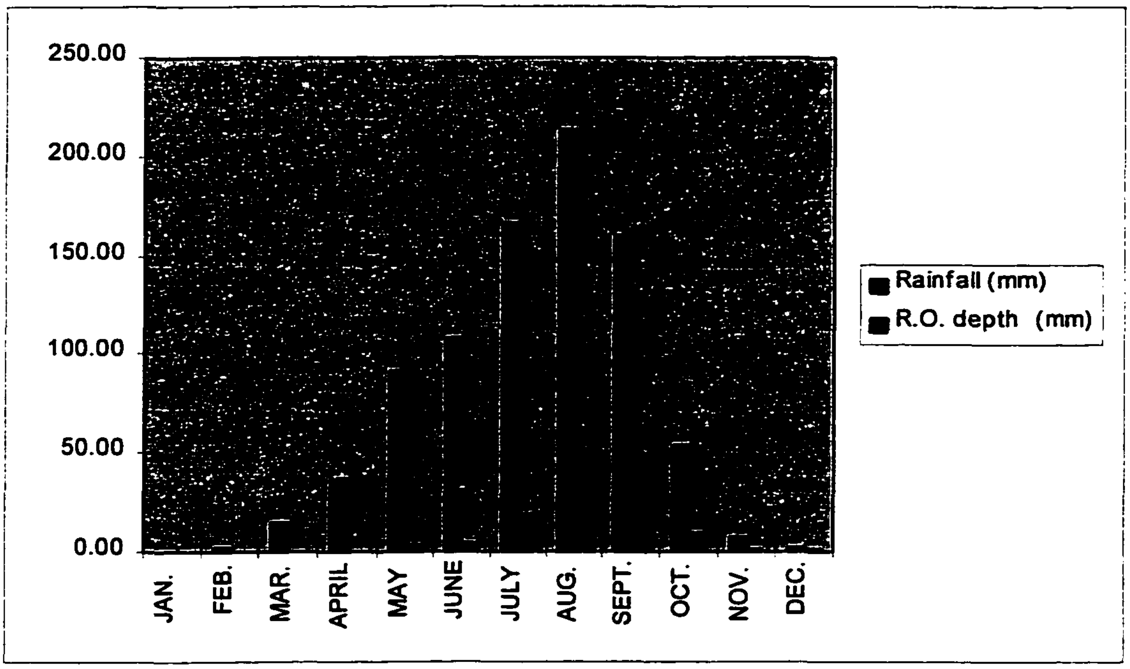


Figure 9. Monthly variation in mean rainfall and runoff depth in Tamne River Basin.

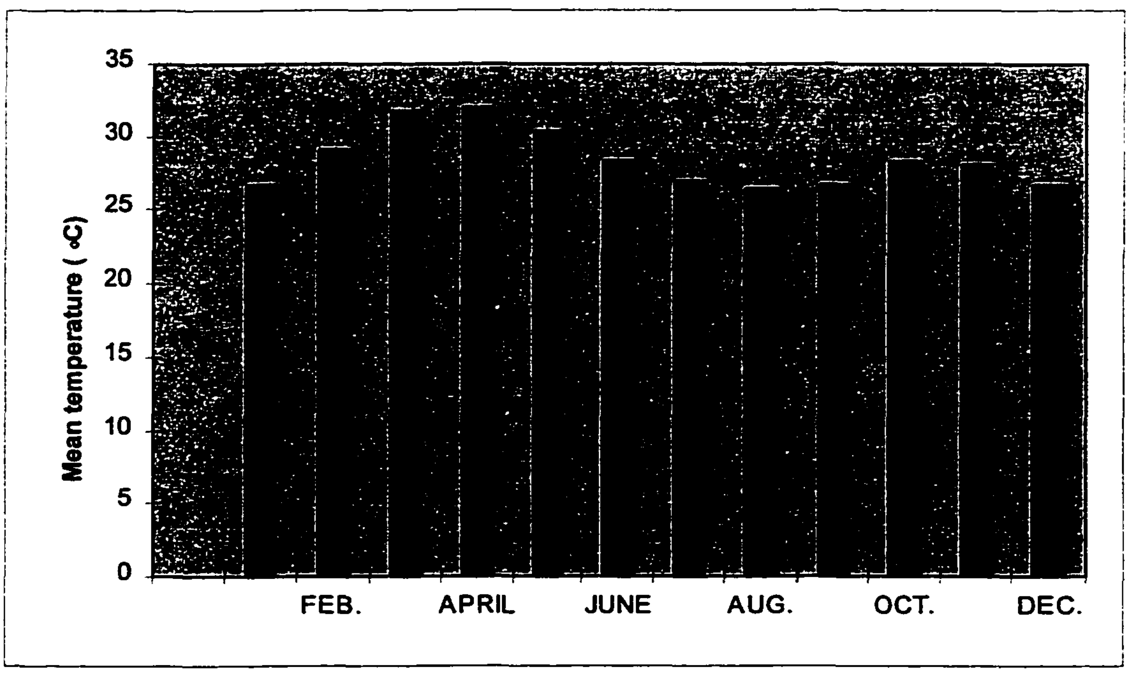


Figure 10. Monthly variation in mean temperature in Tamne River Basin

Table 5. Hypothesis testing of peak flows for Garu station

Year	x = Peak flow (m^3/s)	y = ln x (m^3/s)*	y_z (m^3/s)**
1966	15.18	2.72	-
1967	21.35	3.06	-
1968	26.36	3.27	-
1969	24.15	3.18	-
1970	33.78	3.52	-
1971	49.24	3.90	-
1972	23.98	3.18	-
1973	20.93	3.04	-
1974	18.12	2.90	-
1975	33.78	3.52	-
1976	27.38	3.31	-
-	-	-	-
1980	22.43	3.11	3.85
-	-	-	-
-	-	-	-
-	-	-	-
1990	21.89	3.09	3.85
1991	46.27	3.83	3.85
1992	23.47	3.16	3.85
1993	27.38	3.31	3.85

* The mean, normal variate and standard deviation for y's from 1966 to 1976 were 3.24, 1.96 and 0.31 respectively.

** All values of the upper confidence limit of peak flows (i.e., y_z) were calculated for z at 95% confidence limit (i.e, z = 1.96), mean = 3.24 and standard deviation = 0.31.

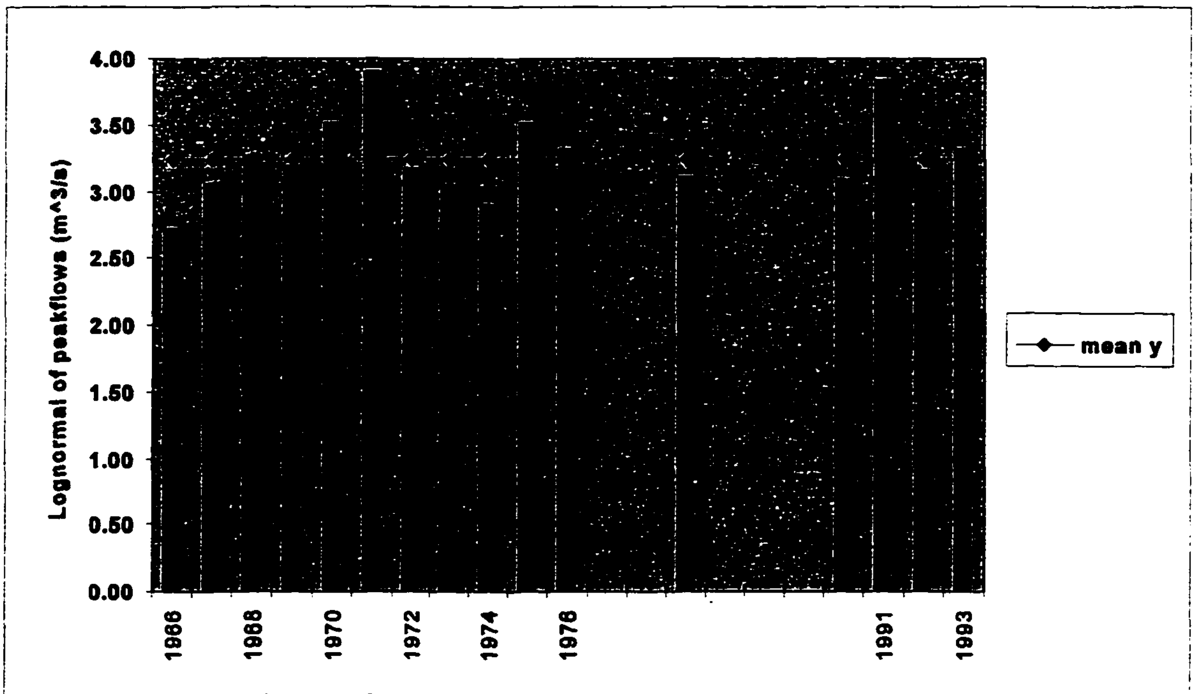


Figure 11. Inter-annual variation in peak flows for Garu station

A comparison of means for the two categories of peak flows, by pooled variance method, yielded t = - 0.31 [Appendix III (a)]. The value of t was not significant at 95 percent confidence level, therefore, the observed change in the pattern of inter-annual variation of peak flows was not significant.

Inter-annual variations in wet season flows, or mean water discharges for the wettest months (i.e., July, August and September), are shown in Table 6 and Figure 12 . The wet season flows were also found to be log-normally distributed, and therefore, the lognormal values (i.e, y_2) of wet season flows were used. Prior to 1976, the mean and standard deviation of y_2 were 1.73 and 0.48 m^3/s respectively.

Table 6. Hypothesis testing of wet season flows (i.e., mean water discharge from July to September) for Garu Station.

Year	x = wet season flow (m^3/s)	$y_2 = \ln x$ (m^3/s) *	y_z (m^3/s) **
1966	7.55	2.02	-
1967	7.25	1.98	-
1968	8.04	2.08	-
1969	8.71	2.16	-
1970	-	-	-
1971	5.60	1.72	-
1972	4.09	1.41	-
1973	6.12	1.81	-
1974	-	-	-
1975	6.31	1.84	-
1976	1.67	0.51	-
-	-	-	-
1980	2.88	1.06	2.67
-	-	-	-
-	-	-	-
-	-	-	-
1990	3.31	1.20	2.67
1991	8.44	2.13	2.67
1992	5.21	1.65	2.67
1993	5.70	1.74	2.67

* The mean, normal variate and standard deviation for y_2's from 1966 to 1976 were 1.73, 1.96 and 0.4 m^3/s respectively.

** All values of the upper confidence limit of wet season flows (i.e., y_z) were calculated for z at 95% confidence limit (i.e, $z = 1.96$), mean = 1.73 m^3/s and standard deviation = 0.48 m^3/s.

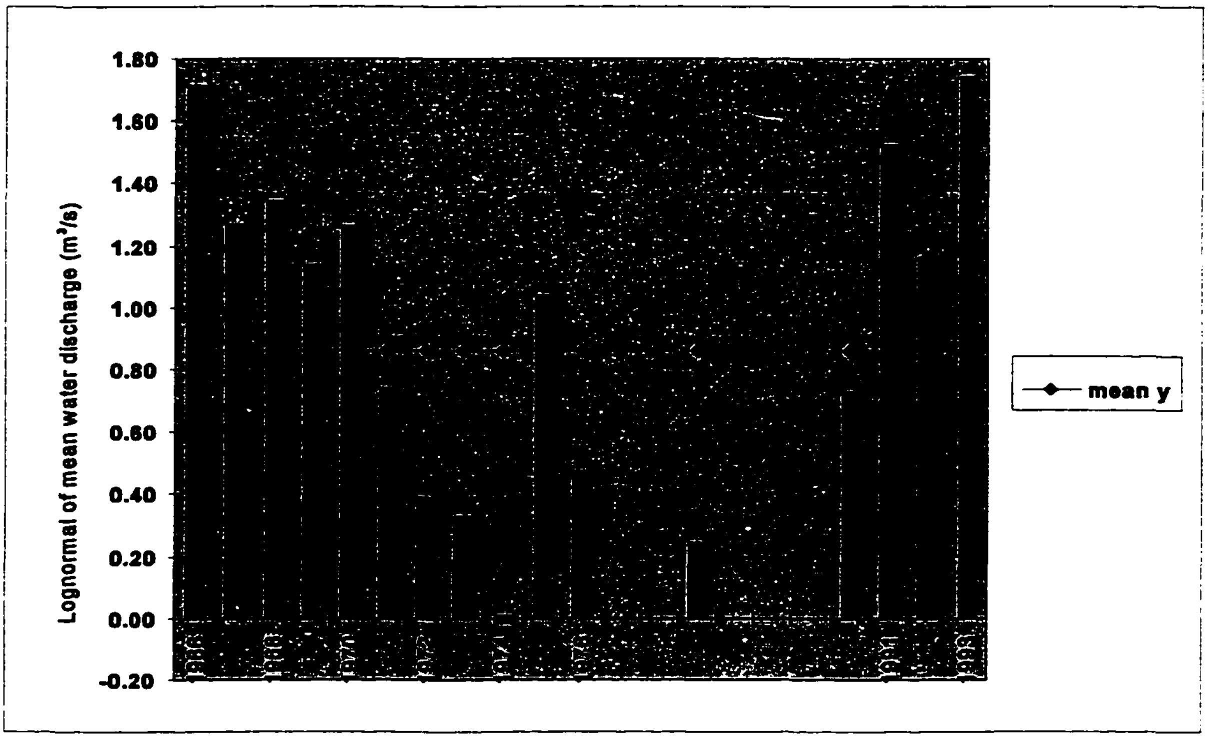


Figure 12. Inter-annual variation in wet season flows (i.e., mean water discharge from July to September) for Garu Station.

The values of y_2 (in m^3/s) for 1980, 1990, 1991, 1992 and 1993 were 1.06, 1.20, 2.13, 1.65 and 1.74 respectively. These y_2 values were lower than the upper confidence limit (i.e., y_z) of 2.67 m^3/s. It was therefore reasonable to assume that the y_2 values from 1980 to 1993 belong to the population based on y_2 values from 1966 to 1976. Prior to 1976, the number of y_2 values above and below the mean were six and three respectively. After 1976, the number of y_2 above and below the mean were two and three respectively. These results and scatter plots indicated that there was a possible change in pattern of wet season flows, [Appendix III (e)]. A comparison of means by pooled variance method also yielded t = 0.59 [Appendix III (b)]. The value of t was not significant at 95 percent confidence level, therefore, the observed change in the pattern of inter-annual variation of wet season flows was not significant.

The variation in annual mean water discharges for the calender year (Table 7 and Figure 13) show a typical change in pattern. The mean water discharge values were also transformed into lognormal values (i.e, y_3). Prior to 1976, the mean and standard deviation of y_3 were 0.86 and 0.57 m^3/s respectively. The values of y_3 (in m^3/s) for 1980, 1990, 1991, 1992 and 1993 were 0.24, ,0.73, 1.52, 1.16 and 1.74 respectively. These y_3 values were lower than the upper limit of 1.98 m^3/s. It was therefore reasonable to assume that y_3's from 1980 to 1993 belong to the same population based on the y_3 values from to 1976.

Before 1976, the number of y_3's above and below the mean were six and five respectively. After 1976, the number y_3's of above and below mean were three and two respectively. These results and scatter plots indicate that there was a possible change in the pattern of mean water discharge [Appendix III (e)]. A comparison of means for the two groups of data, by pooled variance method, yielded $t = -0.65$ [Appendix III (c)]. The value of t was not significant at 95 percent confidence level, therefore, the observed change in the pattern of inter-annual variation of mean discharges was insignificant.

Runoff is usually generated by rainfall, therefore the inter-annual variation in mean rainfall from 1960 to 1993 was also examined (Table 8 and Figure 14). The annual mean rainfall values were also transformed into lognormal values (i.e, y_4). Prior to 1976, the mean and standard

Table 7. Hypothesis testing of annual mean water discharges for Garu station

Year	x = mean discharge (m^3/s)	$y_3 = \ln x$ (m^3/s)*	y_z (m^3/s)**
1966	5.55	1.71	-
1967	3.57	1.27	-
1968	3.82	1.34	-
1969	3.12	1.14	-
1970	3.54	1.26	-
1971	2.10	0.74	-
1972	1.47	0.39	-
1973	1.39	0.33	-
1974	0.82	-0.20	-
1975	2.83	1.04	-
1976	1.61	0.48	-
-	-	-	-
1980	1.27	0.24	1.98
-	-	-	-
-	-	-	-
-	-	-	-
1990	2.07	0.73	1.98
1991	4.59	1.52	1.98
1992	3.20	1.16	1.98
1993	5.69	1.74	1.98

* The mean, normal variate and standard deviation for y_3's from 1966 to 1976 were 0.86, 1.96 and 0.57 respectively.

** All values of the upper confidence limit of mean discharges (i.e., y_z) were calculated for z at 95% confidence limit (i.e, z = 1.96), mean = 0.86 and standard deviation = 0.57.

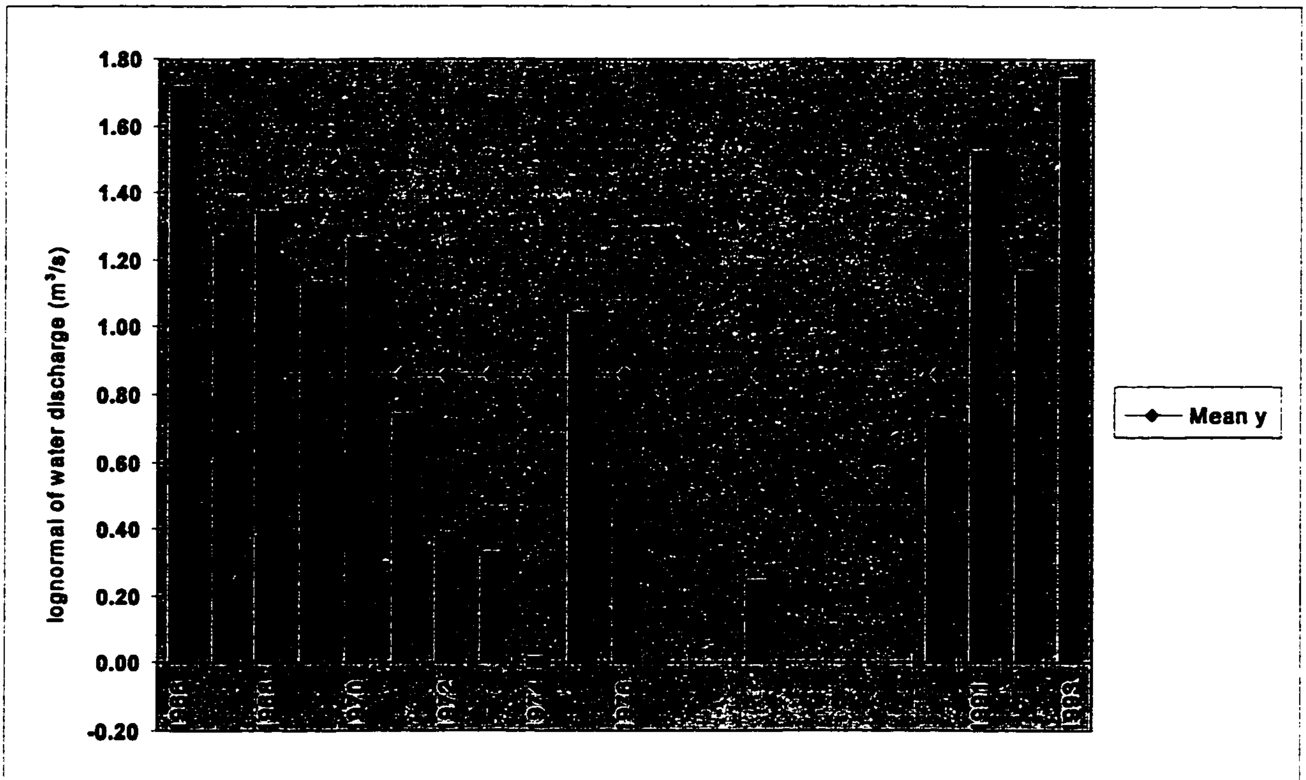


Figure 13. Inter-annual variation in mean water discharges for Garu station

deviation of y_4 were 4.37 and 0.17 mm respectively. After 1976, the values of y_4 were all below the upper confidence limit (i.e., y_z) of 4.70 mm. It was therefore reasonable to assume that y_4's from 1977 to 1993 belong to the same population based on y_4's from 1960 to 1976.

Also before 1976, the number of y_4's above and below the mean were eight and seven respectively. After 1976, the number of y_4's above and below mean were five and 11 respectively. These results and scatter plots indicate that there was a possible change in the

Table 8. Hypothesis testing of rainfall depth for Tamne River Basin

Year	x = mean rainfall (mm)	$y_4 = \ln x$ (mm)*	y_z (mm)**
1960	80.77	4.39	-
1961	61.37	4.11	-
1962	109.27	4.69	-
1963	83.93	4.30	-
1964	78.68	4.37	-
1965	56.87	4.04	-
1966	86.38	4.46	-
1967	96.56	4.57	-
-	-	-	-
1970	78.5	4.36	-
1971	84.82	4.44	-
1972	72.81	4.28	-
1973	86.44	4.46	-
1974	89.30	4.49	-
1975	72.24	4.28	-
1976	66.57	4.20	-
1977	66.87	4.20	4.70
1978	79.03	4.37	4.70
1979	97.73	4.58	4.70
1980	66.99	4.20	4.70
1981	61.89	4.12	4.70
1982	80.14	4.38	4.70
-	-	-	-

(continue)

Table 8 (continued). Hypothesis testing of rainfall depth for Tamne River Basin

Year	x = mean rainfall (mm)	$y_4 = \ln x$ (mm)*	y_z (mm)**
1984	68.69	4.23	4.70
1985	57.27	4.05	4.70
1986	73.62	4.30	4.70
1987	69.03	4.23	4.70
1988	72.84	4.29	4.70
1989	89.07	4.49	4.70
1990	71.97	4.28	4.70
1991	89.46	4.49	4.70
1992	72.52	4.28	4.70

* The mean, normal variate and standard deviation for y_4's from 1966 to 1976 were 4.37, 1.96 and 0.17 mm respectively.

** All values of upper confidence limit of rainfall (i.e., y_z) were calculated for z at 95% confidence limit (i.e, z = 1.96), mean = 4.37 mm and standard deviation = 0.17 mm.

pattern of inter-annual variation in mean rainfall [Appendix III (e)]. However, a comparison of means for the two data sets, by pooled variance method, yielded t = -1.63 [Appendix III (d)]. The value of t was not significant at 95 percent confidence level, therefore, the observed change in annual mean rainfall pattern was not significant.

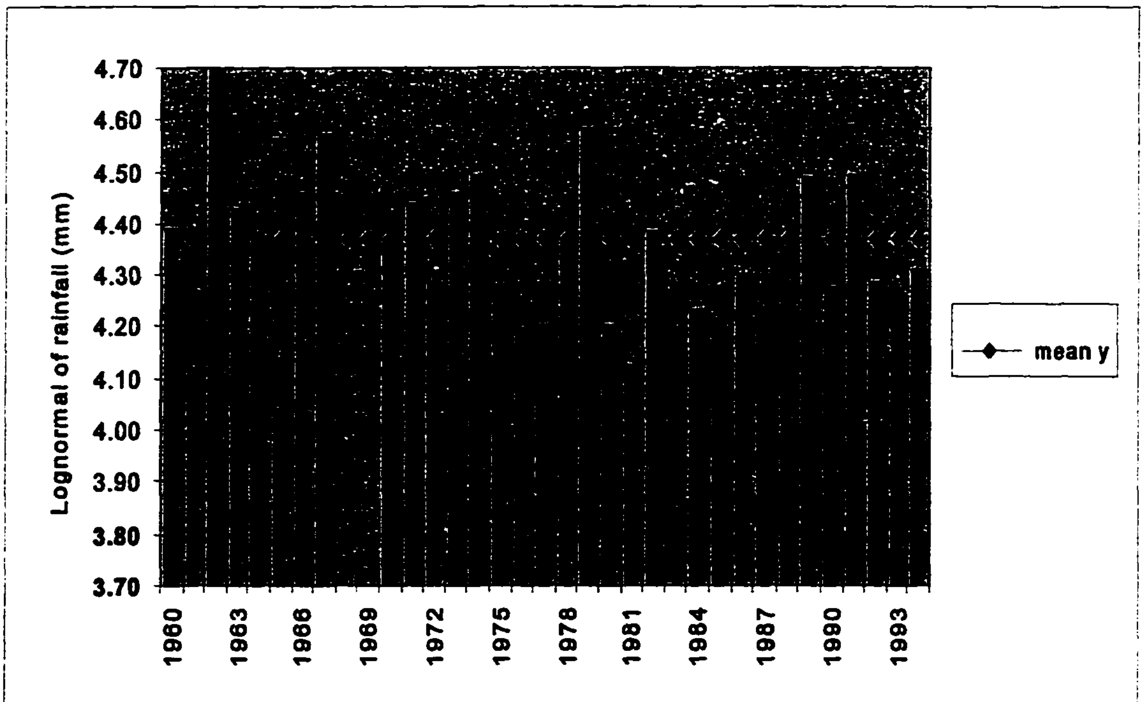


Figure 14. Inter-annual variation in rainfall depth for Tamne River Basin

5.1.2. Flood frequency estimates

Plotting positions used in the flood frequency analysis are shown in Table 9. The plotting positions were fitted by the use of flood estimates for the GEV distribution (Table 10). The flood estimates were superimposed on the plotting positions as shown in Figure 15. Flood discharges with high return period had very low probability of exceedance. For instance, the probability that a 100-year flood discharge of 59.9 m^3/s would be exceeded in any particular year was one percent. Despite this low probability, such a flood can not be disregarded when considering any infrastructure development, especially in the flood plain. Conversely, flood

Table 9. Plotting positions used in frequency analysis

Year	Flood flow (m^3/s)	Ordered flow (m^3/s)	Rank	Probability (%)	Return period (years)
1966	15.18	49.24	1	5.36	18.67
1967	21.35	33.78	2	14.29	7.00
1968	26.36	33.78	3	23.21	4.31
1969	24.15	27.38	4	32.14	3.11
1970	33.78	26.36	5	41.07	2.44
1971	49.24	24.15	6	50.00	2.00
1972	23.98	23.98	7	58.93	1.70
1973	20.93	21.35	8	67.86	1.48
1974	18.12	20.93	9	76.79	1.30
1975	33.78	18.12	10	85.71	1.17
1976	27.38	15.18	11	94.64	1.06

discharges of low return periods were associated with high probability of exceedance. For instance, the probability of a two year flood occurring in any particular year was 80 percent.

5.1.3. Summary of hydrologic analysis

There was no significant change in the pattern of mean rainfall, peak flow, wet season flow (i.e., mean water discharge for the wettest months) and mean water discharge for the calender year. In the case of annual variation of mean rainfall, the observed constant pattern was just as expected.

Table 10. Flood frequency regime obtained from GEV distribution* for Garu station.

Return period (years)	Exceedance probability (%)	flood flow (m^3/s)
1.0	99.7	12.6
1.1	95.2	16.0
1.3	80.0	19.6
2.0	50.0	24.7
5.0	20.0	32.5
10.0	10.0	38.3
20.0	5.0	44.3
50.0	2.0	52.9
100.0	1.0	59.9

* Flood flow estimates were obtained by maximum likelihood method in a Consolidated Frequency Analysis package (Appendix IV).

The inter-annual variations in peak flows, wet season flows and annual mean discharge were expected to show some changes in pattern, but the observed changes were not significant. The flood frequency regime for the peak flows from 1966 to 1976 indicate that, the 100 year flood was 59.9 m^3/s. This estimate is less than the peak flood discharge of 84.6 m^3/s, obtained from reservoir routing for a proposed dam at Kugri (CARDS and GAS, 1994). Since there was no significant change in the pattern of peak flows prior to and after 1976, it is possible to use the flood frequency estimates in flood risk and flood damage analysis.

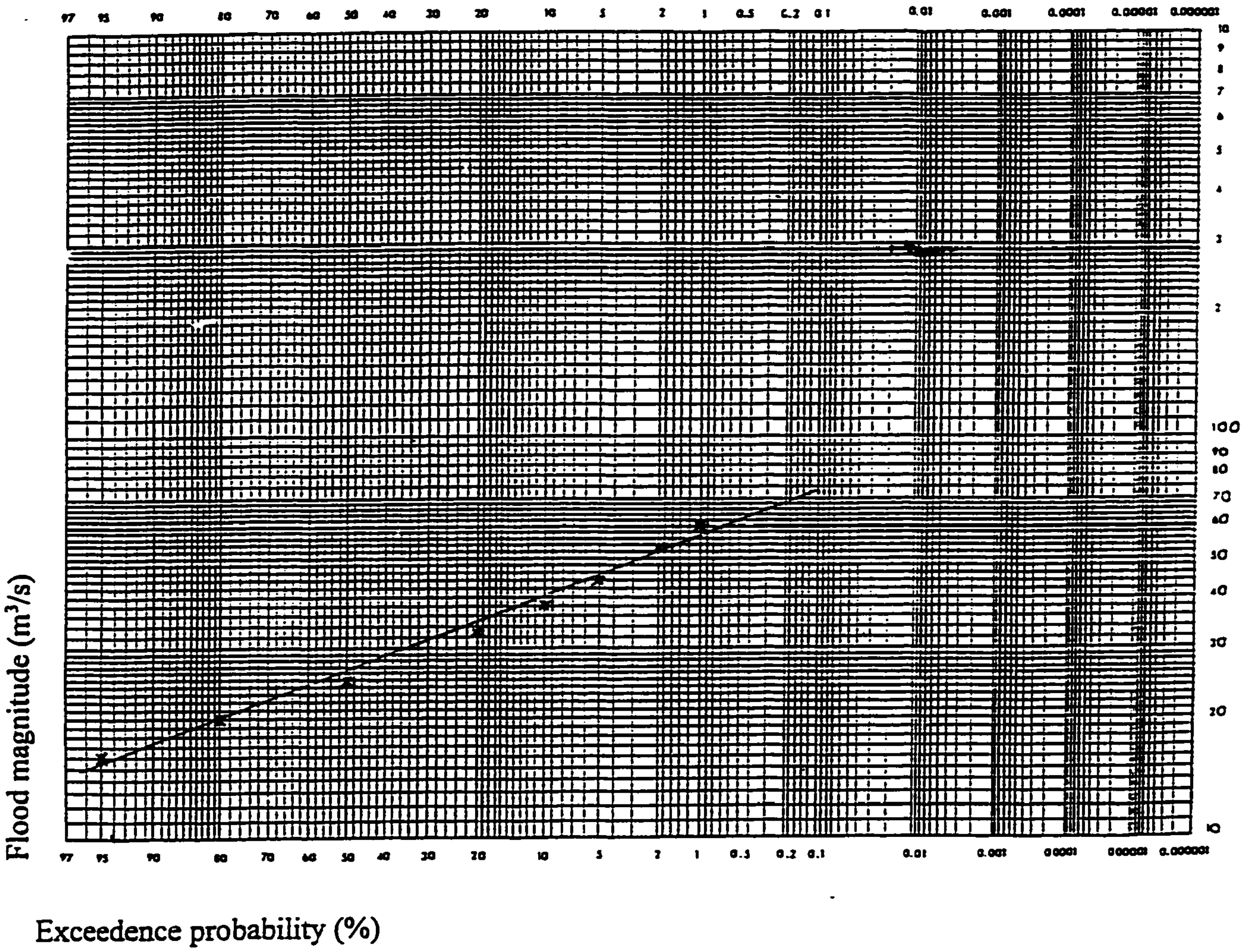


Figure 15. Flood frequency regime obtained by GEV distribution for Garu station

5.2. LAND COVER CHANGE ANALYSIS

The 'potential change-no change' raster GIS file was superimposed unto stream buffer zone, vegetation, soils and road GIS files as shown in Figures 16, 17, 18 and 19 respectively. These figures are explained in the following sections.

5.2.1. Stream buffer

A buffer zone of 300 metres was reasonable because buffer distances below or above 300 metres resulted in clumps and polygons that were unsuitable for the analysis. Most of the potential change areas lie outside the buffer zone (Figure 16). Those potential change areas that lie within the buffer zone occurred in the upstream tributaries. The potential change areas were sparsely distributed above the Garu gaging station. In particular, there was no evidence of change in the area that lie towards the lower right corner of the stream network.

5.3.2. Vegetation and land use

About 90 percent of the potential change areas occurred on cultivated land, see Figure 17. The cultivated land occupies 80 percent of the Tamne River Basin and comprise compound farms, bush farms, land rotation and land planning areas. It was not possible to distinguish between farm land and fallow land, therefore, the two land use categories were lumped into cultivated land. In addition, the land planning areas were abandoned in the 1980's (IFAD, 1990), therefore these areas were included the cultivated land area.

The proportion of potential change areas that occurred on the uncultivated land (i.e., tree savanna) was about 10 percent. The majority of these potential change areas lie close to the Kugri village. This indicate a possible encroachment of farming activities unto the uncultivated lands in the Tamne River Basin. Less than one percent of the potential change areas occurred in the riparian woodland. This situation may due to the remote location of the riparian woodland vegetation type.

5.2.3. Soil groups

Wenchi soil consociation is the largest soil group in the Tamne River Basin (Figure 18). Although about 75 percent of the potential change areas occurred in this soil group, the proportion of potential change areas is relatively small compared to the total land area of the Wenchi soil consociation. About 18 percent of the potential change areas occurred in the Kupela-Berenyase and Pusiga soil groups. The majority of the potential change areas, however, occurred on soil in the upper tributaries of the Tamne river.

The Tanchera association experienced relatively small percentage of the potential change areas, i.e., about five percent. The Siare-Pani, Mogo and Chuchiliga soil association, occupy less than one percent of the land area of Tamne River Basin. While there was no potential change area on the Chuchiliga association, the changes on the Mogo and Siare-Pani association were relatively insignificant i.e., less than one percent of the overall potential change areas.

5.2.4. Road network

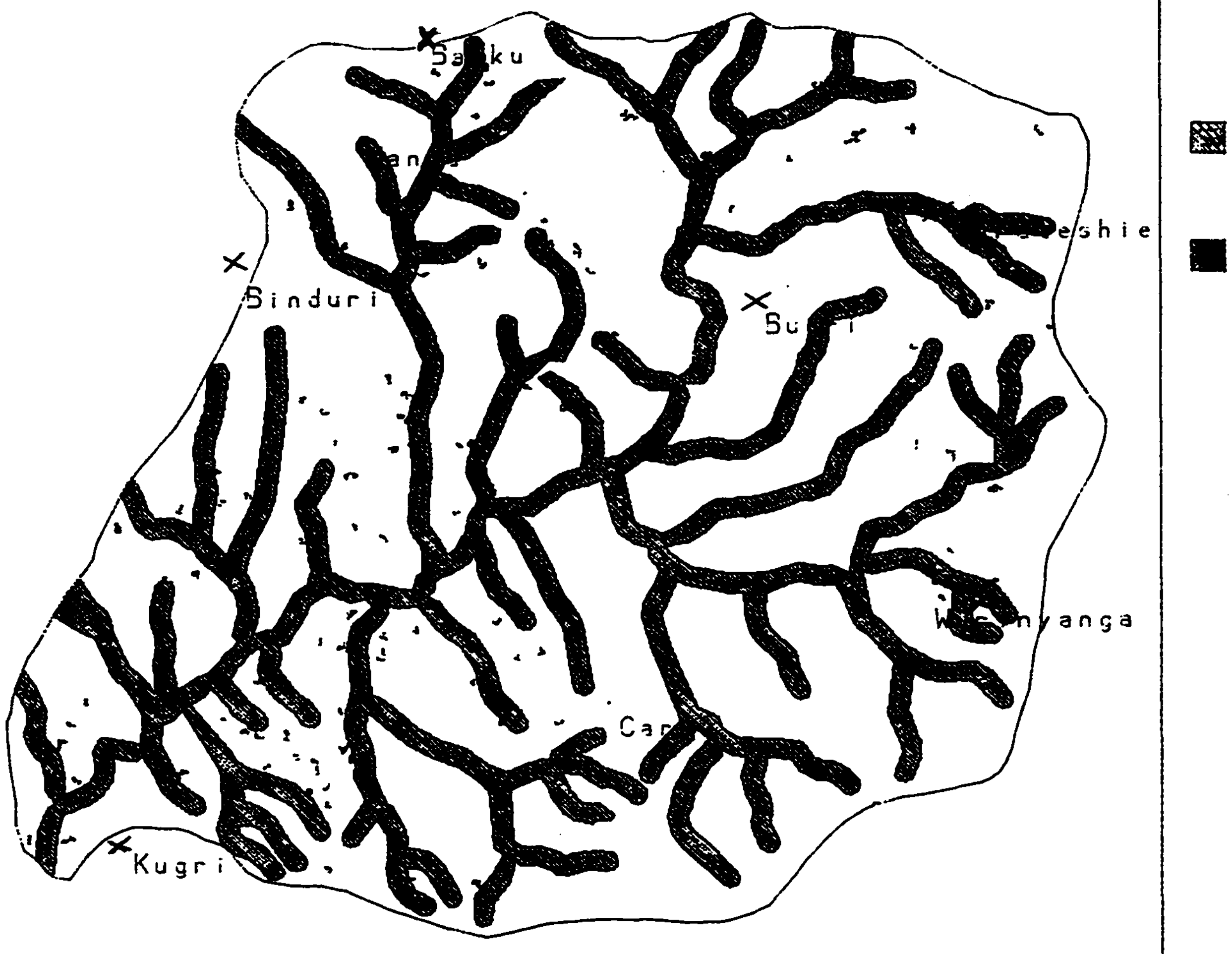
Some of the potential change areas lie close to the road network in the Tamne River Basin, but, it was not possible to quantify the relationship between the potential change areas and the road network. Figure 19, however, indicate a lateral distribution of the potential change areas with respect to the road network in the basin.

5.2.5. Summary of land cover change analysis

Ninety percent of the potential change areas occurred on cultivated land. The remaining ten percent of potential change areas occurred on uncultivated and riparian woodland. With respect to the soil groups, about 75 percent of the potential change areas occurred on Wenchi soil consociation. The remaining potential change areas occurred mainly on Kupela-Berenyase and Tanchera series. For the stream buffer zone, most of the potential change areas lie outside the buffer distance. The few potential change areas that lie within the buffer distance occurred in the upstream tributaries. The potential change areas were also found to be laterally distributed with respect to the road network in the Tamne River Basin. In general, less than one percent of the total land area of the Tamne River Basin showed potential change areas. In spite of this low percentage, the implication of the potential change areas on streamflow volume, flood stage and erosion can not be underestimated.

Figure 16. Potential change areas and stream buffer zone in Tamne River Basin

LAND COVER CHANGE AREAS AND S
STREAM BUFFER IN TAMNE RIVER



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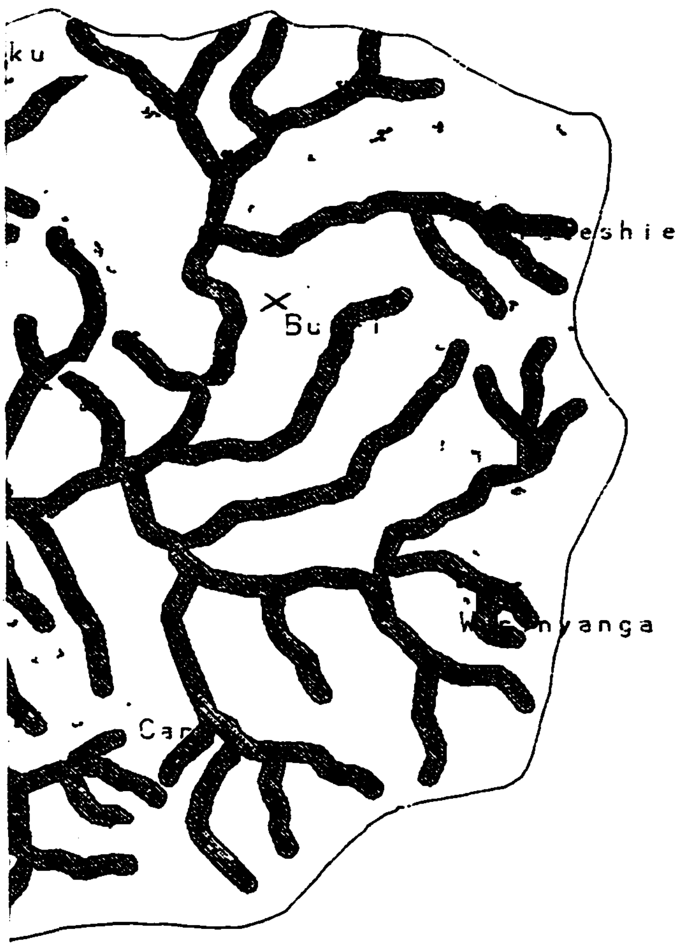
CHANGE AREAS AND 300-METER
ER IN TAMNE RIVER BASIN



LEGEND

Stream Buffer Area

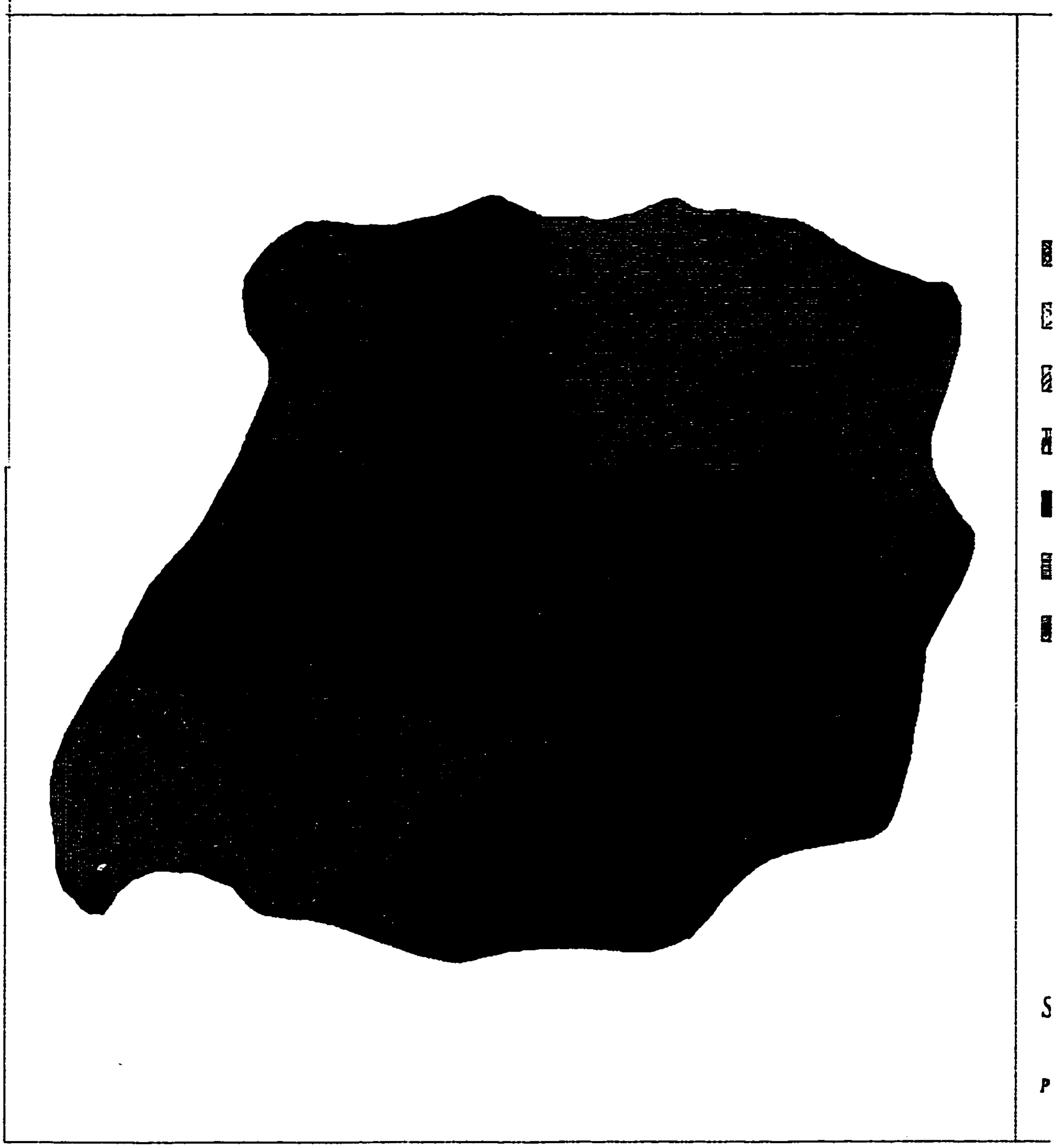
Potential Land Cover Changes

Scale = 1:130000

PROJECTION : TRANSVERSE MERCATOR

Figure 17. Potential change areas and vegetation/land use in Tamne River Basin

LAND COVER CHANGES AND VEGETATIO
USE IN TAMNE RIVER BASIN



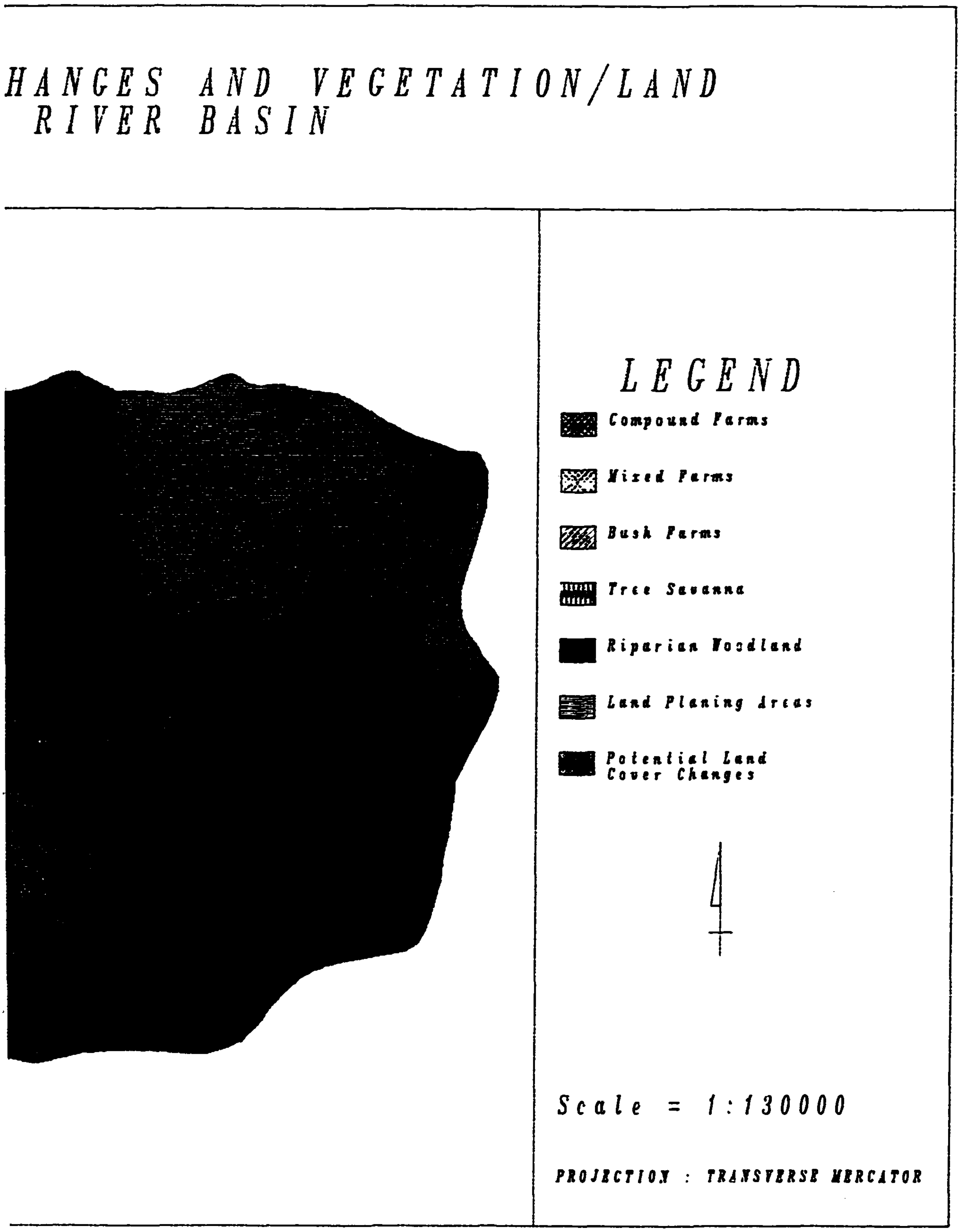
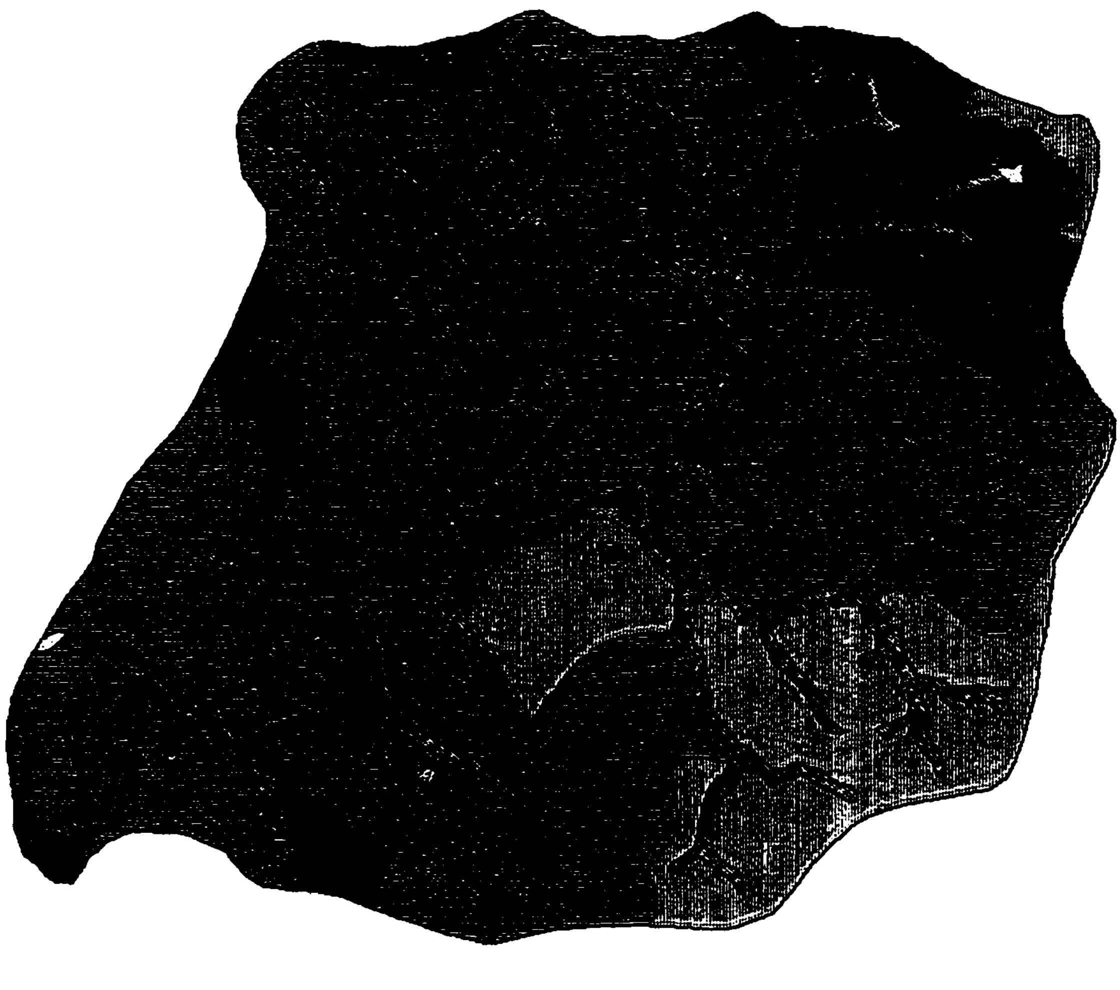

HANGES AND VEGETATION/LAND
RIVER BASIN
LEGEND
Compound Farms
Mixed Farms
Bush Farms
Tree Savanna
Riparian Woodland
Land Planing Areas
Potential Land
Cover Changes
Scale = 1:130000
PROJECTION : TRANSVERSE MERCATOR

Figure 18. Potential change areas and soil groups in Tamne River Basin

LAND COVER CHANGES AND SOIL GROU
IN TAMNE RIVER BASIN



… AND SOIL GROUPS
…IN

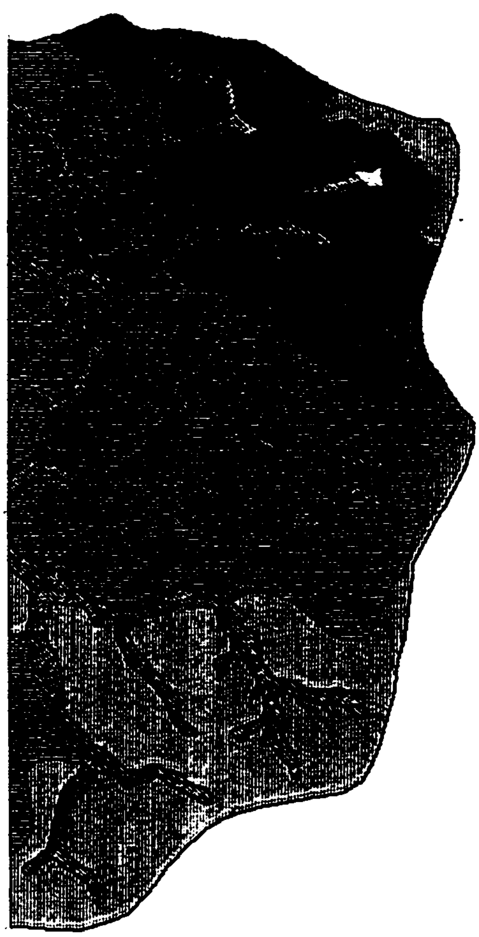
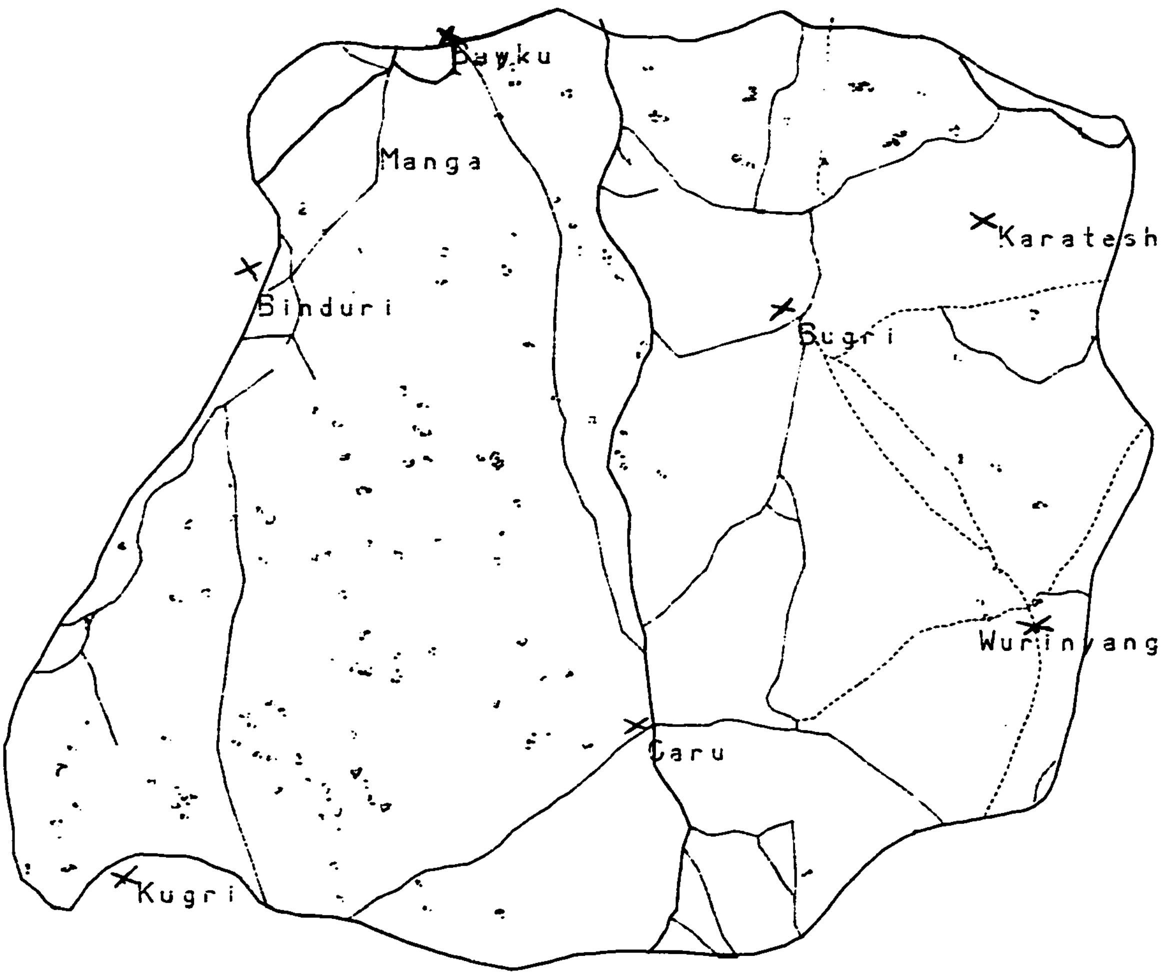
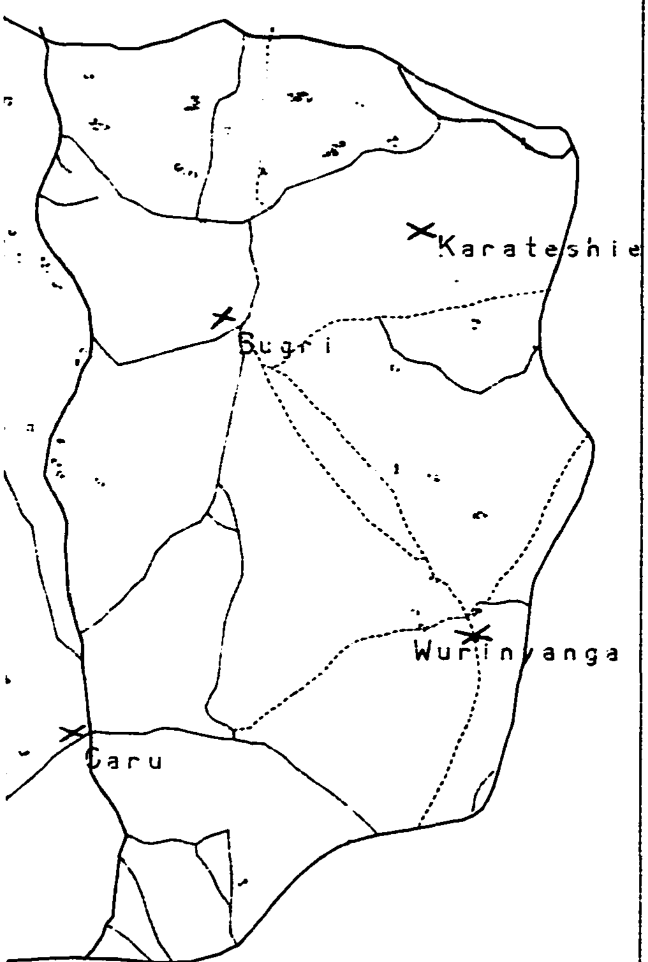


Figure 19. Potential change areas and road network in Tamne River Basin

LAND COVER CHANGE AREAS AM
NETWORK IN TAMNE RIVER BAS



CHANGE AREAS AND ROAD
TAMNE RIVER BASIN



LEGEND

First Class Road

Second Class Road

Third Class Road

Major Footpath

Potential Land Cover Changes

Scale = 1:130000

PROJECTION : TRANSVERSE MERCATOR

5.3. FARMING CHARACTERISTICS

In this section responses of farmers on some farming characteristics regarding flooding, land management and livestock holdings are presented and described.

5.3.1. Flooding and waterlogging

Ninety-three percent of the farmers indicated that they have experienced flooding or waterlogging of their farms and property. The remaining seven percent that did not experience the flood waters or any waterlogging were from Kaadi and Kugrago. While field observations indicated widespread flooding around the Kaadi area, it was not clear what prevails in Kugrago. This was because the farmer from Kugrago was interviewed in Garu. On the average, flood waters or waterlogged areas dry up in about nine days, but, these waters may stay as long as 42 days. The streams in the area dry up in about ten weeks after the end of the rainfall season, usually, around late December or January.

5.3.2. Land management

The farmers have a wide range of farming experience from four to 60 years, with an average of 22 years (Appendix V). In all, 86 percent of the farmers used manual methods of land clearing, while 32 percent depend on burning (Table 11). The manual method involve the use of cutlasses to slash down standing stalks, e.g. millet and sorghum, which were later used as fuel at home. Some of the farmers did combine the manual method and burning. During land preparation, bullock ploughing was the preferred method. About 86 percent of the respondents used bullocks

Table 11. Land management characteristics in Tamne River Basin

Activity	Number of farmers	Percent of farmers
LAND CLEARING		
Manual	24	86
Burning	9	32
LAND PLOUGHING		
Bullock	24	86
Hoe	6	21
Tractor	3	11
FERTILIZER USE		
Inorganic	5	18
Cowdung	25	89
Compost	18	64

which were either owned by the farmers or hired from other farmers. Also, 21 percent of the farmers used hoes to plough the land. This was mostly because they either could not afford a bullock or hire one. About 11 percent of the farmers used tractors to plough their farms. These farmers constituted a major portion of the 18 percent of farmers that used inorganic fertilizers on their farms. Cowdung was the most common source of fertilizer for about 89 percent of the respondents. The demand for cowdung as energy source in the dry season usually limit its availability for use as fertilizer during the growing season. Sixty-four percent of the farmers used compost i.e., household waste, soil, leaves, poultry manure or goat or sheep manure, as fertilizer on their farms.

5.3.3. Livestock holdings

Most of the farmers owned some cattle, goat or sheep (Table 12). On the average a farmer owned about five cattle, but some farmers have as many as 16 cattle. The maximum number of goats and

Table 12. Livestock holdings in Tamne River Basin

Livestock	Average number	maximum number	Number of farmers	Percent of Farmers
Goat	6	23	13	46
Sheep	6	30	13	46
Cattle	5	16	18	64
Pig	2	15	5	18
Poultry*	14	59	10	36
Rabbit	1	6	1	4
Donkey	4	5	2	7

* Poultry in Tamne River Basin are dominated by guinea fowls.

sheep were estimated at 23 and 30 respectively. Pigs were not popular with farmers despite efforts by extension officers to promote their adoption. Although donkeys were commonly used as means of transporting water and farm products, only seven percent of the farmers owned donkeys. The low number of farmers that owned rabbits could be explained by the fact that rabbits do not form a major part of the meat preferences of the people in the area. An average of 14 fowls were kept by a farmer. The maximum number of fowls owned by a farmer was estimated at 60. These are mainly guinea fowls and their eggs provide a cheap source of protein for the people in the area.

5.3.5. Summary of farming characteristics

Ninety-three percent of the farmers interviewed have experienced flooding or waterlogging of their farmlands. Eighty-six percent of the farmers, use manual (or slash and burn) method of land clearing while thirty two percent depend on burning alone to clear the land for farming. Bullock ploughing was employed by 86 percent the farmers that were interviewed. Most of the farmers who used hoe to plough the land, did so because they could not afford the bullocks. Eleven percent of the farmers use tractors to plough the land and most of them used inorganic fertilizers on their farms while the majority of the farmers interviewed used cowdung and compost to fertilize their crops. With respect to the livestock holdings in the area, sixty-four percent of the farmers here own cattle. This is followed by 46 percent for goat and sheep and 36 percent for poultry. The maximum number of cattle, goats, sheep and poultry owned by a farmer are 16, 23, 30 and 59 respectively.

It is important to note that the observation made in respect of the farming systems in the Tamne River Basin were consistent with findings of a socio-economic survey of the Upper East Region (Department of Geography, 1992).

6.0. DISCUSSION

In this chapter, the results and limitations of the study are discussed. The discussions include: hydrologic characteristics of the Tamne River Basin; land cover changes in the basin; implications of land cover change on hydrologic response and land degradation in the basin; use of dry season satellite images; nature of hydrologic and ancillary data; and error issues in land cover change detection.

6.1. HYDROLOGIC CHARACTERISTICS OF TAMNE RIVER BASIN

Results of the study indicated no significant change in the pattern of inter-annual variation in mean rainfall since 1960. This observation agrees with the expected trend in the inter-annual variation of rainfall in the study area (Walker, 1962; Ofori-Sarpong, 1986; Department of Geography, 1992). Rainfall records from the Manga station were used to approximate rainfall conditions in the Tamne River Basin. This approximation may imply underestimation of the aerial average rainfall for the basin. The use of Thiessen polygon methods to estimate the average rainfall for the Tamne River Basin, provided a good basis for the choice of rainfall records from the Manga station (Appendix I). This was because there was no significant difference between the means of monthly rainfall for the Manga station and the aerial average monthly rainfall for the Tamne River Basin. The constant rainfall pattern observed for the Manga station was therefore relevant to the climatic conditions of the Tamne River Basin.

There was no significant change in the pattern of inter-annual variation in peak flows, wet season flows and annual mean discharge, before and after 1976. This observation was contrary to the presumption that the hydrologic response of the Tamne River Basin may have changed over the years. The unequal sample sizes of the water discharge records prior to and after 1976 may have contributed to the observed inter-annual variation in hydrologic response. Hydrologic data for savanna environments, including the Tamne River Basin, are often incomplete with many years of no flow records (Hjalmarson and Thomas, 1992; Bruijnzeel, 1993).

Return periods of 100 years are usually considered in hydrologic analysis. The flood frequency regime for peak flows from the Garu gauging station shows a 100 year flood magnitude of 59.9 m^3/s. The estimate of 100 year peak flow was important because it is less than a peak flow discharge of 84.6 m^3/s, obtained from reservoir routing for a proposed dam at Kugur (CARDS and GAS, 1994). The GEV used in the flood frequency analysis is a three parameter distribution (Ponce, 1989; Bedient and Huber, 1992). Flood frequency relations in savanna environments are affected by the extreme temporal and spatial variability in floods, many years of no records and short systematic annual peaks (Hjalmarson and Thomas, 1992; El-Hames and Richards, 1994).

The short record period of water discharge data used for the three parameter distribution may have resulted in an upper limit that was lower than the peak flow discharge obtained from reservoir routing. This observation confirmed the assertion that, the use of three parameter distribution in estimating flood magnitudes for short record periods, may result in an upper limit that is lower than the actual limit of the flood peak (Ponce, 1989). Bedient and Huber (1992), also cautioned that no flood frequency distribution, when applied even rigidly to available data, can accurately estimate the flood potential of any given watershed. Other modelling techniques (e.g., hydrograph routing and regional analysis) can therefore be used to compliment the estimates of peak flow magnitudes for the Garu station. There was no significant change in the pattern of streamflow after 1976, and, this makes it possible to use the flood frequency estimates in flood risk and/or flood damage modelling analysis. A typical modelling approach that incorporate flood frequency estimates is the 'Basin Runoff and Streamflow Simulation' (McMahon *et al.*, 1984).

6.2. LAND COVER CHANGES IN TAMNE RIVER BASIN

Ninety percent of the potential change areas occurred of cultivated land. It was not possible to distinguish between farm land and fallow land. The compound farms, bush farms, fallow land and land planning areas were therefore grouped together under cultivated land. Cultivated land in the Upper East Region increased by 33 percent (Table 1), while fallow land decreased by 38 percent between 1979 and 1989 (IFAD, 1990; Department of Geography, 1992). The occurrence of the potential change areas in cultivated areas is consistent with the changes observed for the Upper East Region.

The remaining 10 percent of the potential change areas occurred on uncultivated land and riparian wood land. According to IFAD (1990), there was no change in these areas between 1979 and 1989. The 10 percent of potential change areas that occurred on uncultivated and riparian wood lands is reasonable in light of the estimates for the Upper East Region.

6.2.1. Implications of Land Cover Change on Land Degradation.

Implications of the observed land cover changes are discussed with respect to deforestation and erosion in the Tamne River Basin.

Deforestation - The percentage of potential change areas in the cultivated areas confirmed the assertion that the farming systems constitute a major cause of land degradation in the Upper East Region (Dodoo, 1975; Brookman-Amissah, 1988; IFAD, 1990; Department of Geography, 1992). Most of the potential change areas that occurred on uncultivated lands lie close to the Kugri township. This is an indication of encroachment of farmlands unto undisturbed areas.

Bush burning in the Tamne River Basin is also a major factor that influence the deforestation process (Dodoo, 1975; Department of Geography, 1992). Results from the interviews indicated that most of the farmers depend on either slash and burn or burning only to clear their farmlands (Table 11). The long dry season and the presence of dead and dried organic material, make the threat of uncontrolled bushfires a critical environmental concern. The use of fire for land clearing in and around the Tamne River Basin is sometimes considered as customary practice (Dodoo, 1975; IFAD, 1990; Department of Geography, 1992; Bonsu and Obeng, undated). This and other customary practices that are based on the use of fire in various forms, such as fire dancing, make it difficult to eradicate bush fires in the northern part of Ghana.

Eighty-nine percent of the farmers interviewed depend on cowdung to fertilize their farms. This confirms the fact that cowdung is the primary source of fertilizer in the Upper East Region (Adu, 1972; Dodoo, 1975, Brookman-Amissah, 1988; Department of Geography, 1992). The increasing population pressure and its attendant energy demands have undermined the availability of cowdung as fertilizer. This is because the scarcity of fuelwood has led to a dependence on cowdung as a source of energy for household use. The consequence of scarce cowdung (i.e., organic fertilizer) is that, crop yields decrease at an alarming rate. Besides this, a small percentage of the farmers use inorganic fertilizers on their farms. The misuse of these fertilizers have also contributed to a reduction in the crop yield over the years. The consequence of decreased crop yields from farmlands in the Tamne River Basin, is an increase in pressure on the few fertile lands, a reduction in the length of fallow periods and subsequent land degradation.

According to the Department of Geography (1992), it is difficult to estimate the extent of resource and environmental degradation that have occurred over the years in the Upper East Region . This is due mainly to limited access to ground truth information and wet season satellite images. The potential change areas identified in the study can therefore provide tentative indications for areas that require detailed assessment of land cover change dynamics in the Tamne River Basin.

Erosion - The distribution of potential change areas may be used as possible indicators of the erosion potential in the Tamne River Basin. The proximity of some of the potential change areas to the road network in the Tamne River Basin was expected, and this confirms reported correlations between land clearing and proximity to roads (Sader and Joyce, 1988; Ludeke *et al.*, 1990; Department of Geography, 1992). Large scale soil excavations, during road rehabilitation (i.e, regravelling), in the Upper East Region, are responsible for some of the potential change areas that were identified in the study. Some of these cleared areas are barren and prone to sheet and gully erosion.

Seventy-five percent of the potential change areas occurred on the Wenchi soil consociation. This soil group occupied 80 percent of the Tamne River Basin and they are characterised by exposed sheet iron-pans (i.e., laterite) and scanty vegetation cover. It is important that farmers here are encouraged to use simple anti-erosion farming techniques. Information on land cover change and erosion potential in the area can also be used in pictorial presentations about the extent land degradation. The remaining potential change areas occurred mainly on Kupela-Berenyasi, Pusiga and Tanchera soil series. The Tanchera soil series are loose, porous, coarse textured and easy to cultivate. These soils are however highly susceptible to erosion (Adu, 1969). The Kupela-Berenyasi series are poorly drained, occur along the main river valleys, and are prone to seasonal flooding or waterlogging. The Kupela-Berenyasi soils do not support viable farming activity, but can support grassland conditions that are suitable for grazing.

Most of the farmers own cattle, goat or sheep (table 13). The Bawku East district is reported to have the highest density of cattle, goats and sheep in the country (Department of Geography, 1992). The practice of overstocking cattle, goats and sheep in the area has led to overgrazing and trampling on farmlands, as well as fallow lands. This situation, if left unchecked, may aggravate the erosion hazard in the Tamne River Basin. The nature of soil crusting in the Upper East Region facilitate reduced infiltration of rainfall, even at low intensities. Sheet and gully erosion constitute the main forms of erosion in the study area, for instance, Musah (1988) estimated that there are six gullies per 100 metre distance on cultivated lands in the Bawku area. The short but intense rainstorms will therefore generate catastrophic water discharges, erosion and flooding or waterlogging.

6.2.2. Implication of Land Cover Change on Hydrologic Response

Land cover changes resulting from land use or natural phenomena has obvious consequences on the hydrologic response of a watershed, the degree of which depend on the degree of change (Lull and Sopper, 1969). The presumption of the study was that observed trends in hydrologic response are influenced by land cover changes in the Tamne River Basin.

It has been mentioned earlier that inter-annual variation in rainfall in the Tamne River Basin has not changed significantly since 1960. Contrary to the expectation of the study, inter-annual variation in peak flows, wet season flows and annual mean water discharge also showed no significant change in pattern prior to and after 1976. The distribution of the potential change areas with respect to stream buffer zone may help explain the observed pattern of inter-annual variation in hydrologic response (Figure 16). Most of the potential change areas lie outside the 300 metre buffer zone. The few potential change areas that were within the buffer zone occurred mainly around the upstream tributaries. From the distribution of the potential change areas, it would be reasonable to assert that, the potential land cover changes have little or no effect on the hydrologic response in the Tamne River Basin. This is particularly important for the area above the Garu gauging station.

Use of the 300 metre buffer zone accounts for the effect of the *variable source area* on the hydrologic response of the Tamne River Basin. The buffer zone of 300 metres was large enough to account for the variation in source area due to storm duration and seasonal changes. The portion that generates runoff expands during a rainstorm and shrinks after the storm. Hydrologic response of a watershed also varies in recognizable pattern with the seasons (Figure 2), i.e., during periods of excessive rainfall, areas that seldomly contribute to streamflow become active contributors of runoff (Hewllet and Doss, 1984; Satterlund and Adams, 1992). Surface runoff in savanna areas are however less consistent than in high forest. The impact of the potential change areas on surface flow, and subsequent flood volumes, in the main river channel is likely to be insignificant. This is because the potential change areas that fall within the buffer zone, mostly occurred in the upper tributaries of the Tamne river. Increase in source area peak flows may therefore have less significant effect on downstream flood volumes.

Satellite derived land cover or land use change maps can also be used in runoff and flood modelling (Rango and O'Neil, 1980). Classified land use and land cover change maps have been used to relate the degree of land cover change to the imperviousness of the surface, which in turn determines the potential runoff (e.g., Band *et al.,* 1993). Landsat data have been used to obtain land use information for flood frequency analysis (Cermark *et al.*, 1980). In the absence of complete historic hydrologic data in the savanna environments in Ghana, it is anticipated that the end products of land cover change analysis will facilitate the modelling of various watershed processes, including runoff and flood forecasting.

6.3. LIMITATIONS OF THE STUDY

The main limitations of the study are attributable to incomplete hydrologic data (i.e., rainfall and water discharge) and use of dry season satellite images. Other limitations of the study include the nature of ancillary data (i.e., old and outdated thematic maps), lack of recent aerial photographs, and insufficient ground truth information.

6.3.1. Hydrologic Data

Rainfall and water discharge data used for the study contained gaps that made the hydrologic analysis a cumbersome process. The problem with the rainfall data was resolved after additional information were obtained from rain gauging stations that lie immediately outside the Tamne River Basin. The additional data was however no better than those from stations within the basin. The use of Thiessen polygon method, together with comparison of means, provided a good basis for the choice of the Manga station rainfall records to approximate rainfall conditions in the Tamne River Basin. The water discharge records also contained many years of no records. Attempts to get complete water discharge data from nearby watersheds were unsuccessful. This situation is typical of savanna watersheds. In particular, water discharge data for savanna watersheds in the tropics are rarely complete (Hjalmarson and Thomas, 1992; Bruijnzeel, 1993).

6.3.2. Dry Season Satellite Images

The satellite images used for the study were acquired in November, i.e., during the dry season. The percentage of land cover change in the Tamne River Basin could have been higher if wet season (i.e., summer) images were used in the change detection process. This is because, the percentage of green vegetation in the dry season is lower than the biomass in the wet season. According to Quansah (1990), the standing biomass in November is less than 70 percent of the wet season vegetation cover. The presence of rain bearing clouds in the wet season, however, render satellite images unsuitable for image processing and other related analysis (Fraser and Curran, 1976; Jensen, 1986). The interaction between cloud particles and electromagnetic waves is much smaller in the microwave region than in the visible or infrared regions of the electromagnetic spectrum (Fraser and Curran, 1976: Jensen, 1986). Clouds can also change the illumination of the target phenomenon on earth. Active remote sensors (e.g., Landsat MSS and TM) are therefore susceptible to considerable obscurity of the target phenomenon. Passive remote sensors (e.g., Radarsat microwave sensor) can penetrate the cloud cover with less obscurity of the target phenomenon, but, the applicability of Radar data for image analysis in Sub-Saharan Africa is not yet determined. The incorporation of expert systems into integrated remote sensing and GIS (e.g Moller-Jensen; Gyamfi-Aidoo, 1991;) could be a useful approach to increase the accuracy of image analysis tasks in Ghana. The applicability of expert systems in knowledge-based image analysis is therefore an area that also requires research attention in Ghana.

6.3.3. Ancillary Data

The thematic maps that were used to create GIS coverages for the study were produced in the 1960's. Although the information contained in these thematic maps were useful for the purposes of the study, more recent maps could have been used. Attempts to get land cover map by Adu (1972) and IFAD (1990), as well as, soil map by Asiama (1992), were unsuccessful due to the administrative problems involved in securing the said maps. It was not possible for the author to obtain permission to carry aerial photographs of the of the Upper East Region outside the borders of Ghana, partly because the area lies adjacent to the boarders of Togo. The ground truth information acquired during the field work was also insufficient for detailed accuracy assessment for the change detection process in the study.

6.4. ERROR ISSUES IN THE CHANGE DETECTION PROCESS

The product of the change detection process is yet to be checked against detailed field data. A more quantitative assessment of the accuracy of the 'potential change areas' is yet to be done. In the interim, it will suffice to highlight some of the possible sources of error that are likely to affect the reliability of product of the change detection analysis. In a complex natural environment, image differencing alone may be too simple to deal with all the factors involved in change detection (Weismiller *et al.*, 1977). In particular, image differencing in agricultural and suburban areas (e.g., Tamne River Basin), is sensitive to image misregistration. This is due mainly to the recurrence of change in land cover types, which result in a less definable relationship between spectral change and land cover change (Riordan, 1980; Estes *et al.*, 1982; Jensen, 1986; Green *et al.*, 1994).

A root mean square (RMS) error of one pixel was used during the rectification of the MSS satellite image to the TM image. This low RMS value was used to reduce any possibilities of misregistration. The combination of image differencing and spectral/temporal classification, as well as the incorporation of GIS ancillary data, also enhanced the accuracy with which the potential change areas were identified.

The requirements for effective change detection, with respect to satellite sensor, is beyond the scope of the study. With regards to errors due to the integration of GIS and remote sensing, there are some potential errors that are likely to affect the accuracy of the change detection process. The errors due to remote sensing include image processing, analysis and data conversion . Errors arising from the GIS include: error in map reproduction; deformation of map due to shrinkage; error in map generalization; error in digitizing or scanning; uncertainty in definition of features; errors in map transformations; and, error due to feature exaggeration (Lunetta *et al.*, 1991; Thapa and Bossler, 1992; Thapa and Burtch, 1992).

The aforementioned errors are likely to affect the change detection analysis in the study and may accumulate in additive or multiplicative fashion. The use of data of unknown accuracy or incompatible error in spatial analysis usually result in less accurate end products and subsequent misguided management decisions (Lunetta *et al.*, 1991). This explains why detailed spatial analysis were not done in the study. It also emphasizes the need for quantitative assessment of accuracy of products of any change detection analysis. A qualitative evaluation of the accuracy of the potential change areas was however necessary due to the travel to Ghana that is required for field checking of the potential change areas. The potential change areas were judged to be fairly accurate based on available *a priori* information on the study area, but, this must be confirmed by a quantitative accuracy assessment.

6.5. WATERSHED MANAGEMENT AND RESEARCH IN NORTHEAST GHANA

Watershed management initiatives in the northeastern part of Ghana dates back to the early part of this century. These management efforts reached a peak between 1945 and 1960, when systematic and comprehensive land use planning occurred (Department of Geography, 1992). Since the 1960's, there have been a series of management and research activities to combat land degradation and desertification in the Upper East Region (e.g., Adu, 1972; Dodoo, 1975; IFAD, 1990; Quansah, 1990; Kohler, 1993).

The approaches to the environmental problem in the Upper East Region were categorized as ecological conservation approach, socio-economic approach, and combined approach (Department of Geography, 1992). The land planning projects of the 1950's fall under ecological conservation approach. Establishment and operation of the Upper East Agricultural Development Project (URADEP) and its affiliate, Farmers Services Company Limited (FASCOM), constitute a socio-economic approach. The Upper East Region Land Conservation and Small Holder Rehabilitation project, as well as, complementary efforts by the Ministry of Forestry and Non-governmental Organizations (NGO's) constitute a combined approach to watershed management in the Upper East Region.

The Upper East Region was the focus of the Northeast Ghana Savanna Research Project (NGSRP) (Dodoo, 1975). This project was an inter-disciplinary research effort that was initiated by the Natural Resource Committee of the Council for Scientific and Industrial Research, Ghana. The Tamne River Basin was the study area of the NGSRP. Major research components of the project were cultivation practices, bush fires, water availability and distribution, deforestation and socio-economic survey (Dodoo, 1975). The main aim of the project was to integrate research findings in the most effective manner to solve the land degradation problems in Upper East Region. Important findings were made in respect of soil characteristics, surface and ground water, burning, livestock, deforestation and erosion (e.g., Bonsu and Obeng, undated). Some recommendations were made for: detailed land cover and land use monitoring; education; multi-disciplinary planning; and, integration of development projects.

The United Nations Sudane-Sahelian Office (UNSO) mission to Ghana, also made recommendations with respect to forest and water resource management, agro-silvopastoral systems and bush fires (UNSO, 1986). These recommendations and a series of workshops resulted in a National Environmental Action Plan (NEAP) (EPC, 1991). The plan is a desertification monitoring programme which has been accepted by the Government of Ghana for implementation. The NEAP is a major component of the Ghana Environmental Resource Monitoring Programme (GERMP). The GERMP involves several institutions in the production of a wide variety of data sets required for environmental management in Ghana (EPC, 1992). As part of the NEAP, a National Environmental Information Systems (NEIS) has been proposed for effective co-ordination of resource information among the various research institutions, resource managers and planners (EPC, 1992). It is therefore notable that considerable progress have been made in the various efforts to combat the environmental problems of the Ghana, in particular the Upper East Region.

Considering that an effective integration of remote sensing and GIS can provide timely and cost effective resource data in a flexible format, it is not surprising to note the high expectations that integrated remote sensing and GIS technologies will resolve the acute environmental information problem in Ghana. Although remote sensing and GIS can facilitate resource assessment and monitoring in the country, they should not be regarded as a remedy to the urgent need for reliable field data on the various watershed elements, e.g., rainfall, soil moisture, runoff, and vegetation. For instance, serious problems were encountered during the processing of hydrologic data, ancillary data, and dry season satellite images. These problems suggest that, there is more to be done if remote sensing and GIS technologies are to play a leading role in environmental management in Ghana. This is particularly true for the savanna environment of Upper East Region of Ghana.

7.0. CONCLUSION AND FUTURE RESEARCH

7.1. CONCLUSION

The study served as a preliminary enquiry into land cover change and hydrologic response in the Tamne River Basin. As far as the specific objectives of the study are concerned, the results of the study provided tentative indications of land cover change, inter-annual variation in hydrologic response of the Tamne River Basin, and peak flow estimates for specific return periods.

Inter-annual variation in rainfall in the Tamne River Basin has not changed significantly since 1960. Hydrologic response (i.e., peak flows, wet season flows, and annual mean discharge) also showed no significant difference in the pattern of inter-annual variation. It was anticipated that, hydrologic response in the basin may have changed significantly after 1976. The distribution of potential land cover changes with respect to stream buffer zone of 300 metres, helps to explain the relationship between land cover change and hydrologic response in the basin. Most of the potential change areas were outside the buffer zone. It is therefore reasonable to assert that potential changes in land cover, within and outside the buffer zone, have little or no effect on inter-annual variation of the observed hydrologic response. Usually, 100 year flood magnitudes are employed in hydrologic applications. The 100 year peak flow at the Garu gauging station (i.e., 59.9 m^3/s) was less than a flood magnitude of 86.4 m^3/s that was obtained by reservoir routing for a dam at Kugur. The short record period of peak flows used in the flood frequency analysis, may have contributed to the difference in flood magnitudes. This emphasizes the need for financial and infrastructural commitment to long term environmental monitoring, including streamflow, in the northern part of Ghana.

About 90 percent of the potential change areas occurred on cultivated land while the remaining 10 percent occurred on uncultivated and riparian woodland. These results were consistent with estimates of land cover changes in the Upper East Region of Ghana. The distribution of the potential change areas with respect to soil groups and road network, provided some indications of the erosion potential in the basin. Most of the soils here are exposed and prone to crusting and flooding or waterlogging. The potential land cover changes, as well as field observations and interviews with farmers, confirmed the assertion that the farming systems constitute a primary cause of land degradation in the Upper East Region. The potential land cover changes are yet to be field checked for quantitative accuracy assessment. Also, less than one percent of the total land area of the Tamne River Basin showed potential land cover change. The said relationships between land cover change and land degradation, as well as hydrologic response are therefore tentative.

The study demonstrated the usefulness of integrating remote sensing and GIS technologies in the assessment of environmental changes in Ghana. The problems encountered in pre-processing ancillary data, suggest that remote sensing and GIS technologies should not be viewed as a remedy to the acute environmental information problem in Ghana. This is especially true of the savanna environments of the northern part of the country. There is more preliminary work to be done, if remote sensing and GIS technologies are to play a leading role in watershed management and research in Ghana, in particular, Upper East Region.

7.2. SUGGESTIONS FOR FUTURE RESEARCH

Some suggestions for consideration in future research initiatives are as follows.

1. A quantitative assessment of the accuracy of potential land cover changes that were identified in the study.
2. Explore the use of expert systems in incorporating ancillary data into knowledge-based image processing.
3. Develop a land cover classification system that is pertinent to the ecological and land use scenario in Ghana.
4. Explore possibilities for the use of airborne videography in real time flood monitoring in the country. The information obtained from this technology can be useful for modelling various watershed processes and flood damage forecasting.
5. Fill gaps in water discharge data series by means of appropriate methodologies, e.g., stochastic methods, to generate complete daily streamflow in savanna watersheds in Ghana (e.g., Tamne River Basin).
6. Estimate flood peaks for single storm events in at least five sub-catchments in the Tamne River Basin. These flood peaks could then be used in regional analysis and distributed hydrologic modelling.

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APPENDICES

APPENDIX I. Estimation of Aerial Rainfall Average by Thiessen Polygons Method for The Tamne River Basin.

For a given storm event, there is the possibility that the rainfall depths measured by two or more rain gauges in a catchment may not be the same. In particular, for large watersheds like the Tamne river basin, runoff is modelled by assuming that the rainfall vary in time and space. The methods used to estimate this aerial average rainfall are: average rainfall; Thiessen polygons; and, isohyetal method. Although the isohyetal method is more accurate than the Thiessen polygons and average rainfall methods, this is mostly true for hilly terrain. However the topography of the Tamne river basin is relatively flat. Also, the Thiessen polygons method is generally more accurate than the average rainfall method. Therefore the Thiessen polygons was chosen to estimate the aerial rainfall average. In this method, the locations of the rain gauges are plotted on a map of the catchment and surrounding area (Figure A.1). The locations (stations) were joined with straight lines in order to form pattern of triangles. Perpendicular bisectors to the sides of these triangles were drawn to enclose each station within a polygon, called a Thiessen polygon, circumscribing the area of influence. The average precipitation over the catchment was calculated by weighing each station's rainfall depth in proportion to its area of influence as follows:

Station	Area of influence (Km^2)	Proportion
A	478.44	0.54
B	147.96	0.17
C	106.32	0.12
D	153.28	0.17
Total	886.00	1.00

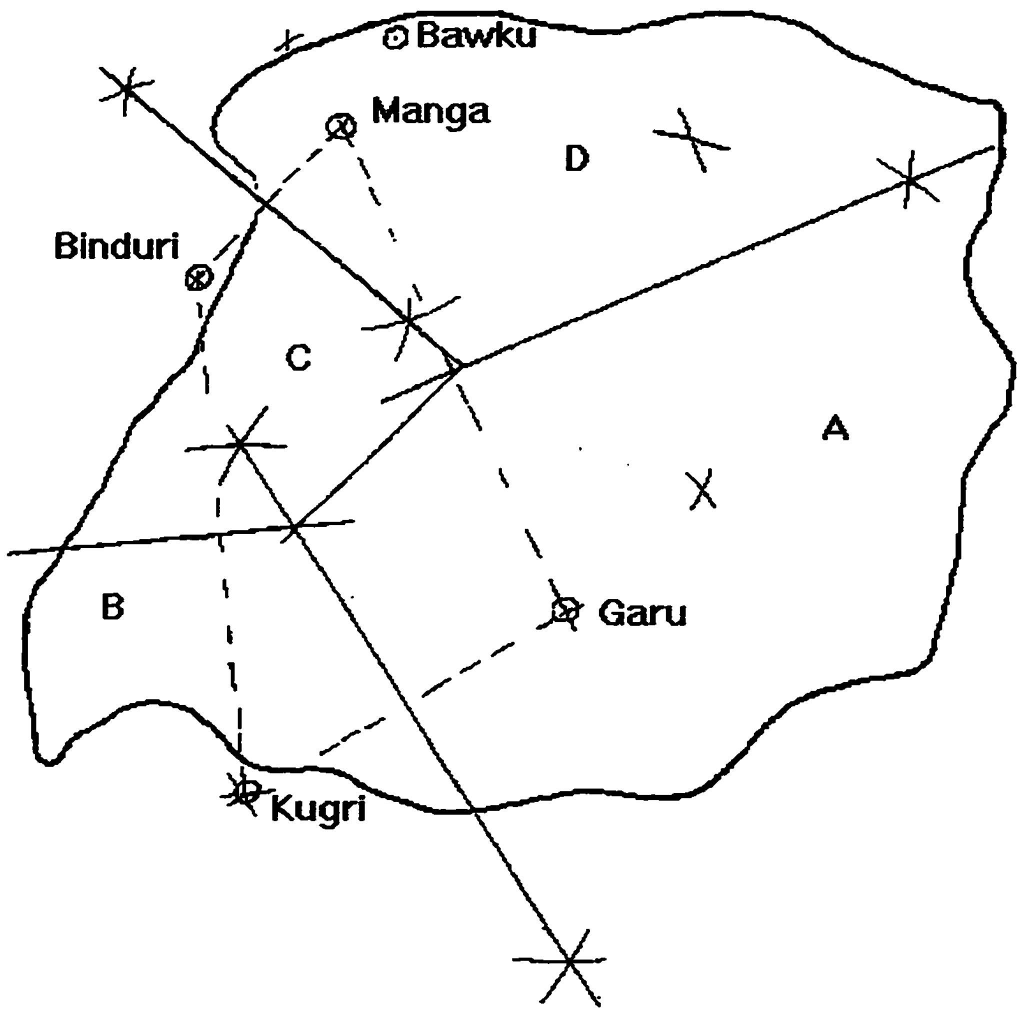


Figure A.1. Thiessen Polygons for Tamne river Basin

The average monthly rainfall Garu, Kugri, Binduri and Manga are shown below in Tables A.1, A.2, A.3 and A.4 respectively . Let R_A, R_B, R_C and R_D rainfall be at Garu, Kugri, Binduri and Manga respectively. The average rainfall (R) was calculated as follows:

$$R = (R_A \times 0.54) + (R_B \times 0.17) + (R_C \times 0.12) + (R_D \times 0.17)$$

Monthly average rainfall comparison

Station	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec
Manga	0.5	2.3	14.4	44.9	99.6	121.5	175.8	233.6	177.6	53.3	4.4	1.9
Garu	0.3	1.7	19.6	41.1	101.8	116.9	183.1	236.2	183.5	64.5	9.8	1.8
Binduri	0.0	0.4	9.9	34.1	105.9	125.1	199.7	217.9	161.0	63.3	11.0	2.9
Kugri	0.8	2.3	15.4	33.3	93.3	116.5	182.2	245.8	162.0	44.4	3.4	3.5
Average*	0.5	1.9	14.9	41.0	99.7	120.3	181.0	234.2	173.9	54.9	6.0	2.3

*** Average (or Tamne) obtained by Thiessen Polygons method**

Station	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec
Tamne	0.5	1.9	14.9	41.0	99.7	120.3	181.0	234.2	173.9	54.9	6.0	2.3
Manga	0.5	2.3	14.4	44.9	99.6	121.5	175.8	233.6	177.6	53.3	4.4	1.9

The two monthly variations in rainfall Tamne River Basin and Manga station showed similar patterns (Figure A.2). This was confirmed by results from a comparison of means as follows:

For lognormal of rainfall from Tamne River Basin,

number of flows (n_t) = 12; mean ($\bar{x}_t$) = 3.18; degrees of freedom (df) = 11

$$\Sigma X^2 = 169.51$$

$$(\Sigma X)^2 \div n_t = (38.17)^2 \div 12 = 121.40$$

$$\Sigma x = \Sigma X^2 - (\Sigma X)^2 \div n_t$$

$$= 169.51 - 121.40 = 48.11$$

For lognormal of rainfall from Manga station,

number of flows (n_m) = 12 mean ($\bar{x}_m$) = 3.16; degrees of freedom (df) = 11

$$\Sigma X^2 = 168.65$$

$(\Sigma X)^2 \div n_m = (37.96)^2 \div 12 = 120.08$

$\Sigma x = \Sigma X^2 - (\Sigma X)^2 \div n_m$

$\Sigma x = 168.65 - 120.08 = 48.57$

The pooled variance $S^2 = (48.11 + 48.57) \div (11+ 11) = 4.40$

Comparing means,

$t = (\bar{x}_t - \bar{x}_m) \div [\surd\, S^2 \{(n_1+n_2) \div (n_1 \times n_2)\}]$

$= (3.18 + 3.16) \div 0.89 = 0.02$

At 95 percent confidence limit, there was no significant difference between the means for the two data sets. The rainfall data for Manga may probably be used to approximate rainfall conditions in the Tamne River Basin.

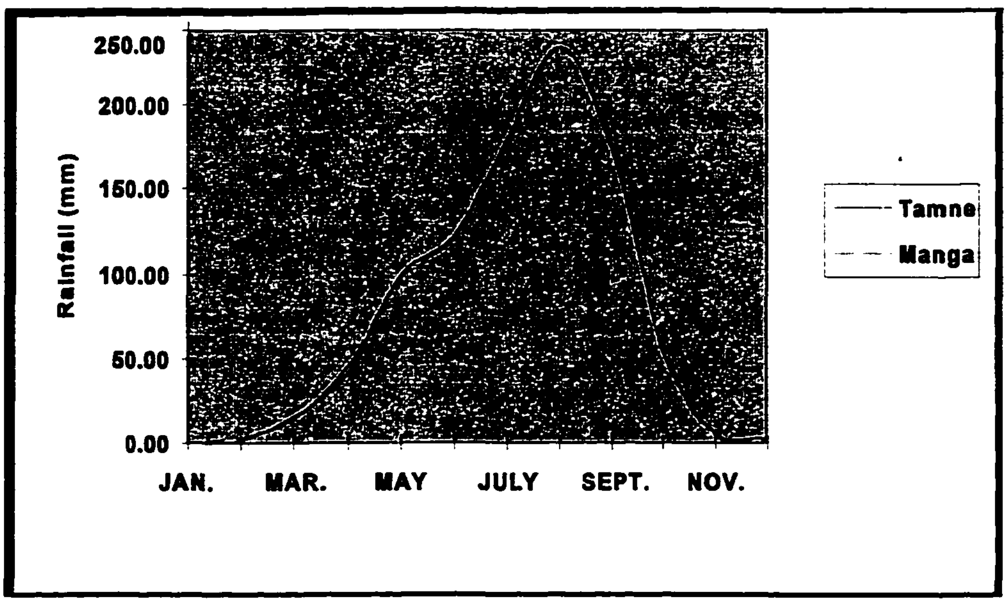


Figure A.2. Monthly variation in mean rainfall Tamne River Basin and Manga station.

Table A1. Monthly mean rainfall (mm) at Garu station

Year	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1960	-	-	-	-	-	25.7	178.3	168.2	192.8	85.3	19.1	1.3
1961	1.0	-	-	16.0	132.8	149.1	207.8	-	-	-	-	-
1962	-	-	-	-	-	129.0	115.3	386.3	207.3	110.7	22.9	-
1963	-	21.3		32.3	64.0	222.8	401.1	390.9	-	62.2	-	-
1964	0.0	0.0	31.0	10.2	67.3	102.6	118.6	-	-	-	-	-
1965	-	-	-	30.2	78.2	-	-	-	-	-	-	-
1966												
1967												
1968												
1969												
1970												
1971												
1972												
1973												
1974												
1975												
1976	-	-	-	-	-	-	141.0	198.7	110.4	170.6	27.7	0.0
1977	0.1	0.0	-	6.6	48.2	39.4	205.5	260.3	173.3	53.8	1.0	1.0
1978	0.0	0.0	4.7	67.1	137.7	126.0	141.0	251.7	75.5	38.0	-	-
1979	0.0	0.0	1.0	80.0	186.7	98.6	252.9	200.1	299.8	70.9	13.9	0.0
1980	4.5	0.0	0.0	34.6	117.4	72.9	72.9	317.9	151.4	98.7	1.0	1.6
1981	0.0	0.0	15.2	28.7	92.3	99.4	130.5	254.0	120.6	18.7	0.0	0.0
1982	0.0	2.9	8.4	74.3	18.0	165.0	187.2	184.1	296.6	46.8	1.5	0.0
1983	0.0	0.0	35.5	30.3	117.4	89.4	201.8	223.2	166.5	0.0	0.0	0.0
1984	0.0	0.0	44.0	106.3	102.3	75.5	74.2	206.2	207.2	61.4	40.9	0.0
1985	0.0	0.0	28.6	24.7	69.1	90.0	154.3	165.3	152.5	11.7	1.0	0.0
1986	0.0	0.0	0.5	55.6	38.5	171.7	176.0	186.5	243.9	114.5	8.6	0.0
1987	0.0	0.0	6.2	1.0	51.1	120.1	169.3	283.6	202.0	69.9	0.0	0.0
1988	0.0	0.0	50.1	45.5	96.6	112.5	114.1	233.1	253.8	19.8	25.6	0.0
1989	0.0	0.0	23.4	1.0	104.2	144.0	220.5	300.3	273.8	58.5	0.0	14.6
1990	0.0	0.0	0.0	29.4	132.4	61.5	228.1	200.0	89.6	22.6	1.0	14.3
1991	0.0	6.3	69.8	123.2	206.6	152.0	172.5	242.0	102.6	106.9	0.0	0.0
1992	0.0	0.0	1.3	25.3	207.0	181.7	251.9	195.0	168.7	64.9	20.8	0.0
1993	0.0	1.0	0.0	41.7	70.8	142.0	296.2	112.1	181.0	68.9	0.9	0.0

Table A2. Monthly mean rainfall (mm) at Kugri station

Year	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1960												
1961												
1962												
1963												
1964												
1965												
1966												
1967												
1968												
1969												
1970												
1971												
1972												
1973												
1974												
1975												
1976												
1977	1.0	0.0	11.1	0.2	164.1	61.4	130.4	250.2	114.1	22.9	1.0	1.0
1978	-	-	-	-	-	-	-	-	-	-	-	-
1979	0.0	0.0	0.6	88.4	151.6	100.6	242.2	423.7	223.4	59.2	3.2	0.0
1980	12.5	1.0	0.0	1.2	36.2	100.6	113.3	294.9	209.2	104.2	1.0	1.0
1981	0.0	0.0	29.9	33.1	106.7	151.3	173.1	296.6	93.7	27.3	0.0	0.0
1982	0.0	1.0	1.0	0.3	9.0	81.8		194.8	166.7	50.3	0.0	0.0
1983	0.0	1.0	21.7	18.5	73.1	124.0	153.8	219.4	98.4	0.0	0.0	0.0
1984	0.0	0.0	10.2	67.0	116.6	61.0	105.3	239.2	109.9	44.2	0.9	0.0
1985	0.0	0.0	10.9	9.7	54.6	80.7	101.9	212.2	195.9	7.2	0.0	0.0
1986	0.0	1.0	0.4	34.0	36.1	134.6	257.0	176.5	150.9			0.0
1987	0.0	0.0	22.0	9.8	51.1	210.7	231.0	324.7	149.6	34.9	0.0	0.0
1988	0.0	0.0	19.2	44.6	71.8	104.6	154.3	256.6	259.5	56.3	26.3	0.0
1989	0.0	0.0	15.2	5.9	145.4	177.7	176.4	267.9	165.5	75.9	0.0	37.5
1990	0.0	0.0	0.0	56.5	151.8	111.4	169.0	169.8	118.3	21.8	0.4	15.9
1991	0.0	32.6	103.5	67.0	147.1	115.3	122.3	312.0	124.7	49.3	0.0	0.0
1992	0.0	0.0	0.3	34.2	148.6	122.8	305.6	189.4	244.3	53.3	17.2	
1993	0.0	0.1	1.0	62.5	29.3	125.0	296.8	104.8	167.1	58.7	1.0	0.0

Table A3. Monthly mean Rainfall (mm) at Binduri station

Year	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1960	-	-	0.8	47.2	148.6	139.7	193.8	233.9	313.4	-	-	-
1961	0.0	0.0	5.1	73.2	105.4	121.4	223.3	122.4	208.8	-	-	-
1962	0.0	0.0	25.1	43.2	94.0	143.8	205.5	-	-	-	-	-
1963	-	-	-	-	88.9	144.3	478.5	273.3	82.3	95.5	-	-
1964												
1965												
1966												
1967												
1968												
1969												
1970												
1971												
1972												
1973												
1974												
1975												
1976	-	-	-	-	-	-	-	154.7	44.7	178.0	1.6	0.0
1977	0.0	0.0	6.5	1.0	162.1	39.7	86.1	24.0	96.2	102.9	0.0	0.0
1978	0.0	0.0	21.0	61.1	119.9	191.6	162.9	157.8	84.5	41.0	25.1	0.0
1979	0.0	0.0	1.0	23.2	155.7	124.6	169.3	183.2	258.0	76.1	45.6	0.0
1980	0.0	0.0	0.0	5.8	46.8	62.8	116.7	315.9	111.6	112.3	4.0	1.0
1981	0.0	0.0	0.8	52.7	82.7	129.1	117.5	190.3	118.7	36.6	0.0	0.0
1982	0.0	4.0	7.5	67.9	72.2	187.8	224.9	152.8	165.7	87.6	0.0	0.0
1983	0.0	0.0	0.0	36.6	114.1	96.0	169.7	244.7	78.5	1.7	0.0	0.0
1984	0.0	0.0	37.5	43.0	149.1	82.7	129.1	146.5	213.7	35.8	50.3	0.0
1985	0.0	0.0	5.5	4.1	99.7	160.6	192.2	242.3	195.4	18.6	5.5	0.0
1986	0.0	1.0	1.0	11.0	60.2	164.1	177.3	-	168.1	-	-	0.0
1987	0.0	0.0	2.5	0.0	25.5	148.2	194.1	284.6	99.4	64.5	0.0	0.0
1988	0.0	0.0	7.5	49.7	93.0	158.4	226.0	220.8	165.7	10.8	19.0	0.0
1989	0.0	0.0	25.6	1.3	34.8	120.1	279.4	382.4	313.4	69.5	0.0	25.0
1990	0.0	1.0	0.0	13.6	76.8	93.7	208.3	262.1	118.8	2.1	18.7	28.5
1991	0.0	0.7	54.0	69.5	227.0	87.8	110.7	242.9	164.7	48.4	0.0	0.0
1992	1.0	0.0	1.0	35.8	160.4	178.4	159.1	191.4	165.3	42.7	28.0	0.0
1993	0.0	1.0	3.0	45.9	48.8	73.7	348.8	201.5	193.8	17.8	0.0	0.0

Table A4. Monthly mean rainfall (mm) at Manga-Bawku station

Year	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1960	0.0	0.0	4.8	58.9	103.1	85.9	218.4	227.1	231.4	34.8	0.0	4.8
1961	0.0	0.0	1.8	54.4	126.0	95.8	174.2	136.9	147.3	0.0	0.0	0.0
1962	0.0	0.0	1.0	61.7	80.3	153.9	202.2	437.4	233.7	117.9	23.1	0.0
1963	0.0	35.3	0.0	17.0	128.0	140.0	208.0	291.8	114.5	71.1	1.5	0.0
1964	0.0	0.0	40.1	31.8	48.8	96.5	204.7	243.6	245.1	33.5	0.0	0.0
1965	10.9	0.0	0.0	83.3	68.6	111.0	129.0	147.8	129.8	2.0	0.0	0.0
1966	0.0	0.0	17.8	93.7	126.0	141.2	157.2	245.4	168.7	86.6	0.0	0.0
1967	0.0	0.0	116.1	108.2	65.0	83.3	93.2	301.0	340.1	51.8	0.0	0.0
1968	0.0	10.9	0.0	77.0	183.4	220.7	303.3	199.6	109.0	-	-	-
1969	-	-	-	-	82.3	126.0	205.0	281.4	-	-	0.0	0.0
1970	0.0	0.0	0.0	11.7	129.3	115.3	74.9	297.9	296.4	16.5	0.0	0.0
1971	0.0	0.0	56.6	45.0	50.5	121.2	181.6	232.9	245.4	79.5	0.0	5.1
1972	0.0	17.8	7.6	132.1	79.5	117.3	177.0	130.5	166.9	45.0	0.0	0.0
1973	0.0	1.8	6.1	73.9	102.1	121.4	241.0	317.8	137.4	35.8	0.0	0.0
1974	0.0	0.0	10.9	43.9	78.5	125.5	199.9	186.7	352.3	73.9	0.0	0.0
1975	5.3	0.0	1.3	60.5	199.6	94.2	225.5	87.4	171.5	15.0	6.6	0.0
1976	0.0	0.0	0.0	6.1	140.5	88.7	73.4	158.2	144.9	183.7	3.3	0.0
1977	0.0	0.0	11.4	0.0	180.4	57.8	116.2	278.7	81.1	74.4	1.0	1.5
1978	0.0	0.0	24.6	100.6	87.8	159.1	175.6	266.0	75.3	54.3	5.1	0.0
1979	0.0	0.0	1.0	34.5	92.5	191.6	240.7	284.1	208.1	99.4	20.9	0.0
1980	0.0	0.0	0.0	6.9	47.9	114.6	84.5	416.7	72.4	49.0	11.9	0.0
1981	0.0	0.0	1.0	79.3	113.2	127.5	111.2	141.8	104.4	64.3	0.0	0.0
1982	0.0	5.1	1.5	61.0	78.7	155.5	285.3	158.5	171.6	44.5	0.0	0.0
1983	0.0	1.5	1.0	4.6	79.1	84.8	125.4	-	-	-	-	-
1984	0.0	0.0	23.4	43.5	-	90.4	100.3	265.7	166.5	51.8	14.0	0.0
1985	0.0	0.0	0.3	0.5	88.9	83.5	109.9	214.0	181.8	7.3	1.0	0.0
1986	0.0	1.0	11.9	28.5	27.2	139.4	175.9	171.8	238.9	83.1	5.8	0.0
1987	0.0	0.0	12.2	21.0	30.7	227.7	193.6	199.2	126.5	17.5	0.0	0.0
1988	0.0	0.0	4.6	24.2	117.6	112.8	241.9	209.3	137.3	20.3	6.1	0.0
1989	0.0	0.0	39.1	1.5	31.7	120.7	206.1	253.7	312.6	76.5	0.0	26.9
1990	0.0	1.0	0.0	2.1	115.0	91.7	200.0	270.3	107.8	14.0	39.1	22.6
1991	0.0	0.3	73.9	66.3	215.3	64.4	125.2	281.0	155.8	91.3	0.0	0.0
1992	1.0	0.0	1.0	15.9	133.1	159.0	161.2	190.3	168.3	37.4	3.0	0.0
1993	0.0	0.5	4.6	30.7	57.2	114.2	256.7	184.2	138.8	20.8	0.0	0.0

APPENDIX II. Water Discharge for Garu Sation

Table A.5. Peakflows selected from mean daily water discharge for Garu

Day/Month/year/	Peakflows (ft^3/s)	peakflows (m^3/s)
2 / 9 / 1966	536	15.18
10 / 8 / 1967	754	21.35
20 / 8 / 1968	931	26.36
9 / 9 / 1969	853	24.15
5, 6, / 9 / 1970	1193	33.37
6 / 9 / 1971	1739	49.24
2 / 9 / 1972	847	23.98
1, 4, 15 / 8 / 1973	640	18.12
4 / 10 / 1974	1193	33.78
23 / 7 / 1975	967	27.38
27 / 10 / 1976	792	22.43
-	-	-
13 / 7 / 1980	773	21.89
-	-	-
-	-	-
2 / 9 / 1991	1634	46.27
31/ 8 / 1992	829	23.47
13 / 8 / 1993	967	27.38

Table A6. Monthly mean water discharges (ft^3/s) for Garu station - water year

Year	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1966/7	-	-	-	-	-	-	267.0	124.0	-	-	-	-
1967/8	-	-	4.0	4.0	9.0	291.0	475.0	96.0	2.0	-	-	-
1968/9	-	-	-	79.0	244.0	358.0	248.0	13.0	0.0	0.0	0.0	0.0
1969/70	-	0.0	25.0	15.0	137.0	370.0	419.0	26.0	0.0	0.0	-	-
1970/1	-	-	-	-	-	-	464.0	33.0	2.0	0.0	0.0	-
1971/2	-	-	1.0	4.0	18.0	219.0	328.0	19.0	3.0	2.0	0.0	-
1972/3	0.0	3.0	12.0	25.0	31.0	87.0	320.0	35.0	6.0	4.0	2.0	1.0
1973/4	0.0	0.0	0.0	12.0	10.0	406.0	-	8.0	4.0	0.0	0.0	0.0
1974/5	-	-	-	2.0	-	-	-	84.0	16.0	15.0	-	-
1975/6	-	-	-	10.0	326.0	123.0	218.0	18.0	5.0	3.0	-	-
1976/7	-	-	-	12.0	34.0	134.0	7.0	172.0	38.0	7.0	-	-
1977/8												
1978/9												
1979/80												
1980/1	0.0	-	7.0	29.0	132.0	57.0	-	-	-	-	-	-
1981/2												
1982/3												
1983/4												
1984/5												
1985/6												
1986/7												
1987/8												
1988/9												
1989/90												
1990/1	-	-	-	9.0	37.0	228.0	84.0	6.0	-	-	-	-
1991/2	-	-	95.0	71.0	195.0	-	404.0	45.0	-	-	-	-
1992/3	-	-	10.0	74.0	127.0	240.0	-	-	-	-	-	-
1993/4	-	-	-	-	120.0	326.0	157.0	-	-	-	-	-

Table 7. Monthly mean water discharges (ft^3/s) for Garu station - calender year

Year	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1966	-	-	-	-	-	-	-	-	267.0	124.0	-	-
1967	-	-	-	-	4.0	4.0	9.0	291.0	475.0	96.0	2.0	-
1968	-	-	-	-	-	79.0	244.0	358.0	248.0	13.0	0.0	0.0
1969	0.0	0.0	-	0.0	25.0	15.0	137.0	370.0	419.0	26.0	0.0	0.0
1970		-	-	-	-	-	-	-	464.0	33.0	2.0	0.0
1971	0.0	-		-	1.0	4.0	18.0	219.0	328.0	19.0	3.0	2.0
1972	0.0	-	0.0	3.0	12.0	25.0	31.0	87.0	320.0	35.0	6.0	4.0
1973	2.0	1.0	0.0	0.0	0.0	12.0	10.0	406.0	-	8.0	4.0	0.0
1974	0.0	0.0	-	-	-	2.0	-	-	-	84.0	16.0	15.0
1975	-	-	-	-	-	10.0	326.0	123.0	218.0	18.0	5.0	3.0
1976	-	-	-	-	-	12.0	34.0	134.0	7.0	172.0	38.0	7.0
1977												
1978												
1979												
1980	-	-	0.0	-	7.0	29.0	132.0	57.0	-	-	-	-
1981												
1982												
1983												
1984												
1985												
1986												
1987												
1988												
1989												
1990	-	-	-	-	-	9.0	37.0	228.0	84.0	6.0	-	-
1991	-	-	-	-	95.0	71.0	195.0	-	404.0	45.0	-	-
1992	-	-	-	-	10.0	74.0	127.0	240.0	-	-	-	-
1993	-	-	-	-	-	-	120.0	326.0	157.0	-	-	-

APPENDIX III. Supplementary Statistical Analysis for Rainfall and Streamflow

(a). Comparison of means for peak flows

For lognormal of peak flows from 1966 to 1976,

number of flows (n_1) = 11; mean ($\bar{x}_{11}$) = 3.24; degrees of freedom (df) = 10

$$\Sigma X^2 = 116.2$$

$$(\Sigma X)^2 \div n_1 = (35.60)^2 \div 11 = 115.21$$

$$\Sigma x = \Sigma X^2 - (\Sigma X)^2 \div n_1$$

$$= 116.27 - 115.21 = 1.06$$

For lognormal of peak flows from 1980 to 1993,

number of flows (n_2) = 5; mean ($\bar{x}_5$) = 3.30; degrees of freedom (df) = 3

$$\Sigma X^2 = 54.82$$

$$(\Sigma X)^2 \div n_2 = (16.50)^2 \div 5 = 54.43$$

$$\Sigma x = \Sigma X^2 - (\Sigma X)^2 \div n_2$$

$$= 0.39$$

The pooled variance $S^2 = (1.06 + 0.39) \div (10 + 4) = 0.10$

Comparing means,

$$t = \frac{(\bar{x}_{11} - \bar{x}_5)}{\sqrt{S^2\left(\frac{(n_1 + n_2)}{(n_1 \times n_2)}\right)}}$$

$$t = (-3.30 + 3.24) \div 0.19 = -0.32$$

(b). Comparison of means for wet season flows (i.e.,mean discharges from July to september)

For lognormal of wet season flows from 1966 to 1976,

number of flows (n_1) = 9; mean ($\bar{x}_9$) = 1.73; degrees of freedom (df) = 8

$$\Sigma X^2 = 28.92$$

$$(\Sigma X)^2 \div n_1 = (15.55)^2 \div 9 = 26.86$$

$$\Sigma x = \Sigma X^2 - (\Sigma X)^2 \div n_1$$

$$= 28.92 - 26.86 = 2.07$$

For lognormal of wet season flows from 1980 to 1993,

number of flows (n_2) = 5; mean ($\bar{x}_5$) = 1.56; degrees of freedom (df) = 4

$$\Sigma X^2 = 12.85$$

$$(\Sigma X)^2 \div n_2 = 12.09$$

$$\Sigma x = \Sigma X^2 - (\Sigma X)^2 \div n_2$$

$$= 12.85 - 12.09 = 0.76$$

The pooled variance $S^2 = (2.07 + 0.76) \div (8 + 4) = 0.24$

Comparing means,

$$t = \frac{(\bar{x}_9 - \bar{x}_5)}{\sqrt{S^2\left(\frac{(n_1 + n_2)}{(n_1 \times n_2)}\right)}}$$

$$t = (-1.73 - 1.56) \div 0.29 = -0.59$$

(c). Comparison of means for mean water discharges

For lognormal of mean discharges from 1966 to 1976,

number of flows (n_1) = 11; mean ($\bar{x}_{11}$) = 0.86; degrees of freedom (df) = 10

$\Sigma X^2 = 11.40$

$(\Sigma X)^2 \div n_1 = 8.21$

$\Sigma x = \Sigma X^2 - (\Sigma X)^2 \div n_1$

$= 3.19$

For lognormal of mean discharge from 1980 to 1993,

number of flows (n_2) = 5; mean ($\bar{x}_5$) = 1.17; degrees of freedom (df) = 4

$\Sigma X^2 = 7.28$

$(\Sigma X)^2 \div n_2 = 5.82$

$\Sigma x = \Sigma X^2 - (\Sigma X)^2 \div n_2$

$= 7.28 - 5.82 = 1.46$

The pooled variance was given $S^2 = (3.18 + 1.31) \div (10 + 3) = 0.11$

Comparing means,

$$t = \frac{(\bar{x}_{11} - \bar{x}_5)}{\sqrt{S^2\left(\frac{(n_1 + n_2)}{(n_1 \times n_2)}\right)}}$$

$t = (0.86 - 1.08) \div 0.34 = -0.65$

d. Comparison of means for rainfall

For lognormal of rainfall from 1960 to 1976,

number of flows (n_1) = 15; mean ($\bar{x}_{15}$) = 4.37; degrees of freedom (df) = 14

$$\Sigma X^2 = 287.19$$

$$(\Sigma X)^2 \div n_1 = (65.59)^2 \div 15 = 286.79$$

$$\Sigma x = \Sigma X^2 - (\Sigma X)^2 \div n_1$$

$$\Sigma x = 287.19 - 286.79 = 0.40$$

For lognormal of rainfall from 1977 to 1993,

number of flows (n_2) = 17; mean ($\bar{x}_{17}$) = 1.17; degrees of freedom (df) = 16

$$\Sigma X^2 = 314.02$$

$$(\Sigma X)^2 \div n_2 = 313.72$$

$$\Sigma x = \Sigma X^2 - (\Sigma X)^2 \div n_2$$

$$= 314.02 - 313.72 = 0.30$$

The pooled variance was given $S^2 = (0.40+0.30) \div (14+16) = 0.02$

Comparing means,

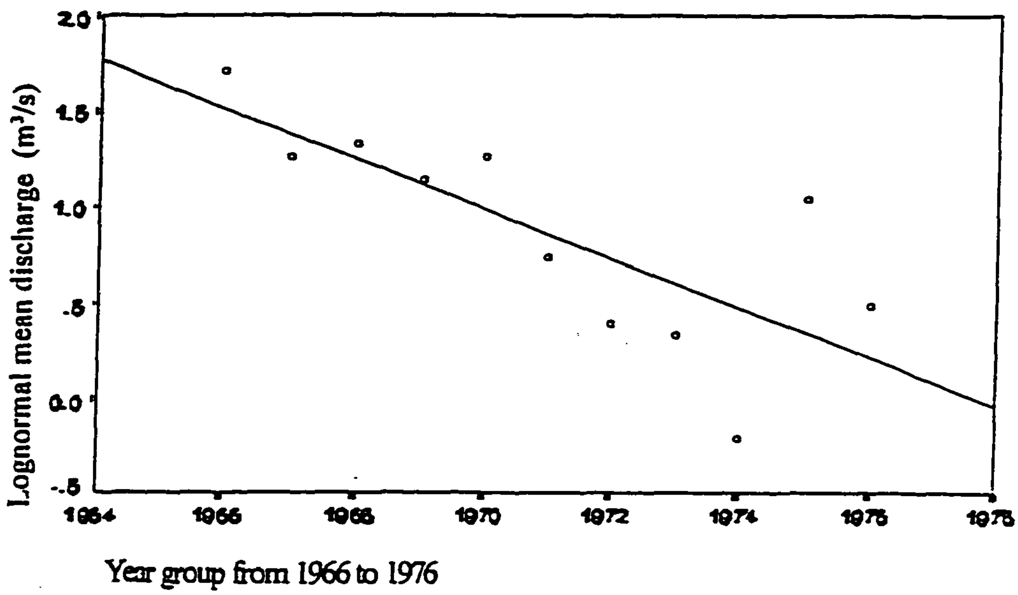
$$t = \frac{(\bar{x}_{15} - \bar{x}_{17})}{\sqrt{S^2\left(\frac{(n_1 + n_2)}{(n_1 \times n_2)}\right)}}$$

$$t = (4.37 - 4.29) \div 0.09 = 0.89$$

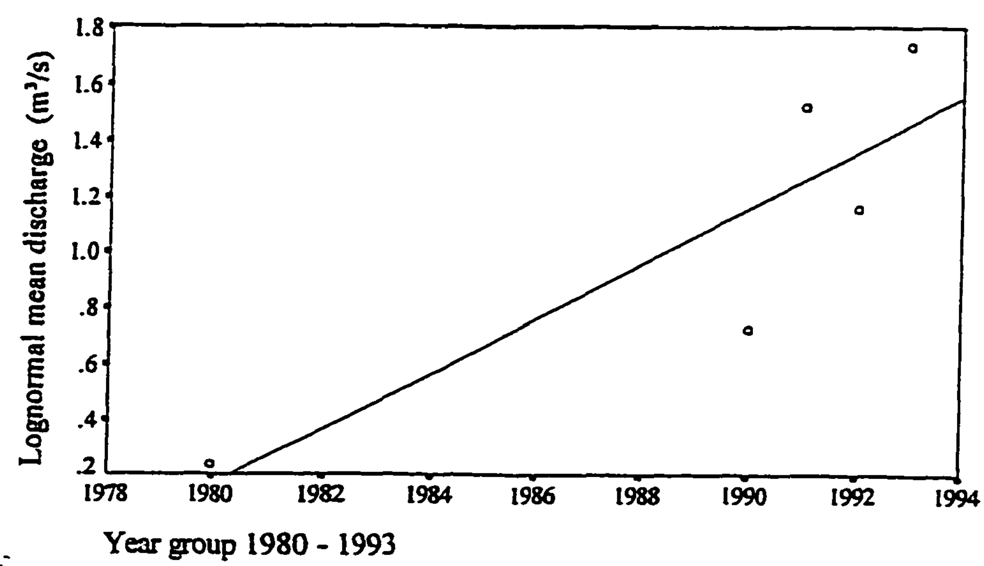
e. Scatter plots for rainfall and streamflow

(i) Scatter plots for lognormal of annual mean water discharge

(a)

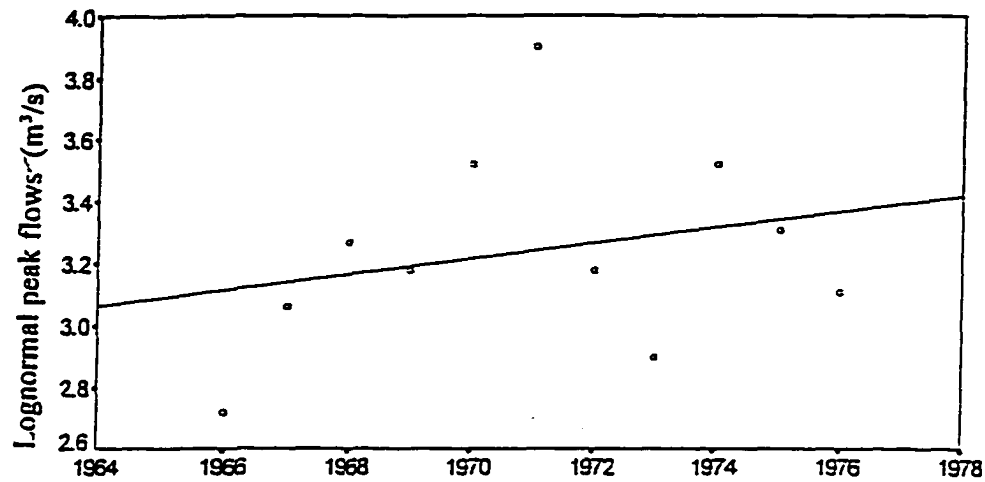


(b)



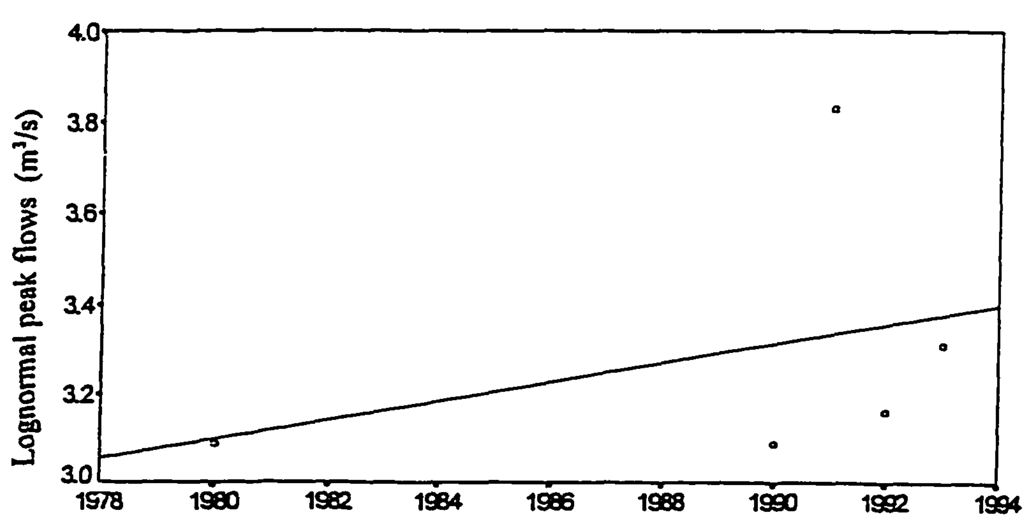
(ii) Scatter plots for lognormal of peak flows

(a)



Year group from 1966 to 1976

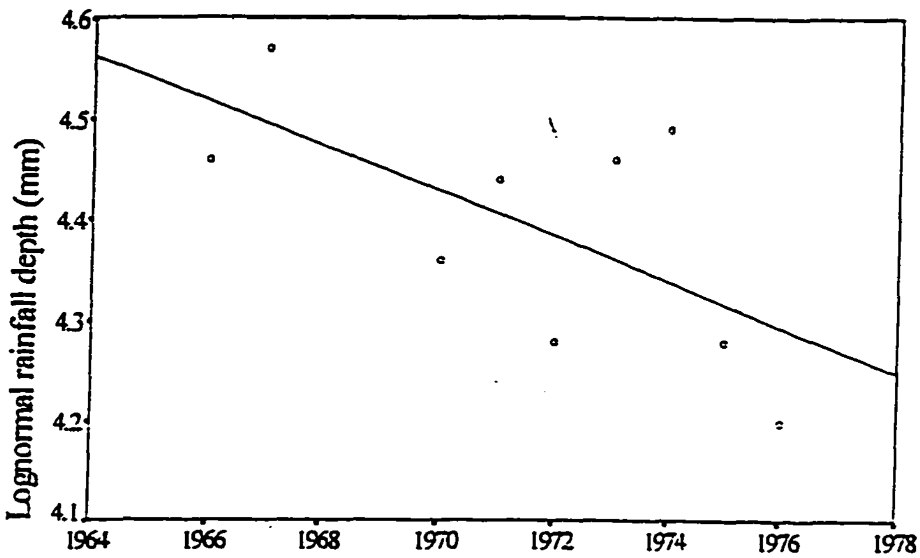
(b)



Year group from 1980 to 1993

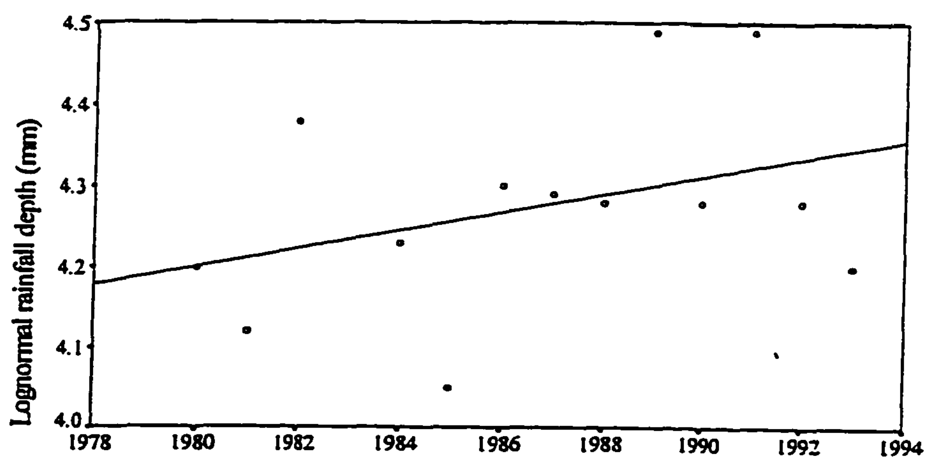
(iii) Scatter plots for lognormal of annual mean rainfall depth

(a)



Year group 1966 to 1976

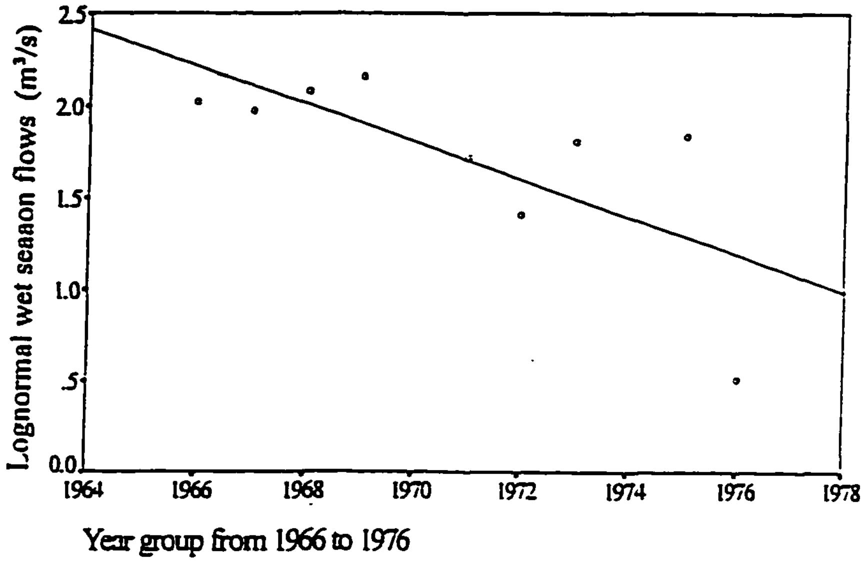
(b)



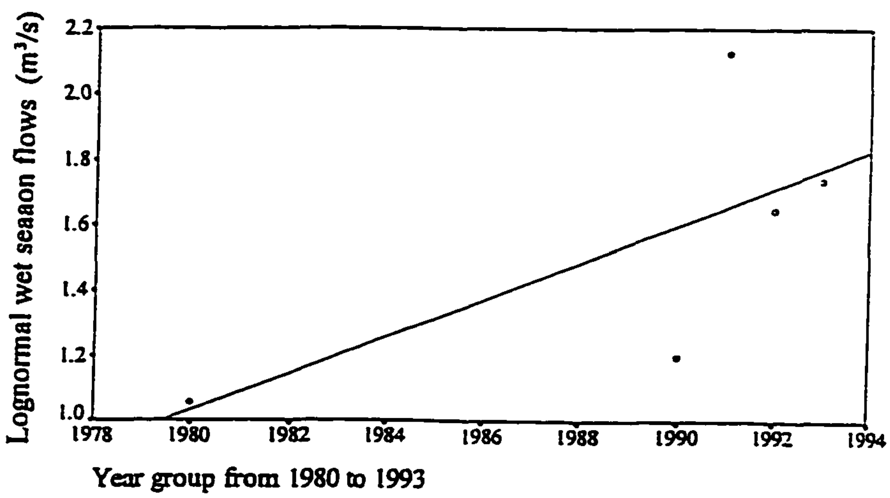
Year group from 1980 to 1993

(iv) Scatter plots for lognormal of wet season flows

(a)



(b)



APPENDIX IV. Consolidated Frequency Analysis of peak flows for Garu station

Consolidated Frequency Analysis Package

--- Screen Data Menu --

Select One of the Following:

1 - Independence, Trend, and Randomness
2 - Homogeneity (Mann-Whitney)
3 - Rank-time Plot
4 - Discharge-Rank Plot
5 - Discharge-Time Plot
6 - Frequency Histogram by % of Maximum Discharge
7 - Frequency Histogram by Month
8 - Frequency Histogram by Discharge
9 - Return to Main Menu of CFAI

(Type one integer value, and press Return.)

--- Run Test for General Randomness ---

01HB002 Tamne River Basin in Upper East Region of Ghana
Annual maximum daily flow series 1966 to 1976
Drainage area = 886.00 Km^2

The number of observations above and below the median (RunAB) = 4
The number of observations above the median (Nl) = 5

The number of observations below the median (N2) = 5

Range at 5 % level of significance: 3 to 9 not significant

Interpretation: the null hypothesis is that the data are random.

At the 5 % level of significance, the null hypothesis cannot be rejected. That is,

the sample is significantly random.

--- Spearman test for Independence ---

01HB002 Tamne River Basin in Upper East Region of Ghana
Annual maximum daily flow series 1966 to 1976
Drainage area = 886.00 Km^2

Spearman rank order serial correlation coeff	= 0.189	D.f.= 8
Corresponds to Students T	= 0.544	
Critical T value at 5 % level	= 1.860	not significant
Critical t value at 1 % level	= 2.896	not significant

Interpretation: the null hypothesis is that the correlation is zero.

At the 5 % level of significance, the correlation, is not significantly different from zero. That is, the data does not display significant serial dependence.

--- Spearman Test For Trend ---

01HB002 Tamne River Basin in Upper East Region of Ghana
Annual maximum daily flow series 1966 to 1976
Drainage area = 886.00 Km^2

Spearman rank order correlation coeff	= -0.287	D.f.= 9
Corresponds to Students T	= -0.899	
Critical T value at 5 % level	= -2.262	not significant
Critical T value at 1 % level	= -3.250	not significant

Interpretation: the null hypothesis is that the serial (lag-one) correlation is zero.

At the 5% level of significance, the correlation is not significantly different from zero. That is, the data do not display significant trend.

--- Mann-Whitney Split Sample Test for Homogeneity ---

01HB002 Tamne River Basin in Upper East Region of Ghana
Annual maximum flow series 1966 to 1976
Drainage area = 886.00 Km^2

Split by Time Span, Subsample 1 Sample Size = 5
Subsample 2 Sample Size = 6

Mann-Whitney U = 12.5 P= 0.363 Not significant

Interpretation: the null hypothesis is that there is no location difference between the two samples.

At the 5 % level of significance, there is no significant location difference between the two samples. That is, they appear to be from the same population.

Frequency Analysis Program

--- Sample Statistics ---

WSC Station No = 0lHB002
Wsc station name = Tamne River Basin in Upper East Region of Ghana
Drainage area = 886.00 Km^2
Number of observations = 11

	X series	LnX series
Mean	26.764	3.2369
S.d.	9.429	0.3254
C.v.	0.3523	0.1005
C.s.	1.3706	0.5051
C.k.	6.5852	4.7119

You should always check: that the data are accurate; for historic information; and that the data and historic information are up to date.

Press Return to Continue.

Frequency Analysis - Generalized Extreme Value Distribution
01HB002 Tamne River Basin in Upper East Region of Ghana

Sample Statistics

	Mean	S.d	C.v.	C.s.	C.k.
X Series	26.764	9.429	0.352	1.371	6.585
Ln X Series	3.237	0.325	0.101	0.505	4.712

X(min) = 15.200
X(max) = 49.200
Lower outlier limit of X = 12.902

Total Sample Size = 11
No. of Low outliers = 0
No. of zero flows = 0

Solution obtained via Maximum Likelihood

GEV parameters: U = 22.43 A = 6.176 K= -0.115

Flood Frequency Regime

Return Period	Exceedance Probability	Flood
1.003	0.997	12.60
1.050	0.95	16.00
1.250	0.800	19.60
2.000	0.500	24.70
5.000	0.200	32.50
10.000	0.100	38.30
20.000	0.050	44.30
50.000	0.020	52.90
100.00	00.01	59.90
200.000	0.005	67.50
500.000	0.002	78.50

Frequency analysis - Three-parameter Lognormal distribution
01HB002 Tamne River Basin in Upper East Region of Ghana

Sample Statistics

	Mean	S.d.	C.v.	C.s.	Ck
X Series	26.764	9.429	0.352	1.371	6.585
Ln X series	3.237	0.325	0.101	0.505	4.712
Ln(x-a)series	2.719	0.533	0.196	-0.063	4.546

X(min)= 15.200 Total Sample Size = 11
X(max)= 49.200 No. of low outliers = 0
Lower outlier limit of X = 12.902 No. of zero Flows = 0

Solution obtained via Maximum Likelihood

3LN Parameters: A= 9.531 M = 2.719 S= 0.533

Flood Frequency Regime

Return Period	Exceedance Probability	Flood
1.003	0.997	13.00
1.050	0.952	15.80
1.250	0.800	19.20
2.000	0.500	24.70
5.000	0.200	33.30
10.000	0.100	39.60
20.000	0.050	46.00
50.000	0.020	54.90
100.000	0.010	62.00
200.000	0.005	69.50
500.000	0.002	80.00

Frequency Analysis-Log Pearson Type III distribution
01HB002 Tamne River Basin in Upper East Region of Ghana

Sample Statistics

	Mean	S.d.	C.v.	C.s.	C.k.
X Series	26.764	9.429	0.352	1.371	6.585
Ln X Series	3.237	0.325	0.101	0.505	4.712

X(min) = 15.200	Total Sample Size = 11
X(max) = 49.200	No. Of Low Outliers = 0
Lower outlier limit of X = 12.902	No. Of Zero Flows = 0

Solution Obtained Via Maximum Likelihood

LP3 Parameters: A = 0.9107E-01 B = 11.78 LOG(M) = 2.164
M = 8.705

Flood Frequency Regime

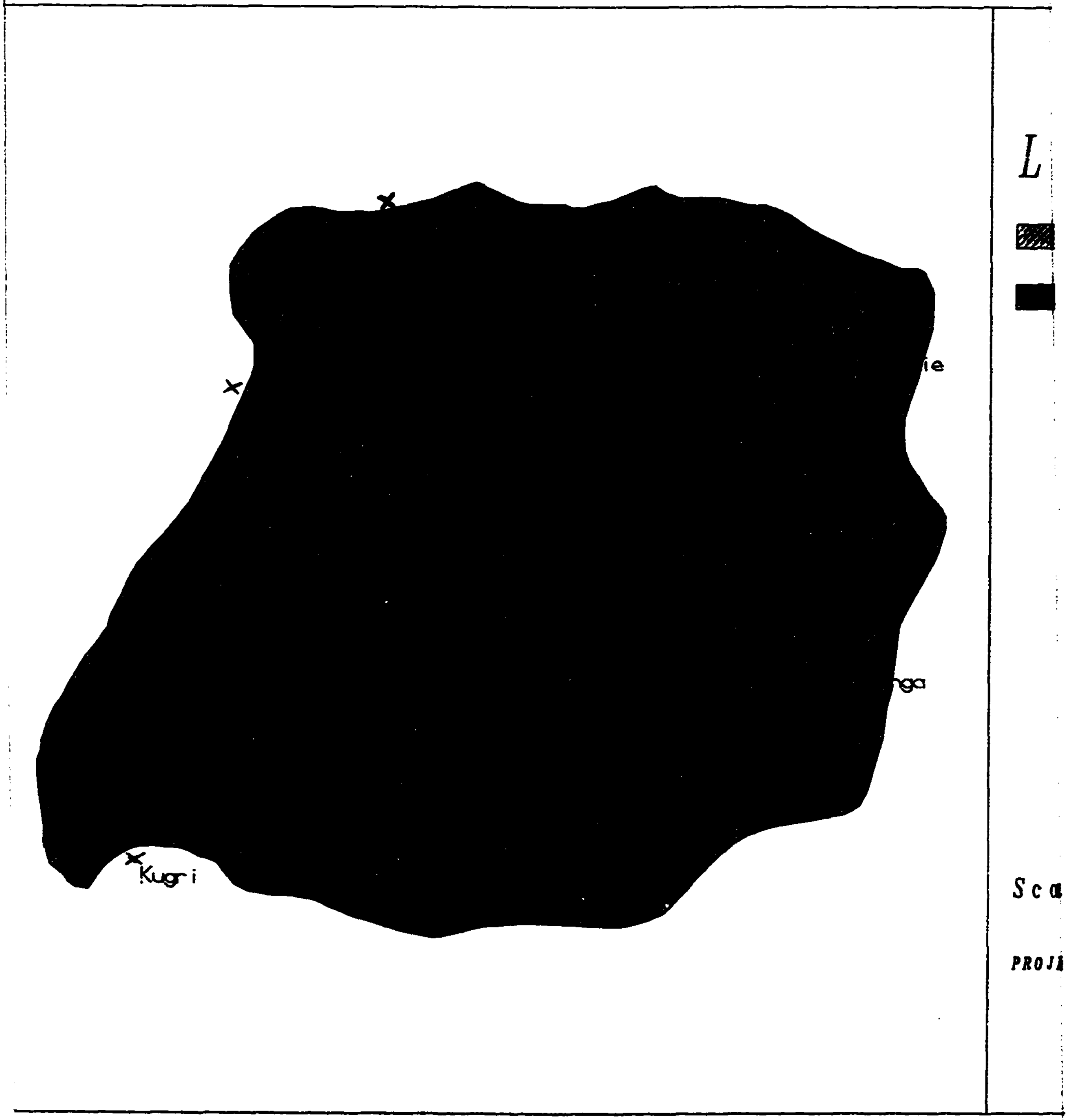
Return Period	Exceedance Probability	Flood
1.003	0.997	13.10
1.050	0.952	16.00
1.250	0.800	19.50
2.000	0.500	24.70
5.000	0.200	32.70
10.000	0.100	38.50
20.000	0.050	44.60
50.000	0.020	53.10
100.000	0.010	60.10
200.000	0.005	67.60
500.000	0.002	78.40

APPENDIX V. Arc/Info Macro Language (AML) for Map Creation

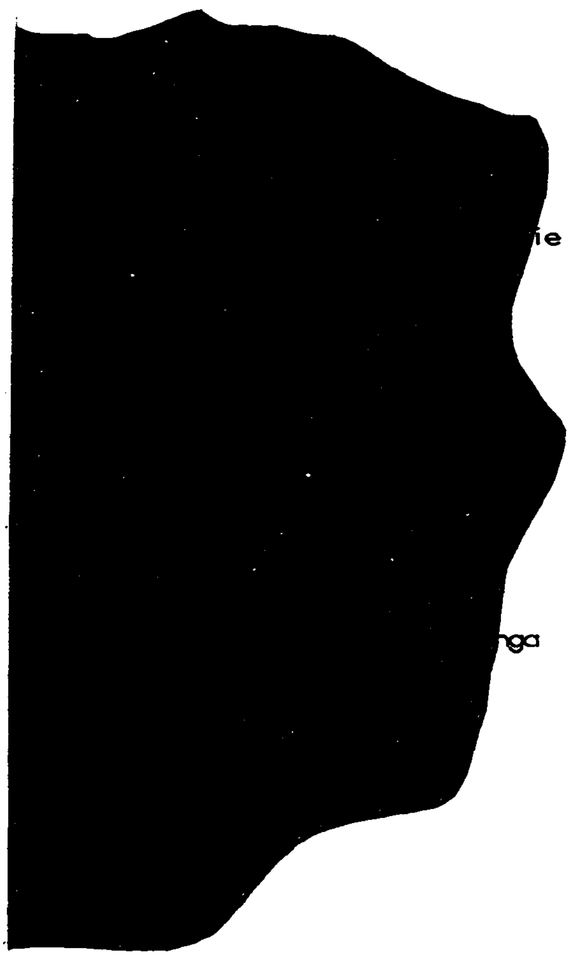
```
Mape chcl
Pageunits cm
Pagesize 65 58
Maplimits 0 0 40 46
Mapposition cen cen
Mapunits feet
Mapscale auto
Box 0 0 60 57
Line 0 46 60 46
Line 40 0 40 46
Polygonshade chcl symbol chcl.lut
Polys chcl
Arclines loctm 1
Annotext loctm
Markersymbol 45
Labels Loctm NoIDS
Move 2.0 53
Textfont 6
Textsize 2.0
Textfile Title.txt
Move 41 39
Textsize 1.7
Text 'LEGEND'
Keyposition 41 37
Textsize 1.0
Keybox 1.5 1.0
Keyseparation 0.6 1.5
Keyshade chcl.key
Move 41 9
Textsize 0.8
Textfile Scale.txt
move 41 6
Textsize 0.5
Textfile Tm.txt
Line 50 15 50 20
Line 49.5 16 50.5 16
Line 49.6 17.2 50 17.2 50 20 49.6 17.2
```

Map of Land Cover Changes in Tamne River Basin

LAND COVER CHANGES IN 1
RIVER BASIN (1975 - 19



CHANGES IN TAMNE
(1975 - 1991)



LEGEND

- No Change
- Potential Land Cover Changes

Scale = 1:127400

PROJECTION: TRANVERSE MERCATOR

APPENDIX VI. Exploratory Data Collection on Farming Characteristics in Tamne River Basin.

Sample questionnaire

(A) 1. Name of Village........................
2. Size of Family..........................
3. How long have you been farming?..........

(B) 1. What types of crops do you grow?
....
....
....
....

2.

TYPE OF LIVESTOCK.	NUMBER
....	....
....	....
....	....
....	....
....	....
....	....

3. How do you clear your land?
....
....

4. How do you plough your land?
....
....

5. Do you use fertilizers?
Inorganic - Yes........... No.............
Cow dung - Yes........... No.............
Compost - Yes........... No.............

(C) 1. Source of water for the family Wet Season Dry season

Source of water for livestock -
Source of water for crops -

2. Do you experience floods/water logging when it raing? Yes........ No........

3. If yes, how long does it last?..........

4. How soon does the stream/river dry up after the wet season?..................

---

5. 5. How far do you have to travel in the dry season to get water for:
- The Family..................................
- Livestock..................................
- Crops......................................

6. Do you have any access to dams? Yes.....No.....

7. Can you think of any other water related Problems?
....
....
....
....
....

D. 1. What type of cropping system do you practise?
Mixed cropping.........Rotational Cropping.....
Monocropping...........Intercropping...........

2. What type of plant combinations do you practise?
....
....
....

3. Do you experience decrease in crop yields?
Yes..........No...........

4. Is the decrease in crop yield related to soil loss/erosion? Yes........NO.............

IMAGE EVALUATION TEST TARGET (QA-3)

150mm

6"

APPLIED IMAGE, Inc
1653 East Main Street
Rochester, NY 14609 USA
Phone: 716/482-0300
Fax: 716/288-5989