UNIVERSITY OF CAPE COAST

DETERMINATION OF FLOOD RISK ZONES IN ACCRA AND TEMA METROPOLIS

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A THESIS SUBMITTED TO THE DEPARTMENT OF GEOGRAPHY AND TOURISM OF FACULTY OF SOCIAL SCIENCES, UNIVERSITY OF CAPE COAST IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTER OF PHILOSOPHY DEGREE IN GEOGRAPHY

AUGUST, 2000

STUDENTS DECLARATION

I hereby declare that this thesis is the result of my own original research and that no part of it has been presented for another degree in this University or else where

Candidate: BENJAMIN KOFI NYARKO

Signature.......................................

Date....24 – 08 – 2000.......

SUPERVISORS DECLARATION

We hereby declare that the preparation and presentation of this thesis was supervised in accordance with the guidelines on supervision of thesis laid down by the University of Cape Coast.

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DEDICATION

This work is dedicated to the Komla family.

ABSTRACT

Accra has been experiencing periodic flooding that affects properties and lives. For instance on 4th and 5th June 1994, 8 persons lost their lives and 80 million cedis worth of properties belonging to Paloma Company were destroyed due the floods that occurred at that time. The government seeing the dangers involved, commissioned institutions such as Ministry of Works and Housing, Town and Country Planning and City Engineers to identify such areas and adopt measures that will help reduce the effect of this unexpected extreme event. The measures used by these institutions in order to identify and prevent the occurrence of such extreme event have been woefully inadequate and inefficient. Hence this thesis examines new methods of identification of potential flood risk zones stressing the possible combination of hydrological models with remote sensing and geographic information system models.

The main objective of the study is to determine flood risk zones in Accra and its environs using a hydrological model and a geographical information system model. Specifically, the study aims at assessing how the urban watershed has been modified in-terms of drainage networking, soil texture, runoff and their influences on flooding. A flood risk zones map and the paleogeomorphology of the study area were also constructed.

Data for the study were from secondary and primary sources. The secondary sources included rainfall, discharge, and topography data, which were collected through literature search from institutions such as Hydro Division of Ministry of Works and Housing, Survey Department, Meteorological Service and Water Research Institute. The primary data collected included drainage cross sectional measurement and soil characteristics. These data were collected using field measurements, field observations, satellite image interpretation and laboratory analyses.

The analyses of the data were based on the integration of the hydrological model into the Geographic Information System model using an overlay operation.

The result of the research showed that potential areas likely to experience periodic floods with a given input of rainfall (140.2 mm/hour) are mostly below the 350-meter contour and about 45 percent of the study areas fall within flood risk zone. It was also noted that the flood experienced by an area is mostly dependant on rainfall intensity no matter the catchment area. However other factors such as, landuse, storage and runoff coefficient were identified as contributory factors to flooding in the study area..

In search for a method to determine flood risk zones, the use of a hydrological model within a geographic information system model is very effective if only the appropriate decision rule is defined. The studies will enable the supervisory agencies such as Ministry of Works and Housing, Town and Country Planning and City Engineers enforce landuse policies to prevent people from developing areas prone to floods.

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CHAPTER ONE

1.0 Introduction

Human values and institutions have set mankind on collision course with the laws of nature. This is due to man clinging jealously to his prerogative to reproduce as he pleases by making the new generation larger than the last, through endless multiplication of the human population on this finite "earth" planet (Ehirlich et al., 1977).

Development through growth of settlement has brought changes within the environment. The features most affected are vegetation, water-bodies, wildlife and the fragile land. Most settlement growth programs, which are meant to enhance human well being, tend to ignore the existence of such important natural environmental components, as the urban watershed. For example construction of houses/residential quarters, service centre's (shops, lorry packs and gas stations) in areas marked by nature as drainage courses, tend to, prevent percolation and therefore confine flow of water, leading to spread of flow generating flood known to cause a lot of damage to property and human life.

Similarly human activities such as sand winning and deforestation of mangroves along the coastal areas have resulted in loss of wetlands that serve as storage point for excess rainfall. Hence such activities of man threaten the natural mechanism that would otherwise militate against erosion and flooding.

Flooding is the inundation of an area by unexpected rise in the water level of a stream, lagoon, or a lake that spreads over its banks and may cause a lot of destruction to property and life as a result of prolong rainfall or dyke failure. Flooding does occur in a number of places including the forest areas and agricultural lands; thus it becomes a problem when human beings are affected. Flooding has therefore become a major concern for nations worldwide.

From the global point of view, every year flooding is estimated to destroy so many trillion dollars of property; lives are lost and people are displaced from their homes. Specifically, countries such as Bangladesh, Thailand, Sri Lanka, Korea, India and the United States are known to experience destructive flooding every now and then. The floods that occurred in Bangladesh in 1987 and 1988 caused a total damage estimated at US$500 million. It was also revealed that in 1987, 39 percent of the entire country was flooded displacing 30 million people and causing loss of the main crop estimated to be 0.8 million tones (Meirjerink et al, 1994). In 1975, flooding in the United States caused an economic damage amounting to 3.8 billion dollars which was projected to reach $4.3 billion per year by the year 2000. Apart from this, flooding in United States claims 100 lives every year and causes considerable psychic tremor (Changnon, 1985). In 1995, the Korean Peninsula, especially the central part of it, including the Han River basin experienced floods that destroyed properties worth $600 million, cultivated land of 57000 hectares and while 9000 houses were destroyed claiming 50 fatal causalities. The transport system came to a halt thus preventing the city from getting her food supply and thereby causing price hikes during that period. (Woo and Kim, 1997).

Ghana has also experienced periodic flooding particularly in Accra, where such flooding displaces people and destroys property. These seasonal floods render most city roads highly unmotorable, creating huge potholes and even washing away bridges. On 4th and 5th June 1994, 8 persons died when they were swept away during flooding which resulted in the Odaw river and Korle Lagoon overflowing their banks (Daily Graphic, June 8th, 1994).

The causes of flooding in Accra have been attributed to a number of factors that include high rainfall, poor drainage systems and to its situation in low-lying topography coupled with the clayey nature of the soil that has poor infiltration rate. Also the massive silting up of the Korle lagoon has reduced the volume of the lagoon and rendered it incapable of holding enough water to prevent overflows that periodically cause a lot of damages to properties and life around. (Gyau-Boakye, 1997; Opoku-Ankomah,1996).

To find solution to the periodic flooding in the Accra Metropolitan Area, Government of Ghana commissioned consultants to study and suggest practicable solutions to help in the planning and control of this natural phenomenon. [WATERTECH, 1991; NEDEC, 1962, 1967 and Engman, 1973]. Reports produced, however, focused mainly on structural designs and improvement of drains within the Accra Metropolitan Area as a way of controlling the periodic flood.

1.1 Statement of the problem

Flooding is a phenomenon that occurs at great cost to individuals and to nations in terms of destruction of physical structures and loss of life. Studies in most developed countries have shown that developing a flood prediction/ hazard prevention model and adapting it in a day to day design of settlements can effectively reduce the hardships brought upon individuals and the nation by such an unexpected events (UNESCO, 1978).

In Accra, private estate development and the erection of concrete structures are on the increase in areas that have been experiencing periodic flooding. It is expected that the Accra Metropolitan Authority (AMA), the Town and Country Planning and the City Engineers Department will prevent such developers from erecting man-made structures in these identified risk zones. Though these statutory supervisory agencies exist and do seem to perform their allotted tasks, the practice of building in these areas continues.

However, during the yearly rainy seasons these unexpected flood events do adversely affect not only building structures but also people's livelihood in and around these areas. One may then wonder if these governmental agencies have enough tools to detect and identify flood risk zones and to advise or indeed prevent development in these areas. As a result to solve this problem, it would be useful to explore new approaches at identifying and managing the problem.

1.2 Objectives

The main objective of this study is to map-out the flood risk zones of Accra and its environs using a hydrological model, Remote Sensing and Geographic Information System techniques. Specifically the study will:

i. Assess how the urban watershed has been modified in-terms of drainage networking, soil texture and their influences on flooding.
ii. Try to construct a map showing flood risk zones.
iii. Assess how surface runoffs have been affected by landuse pattern.
iv. Try to reconstruct the paleogeomorphology of the study area using historical records.

1.3 Rationale for the study

Accra being the capital of Ghana accommodates the major institutions, industries, enterprises and government ministries that control the national economy. For the past years, Accra has been experiencing periodic but catastrophic flooding problems. This has been a concern of the government, hydrologists, civil engineers and planners. Yet no detailed database has been compiled on the factors contributing to these floods nor has any map of flood risk zones in Accra been developed. This vacuum needs to be filled hence the essence of the present study.

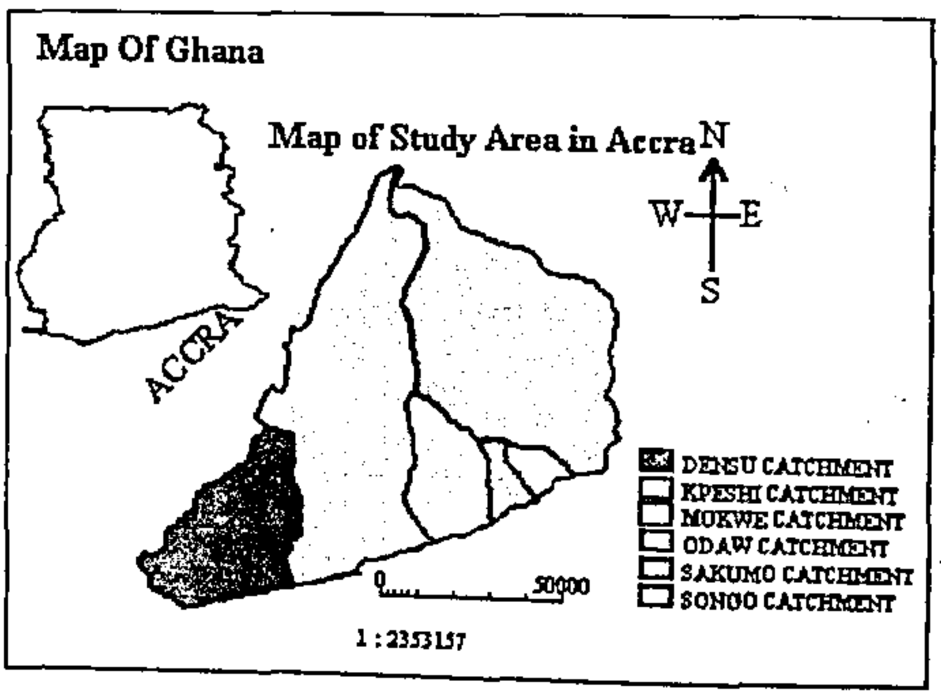
Particularly, it is envisaged that the study will help in the understanding of the major factors that cause flooding in the Greater Accra area. Furthermore, it is hoped that using geographic information system and remote sensing tools will provide an ideal search method for such agencies like Hydro Division of Ministry of Works and Housing, Water Resources Institute of Council for Scientific and Industrial Research (CSIR), Accra Metropolitan Authority, and National Disaster Management Organization in identifying flood risk areas in Accra. Finally, the result of this study would become available to such institutions as the Hydro Division of Ministry of Works and Housing, Water Resources Institute of CSIR, Accra Metropolitan Authority, and National Disaster Management Organisation. The work will contribute towards the search for strategies for policy formulation for development, especially in the development of educational material that would address residents' attitude to manage the occurrence of such events. Also the study has the potential of being used by researchers in hydrology, geomorphology, environmental science and other related fields.

1.4 Study area

1.4.1 Location

The proposed study area is within the Greater Accra area (Figure 1.1). It stretches from Botianor to Sakumo, and James Town to Oyarifa. Tema bounds it on the East, on the South by the sea, West by the Weija dam, and North by the Akwapim hills. Using the geographical co-ordinates it lies within Longitude 0°.03 and 0°.25 West and Latitude 5°.30 and 5°.53 North. The designated study area covers approximately about 786.59km^2.

Figure 1.1 Study Area

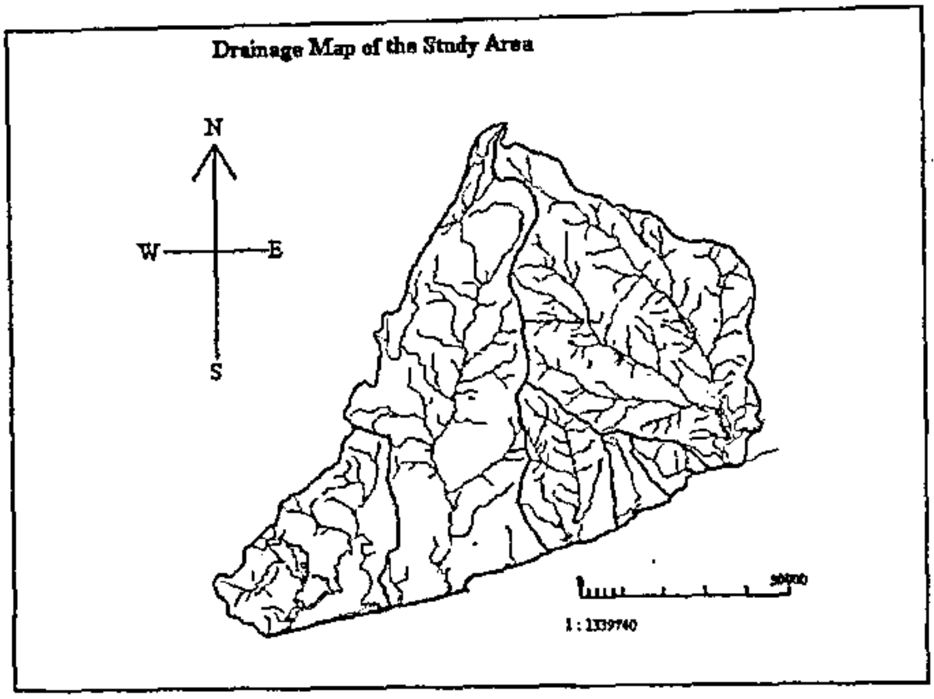


1.4.2 Relief, drainage and hydrology

The area is characterized by lowlands and occasional hills with an average altitude of 20 meters above sea level. The slopes are generally gentle with most slopes below 11 percent, except few places such as MaCarhty hills, the television transmitting station near Abokobi and Kwabenya hills, where slopes are above 22 percent. These hills produce a lot of runoff during the rainy season with a high discharge rate that varies with the steepness of the hills. There are pockets of marshy areas that are liable to flooding and sustained wet conditions. The water table varies between 4.80 meters to 70 meters below the surface at places like Ofankor, Kantamanso and Accra Brewery Limited bottling house in Accra (Water Research Institute, 1984, 1994). Along the shoreline are some of the important lagoons, like the Korle, Sakumo, and Kpeshie.

The area is drained through by natural streams (Figure 1.2) and valley network and artificial drains. Most of the streams like Odaw, Sakumo, Mahahuma, Lador, and Dzorwulu, take their source from the Akwapim range. The artificial drainage is mostly built-up structures that enable quick discharge of waste and storm water.

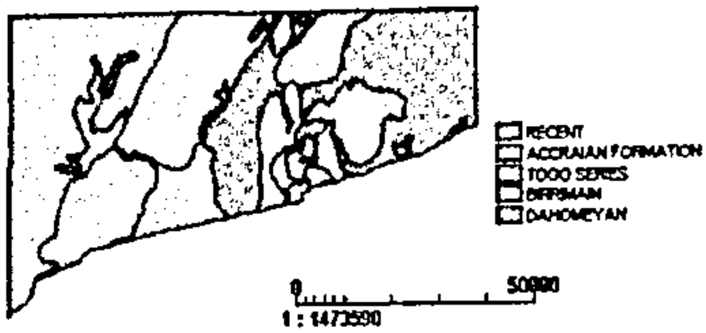
Figure 1.2 Drainage Map of The Study Area



1.4.3 Geology

Geologically (Figure 1.3) the area is underlain by the Dahomeyan of the lower Pre-cambrain series consisting of acidic and basic gneiss, schist, granulite and migmatites. Within the area the Togo series which overly the Dahomeyan series consist of quartz, schist and sericite schist. Also present is the Accraian formation of the early to middle Devonian that consists of alternating Shale, sandstone, mudstone and pebblegrits. Most importantly is the recent deposit of alluvia of drowned valleys mostly along the Densu River (Kesse, 1985).

Figure 1.3 Geological Map Of Accra Area



GEOLOGICAL MAP OF ACCRA AREA

1.4.4 Geo-Hydrology

The occurrence of groundwater in the study area depends on the permeability and potential of the rock to store water at appreciable quantities.

The Dahomeyan system is generally massive with few joints and fractures, but the impervious nature of this system limits the available groundwater. It is only in few weathered zones that successfully yield about 540 to 11,250 litres per hour from drilled boreholes.

The Togo series are folded and fractured, though they are impervious. However there exist some fractures and joints where groundwater can be stored, which depends on the extent of openings in the rock. Also wherever quartzite is in contact with argillaceous rocks within a valley, springs usually occur.

The Accraian series lacks the potential to store groundwater in appreciable quantities as can be verified from the amount of water namely 3900 litres per hour that is being pumped from drilled borehole.

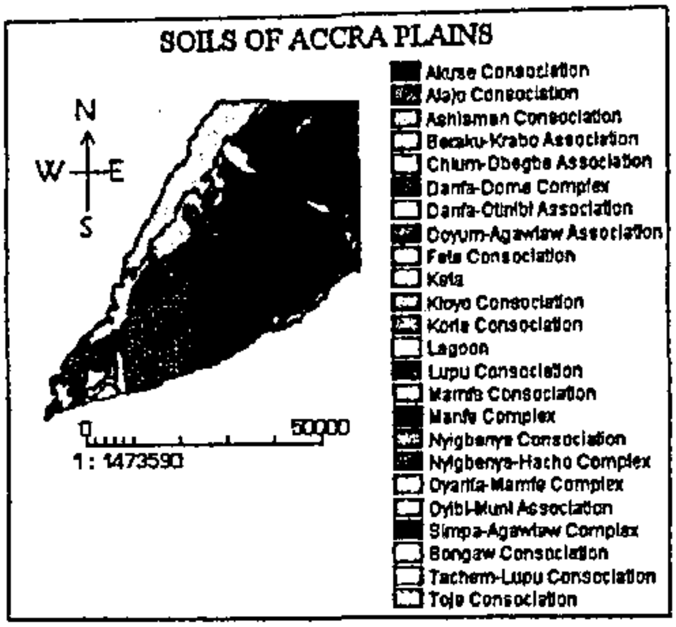
The alluvia are relatively thick, permeable and able to store enough water for many purposes such as for irrigation, industrial and domestic uses. They have the potential to recharge wells and streams.

1.4.5 Soils

Within the study area eight (8) main tracts of soil with their component of soil associations and complexes can be identified (Figure 1.4).

These soil tracks are grouped on the basis of not only on their parent materials, but mostly on the differences in their drainage conditions. Though not much study have been conducted on such soil properties as infiltration, and soil water holding capacity, there seem to be variations in these tracts.

Figure 1.4 Soils of Accra Plains



1.4.6 Climate and Vegetation

The area falls within the anomalous dry equatorial climate region and experiences double maxima rainfall and a prolonged dry season with occasional harmattan winds being experienced. The hottest months are February and March, just before the rainy season, with mean monthly temperatures of 27°C, whilst the coolest months are June-August. During this period temperatures are around 21°C. The climate is controlled by the southwesterly wind that generates rainfall with an annual amount between 780mm and 1200mm. Rainfall in this area has two peak periods June and October.

There are two main vegetation types within the area; namely the Coastal Scrub and grasslands, and mangrove forests. The Coastal Scrub and grasslands are in patches at certain places with occasional trees such as Nim and Baobab. In the wetter parts, East of Accra, fan palms and wild oil palms are wide spread. The mangrove forests are found in the coastal lagoon areas where the soil is waterlogged and salty. The mangrove trees grow to a height of between 12 and 15 meters and are closely packed and green in appearance throughout the year. The white mangrove is the most common plant in this area.

However, vegetation types in this zone to some extent intercept rainfall thereby reducing its erosivity impact on soil. Most of the intercepted precipitation stay on the leaves and latter evaporated, part flow down the stem of the plants as stem flow or fall from the leaves to become part of the through fall. In other words, the rate of interception of the plant depends on, the leave type, hollows in the plant and dead branches on the plant. Since Accra is not highly vegetated, roof of houses also play a part in the interception of rainfall.

1.5 Expected output

The data analysis will be managed and directed towards the specific needs of urban flood management. The first output of the flood survey will be a list of all the parameters that affect flooding and an insight into their influence.

Second will be the production of a flood risk zone map of the entire Accra area to show areas that are likely to experience flooding; this will be based on a 25-year flood occurrence period.

Last will be to verify the effectiveness of the use of Geographic Information System and remote sensing techniques as quicker methods to determine flood risk zones that can be used in other parts of the country.

1.6 Structure of the thesis

The study is divided into six chapters. Chapter one deals with introduction, statement of the problem, objective of the study, rationale for the study, study area and expected output. Problems encountered during the research work and structure of the thesis follow.

Chapter two addresses the related literature that has been written by various researchers on floods and flood generating factors. The next chapter is devoted to the discussion of types of data, sources of data and methods used for their collection. Much consideration was given to the tools to be used for analysis. Chapter four presents the hydrological perspective of Accra highlighting on rainfall, runoff, soil characteristics and drainage. In addition the paleogeomorphological evidences of the study area are also presented.

Chapter five discusses the procedure through which a flood risk zone map can be derived within the geographic information system platform. Chapter six deals with the conclusion that consists of a summary of flood generating factors, implication of the study for policy and recommendations.

CHAPTER TWO

REVIEW OF ISSUES ON FLOOD STUDIES.

2.0 Introduction

This chapter presents the related literature that has been written by various authors on floods and factors that will help in determination of flood risk zones. Understanding of flooding in urban areas can be traced from early works carried out in the field of geomorphology, hydrology, civil engineering and urban Studies. The review of literature for this research will be limited to the following subtitles; impact of flooding, flood generation factors, application of Geographic Information System and Remote Sensing in hydrology and geological past.

2.1 Impacts of flood

Flooding comprises a significant natural hazard causing large-scale human suffering and damages to properties (Bhattcharyya & Bora, 1997; Mustafa & Wescoat Jr., 1997; Ando & Takahasi, 1997). Flooding has been with mankind over the ages. For example, in Genesis 7:1-22 of the Holy bible, we are told of the story of flooding that wiped out a whole generation of people leaving only few survivors.

From the global point of view every year flooding is estimated to destroy so many trillion dollars of property, peoples' lives are lost and displaced from their homes. In the United States of America from 1889 to 1979 an estimated lives of people lost is about 16,661 and a total amount of $18,770 billion of properties were destroyed (Dingman, 1994). According to Bhattcharyya & Bora (1997), floods between 1954 to 1993 in the Brahmaputra valley of India affected 23.3 million hectares of land and caused damage to 3.45 million hectares of cropped land and a total population of 42.2 million people were victims. Similarly, Mustafa and Wescoat (1997) undertook a study in the Indus river basin of Pakistan and found out that from 1950 to 1992, 106,500 villages were affected by this unexpected event and 6,763 lives were lost.

Accra in Ghana has also experienced periodic flooding, where people were displaced and properties destroyed. For instance flooding which occurred on 7th May 1988, destroyed 3.6 billion cedis worth of equipments belonging to Post and Telecommunication Corporation and also resulted in the lost of 3 live (Adinku, 1994). However the historical occurrence of flood in Accra is catalogue in Table 2.1.

TABLE 2.1 HISTORIC FLOODS IN ACCRA; 1955-1994

DATE DAY/MONTH	YEAR	AREA FLOODED	DAMAGE
June 23 June 21	1955	Adabraka, Agbogbloshie, Galloway, Railway Statio, Adiedienkpo Large Areas around the Odaw and Korle Lagon	Train trapped, 3 lives lost, walls collapsed on pregnant woman and daughter. Many injured, properties lost.
June 2 – 3	1959	Selwyn Market areas down Odaw Stream-old Accra Electricity Station area. – Large Areas of Achimota to the Guggisberg road bridge, korle Lagoon	Properties lost
-	1963	Large areas along Odaw. Other areas in the Accra Municipality.	5 lives lost, Properties lost
June 19 – 23	1973	-several Communities flooded, kaneshie South Railway colony/Industrial Area, - major drains Odaw/Onyasia, Nima, Awudome, Kpeshie, Klotey drains. - Ridge Police Station - Labadi, Dansoman - Bubuasie, North Kaneshie	3 lives lost 500 people marooned, properties damaged. A car No. GS 2669 plunged into the Odaw River with driver.
-	1978	Odaw Basin and Communities in Southern wrenches of the Odaw River	Life lost and properties damaged
June 20	1983	Osu Klotey drain Bank of Ghana houses affected Awudome Area	Houses pulled down,properties lost.

Source: Adinku (1994)

DATE DAY/MONTH	YEAR	AREA FLOODED	DAMAGE
August 1	1984	Nima Drains Odaw River Ring Road; Houses flooded	Walls collapsed.
May 2	1985	Kwame Nkrumah Circle, Obetsebi Lamptey Circle, Alajo Caprice Bridge. Ring/Inustrial Area Millet Factory Pepsi –Factory Modern Funiture Mechancial Lioed Blackwood Lodge Ghana Rubber Industeries	Several bags soaked 20,000 crates worth of ¢10,000.00 million destroyed. Many furniture destroyed.
May 4	1986	Kwame Nkrumah Circle, Alajo, Avenor, Odawna and many areas	3 lives lost, P&T switching equipment damaged. ¢3.6 billion lost
June	1987	Alajo, Avenor Caprice Bridge New Abossey Okai Mataheko Nima Drain Standfast Street	Property lost Walls collapsed House pulled down
May 3	1988	Teasano Wabco Est. Kaneshie Nsawam road Sun Lodge Hotel	Walls/gates broken, properites destroyed
June7 - 8	1988	Obsetsebi –Lamptey Kwame Nrumah Circle Industiral Area,Millet factory Old Dansoman, Chewn lagoon Ring Road west. Ghanaian State Re-Insurance Cop. State Insurance Kalk Sew, Mach. Central Automobile, Abossey Okai Kaneshie, Kpehe, Atico Junction, Mateheko, Dansoman, Aladjo, Mamobi Ring Raod South North Industrial Area BBC Builders and industieral Engineers Modern Furniture Mamprobi; near Club Kakalika	houses & sheds destroyed Many cars grounded, traffic disrupted Property and merchandises damaged Schools and houses collapsed 4 houses damaged 1 life lost,

Source: Adinku (1994)

DATE DAY/MONTH	YEAR	AREA FLOODED	DAMAGE
May 8 & 10	1989	North Kaneship Matcheko, Zongo Junction, Walako Hotel Bubuashie, Radio Station, Accra Academy, Industiral Area near Guinness depot, Labadi, Labone Secondary School	Children trapped and 1 died, bridges and properties damaged.
Nov27./Dec.	1990	Awudome, Nima, Kaneshie, Matabeko, tesano, Aladjo, Nsawam Road, Achimota Railway Crossing, Accra Newtown	Bridges, houses collapsed, Roads destroyed.
March 18 July 15	1991	Aladjo, tesano, Avenor, Adabraka, Agege, Matabeko, Achimota, Taifa	Lives, houses, roads, bridges lost
Nov. 18 Dec. 4	1993	Nima	Car, hair Dryers, Personal effects, concrete slaps washed away
June 5 – 6	1994	Mataheko, Abossey Okai, Nima, Hamobi, Dzorwulu, Tesano, Kwame Nkrumah Circle, Aladjo, Asylum Down, Modern Photo Works, Neoplan Station.	Paloma Shooping Centre damaged and lost ¢80 million, 8 lives lost when Taxi cab No. 8127 plunged into the Alajo drains.

Source: Adinku (1994)

2.2 Flood generating factors

Besides, giving account on the occurrence of flood in built–up areas most researches attempt to find the causes of these floods. Viessman and Lewis (1996) expressed in their work that the nature of runoff, which generates flooding within a given area/region, is a function of its hydrological/climatic characteristic, relief features, and vegetation. Similarly Bhattacharyya and Bora (1997) identified some interrelated factors that generate flooding in the Brahamaputa drainage basin, these are natural, hydro-meteorological and anthropogenic. Ward and Robinson (1990) traced the causes of floods to climatological factors. In addition they explained that there are flood intensifying conditions, which include basin, network and channel conditions. Gyau-Boakye(1997) and Opoku-Ankomah(1996) attribute periodic flooding in Accra to poor drainage systems, high periodic rainfall, low lying ground, the clayey nature of the soil and the reduced volume of the Korle lagoon which is incapable of adequately serving as detention storage.

2.2.1 Climatological factors

Of the climatological factors, rainfall and snowmelt have been found to be the most important components of flood generations (Viessman and Lewis, 1996).

Rainfall is generally considered as the primary input vector for generation of runoff (Viessman and Lewis, 1996). When it rains part of it goes into storage on the surface or in the soil and into groundwater reservoirs beneath the surface (Ward & Robinson, 1990). The storage within the groundwater characteristic, relief features, and vegetation. Similarly Bhattacharyya and Bora (1997) identified some interrelated factors that generate flooding in the Brahamaputa drainage basin, these are natural, hydro-meteorological and anthropogenic. Ward and Robinson (1990) traced the causes of floods to climatological factors. In addition they explained that there are flood intensifying conditions, which include basin, network and channel conditions. Gyau-Boakye(1997) and Opoku-Ankomah(1996) attribute periodic flooding in Accra to poor drainage systems, high periodic rainfall, low lying ground, the clayey nature of the soil and the reduced volume of the Korle lagoon which is incapable of adequately serving as detention storage.

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reservoir depends on the soil and rocks of the area. Therefore to understand the rate of runoff that causes flooding, there is the need to take into consideration, the rainfall intensity and duration. Many researchers have expressed that runoff is generated if rainfall exceed the rate of infiltration (Dingman, 1994; Ward & Robinson, 1990; Viessman and Lewis, 1996)
Much concern has been given to the spatial and temporal variability of rainfall. The concern for the spatial variability of rainfall is the result of the general interest involved as a result of new techniques being developed and also the attention given to mesoscale meteorology and climatology (Browning, 1989; Houze, 1989).

The importance of rainfall in the determination of floods can be seen in the works of many researchers. For instance Woo and Kim (1997), noted in their analysis, that amount of rainfall determines the water available as overland flow that generates flood conditions. In the Korean peninsular, they observed that during the August 1995 flood period, the Hans river received heavy rainfall varying from 300 mm to 400 mm in a day which was estimated to be equivalent to rainfall with a 2550-year return–period. Within the Brahmaputra catchment, Bhattacharyya and Bora (1997) observed that the heavy monsoon downpour of high intensity and erosive power made the rainfall increase sediment transport of the river channel, which fills up the channel giving it the capacity to immediately create flash floods. In an examination of the rainfall pattern over Accra, in relation to flooding, Opoku-Ankomah (1996), observed gradual rise in rainfall totals from 1963–1995, but the maximum 24-hour rainfall has been high, relatively.

Thus, the severity of flooding is likely to be caused by increase rainfall intensity and duration. In other words a storm that will result in maximum runoff should have an intensity- duration equal or greater than the concentration time of the catchment (Ward and Robbinson, 1990; Mannearts, 1996). Though rainfall intensity is an important parameter in determining surface runoff that is likely to generate floods, yet it is very difficult to determine. However, the duration of rainfall can reliably be determined using the recording rain gauge (Taur and Humborg, 1992).

Most observed rainfall generate runoff whose relationship (rainfall/runoff) is very difficult to determine. Hence model simulation to identify the parameters that contribute to effective runoff has become important and many researchers are using these approaches. Viessman & Lewis (1996) identified some of the models for the estimation of runoff to include the runoff coefficient, Phi-index, curve number and the rational formula. Mannearts (1996) commented that runoff coefficient; Phi-index, curve number and the rational formula give values for rainfall excess rate. In theory rainfall excess rate is not equal to overland flow flux or depth and is likely to change with flow direction. An observation at a lower part of a plot will give an indication to the fact that runoff differs from excess rainfall rate.

Butchtele, et al. (1996) used the BROOK and SACRAMENTO models to verify the extent to which variables such as rainfall, groundwater system, soil moisture and evapo-transpiration contribute to runoff processes in Liz (Southwest Czech Elbe River basin near German-Austrian borders), Lange Branke, Blanice and Metuje Basins. Their research was to compare the effectiveness of the two models (BROOK and SACRAMENTO) and to identify components that contribute effectively to runoff. Using the models, they were able to identify winter rainfall as an important component to runoff in each of the models.

2.2.2 Soil characteristics

The amount of water that flows as overland flow mostly depends on the infiltration rate of the soil and its water holding capacity. For any amount of rainfall to cause flooding, there should be high overland flows. Ward and Robinson (1990) observed that water that fails to infiltrate the soil surface moves over the surface to the stream channel. Therefore the main cause of these overland flows is the inability of water to infiltrate the soil surface.

An attempt by Horton (1933) to explain overland flow, stressed much on the infiltration capacity of the soil surface, which was defined as the maximum rate at which rain can be absorbed by a given soil when in a given condition. Some factors such as urban area surface compaction, pavement surface and built-up areas, do account for the rate of low infiltration in urban areas and the increase in the generation of high overland flow. In these areas, surface ponding prior to infiltration has been considered to be important depending on whether the time to ponding can be sufficiently appreciable (Ward and Robinson, 1990; Mannearts, 1996). Bonell and Balek (1993) commented that Hortonian overland flow is possible in any environment with high rainfall, if the land surface is compacted to reduce infiltration rate.

To measure infiltration rate of a soil, most researchers try to use some developed models for its estimation. Some of the models used include, Hortons, Richards, Philips and Green-Ampt models. Using Horton's infiltration model, estimates of infiltration rate were determined by the Association of Soil Conservation Engineers on various soil group (Table 2.2).

Table 2.2 Typical f_i (*infiltration rate*) values

Soil Group	f_i(mm/h)
High(sandy soils)	12.50-25.00
Intermediate(loam, clay, silt)	2.5-12.50
Low(clays, Clay loam)	0.25-2.50

Source: Viessman & Lewis (1996) after ASCE
Manual of Engineering Practise, No. 28.

In the works of Viessman and Lewis (1996) it was commented that infiltration capacity changes from one location to the other based on available time, spatial variation, in terms of vegetative cover, soil type and water input. In other words areas with uniform soil type and vegetative cover are likely to have the same infiltration capacity, though it may vary from time to time.

However, soil water detention ability is important to the determination of the rate at which water may flow as overland flow. Various kinds of soil have been noted to show different water retention properties. Loukas and Quick (1996) noted that areas with high vegetation might produce no overland flow because of the high infiltration rate in that zone. However, in the work of.

some researchers like Hewlett and Hibbert (1967); Hewlett and Troedle, (1975); and Mosley (1979) observed that runoff is generated as translatory flow and soil pipes in some soil matrix.

Measurement of runoff is very difficult in various types of soil, as such the Soil Conservation Service of United States of America, developed the curve number where runoff could be forecast and predicted under various conditions in different types of soil, based on their hydrologic grouping (Table 2.3). Dingman (1994) has cautioned that to enhance prediction and forecasting runoff, using the runoff curve method, a detailed observation of storage component is important.

Table 2.3a Runoff Curve numbers for Hydrologic soil cover complex I_a=0.2S (some selected landuse)

Landuse or cover	Treatment or practice	Hydrologic condition	Hydrologic soil Group A	B	C	D
Woods		Poor	45	66	77	83
Farm woodlots		Fair	36	60	73	79
Roads (dirt)		-	72	82	87	89
(hard surface)		-	74	84	90	92

I_a= Initial abstraction

Source: Viessman & Lewis (1996)

Table 2.3b Hydrologic Soil Group

Soil Group	*Description Final*	*Infiltration rate(mm/h)*
A	Low runoff potential soil, have high infiltration rates include deep sands or gravel's, very little silt and clay rapidly permeable.	8-12
B	Moderate low runoff Potential Mostly sandy soils less deep than A, and loess less deep or less aggregated than A, but the group as a whole has above average infiltration after thorough wetting.	4-8
C	Moderately High runoff potential comprises shallow soils and soils containing considerable clay and colliods, though less than those of group D. The group has below average infiltration after pre-saturation.	1-4
D	Highest runoff Potential. Includes mostly clays of high swelling percent, but the group also includes some shallow soils with nearly impermeable sub-horizons near the surface	0-1

Source: U.S. Conservation Service (1964)

Curve numbers in the Table 2.3a are used if only the average antecedent moisture condition is known as in Table 2.3c.

Table 2.3c Antecedent Moisture Conditions.

	Total Rain 5 Previous days (in.)			
			Dormant	Growing
	Condition	Soil wetness	Season	season
I	Dry but above			
	Wilting point		<0.5	<1.4
II	Average		0.5-1.1	1.4-2.1
III	Near Saturation		>1.1	>2.1

Source: Dingman (1994) After U.S. Conservation Service (1964)

Table 2.3d Curve Number for Wet(III) and Dry(I) Antecedent Moisture Conditions(AMC) corresponding to an Average Antecedent Moisture Condition

Corresponding CNs		
CN for AMC II	AMC I	AMC II
100	100	100
95	87	98
90	78	96
85	70	94
80	63	91
75	57	88
70	51	85
65	45	82
60	40	78
55	35	74
50	31	70
45	26	65
40	22	60
35	18	55
30	15	50
25	12	43
20	9	37
15	6	30
10	4	22
5	2	13

AMCI: Lowest runoff potential.
AMCII: The Average condition.
AMCIII: Highest runoff potential.
Source: Dingman (1994) After U.S. Conservation Service (1964)

In addition, most researchers also prefer to use runoff coefficients that basically use landuse pattern rather than soil characteristics of the area under study. Therefore an urban settlement (Table 2.4) will have a high runoff coefficient than a rural agricultural community.

Table 2.4 Runoff Coefficient for various land cover units

Description of Area	Runoff Coefficient
Business-	
Downtown areas	0.77-0.95
Neighborhood areas	0.50-0.70
Residential	
Multiunit, detached	0.40-0.60
Residential (suburban)	0.25-0.40
Parks, cemeteries	0.10-0.25
Play grounds	0.20-0.35
Unimproved areas	0.10-0.30

Source: Viessman and Lewis (1996)

2.2.3 Drainage characteristics

The drainage system consists of drainage pattern, catchment shape and areas for storing water such as ponds, wetlands or perched water table. According to Ward and Robinson (1990) drainage pattern is the basic network form of the system and its effect can closely be linked to the bifurcation ratio and the catchment shape. This drainage system comprises a network of stream channels and the sloping ground surfaces that contribute to overland flow and interflow to those channels, (Strahler and Strahler, 1987). Therefore a drainage system (natural or artificial) conveys surface water and ground water away from areas with high water to prevent flooding (Viessman and Lewis, 1996).

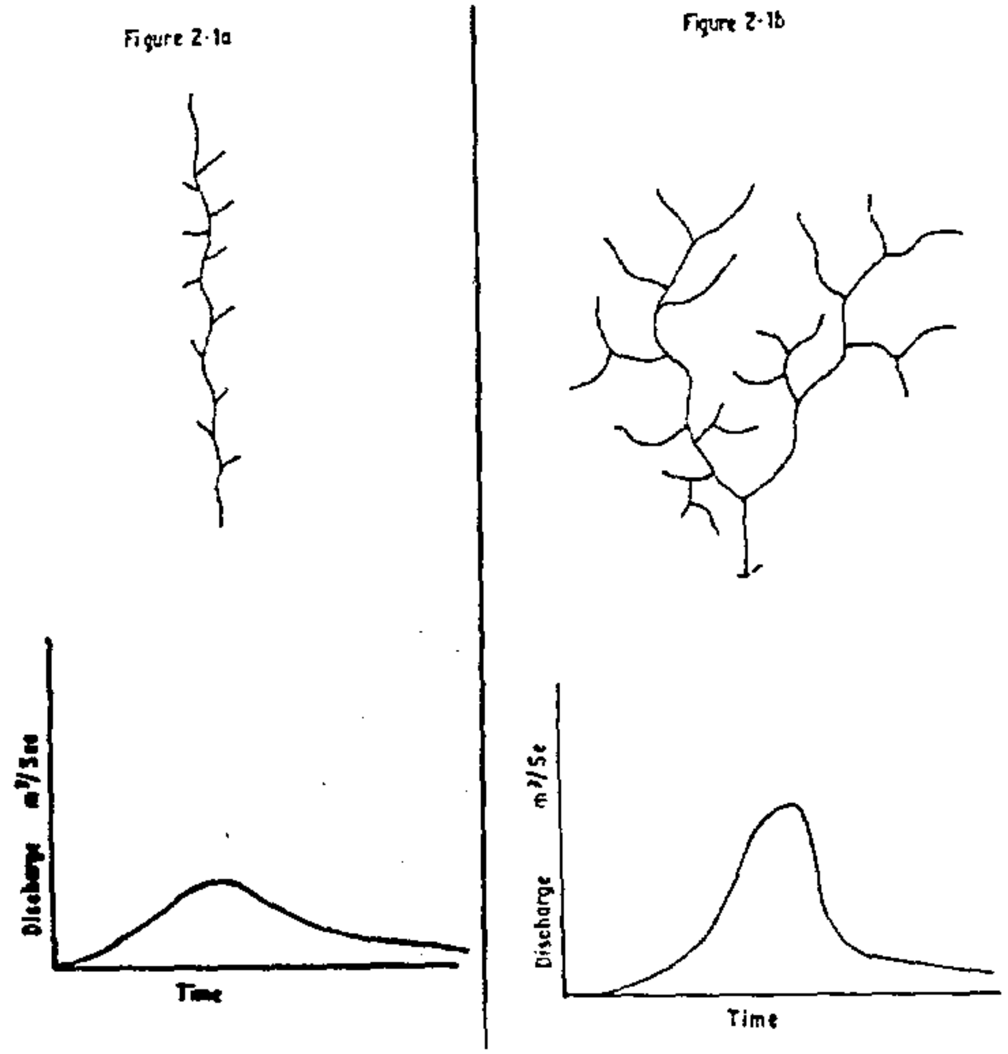
According to Ward and Robinson (1990) drainage pattern is the most conservative network characteristic, its effect closely related to that of bifurcation ratio and catchment shape. Taking into consideration the drainage type, Ward and Robinson (1990) noted that dendritic patterns are associated with sharp high–magnitude flood peaks at catchment outlets, because of coalescence of number of major tributaries. Also some patterns permit the evacuations of flood flows from the downstream tributaries, before those from upstream arrive which often result in more muted flood response.

Though high network of streams is important, high volume of unconnected surface depressions may act as storm reservoir, but can only contribute to a quick flow when these depressions are connected by constant rainfall. In other words, the total interconnected saturated surface within the catchment basically determines the volume of quick flow produced by rainfall. Therefore maximum flood occurs, if rainfall continues and the source area expands, where the entire catchment contributes to quick flow to the stream channels. (Ward & Robinson, 1990; Viessman and Lewis, 1996)

Ward and Robinson (1990) noted that the effect of artificial drainage on floods appears to vary and is not fully understood. But the velocity and magnitude of flood peak within artificial channels can be explained by its variability in terms of the characteristic the channel posses which may include its roughness, constituents of the channel bed, bank material, growth of vegetation within it, its shape and storage properties.

On the other hand, in determining the time at which storm upstream will take to travel down stream to cause flooding, researches have resorted to use the time-area, time-of concentration and the basin shape methods (Selby; 1985). It has been noted that the varied basin shapes produce varied hydrographs. For example with an elongated catchment (see Figure 2.1a) water from the head of the basin takes a long time to reach the outlet of the basin, while the area near the outlet contributes very quickly. In this instance the hydrograph of this elongated shape flattens. A nearly circular catchment (see fig 2.1b), the travel time from the basin perimeter is nearly equal and more peaked.

Figure 2.1 Relationships Between Drainage Pattern, Drainage Area and Flood Hydrograph



Source: Ward and Robinson (1990)

However the determination of peak discharge for a catchment is important for the design of structures and planning of settlement layout (Loukas and Quick, 1996; UNESCO, 1978). In the determination of peak discharge, using a rainfall-runoff model either the rational formula or the unit hydrograph there is the need for the calculation of lag time or time of concentration (Mannaerts, 1996; Bondelid et al., 1982). Bondelid et al (1982) noted that about 75 percent of errors in the estimation of peak discharge is the result of errors in trying to estimate time of concentration.

The importance of time of concentration in runoff processes has prompted researchers to spend time to develop and find an appropriate (technique) equation to determine this variable. The technique used to determine the time of concentration is based on using either regression analysis relating it to physiographic parameters of the watershed and some rainfall intensity or duration (Kipirch, 1940; Watt & Chow, 1985; Sabol, 1993). However other researchers estimate the time of concentration of a watershed by applying mathematics based on kinematics wave approximation of overland flow (Akan, 1986; Aron et al., 1991). Some of the techniques identified by Mannaerts (1996) include TR-55 velocity method for both urban and rural watershed, SWRRB method, Kerby overland flow time equation, Kirpich (Ramser) method and Airport equation.

The drainage density network of an area is generated by a combination of factors such as climate, vegetation and lithology of the area (Selby, 1985).

The changes in land use consequently affect drainage density as a result of deforestation, destruction of soil structure and the sealing of surface, all tending to increase drainage density. Though it's very difficult to establish a relationship between drainage density and flood, therefore changes in landuse, cause floodwater to be conducted more rapidly to lowland areas to increase flood hazards (Selby, 1985; Dingman, 1994).

Most importantly researchers have also noted that the slope of the drainage channel can enormously contribute to the rate of storm runoff to cause flood (Ward and Robinson, 1990; Selby, 1985)

2.2.4 Topography

Loukas and Quick (1996) expressed that overland flow may occur on hillslopes if the level of saturation reaches the top of the hillslope. In this instance surface runoff is generally favoured by topographical and geological condition; for example in areas with steep slopes runoff occurs rapidly (Falkland and Brunel, 1993). A model like that of Hewlett, gave recognition to the role of topography in determining the location of source areas through the downslope movement of moisture, (Bonell and Balek, 1993). Therefore recent developments in the use of geographic information systems to generate digital terrain model, shows that the spatial variation in runoff in an area is propelled by topographic gradient (O'Loughlin, 1986; Beven et al., 1988).

Also Moore et al., (1991) expressed in their work the important role digital terrain model can play as an alternative to physically based models when considering runoff production.

2.3 Remote Sensing and Geographic Information System Application In Hydrology

Geographic information system and remote sensing provide a broad range of tools for determining areas affected by floods or for forecasting areas likely to be flooded due to high river or sea levels. However for an effective management of floodwater in areas prone to flood, geographic information system and remote sensing provide an efficient instrument (Mejerink et al, 1994)

In other words remote sensing techniques are considered to be an important way of collecting hydrological data at reduced cost, since large areas can be depicted on a single image depending on the scale (Engman and Gurney, 1991; Lillesand and Kiefer, 1994). Engman and Gurney (1991) enumerated some importance of remote sensing to the application of hydrology. The first is the ability to give spatial data rather than point data; second, it has the capability of measuring some hydrological variables such as soil moisture; third, the satellite used has the capability to produce continuous and long-term data. Some hydrological parameters like landuse, soil moisture, evaporation and rainfall are variable in time and space, but the development of remote sensing has made it possible to collect most of these data by using multi-temporary images that can be used for spatial and hydrological modeling (Loumagne et al, 1996).

In hydrological modeling within the remote sensing and geographic information system some parameters like soil water storage capacity and vegetation root depth are determined by noting hydrological similar units for all pixels from a digitized map (Mejerink et al, 1994). Some researchers have noted the existence of limitation in the use of remote sensing to measure runoff. But, it is possible to use remote sensing to determine areas covered by swamps, lakes or temporary areas inundated by floods (Schultz, 1997). As in the works of Kuma (1996), he attempted to produce a flood risk map of Accra using satellite image and aerial photographic interpretation without considering the similarity in the units within the image in terms of their hydrological characteristics.

Though most hydrological models are not developed for use with remote sensing capabilities, yet some remote-sensing data can be used in distributed deterministic model. However much questions are asked about whether the values of distributed parameter models truly represent the processes if their fundamental algorithms and assumptions are very difficult to validate (Engman and Gurney, 1991).

Geographic Information System (GIS) has gained much ground in the field of hydrology for monitoring and modeling activities (Doe III et. al., 1996; Baumgartner and Apfl, 1996). Therefore geographic information system (GIS) tool can provide resources managers and decision-makers with a tool for effective and efficient storage and manipulation of remotely sensed information (Este, 1992). Baumgartner and Apfl (1996) explained that remote sensing and geographic information system could be used separately or in combination with hydrological models (where a selected hydrological modeling can be done with geographic information system). It was further observed that in a case of combined application, no matter how efficient or complex the approach of integration of remote sensing, geographic information system analysis, database manipulation and models in a single analysis system might be, it requires that the hydrologist understands not only the hydrological problem, but the technologies being used without being a computer expert.

To solve hydrological problem in an integrated manner requires:

- recognition of the specific hydrological problems;
- measurement of variables using remote sensors and conversional/terrestrial methods; design a geographic information system including data layers;
- attribute information; that is building a database to manage all the data;
- selection or design of an appropriate hydrological model; input variables into model; comparison of results from model computation with actual remote sensing and ground data.

In other words the integration of remote sensing and geographic information enables the hydrologist to model temporal and spatial changes of hydrological phenomena efficiently.

Despite the advantages of the integration of hydrological models into geographic information system models, there are some limitations that need to be taken into serious consideration. Doe III et al. (1996) observed with much concern the problems relating to the quality of data, parameter estimation and grid cell size and how this affects the representation of hydrological processes within a geographic information system model. Also Chen (1998) commented that limited efforts have been made by researchers to develop geographic information system tools into which researchers can easily integrate hydrological models, though there exists some difficulty in dealing with spatial and temporal aspects simultaneously.

2.4 Geological Past

The reconstruction of the paleogeomorphology/geology of an area using varied methods available helps the researcher to understand the present geomorphological phenomena (flooding) in that area (Krumbien & Sloss, 1963; Yardimcilar, 1998). The observation one may make in an area is likely to influence his perception. According to the comments by authorities such as Lyell (1830), the present processes that generate flooding also occurred in the past. This is because present landforms are shaped by slow but relentless forces, therefore the landforms in this present age have gone through a lot of changes that might be distinct from the past as we can observe. It has been observed by some researchers (Krumbien & Sloss, 1963; Davis, 1964; Dei, 1972) that the present environment looked different from the environment of the geological past during the Pleistocene in the Quaternary period. This is because a possibility exists (as encountered in their studies) to show that geological, climatological and human processes have shaped these environments.

To reconstruct the geological past environment some researchers use varied methods, which include heavy mineral, sediment analysis, archeological evidence, geological feature correlation and radiocarbon dating of rock particles (Krumbien & Sloss, 1963; Davis, 1964; Dei, 1972).

Using the heavy mineral analysis it is realized that sediment formed from freshly exposed igneous or metamorphic terrain tend to have clean angular to sub-angular heavy mineral grain, with some cleavage and crystal faces preserved. In other words sediments derived from pre-existing sediments tend to have well-rounded heavy mineral grain composed of the most stable heavy mineral such as tourmaline and zircon (Krumbien & Sloss, 1963). In the works of Dei (1972) he found out that quartz grain can be used as an index for the reconstruction of the paleo-geographic environment of an area by looking at the particle shape, roundness and surface texture. In his view climate may dominate in the process of shaping particles and land surface as seen today.

Davis (1964) commented that the variations in relief within areas especially in Africa might have occurred during the Pluvial and the Inter-Pluvial periods in the Pleistocene of the quaternary.

CHAPTER THREE

METHODS IN HYDROLOGICAL STUDIES AND ISSUES OF FIELD WORK

3.0 Introduction

Flood is a principal natural hazard in many parts of the continents. Sector programs for preventing and decreasing flood damages used different kinds of data, among which hydrological and meteorological data are of basic significance (Sokolov, 1969; Sezstay, 1969). This chapter is devoted to discussing the types of data and sources, methods used for data collection and tools for analysis.

3.1 Data identification and source

Data to be used for this study were sought from two main sources namely, secondary and primary sources. To easily identify and incorporate data to be collected into the proposed geographic information system and hydrological models for analysis, the Terrain Mapping Units (TMU) technique as described in the works of Meijerink (1988), Meijerink et al (1994) and Mitchell (1973) was followed. The Terrain Mapping Units technique is a procedure whereby the study areas are divided into units/classes that can easily be identified and separated on the topographic map and aerial photography or satellite imagery to be cross checked with ground observation. Using 1997 aerial photographs with a scale of 1:10,000 and the 1972 topographic map of scale of 1:50,000, the terrain of the study area was sieved using various cover classes into thematic maps (topography, elevation, slope, land use, and vegetation, drainage channels).

Taken into consideration the Terrain Mapping Units, secondary data were obtained from published information on flood generation factors such as, rainfall, discharge of the various rivers and human activities within the study area. Most of these data have been compiled and used by specialized organizations such as Water Research Institute, Meteorological Services, Hydro-Division of Ministry of Works and Housing and School of Agriculture in the University of Ghana.

It has been noted that most of the data compiled by these organizations are at times not up-to-date and not properly recorded. This makes most users doubt the accuracy of such data for analysis. As observed by Manley and Askew (1993), data entry from some recorder's notebook to the computer for processing is always a problem, since most of those who are charged with recording of events have no knowledge in computing. Therefore, data availability for use becomes a problem since most of these organizations do not have access to computers. In most cases data stored on paper deteriorates rapidly making the writings difficult to read and at times various types of creatures eat part of the records. In this instance, data from secondary sources need to conform to set standards because of their role as sources of data in physical geography for analysis of events and study purposes (Shaw and Wheeler, 1985).

The over reliance on secondary data for research sounds costly to researchers since most of these are derived from models and are also not properly compiled by agencies commissioned by the government. Therefore, some of the data for this research were obtained from the primary sources. The data collected from these sources included vegetation characteristics, landuse pattern, channel characteristics (Cross section area) and soil characteristics. The methods used to collect these data included, field observations, field measurements and satellite/photographic and topographic map interpretations.

The field observations were carried out in areas where complicated equipment was not required, but quick and accurate predictions could be made (Mitchell, 1973). This was to cross check the predictions derived from a model with estimation has received a lot of attention regarding its importance in determining the amount of water that moves through the soil. An attempt was made to obtain infiltration rate using the ring infiltrometer at various points in the study area, but it was not possible due to the unavailability of the equipment and knowledge of usage in taking measurements.

Due to difficulty in the measurement of infiltration rate, researchers have developed various models and coefficients that can be used to estimate infiltration rate. These models take the form of time-dependent and empirical models using detailed equations that describe infiltration rate under continuous ponding (Bonell and Balek, 1993).

Therefore, the researcher used runoff coefficient to estimate infiltration and runoff for areas under study. Despite the efforts put into the use of models in hydrological phenomenon, most authors/researchers are cautioned as to the use of these models in their estimations (Bristow and Savage, 1987).

An attempt was made to acquire data relating to water detention (soil moisture and storage points) in each catchment. However, in the determination of soil water holding capacity and detention storage, the researcher used storage coefficient instead of the laboratory moisture percentage method (Head, 1994). This was because of the cost involved in sending the materials to the laboratory for analysis and the time to submit the research findings. The use of storage coefficient is based on the view that amount of runoff resulting from a particular storm is primarily a function of the existing depression and soil moisture conditions (UNESCO, 1971).

Values relating to drainage density, bifurcation ratio and drainage lengths were calculated using the topographic sheet of Accra No. 0501(B2, B3, and B4) of a scale of 1:50,000. The reason for using the topographic sheet is that, it is very difficult and expensive to have actual field measurement of the drainage parameters. Moreover considerations have to be given to the time limit involved in the data collection and submission of research findings (Taur and Humborg, 1992; Prosser and Abernetty, 1996; Loukas and Quick, 1996).

3.2 Data sampling

It is important to achieve a level of generality through the collection of data using various forms of measurement and observations. Since the total study area cannot be covered in terms of data collection of the identified parameters needed, the multistage sampling method of which purposive-stratified methods (non- probability and probability) were used to select points to collect samples for the study.

To give equal chance to a point of being selected for measurement and observation, using the topographic map and aerial photography, the urban watershed was stratified into river catchment. These catchments were later subdivided into small facets with the information and tools available (cover class, slope). Due to the varied nature of the catchment, time, cost and the total amount of sampling to be done, it appeared inappropriate using simple random sampling method (probability method) to select site for measurement and observation. This is because simple random sample requires a sample frame list of sample sites that is difficult to compile (De Vans, 1993).

Besides using any of the probability method, areas to be selected may be paved, rocky or waterlogged and therefore not suitable for infiltration measurement. Also a drainage channel selected for discharge measurement may be dry or choked. For that reason the two non-probability techniques namely purposive and accidental were used to collect data in the study area.
The non-probability method does not take into consideration the proportionate representation of the samples to be collected, but it is used to select samples

for economic convenience. In this instance the use of purposive sampling enabled the researcher to observe and measure a case in any unit that was important to the study (Shaw and Wheeler, 1985). Despite the urge to use the non-probability sampling techniques, it was noted that they do not give any general view of samples complied (De Vans, 1993).

3.2.1 Summary of main aspects of fieldwork

The data collection was in two parts: those collected from secondary and primary sources. The secondary data mostly included daily rainfall recordings, river discharge measurements, general characteristics of urban watershed and landuse plan (industrial estate, settlement zones and service centers) of the study area. The sources of data were from specialized organizations appointed by the government to compile them.

The collection of primary data involved field observation, field measurement and image interpretation to update or collect information related to landuse, soil characteristics, drainage size and runoff determination.

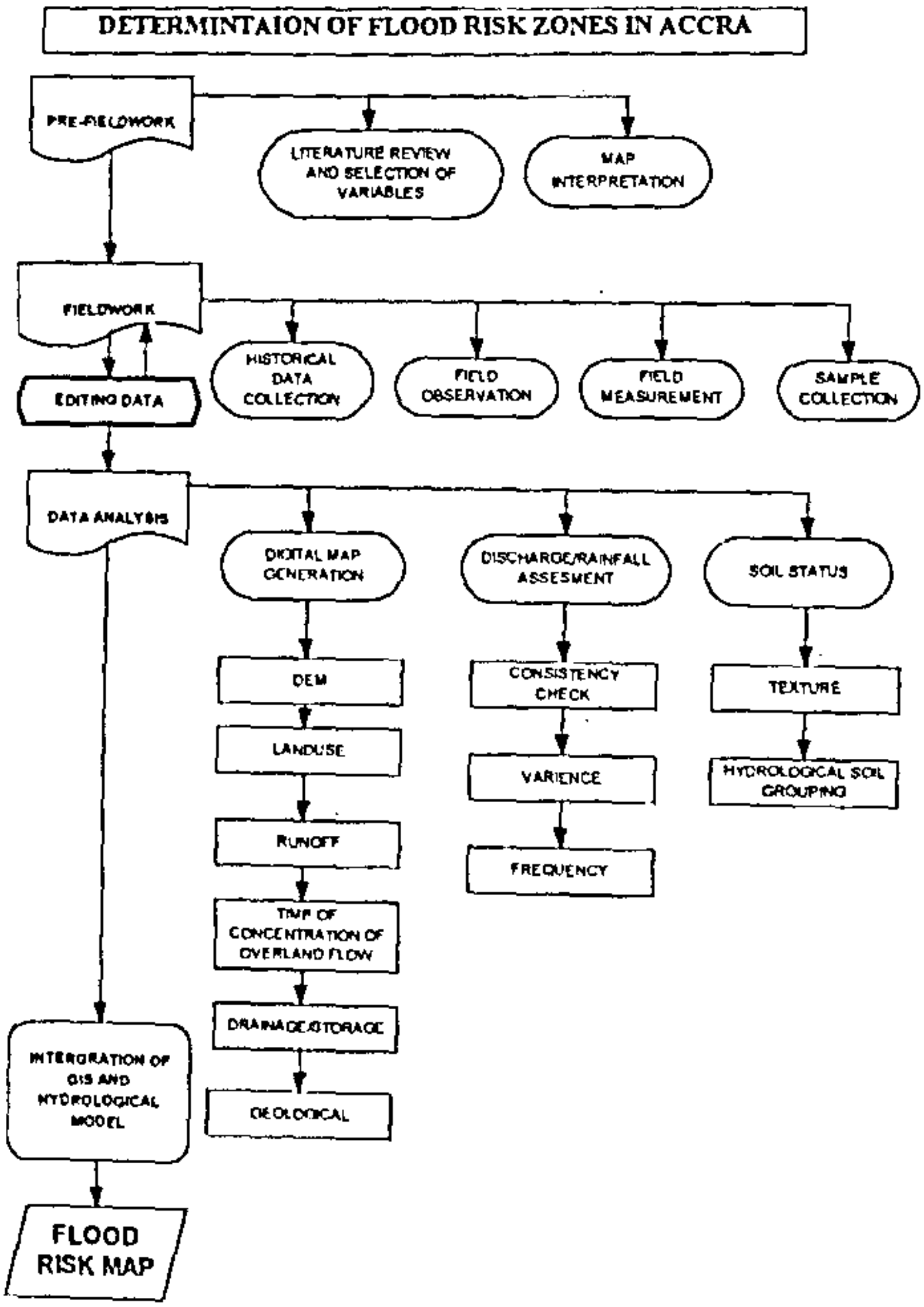
Specifically, variables either observed or measured in the field are listed below;

1. Peak discharge
2. Drainage basin characteristics/storage/shape/ drainage density
3. Soil characteristics (texture)
4. Detention storage points
5. Landuse (settlement, service centers, parks,)
6. Rainfall (intensity, duration, frequency)
7. Slope characteristics (steepness, length)

9. Identification of floodplain

10. Outliers of the Togo-Akwapim rocks

Figure 3.1 Flow chart showing stages of determination and mapping of flood risk zones in Accra



Source: Authors Context, 1999

3.3 Data consistency check

To check for consistency of point data (especially rainfall and discharge measurements) collected, the double mass curve technique, as described in the works of Dingman (1994) was applied.

The double-mass curve, which is a technique for detecting and correcting inconsistent precipitation data that have resulted from obstruction such as growth of trees, urbanization or the appointment of a new observer for the station, was adopted. The double mass curve is a plot of accumulated depth of rainfall against time. The mass curve for a station where its measurement condition has significantly changed was compared with the annual values of other stations within the study area. The inconsistency in the measurement is reflected in change in slope of the mass curve of that station. Moreover inconsistency in measurement is considered significant if the break in slope is more than 5 (five) years.

To correct this inconsistency, the slope for the period after slope change is divided by slope for period before slope change. This gives a constant factor, which is used to multiply the portion that shows a problem in measurement.

Since there was no inconsistency in the measurement no correction factor was applied to the data for analysis.

3.4 Analysis of data

Descriptive and quantitative equation models were used in the analysis. The descriptive method involved the use of charts and graphs plotted on a logarithm graph sheet, whilst the quantitative equation involved selected physical equation models for rainfall-runoff (flood) analysis in hydrology.

3.4.1 Descriptive method

Graphs and charts were used to explain some frequency of occurrence in events such as rainfall depth, rainfall intensities and peak annual discharge of some streams. Some of the graphs plotted were based on exceedence probability method that will help in explaining and predicting extreme events. For easy and quick plotting computer programs Timesplot and Rank-Plot developed by Donker (1996) were used for the graphical representation.

3.4.2 Methods for paleogeomorphology reconstruction

To reconstruct the Paleogeomorphology of the study area, an attempt was made to use methods such as archeological evidences and historical records.

3.4.3 Quantitative method

The quantitative methods for the analysis were based on a runoff simulation model. Therefore, the model selected for analysis should be able to compute severe floods caused by short duration and high intensity rainfall events, simulate runoff during and shortly following discrete rainfall event. Hence the modified rational and kirpich time of concentration method were adopted. The modified Rational model (equation 1) is designed to simulate runoff within any drainage basin no matter the pattern of rainfall. It also, gives the various components to be selected for incorporation into the general model.

$$Q= 0.28*C_s*C*I*A \text{ ---------------------- } \textit{equation 1}$$

Where:

Q= runoff rate [m^3/sec]
C= Runoff Coefficient
C_s= Storage Coefficient
I= Rainfall Intensity [mm/hr]
A= Drainage area [Km^2]

In addition, the modified rational method considers the entire drainage area as a single unit and assumes that rainfall is uniformly distributed over the drainage area. It also includes storage coefficient to account for the recession time. In the original method recession time was assumed to be equal to time of rise.

The use of the rational method is based on the assumption that predicted discharge has the same probability of occurrence (returned period) as the rainfall intensity and runoff coefficient is constant during the rainstorm.

The modified rational method is based on the concept that a rainfall with a steady uniform intensity will cause runoff to reach its maximum rate when all parts of the watershed are contributing to the outflow at the point under consideration. This condition is met after the elapsed time of concentration; that is normally the time taken for a wave of water to flow from the remote part of the watershed to a point under consideration.

The *timing* characteristics of hydrological events are of major importance as they directly affect peak runoff and the flow duration in estimation of floods effects on properties and lives, therefore the Kirpich time of concentration (equation 2) method was used.

$$\mathbf{T_c = 0.0195 * L^{0.77} * S^{-0.385}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \textit{equation 2}$$

T_c= Time of Concentration (min)

L= length of overland flow (m)

S= gradient of surface (m/m)

It has been shown that there are inaccuracies and prediction errors in runoff rates due to faulty estimation of time of concentration. Time of concentration is the time taken for runoff to arrive at outlet from the remotest part of the catchment after rain ceases. The major importance of Kirpich time of concentration method is that it incorporates the basin topography (flow length and slope gradient) to represent gravity. However the only lapse of the Kirpich method is that it does not incorporate surface roughness that represents resistance to surface flow.

3.5 Conceptual framework

Model application in the field of hydrology is so enormous that it can be found in areas such as flood control/prediction, water quality, sedimentation and effect of natural or induced climatic changes on watershed. From these wide ranging problems, there are three main types of model used in hydrological studies namely; physical-based model, hybrid and stochastic models. These models are normally used to analyse point events. They cannot be used for spatial representation of the occurrence of hydrological events. As a result, there is a need to adapt a model that will be able to produce an output showing spatial occurrence of hydrological events.

To find the spatial extent of flood occurrence a spatial model will be used. This is because a spatial model has the capability of using point data to represent an area in which spatial variability of specific parameters of an area can be integrated to help provide an understanding of interdependence in hydrology. The application of a Geographic Information System Model (GISM) to study hydrological event in its spatial form is therefore appropriate. The Geographic Information System Model (GISM) has the capabilities of incorporating physical and stochastic models for spatial analysis of a phenomenon. Also to determine the areas that are likely to be affected by floods.

The Geographic Information System Model (Figure 3.2), adapted and modified for analysis for the study is the Modeling Flow based on the Relational Rule used by (Meijerink et al., 1994).

The model identifies four (4) main stages that could be used for flood risk zoning or assessment.

The first stage involves the generation of various thematic maps of the area of study, using aerial photographs, satellite images, topographic maps and field observation and measurements to check the accuracy of these data.

The second stage involves the incorporation of the thematic data into the Geographic Information System Model (GISM) through digitizing and creation of attribute tables of each theme.

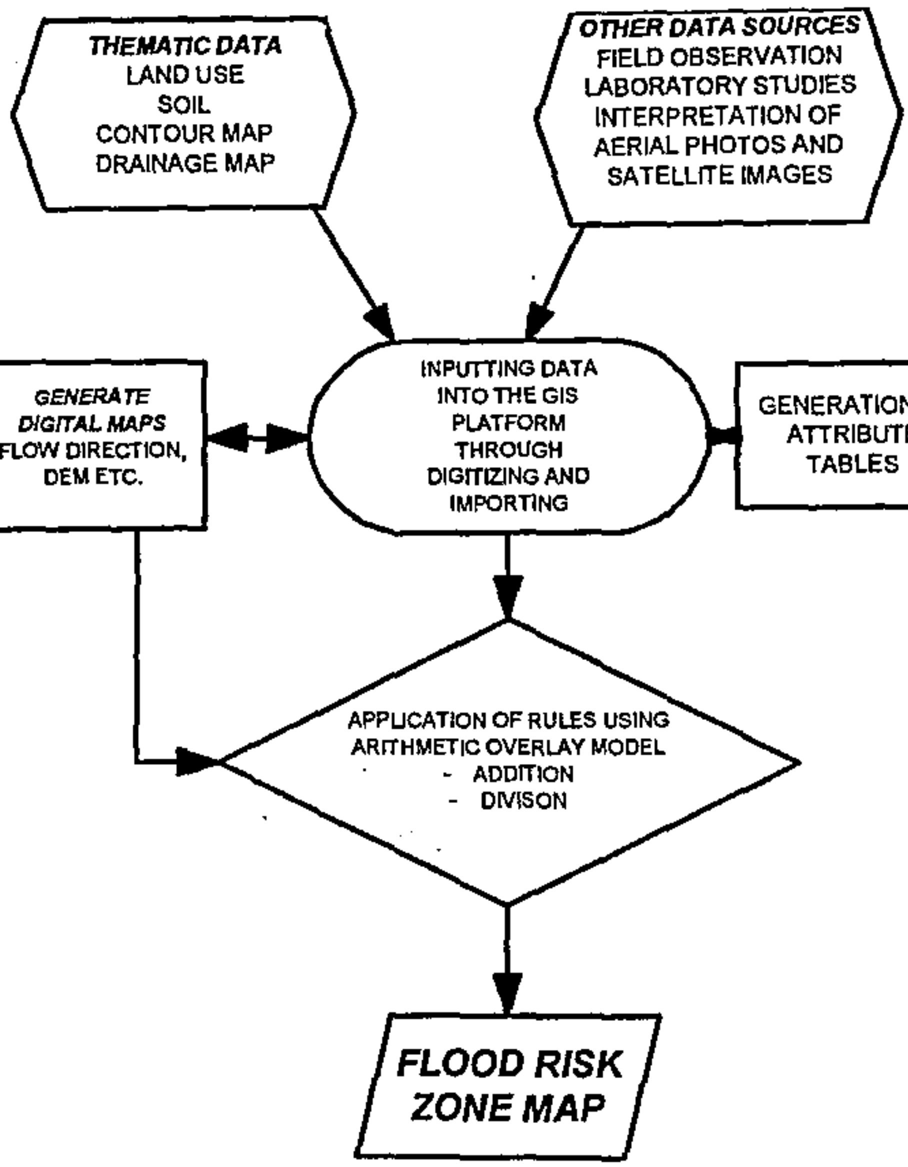
Thirdly, it involves the use of arithmetic overlay operation (addition and division to help integrate the hydrological model into the geographic information system model.

The fourth stage deals with the generation of flood risk hazards maps for the Accra area under investigation.

The use of a geographic information model though advantageous, showed some difficulties that need to be highlighted. First, it demands special software and good knowledge in handling the software to enable one analyse the data. Second, data input using the digitizer proved too tedious and therefore prone to mistakes if care is not taken.

Lastly, to calibrate hydrological model for easy incorporation into the geographic information system model can be very difficult.

Figure 3.2 MODIFIED MODELING FLOW DIAGRAM FOR RELATIONAL-RULE-BASED FLOOD ASSESSMENT



Source: Merjerink et al (1994)

CHAPTER FOUR

HYDROLOGICAL PESPECTIVE OF ACCRA

4.1 Introduction

The hydrological parameters of Accra as a unit are examined. These cover, the general hydrology of the area, taking into consideration rainfall, runoff, soil characteristics, drainage and the paleogeomorphological evidence of the study area.

4.2 Rainfall

4.2.1 Rainfall Consistency Check

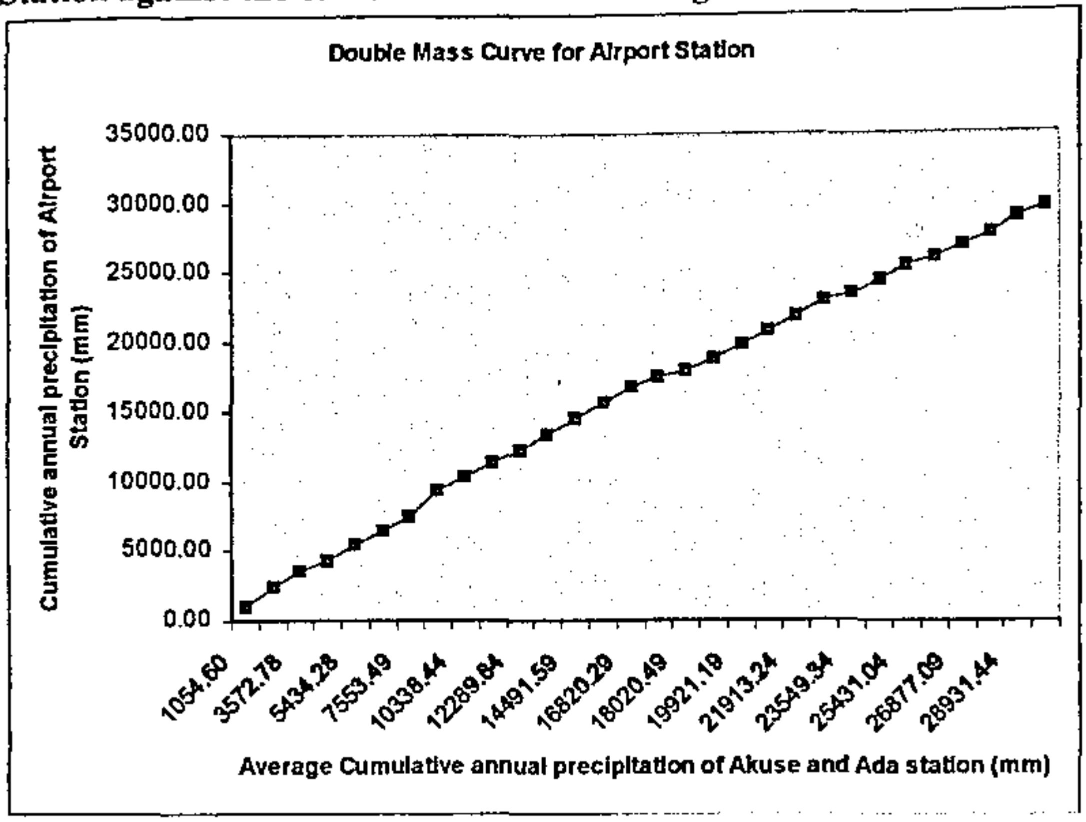
The Airport Meteorological station in the study area is one of the currently operating major stations from which historical and current rainfall records can be obtained for Accra. An examination of 30 years rainfall records from 1961 to 1990 and past records on flood occurrence documented by Adinku (1994) showed that high rainfall that causes floods falls between May and July. Therefore, the maximum daily rainfalls from 1961 to 1990 were isolated for each month to help in the determination of flood-causing precipitation. To check for consistency in the rainfall records isolated (Table 4.1) and its reliability for predictive purposes the mass curve procedure as described in Dingman (1994) was used.

Table 4.1-Measured annual and cumulative precipitation at Akuse, Ada and Accra International Airport station

Year	Akuse Rainfall mm	Ada Rainfall mm	Airport Rainfall mm	Average of Akuse and Ada	Cumulative Average of Akuse and Ada	Cumulative value of Airport Station
1961	1065.5	1044	974.85	1054.60	1054.60	974.85
1962	1353.0	1490	1229.87	1421.30	2475.90	2204.72
1963	1201.3	992.5	1349.25	1096.88	3572.78	3553.97
1964	864.0	597.6	865.63	730.80	4303.58	4419.60
1965	1433.3	828.1	1053.34	1130.70	5434.28	5472.94
1966	1328.5	818.7	574.29	1073.60	6507.88	6047.23
1967	1033.9	1057	811.28	1045.61	7553.49	6858.51
1968	1961.3	1696	1411.73	1828.55	9382.04	8270.24
1969	1293.5	619.3	666.75	956.40	10338.44	8936.99
1970	1176.9	964.4	893.57	1070.65	11409.09	9830.56
1971	874.9	886.6	918.97	880.75	12289.84	10749.53
1972	1262.5	877.5	740.16	1070.00	13359.84	11489.69
1973	1146.2	1117	980.44	1131.75	14491.59	12470.13
1974	1229.9	1327	998.22	1278.50	15770.09	13468.35
1975	1128.8	971.6	869.19	1050.20	16820.29	14337.54
1976	938.6	534.9	549.60	736.75	17557.04	14887.14
1977	563.2	363.7	454.70	463.45	18020.49	15341.84
1978	1169.4	610.4	537.40	889.90	18910.39	15879.24
1979	1136.0	885.6	917.40	1010.80	19921.19	16796.64
1980	1154.7	678.1	1000.80	916.40	20837.59	17797.44
1981	1251.9	899.4	669.70	1075.65	21913.24	18467.14
1982	935.7	1248	774.00	1091.60	23004.84	19241.14
1983	575.5	513.5	333.10	544.50	23549.34	19574.24
1984	1279.4	726.9	704.90	1003.15	24552.49	20279.14
1985	1091.5	665.6	680.60	878.55	25431.04	20959.74
1986	888.3	495.8	462.10	692.05	26123.09	21421.84
1987	883.0	625	640.80	754.00	26877.09	22062.64
1988	1007.2	848.2	988.90	927.70	27804.79	23051.54
1989	1303.4	949.9	656.70	1126.65	28931.44	23708.24
1990	911.7	669.7	568.40	790.70	29722.14	24276.64

Source: calculated from 1961-1990 meteorological data from Meteorological Service, Ghana

Figure 4.1 Double Mass Curve for the Accra International Airport Station against the cumulative annual averages of Akuse and Ada.



Source: Table 4.1

It is observed from the mass curve (Figure 4.1) that the plotted line graph shows no significant break in slope, to merit the application of a correction factor (Dingman, 1994). Hence, the data collected seem reliable for predictive purposes. However, it was observed that the daily rainfall records of Accra from which the annual rainfall was derived had some missing values, which made it incomplete when compared to those of Akuse and Ada. The missing values were due to breakdown of equipment during the period. These have since been replaced.

4.2.2 Rainfall occurrence

It is worth mentioning that daily rainfall does contribute to and gives an idea about flooding situations in Accra. This is because it adds up to the soil moisture and decreases the water holding capacity at any moment. However, an isolation of peak rainfall showed that variations did exist between the peak rainfall records for the various months.

As presented in Table 4.2, in the months of June within the period of 1961 to 1990 for Accra, the maximum and the minimum daily rainfall values recorded were 175.95mm and 6.60mm respectively. The mean rainfall value of 60.45mm showed that June always had high rainfalls as compared to the months of May and July within the same period.

Table 4.2 Differences in rainfall for Accra for selected Months (1961-1990)

Month	Maximum .(mm)	Minimum .(mm)	Mean	Standard deviation	Skew coefficient
May	159.90	14.90	46	29.016	2.046
June	175.95	6.60	60.45	34.284	1.120
July	157.20	1.78	42.27	38.219	1.714

Source: Calculated from 1998 Meteorological Service Data

However, antecedent rainfall during the rainy season, at any given intensity or duration, helped to replenish soil moisture; any subsequent rainfalls therefore with least intensities, are likely to cause flooding conditions. From Table 4.2, rainfall in June was nearly evenly distributed having a skewed coefficient of 1.120. This showed that any amount of rainfall within this period as has been observed, had the potential to cause flood because soil pores within the period are mostly filled with water, which reduced infiltration and increases runoff at the slightest rainfall duration.

4.2.3 Rainfall Frequency

In flood forecasting, the standard practice involves the determination of rainfall frequency that will help in the designing and planning of structures to protect life and property (Shaw, 1988). Therefore, RankPLot computer program (Donker, 1996) was used to estimate the rainfall frequency (return period) and its magnitude to which the maximum daily rainfall will occur in each month.

The return period in Table 4.3 is the occurrence of a maximum rainfall event within a certain period. Within the RANKPLOT daily rainfall records are ranked from high (R=1) to low (R=N) to calculate probabilities that estimates their return periods. The probability is calculated using:

$$\frac{R}{(N+1)} \qquad \text{..........}equation3$$

Where: R = Rank, N = Number of observations.

However, calculation of the return period 'T' using the probabilities is generally expressed as:

$$T = \frac{1}{P(F)} = \frac{1}{1 - P(F)} \qquad \text{............}equation4$$

P (F)= Probability of flood occurring **T** = Return periods (Years)

Therefore, a probability of risk level of a flood causing rainfall that may be equal or exceed once in 'n' successive years is defined as:

$$R = 1 - \left(1 - \frac{1}{T}\right)^{n} \qquad \text{...........}equation5$$

R= Risk

Table 4.3 Return Periods of Daily Maximum Rainfall (mm) for Airport Station, Accra

Return Period Years / Month	10 Years	15 Years	20 Years	25 Years	30 Years	100 Years
May	89.7	100.5	108.0	113.8	118.5	149.4
June	111.8	124.5	133.4	140.2	145.8	182.3
July	100	114.5	124.5	132.2	138.5	179.6

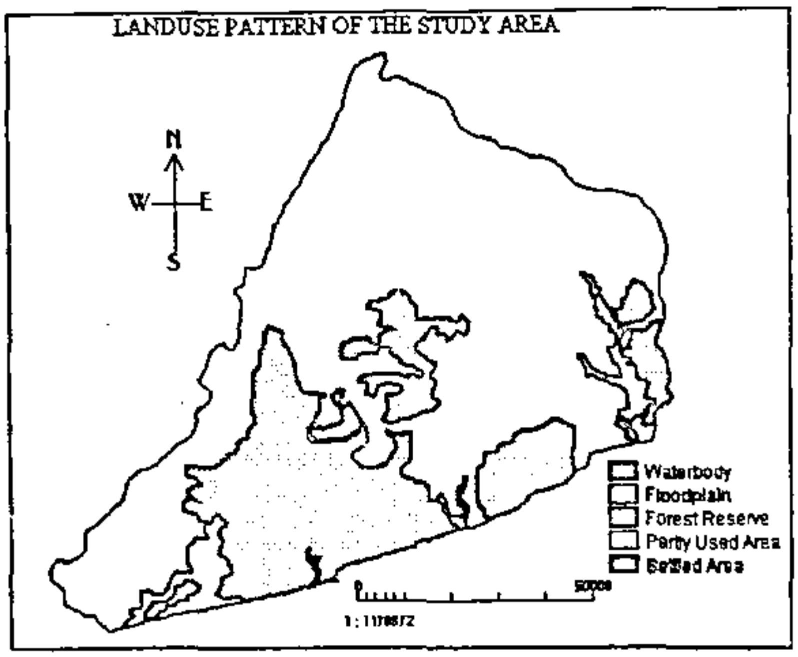
Source: Calculated from (1998) Meteorological Service Data

The design of structures to accommodate worst rainfall conditions expected to occur at that frequency should be at least cost. Therefore, a selection of a return period that a structure size will accommodate should be based on testing several frequencies in the model adopted for the design. Values in Table 4.3 showed that in June, a rainfall value of 140.2mm is likely to occur once every 25 years, whiles in May and July of the same period rainfall values of 113.8mm and 132.2mm respectively would occur in the same period. June's subsequent return period was always higher than that of May and July. To select a rainfall value with a return period for design purpose will depend on the rainfall value that will give a least cost for constructing the structure after testing it in the model to be adopted. In most of the works for drainage design in Accra a return period of 25 years was used as the basis (WATERTECH, 1991; NEDEC, 1962, 1967)

4.3 Land use

Using aerial photograph interpretation, supervised classification of satellite images and field observations, landuse types in the study area could be classified as settled area, water-body, floodplain, forest reserve, and partly used area.

Figure 4.2 Landuse Pattern of The Study Area



The landuse classification in the ILWIS2.1 platform presented in Figure 4.2 shows that about 67.91 percent of the study area is partly used for agriculture, rural settlement or is lying fallow. In addition, 27.24 percent of the area is highly urbanized with greater portions of the area paved but not continuously connected. The percentage coverage for other landuse purposes are presented in Table 4.4

Table 4.4 Land use types

Landuse type	Area (m^2)	Percentage of Study Area
Floodplain	28834323.99	3.67
Forest Reserve	4342723.241	0.55
Partly Used Area	534163996.3	67.91
Settled Area	214255068.2	27.24
Waterbody	4986648.748	0.63
Total	786582760.5	100

Source: Derived from (1992) TM Satellite Image of Accra

Table 4.4 shows the percentage of landuse pattern within the study area. For instance water bodies and floodplains cover about 4.30 percent, they serve as storage points for storm water that would have flowed over the surface and entered homes to destroy property. In addition, the floodplains enable some amount of excess water in the streams to spread over for a period determined by the duration and intensity of meteoric water.

4.4. Rainfall-Runoff

Runoff in this area occurs because excess rainfall reaching and filling up storage points such as streams, ponds, pits, water-logged areas and lagoons exceeds that part which evaporates, and the part that infiltrates to replenish the soil moisture. Consequently, flood-causing storm depends on the magnitude of overland flow per unit time (m^3/sec).

4.4.1 Time of concentration of overland flow

The time a flood-causing wave will travel from its source region to a point that comes under its effect, is normally expressed in terms of time of concentration. From the onset of rain, areas affected by flood are the result of overland flow from upstream adding up continuing runoff from nearer points until flow eventually arrive from all points on the study area at a point that comes under its effect. Using Kirpich method the time of concentration for the overland flow was calculated for various sections of the catchment (Table 4.5).

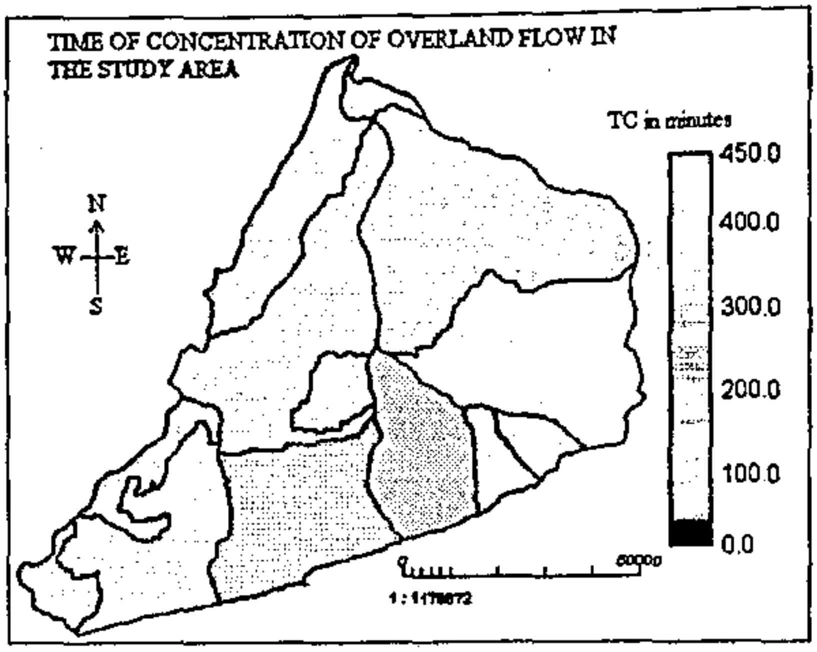
Table 4.5 Estimated TC for estimated overland flow rates of the study area.

Contributing Areas	Area (Km^2)	Average Length of Contributing Areas (m)	Gradient (m/m)	Time of Concentration (min)
Kpeshie Catchment	62.55956	12651.23	0.003614	244.83
Lower Densu	79.36378	12232.04	0.001246	359.46
Lower Odaw	90.07702	9535.30	0.001598	269.60
Lower Sakumo	115.6317	10838.45	0.002812	239.37
Middle High Odaw	18.68761	6040.36	0.012615	85.63
Middle Odaw	118.4495	22094.75	0.002759	417.30
Middle Sakumo	155.0071	15505.58	0.002949	309.68
Mokwe catchment	13.87995	5286.25	0.002883	136.40
Songo catchment	16.78624	6334.811	0.004812	128.73
Upper Densu	24.91854	2293.647	0.066444	21.43
Upper Odaw	64.47231	5133.262	0.071253	38.79
Upper Sakumo	9.416363	3617.677	0.090993	26.97
West Densu	17.33194	5481.032	0.022244	63.88

Source: 1975 Topographical sheets (0501B2, 0501B3 & 0501B4) of Surveys Department, Ghana on a Scale of 1:50,000

Table 4.5, showed that at any given rainfall event, the land unit absorbs a percentage and the rest passes as runoff. Different portions in the catchment that have the potential to present different runoff rates were identified and mapped (Figure 4.3) based on the gradient of the area; this helped estimate the time of concentration for overland flow. Using the Kirpich model, an estimate of time at which a drop of water will travel as overland flow to reach points of outlet varied for different portions of the catchment. The Odaw catchment presents four (4) different time of concentration estimated for the Upper Odaw, Middle high Odaw, middle Odaw and Lower Odaw portions as 38.79 min, 85.63 min 417.30 min and 269.60 min respectively (Table 4.5).

Figure 4.3 Time of Concentration of Overland Flow in The Study Area



4.4.2 Runoff estimation

Rainwater flowing over the land surface that exceeds infiltration becomes surface runoff to recharge the drainage system. Runoff generation within the study area may come from a variable (expanding and contracting) or partial area (fixed area). As a result researchers have developed models to estimate runoff since it always poses a problem when measuring it.

Considering the difficulty in measuring runoffs for the study area, the typical runoff coefficient (Table 4.6) extracted from Viessman and Lewis (1996) based on landuse type was used in its estimation.

Table 4.6 Runoff Coefficient for various land cover units

Description of Area	Runoff Coefficient
Business-	
Downtown areas	0.77-0.95
Neighborhood areas	0.50-0.70
Residential	
Multiunit, detached	0.40-0.60
Residential (suburban)	0.25-0.40
Parks, cemeteries	0.10-0.25
Play grounds	0.20-0.35
Unimproved areas	0.10-0.30

Source: Viessman and Lewis (1996)

As to be seen later in Table 4.14, the soil texture of the same soil unit appears different in textural composition making it difficult to classify the units into hydrologic soil groups that will help in assigning runoff coefficients. As a result the land use type was adopted to determine runoff coefficient for the study area. Hence, the estimate made, using the runoff coefficients, showed that the partly used area having a runoff coefficient of 0.61 does experience moderately high runoff rates. In addition, the settled areas, having a coefficient of 0.89, contribute very high runoff rates, mostly at places like Avenu, Mallam, La Township, Teshie, Nungua, Madina, North Kaneshie, Dzorwulu, Alajo and Achimota.

In addition, it has been noted that the velocity of flow is not swiftly uniform over the landscape in the study area. Therefore, elements such as landuse, depressions, slope and soil characteristics contribute to retard the overland flow velocity. Since it is very difficult to measure this retard rate, the use of roughness coefficient (Table 4.7) described in Viessman and Lewis (1996) was adopted to help in calculating runoff discharge rates.

Table 4.7 Retardness Coefficient for the Study area

Contributing Areas	Area Km^2	Roughness Coefficient
Upper Sakumo	9.41636	0.075
Mokwe catchment	13.87995	0.038
Songo catchment	16.78624	0.035
West Densu	17.33194	0.085
Middle High Odaw	18.68761	0.035
Upper Densu	24.91854	0.085
Kpeshie Catchment	62.55956	0.035
Upper Odaw	64.47231	0.085
Lower Densu	79.36378	0.078
Lower Odaw	90.07702	0.031
Lower Sakumo	115.6317	0.051
Middle Odaw	118.4495	0.035
Middle Sakumo	155.0071	0.083

Source: Viessman and Lewis (1996) and Mannaerts (1996)

Since the runoff coefficients differ in terms of landuse, so is the initial abstraction (Ia) of water for that particular unit. Initial abstraction is all losses before runoff begins; this includes water retained in surface depressions, water interception by vegetation, evaporation and infiltration. However 'Ia' correlates with soil and cover patterns. The estimate of initial abstraction (Ia), which is 0.2 of the storage term of the area, was obtained from the SCS table on Ia for runoff curves an abstract of which is presented in Table 4.8.

Table 4.8 Initial Abstraction for Land use type

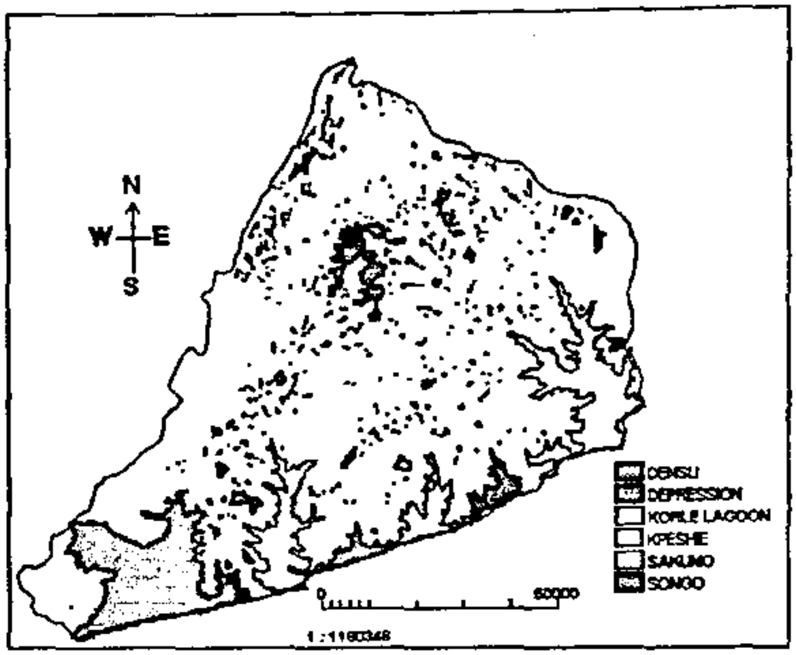
Land use type	Runoff coefficient	Initial abstraction Ia (mm)
Floodplain	0.40	76.2
Forest Reserve	0.49	52.88
Partly Used Area	0.61	32.49
Settled Area	0.89	6.27
Waterbody	0.40	76.2

Source: Viessman and Lewis (1996)

4.4.3 Storage points

The estimation of runoff based on runoff coefficients for the various landuse units is based on the view that all parts of the catchment contribute to storm flow (Viessman and Lewis, 1996). However, observations made showed that not all the parts in the catchment contribute to runoff during a rainstorm because of the numerous depressions scattered all over the catchment. Therefore, for all parts to contribute to runoff there must be continuous rainfall of a long duration, to create the necessary interconnection between the numerous depressions as shown in figure 4.4 that stores storm water.

Figure 4.4 Storage Points Within the study Area



In other words, water stored in these depressions/pits are likely to overflow and connect other depressions/pits when the next rainfall event is high enough to overfill the depressions. From the topographic map, it was calculated that 15.85 percent of the study area has depressions that could serve as detention points. These depressions are either man-made or natural. It was very difficult to measure the depth of these points because of lack of the necessary equipment. However, only the surface areas of some of them were measured (Table 4.9) from topographic sheets of Accra (0501B2, B3 and B4). Most of these points lie below the 76.2-meter contour.

Table 4.9 Measurement of Surface areas of some storage Points

Name	Area m^2	Percentage of Coverage
DENSU DEPRESSION	52087298	36.05
OTHER DEPRESSION	22892798	15.85
KORLE LAGOON DEPRESSION	19230344	13.31
KPESHIE DEPRESSION	9783667.9	6.77
SAKUMO DEPRESSION	34858986	24.13
SONGO DEPRESSION	5626191.4	3.89

Source: 1975 Topographical sheets (0501B2, 0501B3 & 0501B4) of Surveys Department, Ghana on a Scale of 1:50,000

4.5 Drainage

The drainage networks (Figure 1.2) in the study area contribute to the channeling of excess rainfall to a common point of outlet. This network appears to be channels carved on the surface by flood storms that can contain and convey the total runoff produced within the area to points of outlets. Drainage pattern in the study area is mostly dendritic though it appears to have a characteristic of a multi-basin.

The effect of drainage systems on flooding is very difficult to determine directly; it is most useful if some parameters could be identified that will help in this process. Some drainage parameters identified include the size of drainage area, drainage density, stream order, bifurcation ratio, and the slope of the area/channel. Therefore, the 1972 topographical sheet (0501B2,B3 &

B4), 1992 satellite image and 1997 aerial photograph of Accra, helped to delineate the drains (seasonal and perennial) to determine the extent to which drainage systems contribute to flooding in the area.

4.5.1 Catchment Area

The area of a catchment is one of the factors used to determine the rate of runoff with a given input of rainfall event. However, variations in catchment shape, length and area extent produce hydrograph of different nature or shapes. The Odaw and the Sakumo being the biggest catchment areas (Table 4.10), produce different rates of total runoff at a given rainfall input. The reason being that, these two catchments have the tendency to receive much rainfall because of their areal coverage.

Table 4.10 Measurement of Catchment Areas and Longest Channels

Catchment	Area (m^2)	Length of longest channels (m)	Time of concentration for the channels (min)	Gradient of the Channels (m/m)
Kpeshie	62559278.76	19000	335.35	0.0036
Mokwe	13879952.25	9500	213.73	0.0029
Odaw	291689681.90	52680	143.71	0.25
Densu	121614168.94	2900	14.74	0.26
Sakumo	280055042.40	44260	161.66	0.13
Songo	16786244.38	13500	230.74	0.0048

Source: 1975 Topographical sheets (0501B2,0501B3 & 0501B4) of Surveys Department, Ghana on a Scale of 1:50,000

4.5.2 Drainage channels

The drainage channels identified in the study area are of two types namely, natural and artificial. The natural channels were the major means of conveying excess storm water to points of outlet since early 1960. In spite of that, artificial channels have now come to add up to the means of conveying excess water to points of outlet. Some of the natural channels have been paved (Plate 1) due to urbanization to increase the density of artificial channels to convey excess rainfall. Drains carved and constructed within the catchment should thus be able to convey the total estimated runoff.

However, channels to convey storm water in the Odaw catchment have varied shapes (trapezoid and parabolic) and cross sectional areas. A measurement made on six selected channels within the Odaw catchment as presented in Table 4.11 showed that with a given length of 1 meter, a channel with an area of 65.623m^2 should be able to convey 65.623m^3 of water flowing through it.

Table 4.11 Cross Sectional Measurement of Some Selected Drains Within the Odaw Catchment.

Channel Number	Depth (m)	Open Length (m)	Base (m)	Wetted Perimeter (m)	Area of Channel (m^2)
1	3.720	7.500	3.650	12.490	20.774
2	1.524	6.000	3.353	8.477	7.125
3	0.780	1.950	0.450	3.932	0.935
4	2.134	8.910	6.450	12.391	16.510
5	5.500	15.550	8.100	20.404	65.623
6	0.550	0.660	---	2.127	0.242

Source: fieldwork (1999)

Consequently, in settled areas channels are usually paved with concrete, which has increased the velocity of water flowing through them thus decreasing the time of concentration. At some places, the paved channels do interchange with unpaved channels giving varied flow rates. Therefore the 'Manning roughness coefficients' for the channels to stress the rate at which water swiftly flow through them is estimated to be 0.070 and 0.021 for paved and unpaved channels respectively.

4.5.3 Stream Density

The number of streams that drain these catchments may have an influence on the rate at which storm water is conveyed to a storage point or an outlet. On that account, stream density gives an indication of how well storm water will flow in a confined channel other than over the land surface. Table 4.12 shows variation of stream density within the various catchments. Kpeshie has the highest stream density of 0.014m/m^2 as compared to the Songo catchment with a network density of 0.00061m/m^2 indicating a poorly drained area. This implies that in the Mokwe and Songo catchments storm water has the tendency of flowing over the land surface rather than through a channel.

Table 4.12 Drainage Density of the Study area

CATCHMENT NAME	STREAM DENSITY (m/m^2)
SAKUMO	0.0027
ODAW	0.0040
KPESHIE	0.0140
MOKWE	0.000062
SONGO	0.000061
DENSU	0.000086

Source: 1975 topographical sheets (0501B2, 0501B3 & 0501B4) of Surveys Department, Ghana on a Scale of 1:50,000

Even though the density of channels in these areas does help in storm water conveyance to points of outlet, most of these channels (Plates 3 and 4) are choked with refuse and sediments. In addition, people living in heavily populated areas such as Nkrumah Circle, North Kaneshie, Nima, La Township and James Town have built structures either close or across drainage channels (Plates 5 and 6). This prevents the straight flow of water thus creating backwater effect that causes flooding of the areas around the drains. Residential areas like Tabora, South Odorkor, Kwashiman, Malam, parts of Achimota, Awoshie, Dansoman, La Apapa, East Legon, North Legon and Gbawe do not have well defined drainage systems. Consequently, storm waters flow over the surface as an alternative course and enter houses to destroy property (Plates 7 and 8).

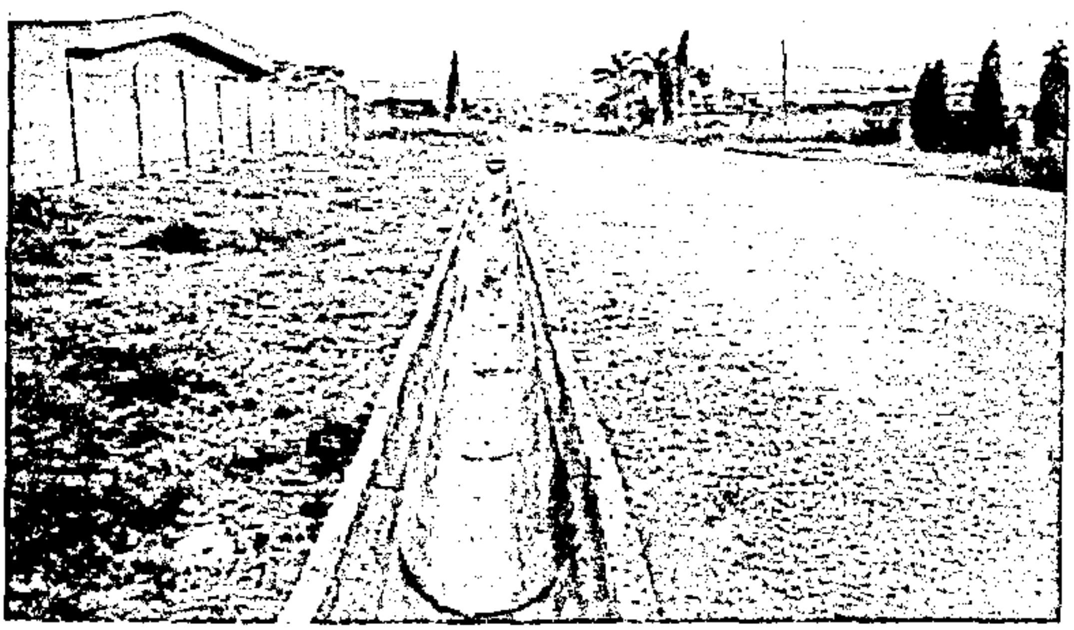


Plate1: A paved drain in a newly Developed area, North Legon

Plate 2: Partly paved and unpaved drain in Achimota

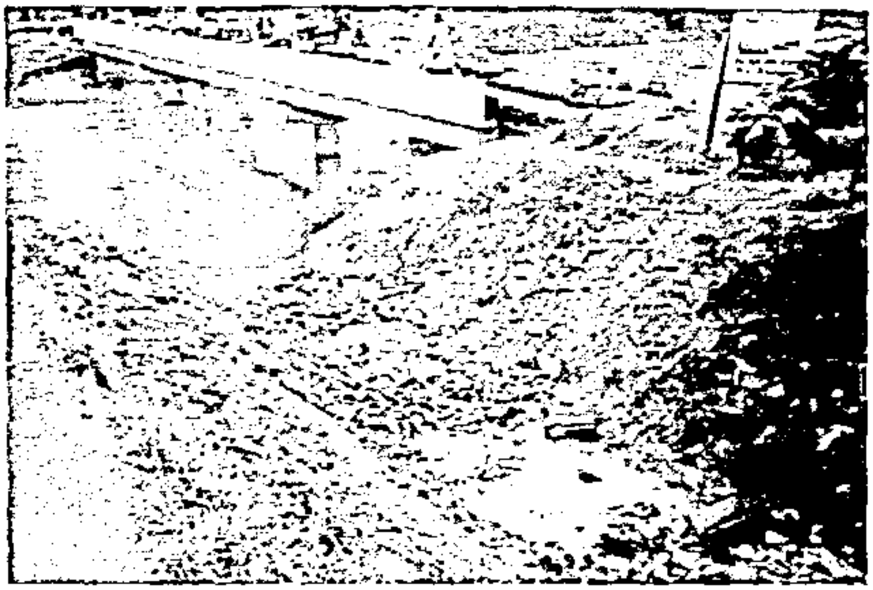


Plate 3: A subsidiary drain of the main Odaw River choked with refuse

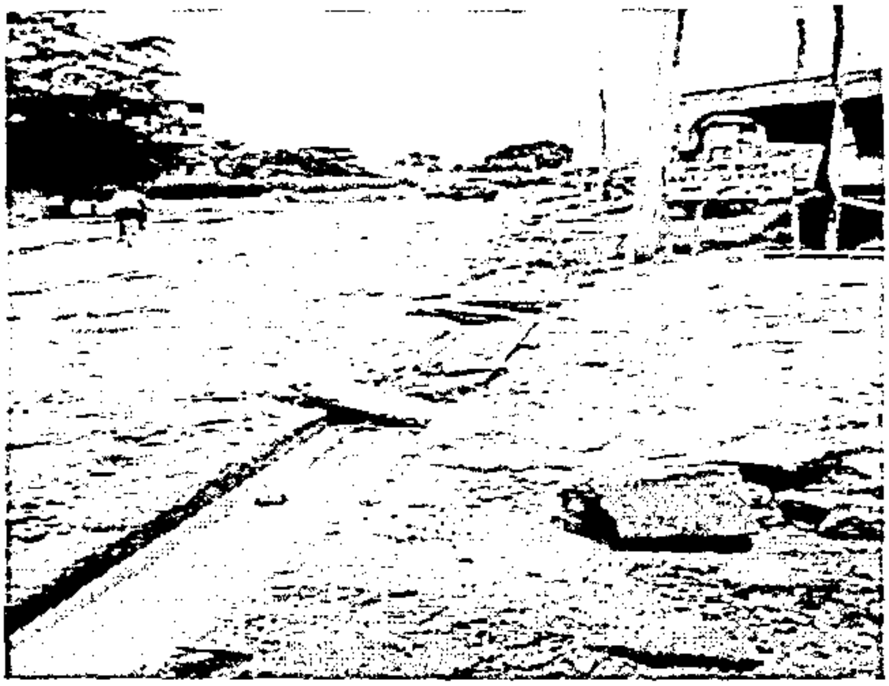


Plate 4: Drain filled with sediment, Swan lake

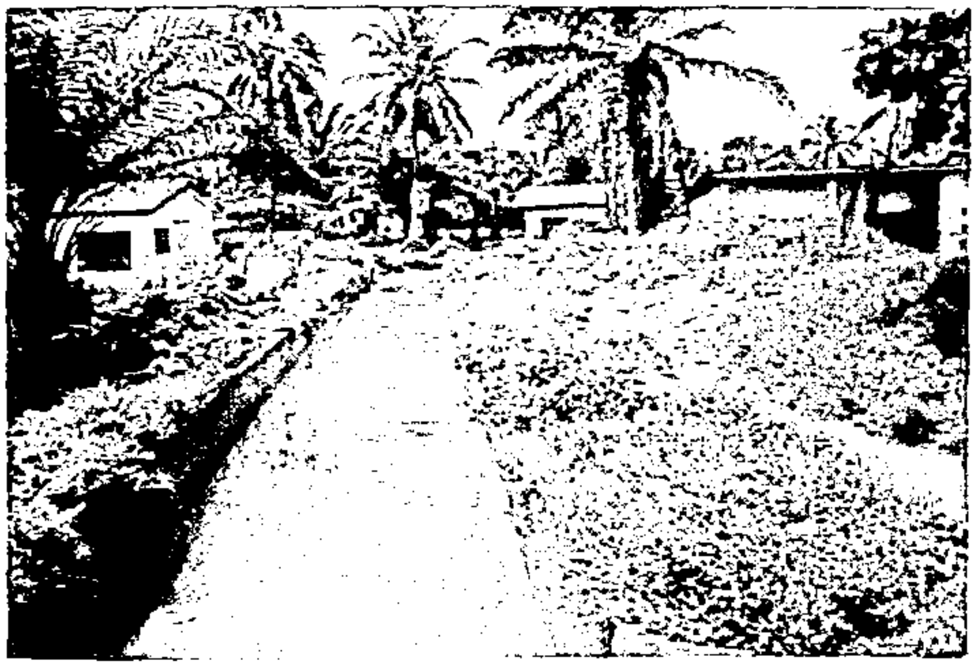


Plate 5: Houses close to a major drain, North Kaneshie

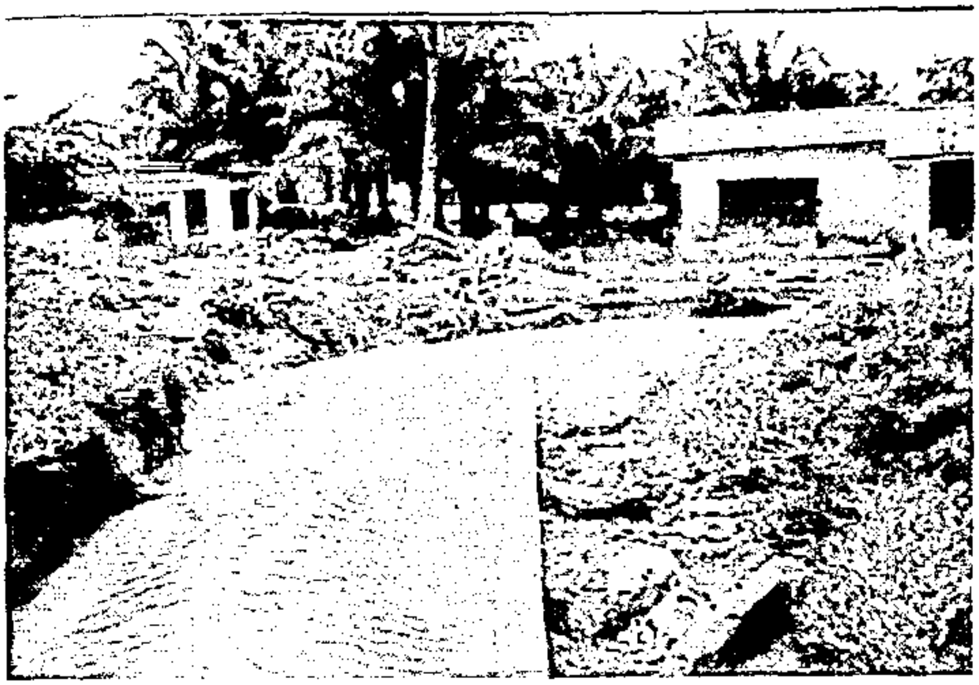


Plate 6: Diversion of a stream channel due to a building across the normal course of the stream, North Kaneshie

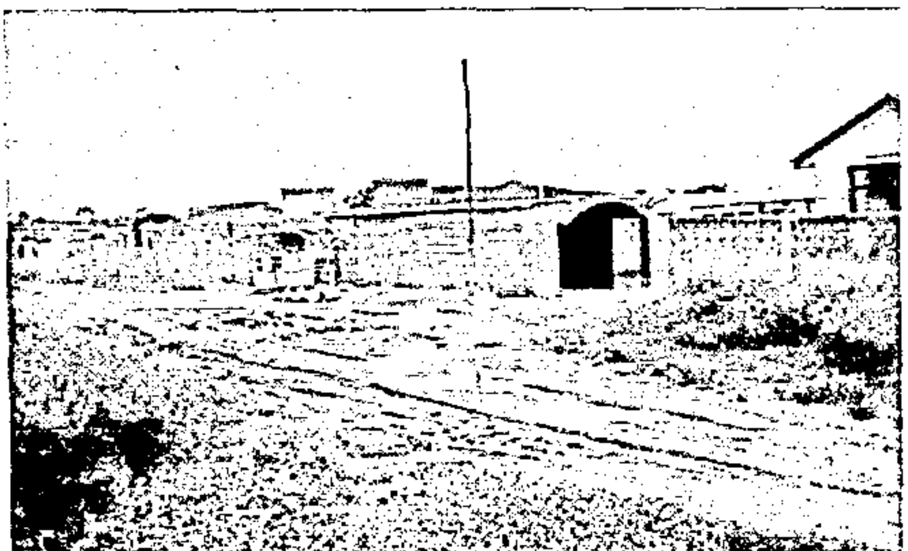


Plate 7: Newly developed area without a drain, North Legon

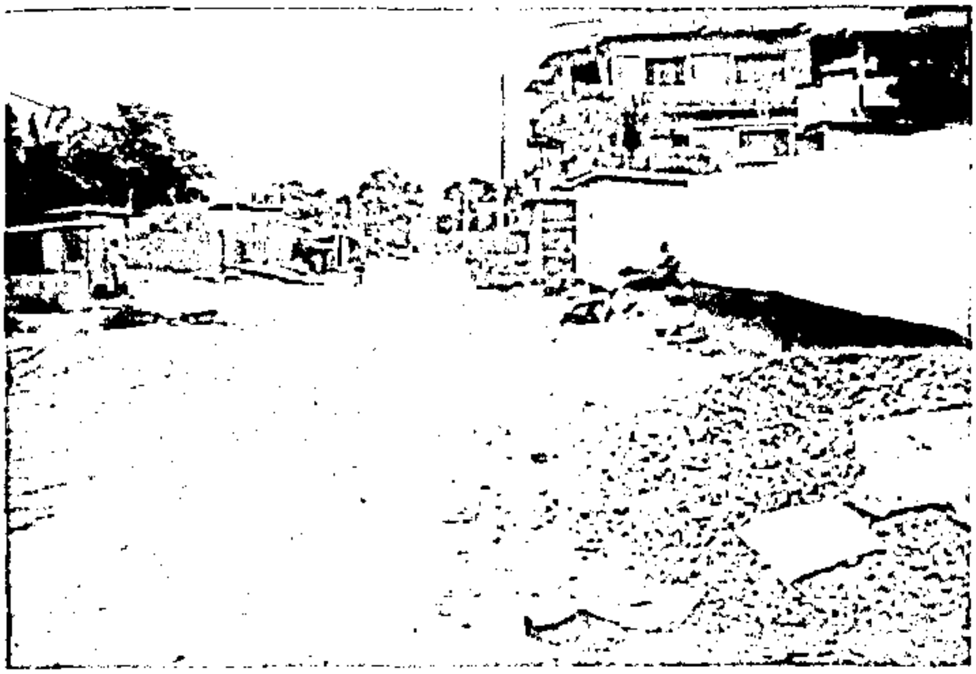


Plate 8: A developed area without drains, Swanlake

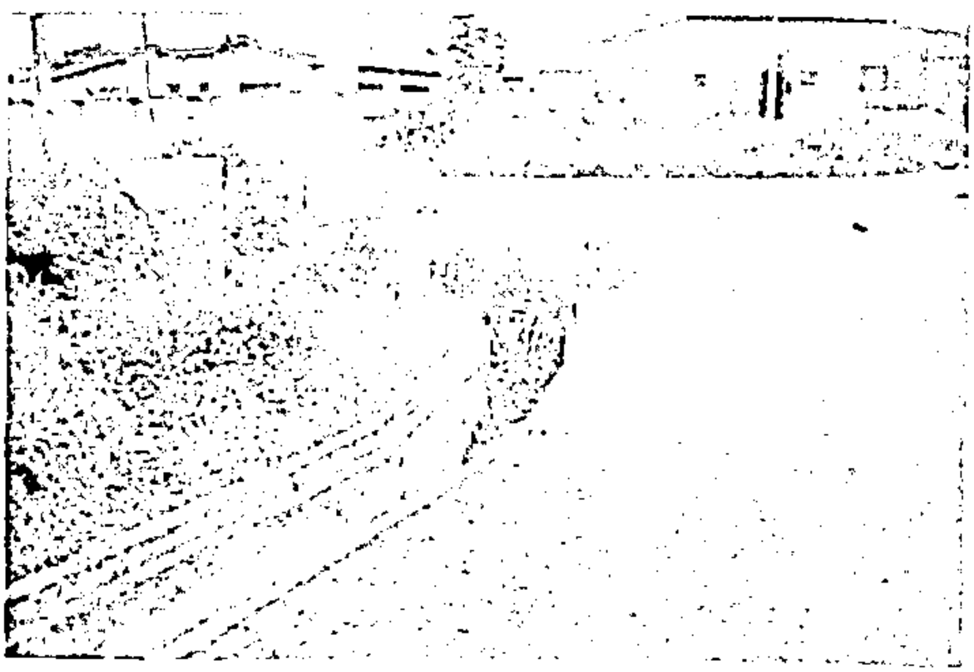


Plate 9: Unconnected drain in a newly developed area, North Legon

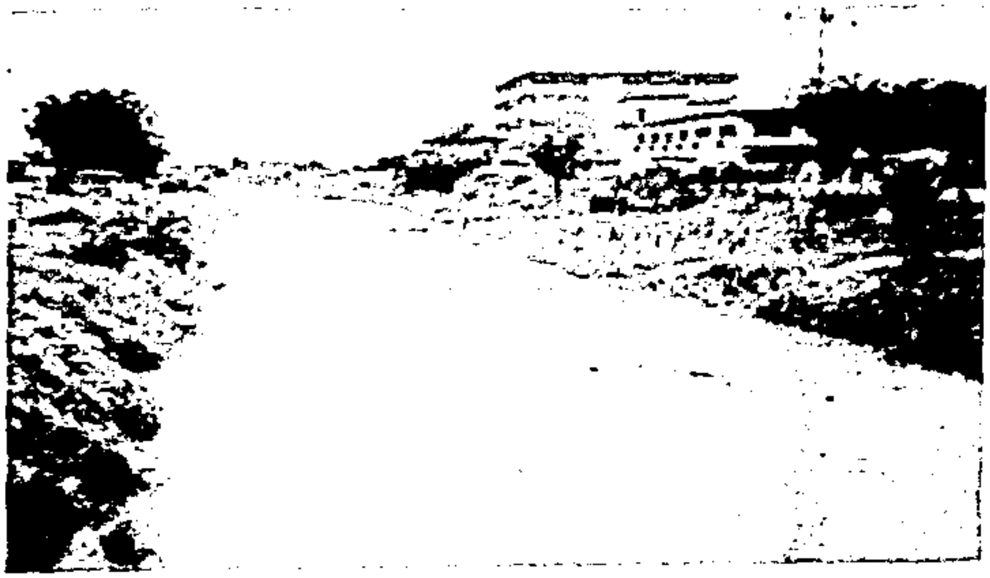


Plate 10: Unpaved part of the main Odaw River, Neoplan Station, Kwame Nkrumah Circle

Plate 11: Water mark (arrow) and pool of water in a walled House after a flood event, North Kaneshie

4.5.4 Stream Order

Streams or drains within the catchments help to convey storm water from the remotest parts of a catchment to major stream to avoid overland flow. The rate at which these streams spread and join the next bigger stream channel is therefore very important in flood controls. For that reason, the number of streams that flow into a channel determines the amount of runoff it can convey into the next bigger or wider channel. From the topographical sheets various orders of streams are found in the catchments, these orders vary in their length and ratio at which they join the next stream.

Table 4.13a Bifurcation Ratio for the Odaw Catchment.

Stream Order	Number Of stream Channels	Length (m)	Bifurcation Ratio		
1	58	136500			
2	15	52500	3.86		
3	3	42500		5	
4	1	17500			3

Source: 1975 Topographical sheets (0501B2, 0501B3 & 0501B4) of Surveys Department, Ghana on a Scale of 1:50,000

Table 4.13b Bifurcation Ratio for the Sakumo Catchment

Stream Order	Number	Length (m)	Bifurcation Ratio			
1	112	178000				
2	24	59500	4.7			
3	6	42500		4		
4	2	36000			3	
5	1	7500				1

Source: 1975 Topographical sheets (0501B2, 0501B3 & 0501B4) of Surveys Department, Ghana on a Scale of 1:50,000

Table 4.13c Bifurcation Ratio for the Kpeshie Catchment

Stream Order	Number	Length (m)	Bifurcation Ratio		
1	29	60000			
2	3	19500	9.7		
3	1	110000		3	

Source: 1975 Topographical sheets (0501B2, 0501B3 & 0501B4) of Surveys Department, Ghana on a Scale of 1:50,000

Table 4.13d Bifurcation Ratio for the Songo Catchment

Stream Order	Number	Length (m)	Bifurcation Ratio	
1	3	7000 ·		
2	1	10000	3	

Source: 1975 Topographical sheets (0501B2, 501B3 & 0501B4) of Surveys Department, Ghana on a Scale of 1:50,000

Table 4.13e Bifurcation Ratio for the Mokwe Catchment

Stream Order	Number	Length (m)	Bifurcation Ratio
1	4	10500	
2	1	7500	3

Source: 1975 Topographical sheets (0501B2, 0501B3 & 0501B4) of Surveys Department, Ghana on a Scale of 1:50,000

Table 4.13f Bifurcation Ratio for the Densu Catchment

Stream Order	Number	Length (m)	Bifurcation Ratio			
1	29	5500	4.14			
2	7	2450		3.5		
3	2	1400			2	
4	1	1050				

Source: 1975 Topographical sheets (0501B2, 0501B3 & 0501B4) of Surveys Department, Ghana on a Scale of 1:50,000

From Table 4.13a, shows that the stream ratio of joining each other in the Odaw catchment is highest between stream orders 2 and order 3.

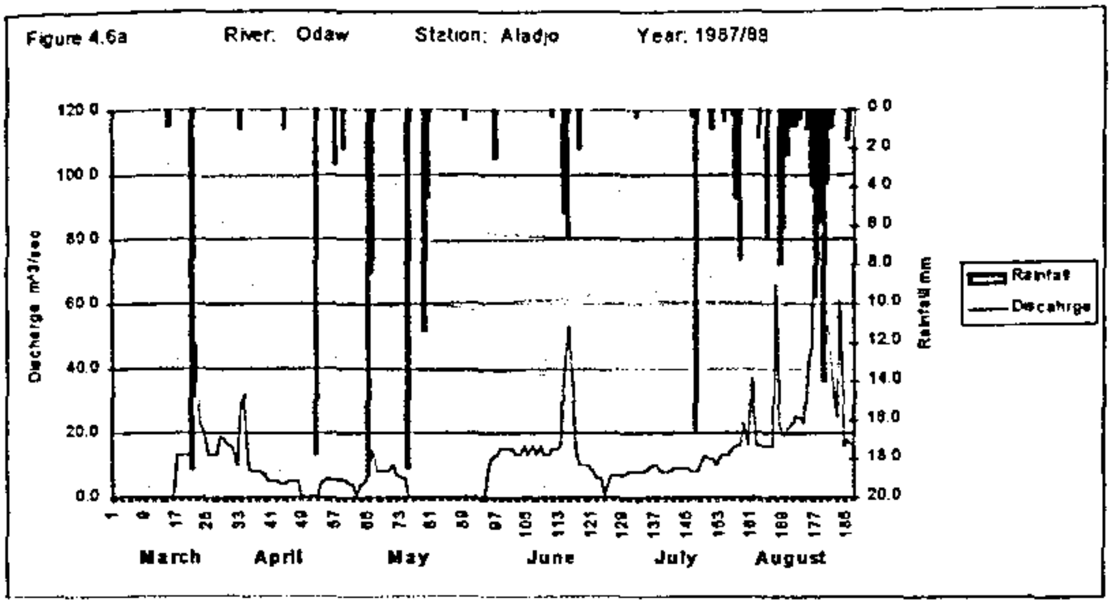
Comparatively the ratio between order 1 and order 2 is higher than that of order 3 and order 4. To some extent streams' bifurcation ratio decreases as you move to a higher order (Table 4.13f). The bifurcation ratio in the study area gives an indication as to the rate of increase in stream size from one order to the next. A bifurcation ratio of 3 as representing the Mokwe catchment shows that the stream order 2 is 3 folds of the order 1 streams. The increase in the higher order stream should be able to contain the stream discharge of that of the lower order.

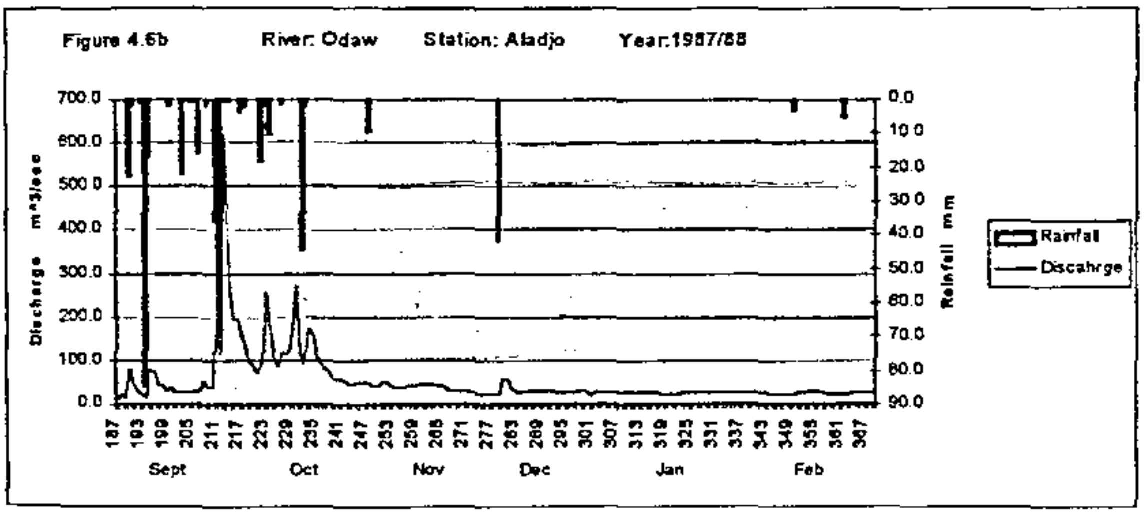
4.6 Drainage Discharge

The total amount of water flowing in a river channel at any time is important in flood control, reservoir design, management of wetland and waste water treatment (Viessman and Lewis, 1996). Though discharge data for most of the rivers are not available except for Odaw River, it was observed that most of the stream flow is generated by precipitation and groundwater entering the surface channels.

An examination of discharge data of the Odaw River showed that the peak discharge varies between May and August when the rainfall is at its maximum (Figure 4.5a-h).

Figure 4.5 Daily Discharge of the Odaw River





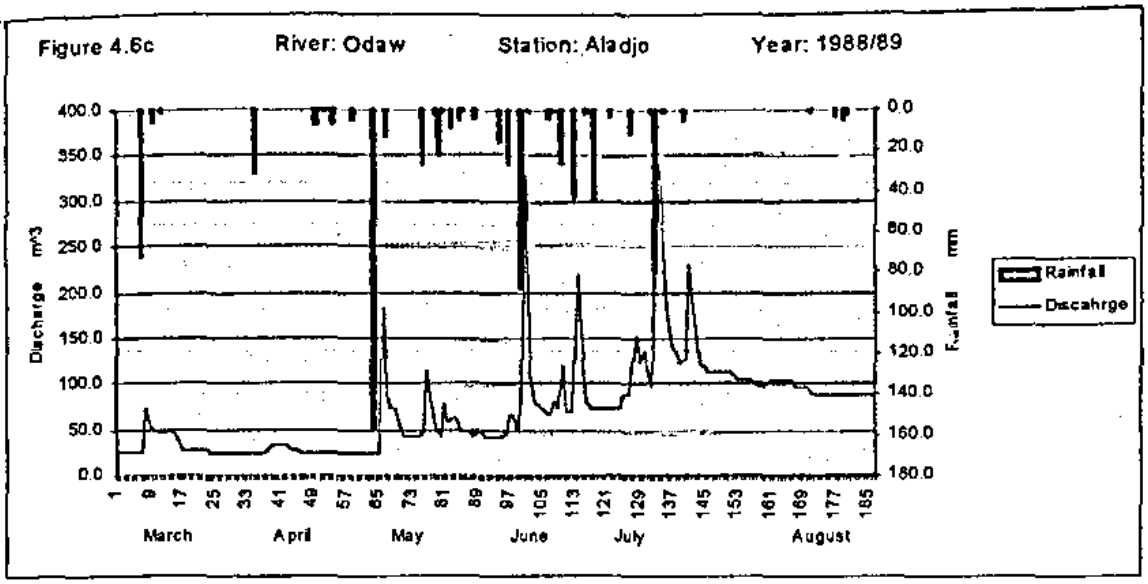


Figure 4.6c
River: Odaw
Station: Aladjo
Year: 1988/89
Discharge m^3
Rainfall mm
Rainfall
Dscahrge
March
April
May
June
July
August

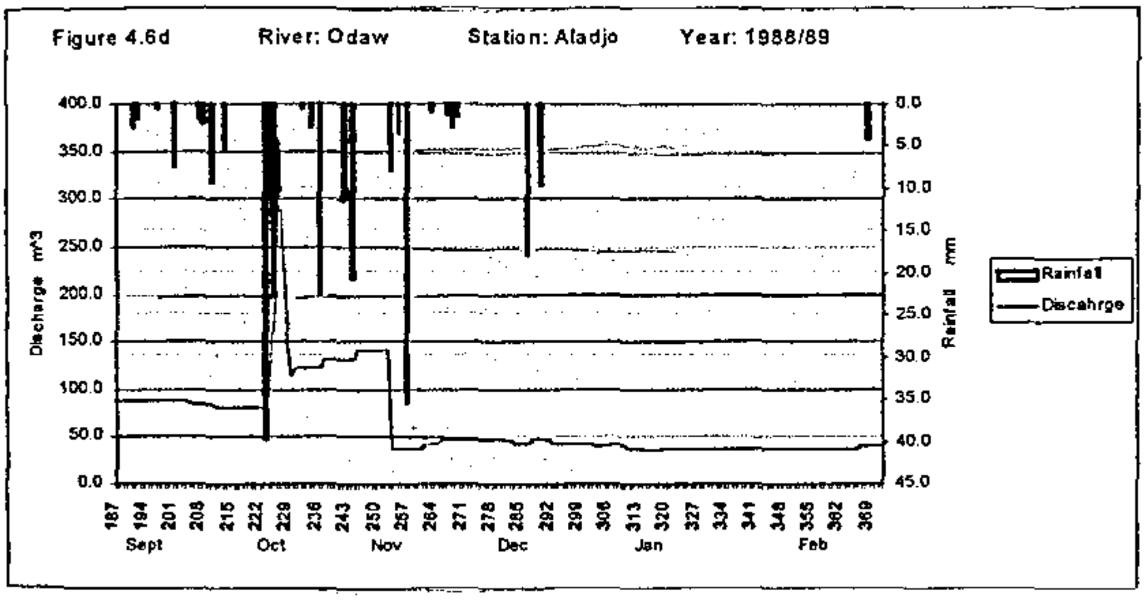


Figure 4.6d
River: Odaw
Station: Aladjo
Year: 1988/89
Discharge m^3
Rainfall mm
Rainfall
Dscahrge
Sept
Oct
Nov
Dec
Jan
Feb

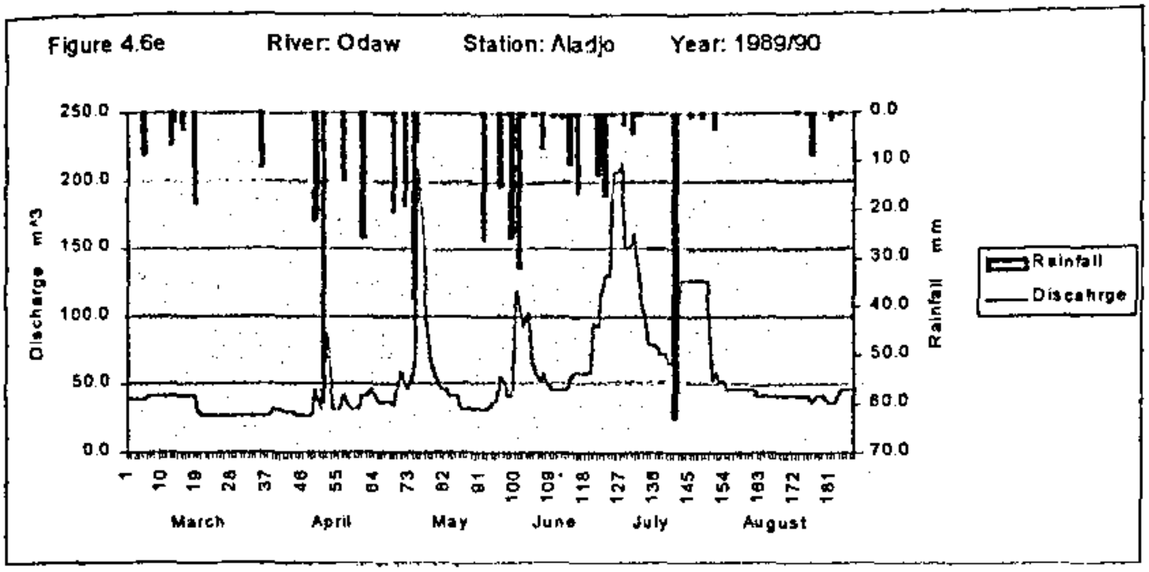


Figure 4.6e
River: Odaw
Station: Aladjo
Year: 1989/90
Discharge m^3
Rainfall mm
Rainfall
Discahrge
March
April
May
June
July
August

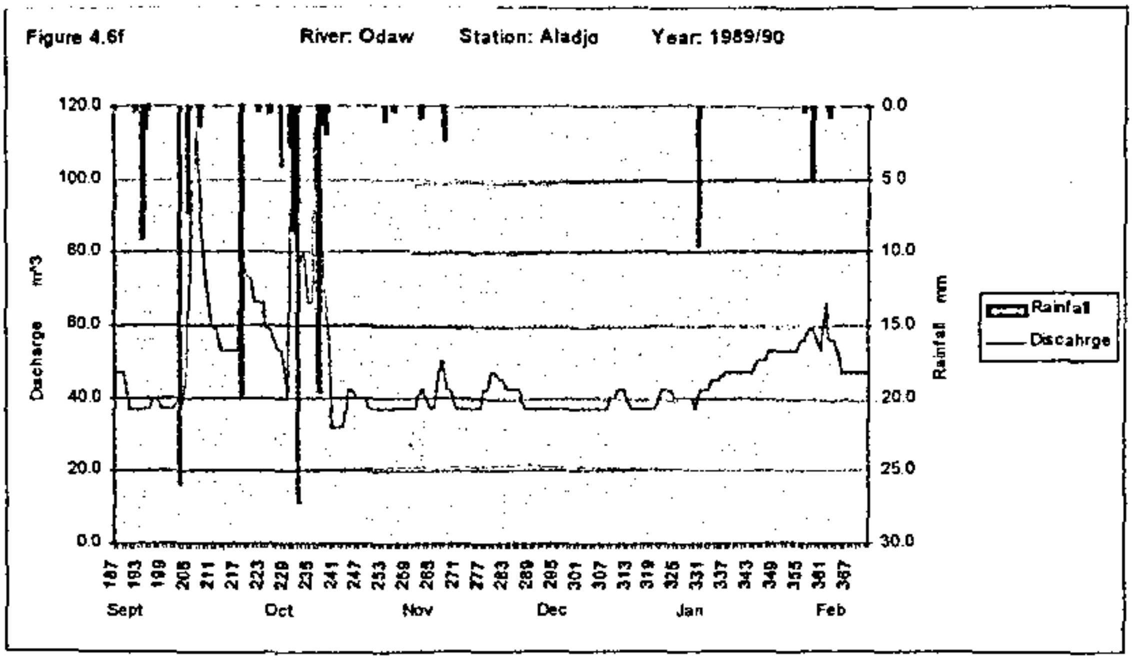


Figure 4.6f
River: Odaw
Station: Aladjo
Year: 1989/90
Dscharge m^3
Rainfall mm
Rainfall
Discahrge
Sept
Oct
Nov
Dec
Jan
Feb

Figure 4.6g River: Odaw Station: Aladjo Year: 1990/91

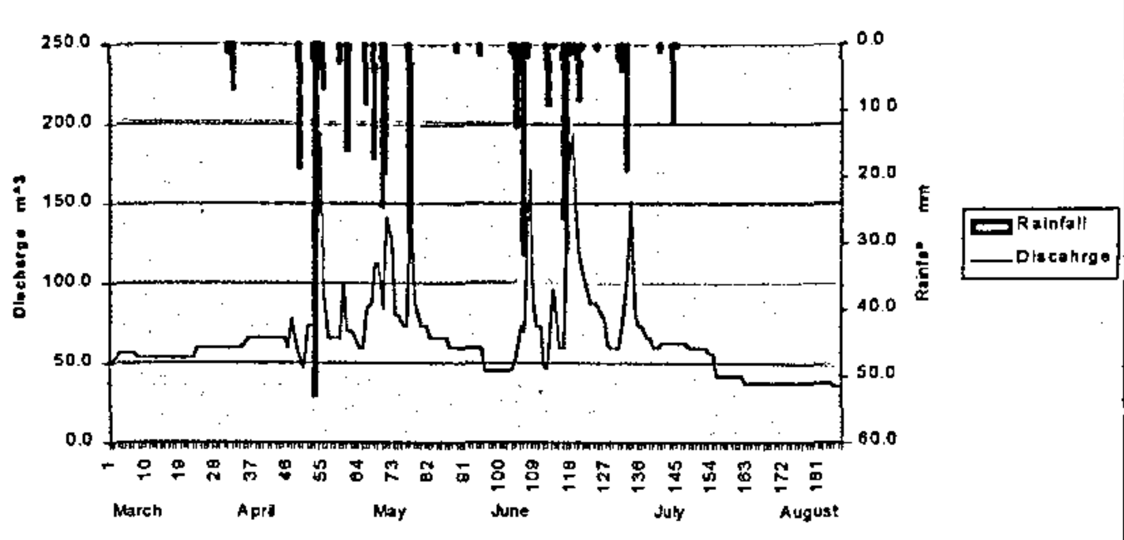
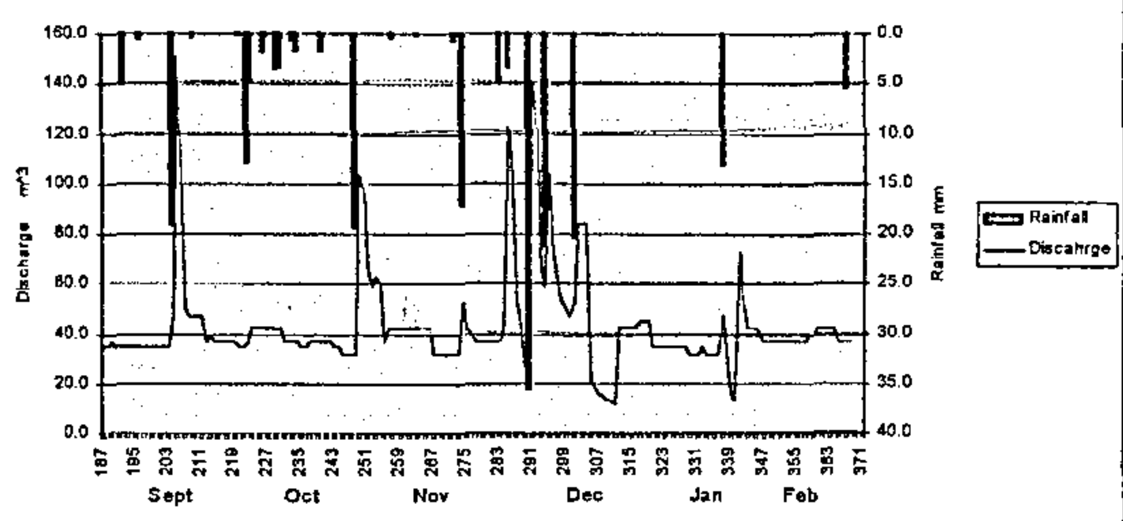


Figure 4.6h River: Odaw Station: Aladjo Year: 1990/91



However during the dry month (November to February), the Odaw River shows a continuous flow that gives an indication that the flow of the river is also supported not only by groundwater, but also by some domestic sewage water.

It is worth noting that the time taken for the channels to discharge water through them from the remote part of the catchments shows variations, which mostly depend on the slope and length of the channel. Table 4.10 shows that the time for which a drop of rainfall will travel from the remotest part of the Kpeshie catchment through the longest channel to points of outlet will take about 335.35 minutes. On the other hand, it will take about 143.71 minutes and 161.66 minutes for the Odaw and Sakumo stream, respectively, to reach various points of outlets. This shows that variations of time of concentration may exist at different points along a drainage channel.

4.7 Topography

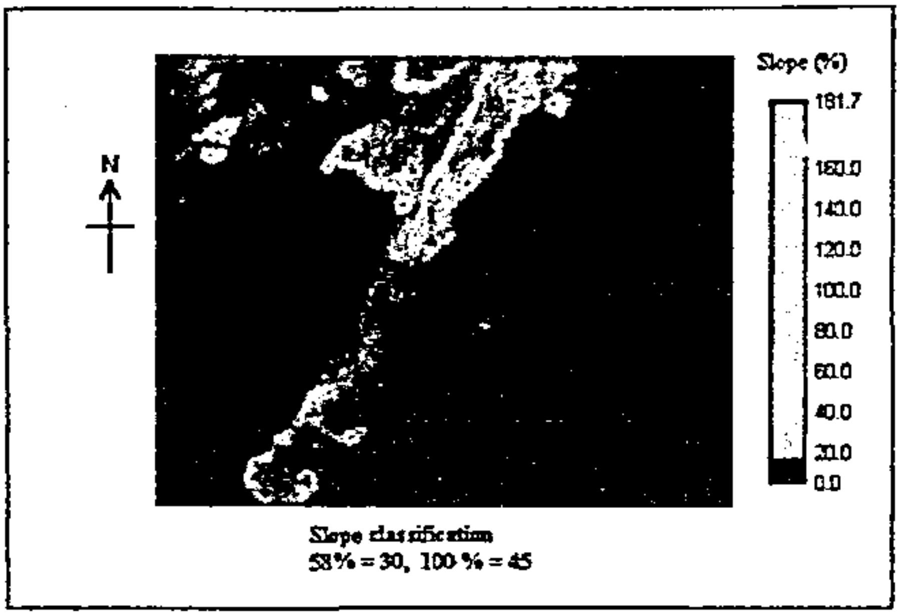
The topography of the entire area varies in slope and elevation. The creation of a digital elevation model (DEM) from a digital contour (0501B2,B3, and B4) map in the ILWIS 2.1 platform gave a clear indication regarding the heights at various places. Figure 4.6 shows that the highest elevation of 487.68 meters is found in the Akwapim-Togo areas, while areas such as Tunga, Labadi and Teshie are only 15.24 meters above sea level. However, greater parts of the catchment such as the Mokwe, Songo, parts of Sakumo and Odaw have elevation below 106.68 meters.

Figure 4.6 Digital Elevation of The Study Area

4.7.1 Slope

It has been revealed from field observations and topographical sheet measurements, that there exists a great variability in slope within the study area. Generally, the slope for the entire area ranges from 0^0 and 56^0 (Figure 4.7). However for greater part of the study area the slope is below 25^0.

Figure 4.7 Slope of The Study Area in Percentage



Taking into consideration differences in topography, the catchments showed differences in gradient. Specifically in the Odaw an average gradient of 0.25m/m was recorded. For instance from the sea coast to Achimota a gardient of 0.028m/m was recorded, in the western part from the coast to Kwabenya based on a vertical distance, showed a gradient of 0.07m/m. From the Tetteh Quarshie circle to Legon a gradient of 0.108m/m was measured, at a given distance of 3250 meters while from Akweteman to Kwabenya, a distance of 6724 meters, a slope of 0.045m/m was recorded.

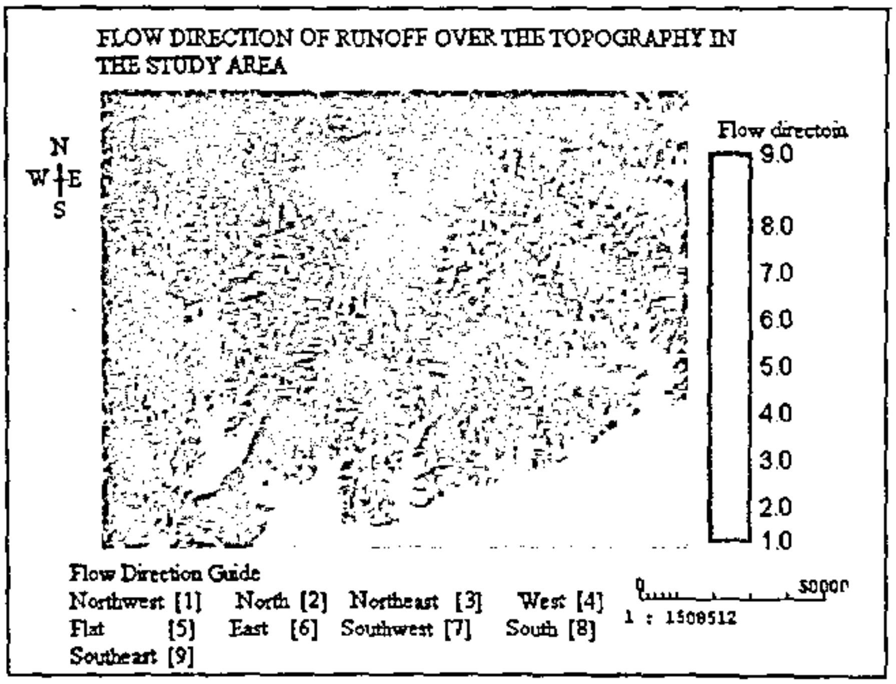
Dividing the Odaw catchment into upper and lower parts depicts variability in gradient. The lowest part, that is from the seacoast of the 15.24m to the 76.2m contour of a distance of 33500 meters, showed a gradient of 0.007m/m. in addition the upper part from the 76.2m to the 289.56m contours, a distance of 1400 meters had a slope of 0.679m/m.

4.7.2 Flow direction

Slopes of the study area give a clear indication of the direction in which a given input of rainfall on the topography will flow to an outlet, which in the study area differs from one unit to the other. Using the ILWIS 2.1 software, a direction of flow map was generated from the contour map of the area; which showed that rainfall on the topography would flow in all directions. Figure 4.8 shows that greater part of flow is towards the south and north directions. Hence, areas with no directional flow serve as receptacles to water flowing over the relief area; implying that these areas are virtually low-lying points within the system.

Within a given topography it is expected that the flow of excess rainfall over the topography follow the general slope of the area as shown in figure 4.7 where the slope is generally towards the southern direction. However, comparing the flow directional map (Figure 4.8) and the slope (Figure 4.7), the flow of excess water over the topography does not follow the general slope trend as presented in (Figure 4.7). This trend change presents a view that the flow direction as presented in Figure 4.8 might have resulted from human activities.

Figure 4.8 Flow Direction of Overland Flow



4.8 Soil

Soil distribution in the study area is remarkably influenced by a variety of factors including topography, climate and parent rock. These soils fall into eight major categories namely: Shallow rocky soils, Red earth, Pallid sands, Grey earth, Black earth, Alluvial Clay, Levee and Dune sands (Brammer, 1967). Within these major categories about twenty-four soil units were identified and mapped. (Figure 1.4)

These soils mapped were found to differ in drainage and water retention characteristics, as presented in Table 4.14. The list includes some of the major soils that can be found in the study area.

Table 4.14 Some Major soil units and their Drainage Characteristics

SOIL TYPE	DRAINAGE	WATER RETENTION
NYIGBENYA-HACHO COMPLEX	Well drained	More satisfactory
FETE CONSOCIATION	Well drained	Very satisfactory
OYARIFA-MAMFE COMPLEX	Ill drained	Satisfactory
KORLE CONSOCIATION	Excessive	Becomes droughty quickly
SONGAW CONSOCIATION	Well drained	High
ALAJO CONSOCIATION	Poorly drained	Satisfactory
DANFA-DOME COMPLEX	Poorly drained	Poor

Source: Brammer (1967)

Notably the infiltration rate of the soils shows great variations. From Table 4.15, the Nyigbenya soil has an estimated value of sorptivity of 0.916 x 10 ^{3}m/sec. This varies at the wetting front, which has been estimated to be 0.274 x 10^{-2} m/sec (Mickson, 1984). The estimated infiltration values for the Toje and Adenta (Table 4.15) are higher than those of Akuse and Nyigbenya

Table 4.15 Infiltration rate in some selected soils

Soil type	Estimate of sorptivity at wetting front (m/sec)	Estimate of sorptivity (m/sec)
Akuse	0.158 x 10^{2}	0.600 x 10^{2}
Toje	0.350 x 10^{2}	1.188 x 10^{2}
Adenta	0.306 x 10^{2}	1.005 x 10^{2}
Nyigbenya	0.274 x 10^{2}	0.916 x 10^{2}

Source: Mickson (1984)

Since the hydrologic properties of the soil are different, samples analyzed (Table 4.16) can be classified into hydrologic soil groups based on the SCS hydrologic soil groupings. Table 4.16 shows most of the soils belong to groups A, B and C. Areas with these types of soil group will produce moderate overland flow in their natural conditions. Nearly all of the soils in Accra have been tampered with due to man's constructional activities. Indeed samples of soils collected in parts of the study area showed traces of transported materials from the hinterland or the seashore, thereby causing changes in their textural characteristics.

Table 4.16 Soil texture at some selected locations

Location at which Sample was Taken	CLAY %	SILT %	SAND %	Gravel %	Hydrologic Soil Group
Akuse	31	9.97	59.03	---	A
Avenu	23	55	13	10	B
Mallam	47	36	5	15	B
Legon	46	36	5	13	C
Teshie	47	48	12	—	C
Airport	12	15	10	63	A
Frafraha	2	20	6	72	A
Sakumonu	50	35	15	---	C
Batsonaa	50	47	3	—	C

Source: fieldwork (1999)

Soils in places like Batsonna, Sakumonu, Legon and Mallam have a higher percentage of clay and therefore have a high potential for creating runoff and for impounding water. On the other hand, areas like Airport and Frafraha have a high percentage of gravel, which should encourage high water infiltration.

Soils of the same unit tend to show variability in their textural composition in different localities. For example, soils in the upper part of Nyigbenya-Hacho complex have different textural composition from those in the lower part.

This difference in the soil properties of the Nyigbenya-Hacho unit is shown in Table 4.17 comparing samples taken near Airport and Mallam.

Table 4.17 Comparison between soils of the same unit at different locations

SOIL Sample Location	CLAY %	SILT %	SAND %	Gravel %
Airport	12	15	10	63
Mallam	47	28	10	15

Source: Fieldwork (1999)

4.9 Paleogeomorphological Evidences

Accra and its environs are underlain by six major geological formations namely, the Dahomeyan, Accraian, Togo Series, Birrimian and Recent deposits (Figure 1.3).

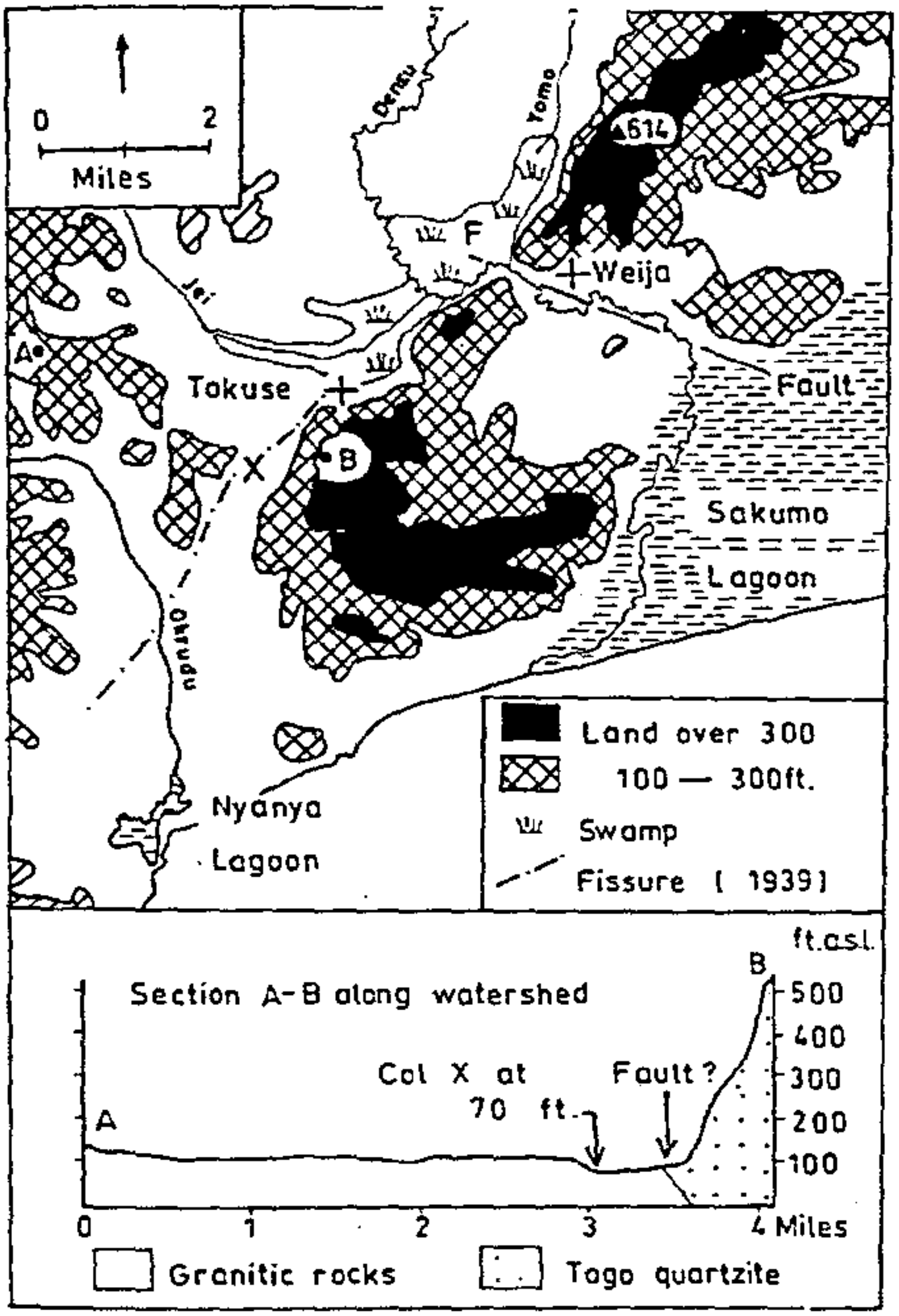
Evidence from the field and from the geological map of the area shows that the Togo Series initially covered Accra. This is because outliers of the Togo series can be found in and around places such as the Airport area, Cantonments, Achimota forest and Dahwenya near Prampram. The work of erosional agents throughout geological time has left out gaps between all the outliers and the main Togo Series range. An example is the gap between the

Airport patch and the Cantonment patch. The rapid erosion of the Togo series has led to the exposure of the Dahomeyan at certain places like Kwashieman, Sakaman, Odokor, parts of Achimota and Labadi.

Davis (1964) observed that there has been an uplift of the coastal zones within the study area since the Pliopleistocene. Beaches having heights between 13 and 17 meters above sea level can be found at places like the mouth of the Densu River, Korle Bu, Mamprobi, Accra Bishops School and the Marine Drive. The date of occurrence of the uplift was deduced from the deposit of sand and pebbles, which dates to the Pliopleistocene period. These sand and pebbles extend as far as west of Nungua and Asokrochona. Indeed a boring on the coastal plain of the Densu revealed a rock at a depth of 22 meters below the surface

In addition, Hayward (1967) observed in his study that the Densu River used to drain into the Nyana Lagoon (Figure 4.9). However, due to the process of capture, the course of the river has been diverted through the Weija gap, not later than the early Pleistocene.

Figure 4.9 Flow of the Densu River through the Weija Gap



Source: Hayward (1967)

4.10 Summary

Accra has been experiencing periodic flooding that affects properties and lives. The variables identified to cause flooding within Accra included rainfall, landuse, topography, drainage and soil texture.

Rainfall has been noted as a major factor in determining flood. This is evident in times when we have high rainfall intensity. Accra experience high rate of flooding especially within the month of June.

Landuse pattern as identified falls into 5 category, namely forest reserve, water body, floodplain settled and partly used area. Out of this settled area constitutes 27.24 percent of landuse pattern, while partly used area is about 67.91 percent.

The slope of the area, show a lot of variability with a given elevation, for instance at an elevation of 1550 meter on the Togo-Akwapim ranges high runoff rate is produced, while areas with low elevation create sluggish overland flow thereby creating backwater effect that has the potential to cause flooding.

Soils within the study area show great variability in their textural composition and hydrologic properties.

Drainage within the area is of two different types, artificial and natural. The natural channels are mostly found at the remotest parts of the area and artificial ones are mostly in the settled areas, either paved or unpaved.

However, with regards to the paleogeomorphology, evidences exit to show that a lot of erosional activities occurred in the past since the pliopleistocene period leaving gaps between outliers and the main Togo series at places like Airport, Cantonment and Achimota forest. Also, evidences were established that the Densu river was diverted to pass through the weija gap and coastal uplift exists at places like Korle Bu, Mamprobi and Marine Drive.

CHAPTER FIVE

DETERMINATION OF FLOOD RISK ZONES

5.0 Introduction

In traditional hydrologic methods, estimating surface runoff does not always use elevation/height (DEM), because derivation of elevation/height (DEM) information involves laborious operation (Bonell & Balek; 1993). Despite that, the combination of DEM and discharge maps should lead to derivation and the understanding of spatial association between the two; which could be used to predict runoff rates and flood risk zones.

This chapter presents the procedure through which the flood risk zone map of Accra was generated by first discussing the concept of risk. The process involved, the use of the total discharge map for 25 years rainfall recurrence interval, digital elevation model (DEM) and an arithmetic operation for map combination within the geographic information systems platform.

5.1 Concept of risk

Risk is a factor, element, or course involving danger or can be seen as the possibility of suffering harm or loss (Encarta 99).

The concept of risk has become an issue that is being discussed in various fields, in which varied definitions have been given; has developed without any discipline claiming authority (Stig, 1996). Studies of risk cover issues like identification and estimation of risk, risk assessment and evaluation, including monitoring and management of risk (Gerrard, 1995). However, different approaches have been developed and streamlined to help in the understanding of the risk concept. Some disciplines notably epidemiology, economics, management, engineering and psychology have established their worldview of the concept.

Renn (1992) classified the concept of risk into seven units namely:

- The actuarial
- The epidemiological (toxicology)
- The engineering (including probabilistic risk assessment)
- The economic (including risk-benefit comparisons)
- The psychological (including psychometric analysis)
- Social theories of risk (sociological and anthropological studies)
- Cultural theories of risk (using grid groups analysis)

Renn's categorization of risk as stated above is always based on some underlying assumptions and methodologies as well as their functions. This categorization provides a framework for comparing and analyzing different risk concepts that will help define common elements and distinctions between different risks concepts used by various disciplines.

According to Stig (1996), three main approaches to risk usage can be identified in the following areas in geography, namely;

- Medical geography (corresponding to epidemiology)
- Applied geography and planning (bearing connections to probabilistic risk analysis)
- The hazard-tradition (with connection to physical geography as well as social theory and cultural theories)

In medical geography, risk factors have been expressed in disease contraction associated with production and consumption. Most medical geographers attempt to map risk of contracting disease at various scales. This is to show its distribution and pattern of the risk factor based on analytical presentation.

In applied geography and planning the risk factor is implicit and embraces various specialties such as planning and modeling of land use and geographical pattern of networks. In reducing risk through planning, usually one has to use a lot of assumptions and models.

The hazard geography tradition emphasizes on the interaction between technology, society and environment, pointing out that risk is a probability of the occurrence of a hazard. However not much distinction has been made between hazard and risk in most geographical disciplines. Hazards are perceived as natural or geographic events that threaten the economy and health of individuals. Hazard is either man made or influenced by the activity of man. In most instances, most of the physical hazards are focused on flooding, earthquakes, volcanic eruptions, droughts and hurricanes.

In this study the risk concept is used to imply the probability of human life and properties within the study area to be affected by high rainfall that generates into flood.

5.2 Flood risk zones determination

In determining flood risk zones the modified rational method used for the calculation of runoff discharge was integrated into the geographic information system platform using an overlay operation method.

5.2.1 Runoff discharge of the study area

The modified rational model (equation 1, Pg. 57) presented a general step to help calculate individual discharge for each section in the entire catchment areas (Figure 5.1).

The model (equation 1, Pg. 57) used presented varied calculated runoff discharge rate (Table 5.1) for the different segments within the catchment areas.

Table: 5.1 Total discharge of section of the Study area

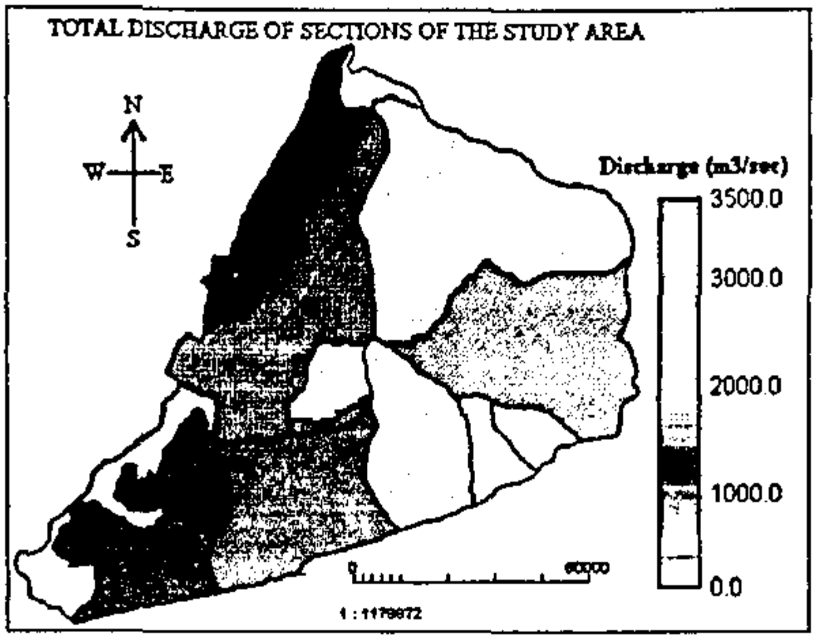
Catchment Name	Area (Km2)	Runoff coefficient	Storage coefficient	Rainfall (mm)	Discharge M^3/sec
Kpeshie Catchment	62.6	0.7	0.2	140.2	344
Lower Densu	79.4	0.4	0.6	140.2	748.1
Lower Odaw	90.1	0.9	0.2	140.2	636.7
Lower Sakumo	116	0.7	0.4	140.2	1271
Middle High Odaw	18.7	0.7	0.2	140.2	102.8
Middle Odaw	118	0.7	0.2	140.2	650.7
Middle Sakumo	155	0.6	0.5	140.2	1825
Mokwe catchment	13.9	0.7	0.3	140.2	114.6
Songo catchment	16.8	0.8	0.2	140.2	105.5
Upper Densu	24.9	0.6	0.7	140.2	410.5
Upper Odaw	64.5	0.6	0.7	140.2	1063
Upper Sakumo	9.4	0.6	0.7	140.2	155
West Densu	17.3	0.6	0.7	140.2	285.2

Source: Authors Context, 1999

From Table 5.1 the total runoff discharge over the land surface of the study area determines the maximum flood that an area under consideration is likely to experience. Various segments covering the topography (Figure 5.1) produced varied runoff rates, for instance, the Odaw and the Sakumo being the biggest catchments produce a total discharge rates of 1825 m^3/sec and 1271 m^3/sec respectively, that is if all the entire catchment contributes to runoff at the same time. However, segments within the catchments also produce varied runoff rates. For instance, the Sakumo catchment presents three different runoff discharge rates of 155 m^3/sec, 1825 m^3/sec and 1271 m^3/sec for the Upper, Middle and the Lower catchment areas, respectively.

As noted in the use of the modified rational model (Table 5.1) the rate of discharge is mostly dependent on rainfall intensity and area. For instance the lower and middle Sakumo with area measurements of 116 km^2 and 155 km^2 presented calculated runoff discharge rates of 1271 m^3/sec and 1825 m^3/sec, respectively. The Kpeshie and Songo catchments, having smaller area measurements of 62.6 km^2, and 16.8 km^2 produce a discharge of 344 m^3 and 105.5 m^3, respectively. However, with the given segment area that is constant over the topography within the catchments, an increase in rainfall will also lead to an increase in the total runoff discharge rate.

Figure 5.1 Total discharges of sections within the study Area.



5.2.2 The modified relational Model in risk zone Determination

The modified relational flow models are in four main stages, stages one and two have been carried out and the results presented in Chapters Four of this thesis. Stages three and four are being followed to generate the flood risk map.. are:

- The application of the rule using arithmetic overlay operation, addition and division to help integrate the hydrological model into the geographic information system model.
- The generation of flood risk zone maps for Accra and its environs.

5.3 Mode of model integration

Among the various methods of determining runoff, it has been noted that the combination of a physical, deterministic or hybrid model with a digital elevation model within the geographic information system model offers an alternative to these models giving point results instead of a spatial view of a phenomenon as its end result. Therefore, to achieve this an attempt was made to use an arithmetic overlay method to combine DEM and discharge map within the geography information system model to determine flood risk areas. Operators such as addition and division were used in the combination procedure. The essence of using the arithmetic overlay method is that possibilities exist for the derivation and examination of spatial patterns caused by interactions of one map with the other. Secondly, the rule also provided the possibility of restricting areas on the output map according to a binary map that acts as a mask.

The arithmetic overlay method involves two main stages:

1. The first stage involves the determination of runoff within various segments over the landscape.
2. The second stage is estimation of values that can be used to infer potential areas that are likely to be in flood with any storm event.

Formula:

The formulas for the arithmetic overlay operation are stated in equations 6 and 7 below:

$$X + Y = Z_{ct} \qquad equation----6$$

$$\frac{X+Y}{X} = Z_{FRA} \qquad equation----7$$

Where:

X (m) is the Digital Elevation Model
Y (m^3/Sec) represents total discharge
Z_{ct} (m^3/Sec/m) is the runoff concentration at various elevations
Z_{FRA} is the value for flood risk areas.

Both equations 6 and 7 were used separately to calculate the discharge that each pixel within the segment generated at a given elevation. Another result is a weighted pixel indicating areas that fall within the zone that experience flood or not.

5.3.1 Assumptions for using the overlay operation

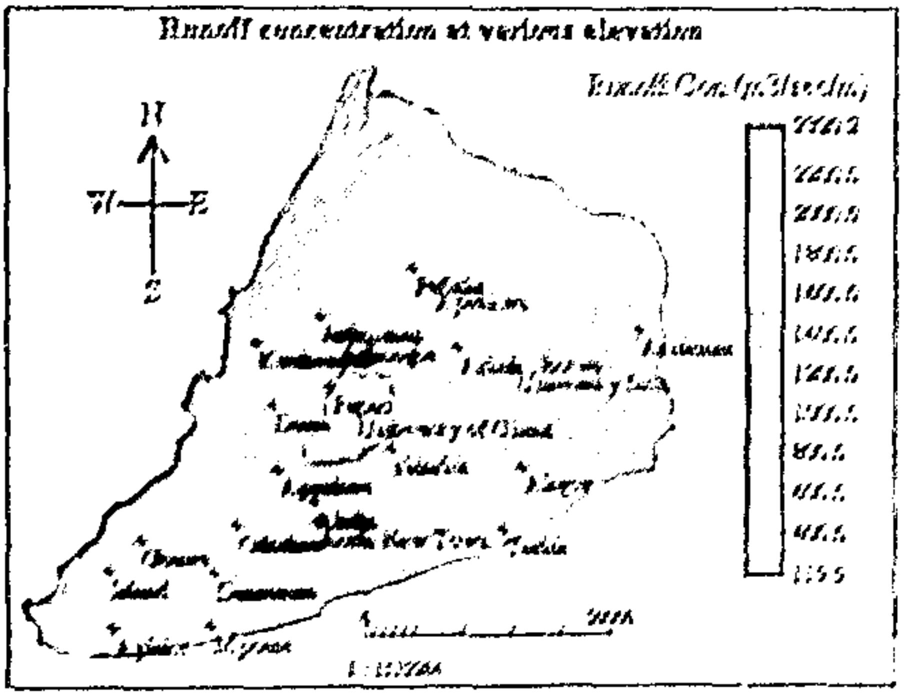
The application of the arithmetic overlay method for the study was based on the following assumptions:

1. A steady state condition exists within the variables to be used.
2. The discharge parameter [X] only varies if total rainfall changes.

5.4 Runoff Concentration on Elevation

In section 5.2, the modified rational method gave a general view of the rate at which sections within each catchment area produced runoff with a given rainfall event. In order to show variability of runoff within a given topography, equation (6) was used for the map integration.

Figure 5.2 Runoff Concentration on elevation



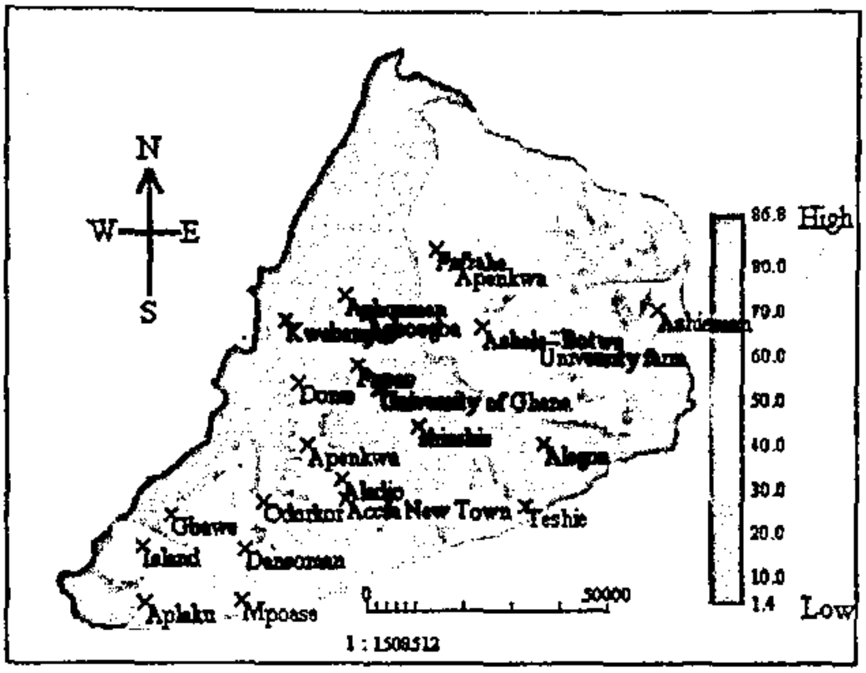
The resultant map (Figure 5.2) showed discharge rate over the topography at varied elevations within Accra and its environs. With a given discharge rate, the catchment runoff concentration value would only vary with elevation. For instance, a discharge value of 155 m^3/sec for Upper Sakumo, when combined with an elevation of 1550 meters resulted in a calculated discharge of 1705 m^3/sec/m. Also an elevation of 250 meters will experience a discharge of 405 m^3/Sec/m. Hence, any point within the 155 m^3/sec discharge zone will experience the same runoff rate if only they are of the same elevation. Therefore, the discharge concentration values determined from the arithmetic map overlay decreases as elevation decreases, indicating a slow runoff rate that has the potential of creating a backwater effect and generating flooding.

However, it is noted that no matter the elevation if the area contributing to discharge is large as in the case of the Middle Sakumo, a high runoff concentration is produced as compared with the Upper Sakumo. In other words elevation is not the only determinant of high runoff concentration, but a critical attention should also be paid to the catchment area.

5.5 Flood Risk Areas

The runoff concentration map (Figure 5.2) does not show the areas that are liable to flooding, though high elevated areas showed a comparatively high discharge rates than the low lands.

Figure 5.3 Flood risk areas



Using equation (7) for the map combination, it came out that areas within the study area presented different pixel value ranging from low to high. Upon close examination of the map, high-elevated areas of 350 m to 1550 m had low pixel value between 0-20 and the low elevated areas of below 350 m presented high pixel value between 20-87. Based on ground truth, areas with high elevation have low pixel values indicating that they fall within the low flood risk zones. However areas with low elevation indicated high pixel values, this falls within locations that experience periodic flooding at a given rainfall event. This confirmed that areas such as Aladjo, Ashiaman and

Sakumonu that fall within the high pixel values experience destructive floods with high rainfall intensities.

It is important to note that the arithmetic overlay method helped to identify areas even as small as the area within the Densu flood plain (labeled Island) was isolated and assigned the flood risk category that it falls in.

5.6 Flood risk zoning

Figure 5.3 show pixel values that can be used to represent the several flood risk areas. These pixel values can be grouped to show a general pattern in the degree of flood intensity of regions that exist within Accra and its environs.

Thus, with a clearly defined domain of: very high, high, moderate, very low and low risk zones, the technique of density slicing made it possible to reclassify the flood risk map. This helped to differentiate between areas that experience different intensity of flood (Figure 5.4).

Figure 5.4 Flood risk zones of the study area

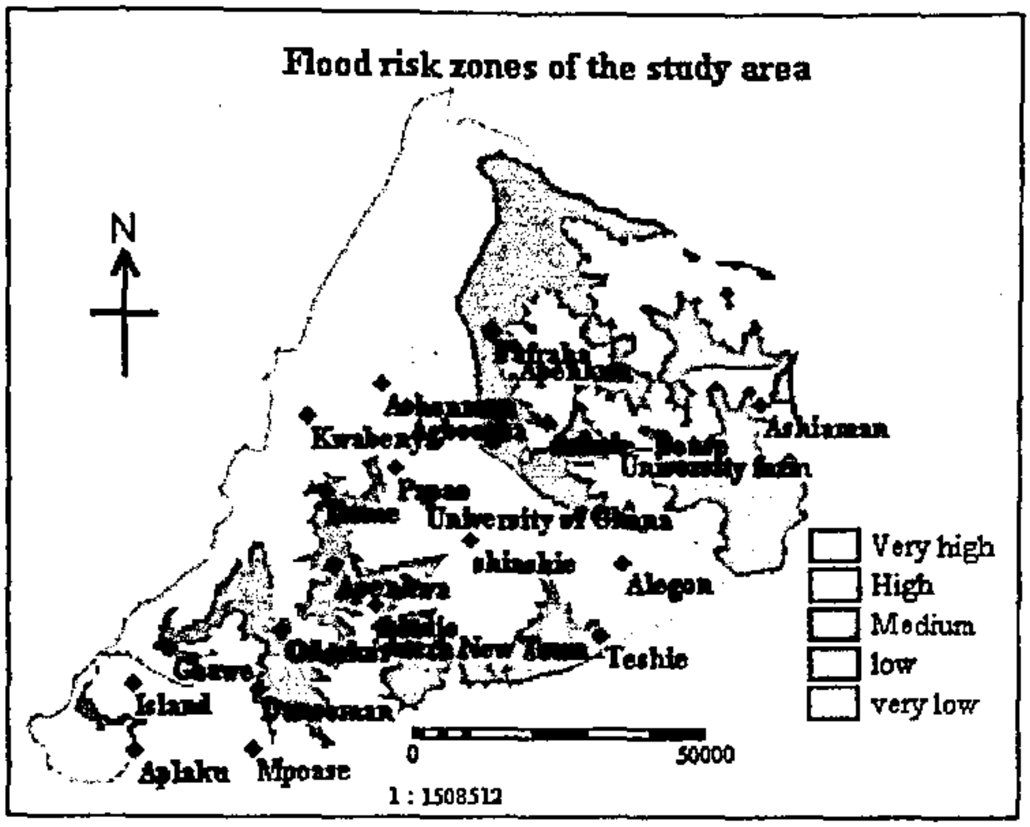


Table 5.2 Flood Risk Zone Coverage

Flood Intensities	Area (m^2)	%
Low	2269185000	26.85
Medium	2652485000	31.39
High	3012897500	35.66
Very high	515355000	6.10

Source: Figure 5.4

Table 5.2 shows areas that fall within the very high flood risk zone covering about 6.09 percent of the study area. However the combination of the Very high and high-risk zones constitutes a total of 41.76 percent of the entire study area. Hence, the area coverage of the flood risk zone will expand if the rainfall intensity increases above 140.2 mm/day.

5.7 Summary

To determine flood risk zones in Accra and it environs a hydrological model (modified rational model) was integrated into the GIS platform, by the arithmetic overlay operation method, using operators such as addition and division. The results show that the delineated areas however experience same rainfall intensity of 140.2 mm yet the flood intensities of these areas differ. For instance, the high flood risk zone covers 35.66 percent of the study area, whiles the low risk zone covers 26.85 percent.

CHAPTER SIX

SUMMARY, CONCLUSION, IMPLICATION FOR POLICY AND RECOMMENDATION

6.1 Introduction

The purpose of this thesis is to find out whether geographic information system and hydrological model could be used to determine flood risk zones in Accra. To achieve the objectives of the study, hydrological and meteorological data were collected. Methods used to collect these information included field observation, field measurement, laboratory analysis and remote sensing image interpretation. As a result, the thesis was written in accordance with the modified relational rule of Meijerink et al., (1994) and modified rational models stated in Veissman and Lewis (1996).

The output derived from the rational model was integrated into the geographic information system model using an arithmetic overlay operation. This helped to generate flood risk areas in Accra.

In this chapter a summary of findings of the thesis, problems encountered in the research, conclusion, highlights for future research and policy implications and pertinent recommendations are also made.

6.2 Summary

Accra has been experiencing periodic flooding that affects property and lives as happened on 4^{th} and 5^{th} June 1998. Aware of such dangers, the government commissioned institutions such as Ministry of Works and Housing, Town and Country Planning and City Engineers Department to find ways of reducing the effects of this unexpected natural disaster. These institutions, in order to prevent the occurrence of such extreme events have been identifying flood risk zones using conventional methods such as watermarks on buildings and reported cases in the news media. But these methods are inadequate and inefficient.

To minimize the effect of flooding these institutions have initiated projects on the expansion of drains to accelerate the conveyance of excess water from identified risk areas. The efforts so far have not been able to provide details of potential flood risk areas. Hence, only the already known areas have attracted attention. Therefore, it is very essential to search for alternative methods which will help to identify all potential flood risk zones, hence the combination of hydrological models with remote sensing and geographic information system models used in this study is a better alternative.

Important variables that determine floods within the Accra area were identified to be rainfall, landuse, topography, drainage, and soil texture; with rainfall and landuse, as the most crucial variables.

Rainfall has been found to be a major factor in determining flood. This is evident in the frequency the study area experiences high rainfall intensities. Analysis of rainfall records from 1961 to 1990 showed that Accra experiences high rainfall intensities from the month of May to July, during which the most destructive storms have been found to occur in June. The mean rainfall occurrence for May, June and July are 46 mm/day, 60.45 mm/day and 45.27 mm/day respectively. In spite of this, the rainfall is more evenly distributed in June than in any other months since it has a skew coefficient of 1.126. Also, with the recurrence interval of 25 years for the daily rainfall storm, June has a higher value of 140.2 mm/day than any other month. Therefore for structural design purposes it is most appropriate to use the recurrence interval for June.

Landuse pattern was also observed to be a factor and the most important being settlement constitutes 27.24 percent of landuse pattern that exacerbate flood generation process. This is because areas like Dansoman, New Town, Aladjo, East Legon, North Legon, North Kaneshie and Mallam which are heavily settled also have much paved sections which contribute to increased overland flow coupled with reduced infiltration rate. More so, the conversion of storage points especially the Densu, Odaw and Sakumo floodplains into settlements greatly exacerbate the flood risk situation.

Topographically the rate of runoff is high in areas that have high elevation and rather low in low-lying areas, which tend to create the backwater effect which forces the excess runoff to find alternative courses. It is evident from the flood risk map that low land areas have a high risk flood potential.

Soils within the study area show great variability in texture and therefore tend to vary in their hydrologic properties even in similar soils at different location. For example, the Mallam and Airport areas that belong to the Nyegbenya soil type present different textural compositions.

The natural drainage channels within the area are mostly found in the remotest parts of the area while the artificial ones are prevalent in the settled areas. However most of the drainage channels in places like Dansoman, New Town, Aladjo, North Legon, North Kaneshie and Mallam are choked with sediments and refuse, thus preventing the free flow of storm water. Also most of these areas including East Legon, Mallam, Odorkor, Kwashiman, Achimota, Dome and Labadi do not have well defined drainage channels.

Paleogeomorphological evidences exist to show that a lot of erosional activities has occurred in the past since the pliopleistocene period; leaving gaps between outliers and the main Togo series at places like Cantonment, Achimota forest, Airport and Dahwenya. There is evidences from the work of Hayward (1967) to suggest that the Densu River has been diverted from its normal course to flow through the Weija gap instead of draining into the Nyanya Lagoon.

6.3 Problems encountered in the research

There are series of problems the researcher encountered when conducting this research. These problems prevented him from using some of the parameters, stated in the methods for analysis. Some of the problems are enumerated below.

The first is lack of funds. The government and Universities do not advance funds for research at the masters/ doctorate level, hence the researcher had to fund this research from his limited resources. This prevented the researcher from hiring the expected research assistants during the fieldwork to collect data, and also acquire equipment (infiltrometer, satellite image, computers, and software's) thereby limiting the extent of the study.

Second, lack of equipment to help in the measurement of infiltration, runoff and other hydrological parameters that are important component of flood studies. Hence, only models were used for estimation, which does not give the true picture of the hydrological behavior of the soils of the area.

Third, most of the governmental departments such as the Hydro-Division of Ministry of Work and Housing, Soil Research Institute, Water Research Institute and Accra Metropolitan Assembly established to study the hydrological parameters (drainage discharge, soil texture, soil moisture, hydraulic conductivity and rainfall distribution) do not have up to date records on the event they deal with. Some of the equipment they use for data collection are spoilt and have since not been replaced.

Lastly most of these agencies do not co-operate in giving out information, since most of them are said to be classified information and not made available to the public. In addition, even if the organization has the required data, the bureaucratic nature of these organizations makes it very cumbersome and frustrating to get the data for ones work.

6.4 Conclusion

The results of the study show that potential areas likely to experience periodic floods with a given input of rainfall intensity of 140.2 mm are mostly areas below the 350 meters contour. It was also observed that flooding experienced by an area is mostly dependent on the rainfall intensity but not on the catchment area. Other factors such as storage coefficient and landuse factor were identified as contributory factors to flooding in the study area.

In the search for a method to determine flood risk zones, the use of a hydrological model within a geographic information system model was found to be very effective in the process because an appropriate decision (using the arithmetic operators) rule was defined. It was observed that about 45 percent of the study areas fall within flood risk zone.

Drains constructed as a means of controlling flooding in affected parts, is not always effective, because most of them are always filled with refuse and sediments which prevent free flow of water.

The study recommends that for effective flood control, potential flood risk areas mapped should be cross-checked with ground truth survey. In addition, drains constructed should be well connected and always clear of refuse to make way for free flow of water. The supervisory agencies such as Ministry of Works and Housing, Town and Country Planning and City Engineers Department should enforce the landuse policy or bye-laws to prevent people from settling at places that are marked as flood prone zones.

6.5 Policy Implications and Recommendation

The strategy to reduce flooding in Accra and its environs involves some major considerations. Firstly to strengthen the supervisory institutions to implement existing land use policy of the area. Secondly government should set aside funds for drain construction. Lastly, a massive educational campaign on land use policy of the Accra area must be instituted.

It has been observed that the supervising institutions on landuse policy have not been performing their tasks of restraining residents from using marked restricted (Densu flood plains) areas for settlement purposes. Legal agents of Ministry of Works and Housing should be empowered by law to ensure the adherence to land use regulations. Even those organizations with mandate to ensure adequate land use pattern are mostly constrained by logistics such as means of transport, updated thematic maps and equipment. In this instance the government budget for these agencies should be increased to help them meet their expenditure for monitoring the land use pattern.

Also, evidence from field observations showed that drains constructed cannot contain excess water because some of them are choked with refuse and sediment. Hence, a lot of storm water flows over land surface as an alternative course. Choked drains should therefore be cleaned up of debris at regular intervals. Most of the existing drains need to be expanded and new ones constructed at places such as East Legon, North Legon, Mallam, Odorkor, Kwasihman, Kaneshie and Dansoman, which do not have adequate drains to convey excess water to outlets.

Furthermore most people are not well informed about the possible hazards that they are likely to encounter when they settle at places that are potentially flood risk zones. Therefore, a well-structured educational campaign launched by the supervisory agencies using fora, electronic or print media for their campaign will help sensitize the people on these environmental hazards.

In addition, dealing with flood situations requires that much consideration should be given to the paleogeomorphology of the area. This is because historical geomorphological evidence will guide the policy makers in their decision-making, regarding allocation of plots of land for development activities.

Also, a data bank should be created so that all data collected either routinely or on ad hoc basis by any organization will be properly, standardized, catalogued and stored to meet the needs of researchers working in that field. In addition, the data bank should provide a structured technical and management support to researchers and agencies in data acquisition processes.

The government should encourage agencies support researchers with funds or material so that their findings will be meaningful that will help these agencies in their planning and decision-making processes. In addition, agencies should be encouraged to make data available to researchers to help them come out with meaningful findings.

However the use of geographic information system model needs thorough assessment of its ability to integrate a hydrological model to give a spatial picture of hydrological phenomenon. Aside this, it is recommended that the use of both the conventional method and the geographic information system model will be effective for cross checking flood risk zones within a given environment.

6.6 Recommendation for future research

The study has shown that a complexity of factors affects flood generation in Accra and its environs. Since these factors are not mutually exclusive, more research needs to be conducted to explain the role each factor plays in flood generation in same risk zones but in different location; taken into consideration the net effect of other factors. Further research should examine the spatial variability of these factors using appropriate models.

REFERENCES

Adinku, S.A. (1994) Disaster preparedness: A sociological study of the flood problem in the Odaw catchment in Accra. Unpublished thesis presented to Dept. of Sociology, University of Ghana.

Akan, O.A. (1986) 'Time of Concentrations of overland flow'. **Journal of Irrigations Drainage Engineering** 112(4) : 283-292.

Ando, Y. and Takahsi, Y. (1997) 'Recent flood control measures for urban Rivers in Japan: Case Study of the Kanda River in Tokyo'. **Water international** 22 (1997): 245-251.

Aron, G. Ball, J.E. and Smith, T.A (1991) 'Fractal Concept used in time of concentrations estimates'. **Journal of irrigation Drainage Engineering** 117(5) : 635-641.

Baumgartner, M.F. and Apfl, G.M. (1996) 'Remote Sensing and Geographic Information system'. **Hydrological Sciences – Journal des Sciences Hydrologiques**, 41 (4) August 1996 : 593-607.

Beven, K.J., Wood, E.F. and Murugesu, S. (1988) 'On hydrological heterogeneity-Catchment morphology and catchment response'. **J. Hydrol.** 100 : 353-375.

Bhattacharyya, N.N. and Bora, A.K (1997) 'Floods of the Brahmaputra River in India'. **Water international** 22 (1997) : 222-229.

Bondelid, T.R McCuen, R.H, and Jackson, T.J (1982) 'Sensivity of SCS models to curve numbers variation'. **Water Resources Bullitin** 18(1) : 111-116.

Bonell, M. & Balek, J (1993) 'Recent Scientific Development and Research Needs in Hydrological Processes of Humid tropics: 167-260. In: **Hydrology and water management in the humid Tropics: Hydrological research issues and strategies for water management, ed.** Bonell M., Hufschmidt, M.M. and Gladwell J.S., Cambridge University Press, Great Britain.

Brammer, H. (1967) **Soils of The Accra Plains, Memoir No.3.** Soil Research Institute, Accra.

Bristow, K. L. and Savage, M. J. (1987) 'Estimation of parameters for two-term infiltration equation applied for field soil experiment'. **Aust. J. Soil Res.** 25: 369-375.

Browning, K.A. (1989) 'The Mesoscale database and its use in mesoscale forecasting'. **Quarterly Journal Royal Meteorological Society** 115:717-762.

Buchtele, J. Elias, V., Tesar M. and Herrmann A (1996) 'Runoff components simulated by rainfall runoff models'. **Hydrological Sciences Journal-de Sciences Hydrologiques.** 41(1) February 1996: 49-60.

Changnon, S.A. (1985) 'Research Agenda for floods to solve a policy failure American Society for Civil Engineers proceedings'. **Journal of Water Resources Planning and management.** 111:54-64

Chapman, K. (1979) **People, Pattern and Process: An introduction to human geography.** Ewdard Arnold (Publishers) Ltd. London.

Chen, J. (1988) 'The Simulation of runoff using a time-area graph derived from DTM'. **ITC Journal** 1988-2 : 113-117.

Daily Graphic June 8, 1994 : 1.

Davis, O. (1964) **The Quaternary in the coastline of Guinea.** Jackson & son Company, Glasgow.

De Vans, D.A. (1993) Surveys in Social Research: **Social Research Today 5.** University College London. U.K.

Dei, L.A. (1972) 'The central coastal plains of Ghana: A morphological and sedimentological study'. **Z. Geomrph. N. F.**, 16(4): 415-431.

Dingman, S.L. (1994) **Physical Hydrology.** Macmillan Publishing Company, New York.

Doe III, W.W., Saghafian, B and Julien, P.Y (1996) 'Landuse impact on watershed response: The Integration and Geographic Information systems'. **Hydrological Processes.** Vol. 10 : 1503-1511.

Donker, N.H.W (1996) **Computer Program RANKPLOT: Analysis of frequency Distribution of hydrological events.** ITC., Enschede, Netherlands.

Ehrlich, P.R. et al (1977) **Ecoscience. Population Resources. Environment**, W.H.Freeman and Company, San Francisco.

ENCARTA '99' Encyclopedia, 1993-1998 CD-ROM Microsoft Corporation 1998 Part No.X03-93760.

Engman, E.Y.S. (1973) Report of drainage committee appointed by the NRC to study the flood drainage of Accra.

Engman, E.T and Gurney, R.J. (1991) **Remote Sensing in Hydrology.** Chapman and Hall, New York, USA.

Estes, J.E. (1992) 'Remote sensing and GIS Integration: Research needs, status and trend' **ITC Journal 1992-1: 2-10**.

Falkland, A.C. and Brunel, J.P. (1993) 'Review of Hydrology and water Resource of Humid Tropic Islands', : 135-163. In: **Hydrology and water management in the humid Tropics: Hydrological research issues and strategies for water management. ed.** Bonell M., Hufschmidt, M.M. and Gladwell, J.S., Cambridge University Press, Great Britain.

Gerrard, S. (1995) 'Environmental risk management' In: **Enviornmental science for environmental management**, ed. O'Riordan T., Longman ltd, London.

Gyau-Boakye, P. (1997) **Flood Control Measures: Hazard Mapping**, Water Research Institute of CSIR, Accra. Unpublished.

Hayward, D.F (1967) Aspects of Geomorphology of the Densu Basin, Unpublished Msc Thesis, presented to University of Wales, U.K.

Head, K.H. (1994) **Manual of Soil Laboratory testing Volume1: Soil Classification and Compaction Tests**, PENTECH Press, London.

Hewlett, J.D. and Hibbert A.R. (1967) 'Factors affecting the response of small watersheds to precipitation in humid areas', In: **Forest Hydrology, ed.** Sooper W.E. and Lull H.W., : 275-290, Pergamon Oxford, U.K.

Hewlett, J.D. and Troendle (1975) 'Non-point and diffused water sources: a variable source area problem', In: **Proceedings of symposium on watershed management American society of Civil Engineers : 21-46**, New York.

Horton, R.E. (1933) 'The role of infiltration in the hydrologic cycle', **Trans. AGU**, 14 : 446-60.

Houze, R.A. (1989) 'Observed Structure of mesoscale convective systems and implications for large-heating', **Quarterly Journal Royal Meteorological Society** 115:425-461.

ILWIS 2.1 Application Guide (1997) Ilwis Dept, International Institute for Aerospace Survey and Earth Science, Enschede, The Netherlands

Kesse G.O. (1985) **The Mineral and Rock resources of Ghana**, A.A. Balkema Publishers, The Netherlands.

Kipirch, Z.P. (1940) 'Time of concentrations of Small agricultural watershed', **Civ. Eng.** 10 (6) : 362.

Krumbein W.C. and Sloss, L.L (1963) 'Strategraphy and Sedimentation', In: **A Geology Series, ed.** Gilluly J. and Woodford A.O. W.H., Freeman and Company, London

Kuichling, E. (1889) 'The relation between the rainfall and discharge of sewer in populous distrcts'. **Trans. ASCE. 20 (1889).**

Kuma, D.O.K. (1996) 'Use of Maps, Aerial Photographs and other Remote Sensed data for engineering geology evaluation of flood prone disaster areas of Accra'. **Ghana Engineer** Vol 15 No 2 & Vol 16 No 1, March 1996.

Lillesand, T.M. and Kiefer, R.W. (1994) **Remote Sensing and Image Interpretation,** John Wiley & sons Inc. New York.

Loukas, A. and Quick, M.C. (1996) 'Physically-based estimation of lag time for forested mountainous watershed'. **Hydrological Sciences – Journal des Sciences Hydrologiques,** 41 (1) : 1-19.

Loumagne, C., Chkir, N., Normand, M., Ottle, C. and Vidal-Madjar, D. (1996) 'Introduction to soil/vegetation/ atmosphere continuum in a conceptual rainfall runoff model'. **Hydrological Sciences – Journal des Sciences Hydrologiques,** 41 (6) : 889-902.

Lyell, C. (1830) **Principals of Geology,** ed. Lyell, Gregg International Publishers (1970) reprint of 1881 edt.

Manley, R.E. and Askew, A.J. (1993) 'Operational Hydrology Problems in the Humid tropics'. : 34-66. In: **Hydrology and water management in the humid Tropics: Hydrological research issues and strategies for water management, ed.** Bonell M., Hufschmidt, M.M. and Gladwell J.S., Cambridge University Press, Great Britain.

Mannaerts, C.M. (1996) 'Watershed hydrological methods'. ITC postgraduate course in water resources survey lecture notes (MOR46), ITC., Enschede, The Netherlands.

Meijerink, A.M.J (1988) 'Data acquisition and data capture through terrain mapping units'. **ITC Journal** 1988-1: 23-44.

Meijerink, A.M.J, De Brouwer, H.A.M, Mannaerts, C..M. & Valenzuela, C.R. (1994) **Introduction to the use of Geographic Information System for Practical Hydrology,** International Hydrological Programme, UNESCO and ITC. Netherlands.

Mitchell, C. (1973) **Terrain Evaluation The world landscapes Terrain evaluation,** Longman Group Limited, London, U.K.

Mickson, B. S. (1984) Scaling of infiltration into Homogeneous soil, Dept of Soil Science, University of Ghana.

Molenaar, M. (1998) 'To see or not to see'. **ITC. Journal** 1998-1: 39-45.

Moore, I.D., Grayson, R.B. and Ladson, A.R. (1991) 'Digital terrain modeling: A review of hydrological and biological applications'. **Hydrol. Processes** 5: 3-30.

Mosley, M.P. (1979) 'stream flow generation in forested watershed New Zealand'. **Water Resources Research** 15: 795-806.

Mustafa, D,. And Wescoat J.L.Jr (1997) 'Development of flood Hazards Policy in Indus River Basin of Pakistan 1947-1996'. **Water International** 22(1997) : 238-244.

NEDECO Netherlands Engineering Consultant (1962) Preliminary Report on the feasibility of storage or diversion of Onyasia/Odaw stream, The Hague Holland.

NEDECO Overall drainage Scheme for Accra (1967), Ministry of Communication and Works, The Hague Holland.

O'loughlin, E.M. (1986) 'Prediction of surface Saturation zones in natural catchments by topographic analysis'. **Water Resource Research** 22 : 794-804.

Opoku- Ankomah, Y. (1996) 'Rainfall Patterns in Ghana -1935-1995 and Flooding in Accra'. Paper Presented at a **seminar on The Accra Floods: Organized by Ghana Institute of Engineers** on 8th July 1996, Accra.

Prosser, I.P. and Abernetty, B (1996) 'Predictiong the topographic limit to a gully network using a digital terrain model and process thresholds'. **Water Resources Research** Vol. 32 No.7 : 2289-2298.

Renn, O. (1992) 'Concept of risk: A classification'. : 5-23. In: **Social theories of risk, ed.** Krimsky and Golding, Westport: Praeger.

Report on Road and Drainage Rehabilitation on Accra, URBAN II Project (1991) Drainage Master Plan, Volume 1, WATERTECH, McDonalds International Ltd. : 3-1 to C4.

Sabol, G.V. (1993) 'Lag relations for Semi arid regions and urban areas'. In: **Engineering Hydrology Proceedings** , San Francisco ASCE Symposium, August 1993 : 168-173.

Schultz, G.A.(1996) 'Remote sensing application to hydrology: Runoff'. **Hydrological Sciences – Journal des Sciences Hydrologiques,** 41 (4) : 453-475.

Selby, M.J. (1985) **Earths changing surface: An introduction to geomorphology,** Clarendon Press, Oxford.

Shaw, E.M.(1988) **Hydrology in practice,** Van Norstrand Reinhold (International) Co. Ltd. London.

Shaw, G. and Wheeler, D. (1985) **Statistical Techniques in Geographical Analysis,** John Wiley and Sons Ltd., New York.
Solokov, A.A. (1969) 'Data Requirements for assessment of floods'. UN inter-regional Seminar, Tbilisi.

Stig, J. (1996) 'Perspective on risk, geography and the traffic system'. Unpublished paper, Department of Geography, NTNU., University of Trondheim.

Strahler, A. N. and Strahler, A. H. (1987) **Modern physical geography**, John Wiley & Son's, New York.

Szesztat, .K. (1969) 'Review of Research and Development in flood damage prevention technology'. UN inter-regional Seminar Tbilisi : 21.

Taur, W. and Humburg, G. (1992) 'Runoff Irrigation in the Sahel zone, Remote sensing and Geographic information systems for determining potential sites'. **Technical Center for Agricultural and Rural** Co-operation, Wageningen Netherlands : 66-67.

The Holy Bible (1993) Genesis 7:1-22, Kings James Version, Thomas Nelson Inc, USA.

UNESCO (1971) **Flood Studies: An international guide for collection and processing of data**, UNESCO, France.

UNESCO (1978) **Researches in Urban hydrology: A contribution to International Hydrological Program** UNESCO Vol. 2 : 13-20.

US Soil Conservation Service (1964) Hydrology: Section 4 SCS national Engineering Handbook, Washington D.C. US Soil Conservation Service.

Viessman, W. Jr. and Lewis, G.L.(1996) **Introduction to Hydrology,** Happer Collins College Publishers, New York.

Ward R.C., and Robinson M.(1990) **Principle of Hydrology,** MaGraw-Hill Book Company, U.K.

Water Resources Institute, Council of Scientific and Industrial Research.Report on geophysical exploration for groundwater at the Kantamanso farm, Kantamanso Accra, October 1994

Water Resources Institute, Council of Scientific and Industrial Research Report on groundwater investigation at the ABL New bottling Hall and Warehouse site, Accra, May 1994.

Water Resources Institute, Council of Scientific and Industrial Research.Report on groundwater investigation at the ACME farm Ofankor, November 1984.

Watt, W.E., and Chow, K.C.A (1985) 'A general expression for basin lag time'. **Canadian Journal of Civ. Engineering** 12 : 294-300.

Woo, H. and Kim, W. (1997) 'Floods on the Han River in Korea'. **Water International** 22 (1997) : 230-237.

Yardimcilar, C. (1998) 'Evidence for the Fit of Madagascar against East Africa from Magnetic Anomaly Mapping'. **ITC. Journal** 1998-2 : 140-141