THE EFFECT OF DEFORESTATION ON CATCHMENT RESPONSE IN THE TROPICAL CLIMATE REGION:
CASE STUDY FOR SUNGAI PADAS CATCHMENT

By

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LIST OF ABBREVIATIONS

AEP	- Annual Exceedance Probability
AMC	- Antecedence Moisture Condition
AMC I	- Antecedence Moisture Condition Type I
AMC II	- Antecedence Moisture Condition Type II
AMC III	- Antecedence Moisture Condition Type III
ARI	- Average Recurrence Interval
ASL	- Above Sea Level
CN	- Curve Number
CN’	- Adjusted Curve Number
CN(I)	- Curve Number for AMC Condition Type I
CN(II)	- Curve Number for AMC Condition Type II
CN(III)	- Curve Number for AMC Condition Type III
CWMS	- Corps Water Management System
DID	- Department of Irrigation and Drainage
DOA	- Department of Agriculture
DOE	- Department of Environment
DRH	- Direct Runoff Hydrograph
DSS	- Data Storage System
EIA	- Environment Impact Assessment
ENVI 512	- Environment 512 Manual
EPD	- Environment Protection Department
FAO-UNESCO	- Food and Agriculture Organization-United Nations Educations, Scientific and Cultural Organization
GIS	- Geographic Information System
HEC-1	- Hydrologic Engineering Centre no.1 (for hydrologic simulation)
HEC-2	- Hydrologic Engineering Centre no.2 (for river hydraulic)
HEC-3	- Hydrologic Engineering Centre no.3 (for reservoir analysis)
HEC-4	- Hydrologic Engineering Centre no.4 (for stochastic streamflow generation program)
HEC-HMS	- Hydrologic Engineering Centre – Hydrologic Modelling System
HEC-RAS	- Hydrologic Engineering Centre – River Analysis System
HEC-FDA	- Hydrologic Engineering Centre – Flood Damage Analysis
HEC-ResSim	- Hydrologic Engineering Centre – Reservoir System Simulation
HP-1	- Hydrological Procedure no.1

HP-11	- Hydrological Procedure no.11
HP-26	- Hydrological Procedure no. 26
HQUSACE	- Headquarter of the United State Army Corps of Engineers
ICMP	- Integrated Catchment Management Plan
IDF	- Intensity-Duration-Frequency
IDM	- Inverse Distance Gauge Weighting Method
IWR	- Institute of Water Resources
JPS	- Jabatan Pengairan dan Saliran
NRCS	- Natural Resource Conservation Service
SAFODA	- Sabah Forest Development Authority
SCS	- Soil Conservation Service
SCS CN	- Soil Conservation Service Curve Number
SEB	- Sabah Electricity Board
SFI	- Sabah Forest Industry
SLUSE – Malaysia	- Sustainable Land Use – Malaysia
SMA	- Soil Moisture Antecedence
SSSB	- Sabah Softwoods Sdn. Bhd.
UH	- Unit Hydrograph
USACE	- United State Army Corps of Engineers
USDA	- United States Department of Agriculture
Sub-A	- Subcatchment – A
Sub-B	- Subcatchment – B
Sub-C	- Subcatchment – C
Sub-D1	- Subcatchment – D1
Sub-D2	- Subcatchment – D2
Sub-E	- Subcatchment - E
WRSC	- Water Resource Support Centre
XP SWMM	- XP Stormwater Management Model

LIST OF SYMBOLS

SYMBOL	DESCRIPTION
t_c	- Time of concentration (hr)
f_c	- Minimum soil infiltration rate (mm/hr)
Φ	- Soil porosity (mm^3/mm)
CN(I)	- Curve Number for AMC condition I
CN(II)	- Curve Number for AMC condition II
CN(III)	- Curve Number for AMC condition III
CN_c	- Composite Curve Number
CN’	- Adjusted Curve Number
R or S_c	- Storage coefficient (h)
ΔS	- Change of storage
P	- Precipitation
E	- Evapotranspiration
T	- Transpiration
G	- Groundwater flow
Q	- Surface runoff rate
I	- Infiltration
L	- Hydrologic losses
$\overline{P}$	- Precipitation average
W_i	- Weighted area
i	- Rainfall intensity
S	- Slope
n	- Manning’s roughness coefficient
A	- Area
dS/dt	- Rate of change of storage with time
R	- Constant linear reservoir parameter (Clark storage coefficient)
O_t	- Outflow from reservoir or storage during period of time
$\overline{O}_t$	- Average outflow during period of time
I_t	- Average inflow to storage during period of time
Δt	- Computational time step
I_a	- Initial abstraction (mm)
R_c	- Recession constant
R^2	- Coefficient of Determination

TINDAK BALAS KAWASAN TADAHAN TERHADAP AKTIVITI PERHUTANAN DI KAWASAN BERIKLIM TROPIKA: KAJIAN KES UNTUK KAWASAN TADAHAN SUNGAI PADAS

ABSTRAK

Aktiviti perhutanan merupakan salah satu faktor penyebab kepada kemusnahan sistem sungai dan sistem ekologi dalam suatu kawasan tadahan. Aktiviti perhutanan telah menyebabkan beberapa bahagian di kawasan tadahan Sungai Padas mengalami perubahan tumbuhan tutup bumi, misalnya di kawasan Tambunan, Sook dan Sipitang. Kajian ini dijalankan untuk menganggar hidrograf aliran langsung Sungai Padas, yang disebabkan oleh perubahan guna tanah yang berpunca daripada aktiviti penebangan hutan menggunakan pemodelan hidrologi iaitu HEC-HMS (versi 2.2.2) berdasarkan senario perbandingan guna tanah sebelum dan selepas penebangan hutan di kawasan tersebut. Aliran hidrograf rekabentuk yang terhasil daripada hujan rekabentuk selama 72 jam untuk 2, 5, 10, 25, 50 dan 100 tahun ARI digunakan sebagai hujan perbandingan untuk menganggar pelbagai nilai magnitud hidrograf aliran langsung akibat daripada aktiviti gangguan hutan. Keputusan yang diperolehi daripada kajian ini telah menunjukkan bahawa pengurangan luas kawasan hutan kira-kira 20% telah menyebabkan peningkatan isipadu aliran antara 3.34% sehingga 5.71%, dan aliran puncak antara 3.30% sehingga 5.93%, untuk 2, 5, 10, 25, 50 dan 100-tahun ARI dalam tempoh masa hujan 72 jam. Selain daripada itu, kajian ini juga telah dijalankan untuk meramal luahan aliran hidrograf akan datang yang disebabkan perubahan kawasan yang ditebang kepada kawasan ladang yang luas seperti getah dan kelapa sawit. Keputusan kajian mendapati hidrograf aliran langsung telah meningkat lebih tinggi berbanding kawasan yang terbiar selepas aktiviti pembalakan dijalankan tanpa sebarang tanaman seperti getah dan kelapa sawit.

Keputusan keseluruhan kajian tersebut telah mendapati bahawa pengurangan luas kawasan hutan kira-kira 20% telah menyebabkan pertambahan puncak aliran hidrograf antara 3% hingga 6%, manakala perubahan kawasan hutan yang ditebang (iaitu 20%) kepada kawasan pertanian yang luas seperti kelapa sawit dan getah telah meningkatkan lagi puncak aliran hidrograf antara 19% hingga 30%.

THE EFFECT OF DEFORESTATION ON CATCHMENT RESPONSE IN THE TROPICAL CLIMATE REGION: CASE STUDY FOR SUNGAI PADAS CATCHMENT

ABSTRACT

Deforestation activities have been widely known as one of the devastating factor to the river system and ecological system in a catchment. Deforestation activities at some areas within the Sungai Padas catchment has resulted in the changes of land cover particularly in Tambunan, Sook and Sipitang catchment area. The main objective of this study is to investigate the direct runoff hydrograph in Sungai Padas, due to the changes of land cover caused by deforestation activities using HEC-HMS (version 2.2.2). The design direct runoff hydrograph resulting from 2, 5, 10, 25, 50 and 100-yr ARI for 72 hours rainfall duration were applied to evaluate the effect of deforestation on catchment response. The results of the study indicated that the increase of deforestation approximately 20% has led to the increase of the runoff hydrograph peak and volume between the ranges of 3.34% to 5.71%, and 3.30% to 5.93%, respectively, based on 2, 5, 10, 25, 50 and 100-yr ARI for 72-hours rainfall duration. In addition to the evaluation of runoff hydrograph due to the land cover changes from forest area into logged forest area (disturbed forest), the model (HEC-HMS model) has also been used to evaluate the generation of runoff hydrograph resulted from the changes of land uses in the future when logged forest converted into large scale agriculture (e.g. rubber or oil palm). The result from the study indicated that the cultivation of large scale agriculture activity causes the additional increase in runoff hydrograph peak and volume compared to hydrograph resulted from the logged forest area. The overall results of the study summarized that the increase of runoff hydrograph peak at Beaufort discharge station is ranging from 3% to 6% due to 20% increase of deforestation area without cultivation, and 19% to 30% due to 20% of the total area converted from deforested area into large scale agriculture such as palm oil and rubber trees.

CHAPTER 1

INTRODUCTION

1.1 Introduction

Problem relating to flood is a common phenomenon in many countries in the world today and it usually occurs in urbanized area. Generally, flooding is a result of increasing surface runoff due to either an increase of imperviousness area (urbanisation) or land use change such as deforestation activities at the rural area.

The disturbance of natural forest by logging activity leads to the soil erosion phenomenon and some increase in sediment contaminant to the river system. Sedimentation in the river flow discharge alters the stability of the river system which leads to aquatic habitat destructions, reduction in hydraulic carrying capacity, and degradation of water quality. The reduction of land cover decreases the hydrologic losses within the catchment. This leads to an increased in surface runoff flow into the river and receiving water body. Canopy interception is also reduced, allowing more direct delivery of precipitation to the forest floor (Keppeler, 1998). The hydrologic losses decrease due to the less amount of rainfall is intercepted by the vegetation cover. Illustration of deforestation activities are shown in Figure 1.1.

Figure 1.1: Deforestation Activities

Deforestation is the conversion of forest areas to non-forest land use such as arable land, urban use, logged area or wasteland. The conversion of forest area into non-forest is carried out either by wood cutting, commercial logging, slash and burn for shifting cultivation or over grazing. Instead of impact to the biodiversity (habitat for wildlife), deforestation can also deteriorate the environment by altering the hydrologic cycle which causes the reduction of the amount of groundwater and soil moisture contents. Elimination of forest cover reduces the catchment capability to intercept and retain rainwater because bared areas can increase the surface runoff which moves much faster than that of the subsurface flows. The rapid generation of surface water can increase the peak discharge and flood frequency. Deforestation also decreases the moisture in the atmosphere due to the decrease of evapotranspiration process from the vegetation cover.

In many cases, unsustainable deforestation affects the environment, biodiversity, and water resources. Forest areas can play an important role in the hydrologic cycle process. The existence of trees in the forest area effects the hydrologic cycle in many ways, in which their canopies intercept rainfall where some will evaporates back to the atmosphere, their litter, stems and trunks slow down the surface runoff, their roots create macropores in the soil that increase infiltration of water, reduce soil moisture via transpiration, and their litter and other organic residue change soil properties that affect the capacity of soil to store water. The quantity of surface water, groundwater and the atmosphere moisture contents are affected by the presence of vegetation cover and forest. Forest may reduce the impact of flooding in a catchment especially during large rainfall events.

1.2 Statement of Problem

The main problem in Sungai Padas Catchment is flooding from the main river, Sungai Padas to the surrounding lowland area. The flood events particularly occurred at the downstream near Beaufort area. According to many studies in other country, problems relating to flood at the downstream area are resulted from some factors, such as urbanisation activities and vegetation clearance at the upstream area. A natural catchment like Sungai Padas Catchment is not subjected to urbanisation but other activities such as deforestation and land clearance for commercial agriculture.

1.2.1 Deforestation Activities in Sungai Padas Catchment

The population within the Sungai Padas catchment mostly depend on agriculture resource as their needs and source of income. At the lower elevation area, paddy cultivation is the most dominant crops, while rubber is cultivated at the hilly area. Uncultivated cleared forest has transformed some primary forest area into secondary forest mainly at the upstream catchment. Some primary forests were changed into large scale agriculture such as rubber estates at the hilly area, and palm oil estates and paddy fields at the plain area at downstream.

Deforestation activities are still carried out at the upstream of Sipitang for commercial logging and shifting cultivation. Loggings are being carried out on primary forest and matured timber plantations at the upstream of Sungai Padas near Long Miau and Long Pasia (DOE, 1999). The availability of abundant logging sources in this area attracted several companies to do logging activities such as a licensed concessionaire, the Sabah Forest Industry (SFI).

There are some catastrophic flood event frequently cause in the great deterioration mainly at the lower Sungai Padas Catchment (e.g. December 1996 and

January 1997). The causes of the flood events might contributed by many factors (DID, 1998) such as degradation of forest and large scale agriculture.

The Padas catchment has also received a great attention when the local residents from the villages in Long Pasia and Long Miao, in the headwaters of the river, complained of the severe destruction of habitat and river degradation due to deforestation at high elevation areas. This was due to the degradation of landcover which has affected the quantity and quality of the water in the main stream (DOE, 1999).

Since, deforestation activities cause undesirable effects to the environment and water quality, the cleared forest areas should need to be recovered by afforestation to replace the logged or disturbed forest with new commercial forest, for example the pulp trees. The plantation of pulp trees in Sipitang area is the main support to the SFI paper industry in Sabah. On other part of the Sungai padas catchment (e.g. Keningau, Tambunan, and Tenom) small scale agriculture and mix agriculture cultivations are practiced such as banana, coconut, cocoa, coffee, and various types of vegetables.

The deforestation activities at Sungai Padas catchment mainly occur at the upland near to the protected and reserved forest areas. These areas are prone and vulnerable for soil erosion and landslide as a result from logging activities, since these areas are located at the steep land. Moreover, the higher elevation areas are subjected to intense rainfall than that of the lower elevation areas. Some areas at the upstream of the catchment had been allocated as reserved and protected areas by the State Government.

1.2.2 Reserved and Protected Forest Area

Approximately 3.9 million hectares of area throughout Sabah are classified as reserved land that is, forest reserved, park, and wildlife sanctuaries (EPD, 2003). The protected and reserved forests are mainly located at the interior part of the state. The reserved land in Sungai Padas catchment (Figure 1.2) are mainly converged to higher elevation land such as the Crocker Range, Witti Range, upstream of Sook catchment, and upstream of Sipitang catchment. The protected forest mainly consists of primary forest which had never been disturbed by any deforestation activity, whereas reserved forest areas are the secondary forest which had undergone the deforestation activities and in the process of reverted to secondary forest.

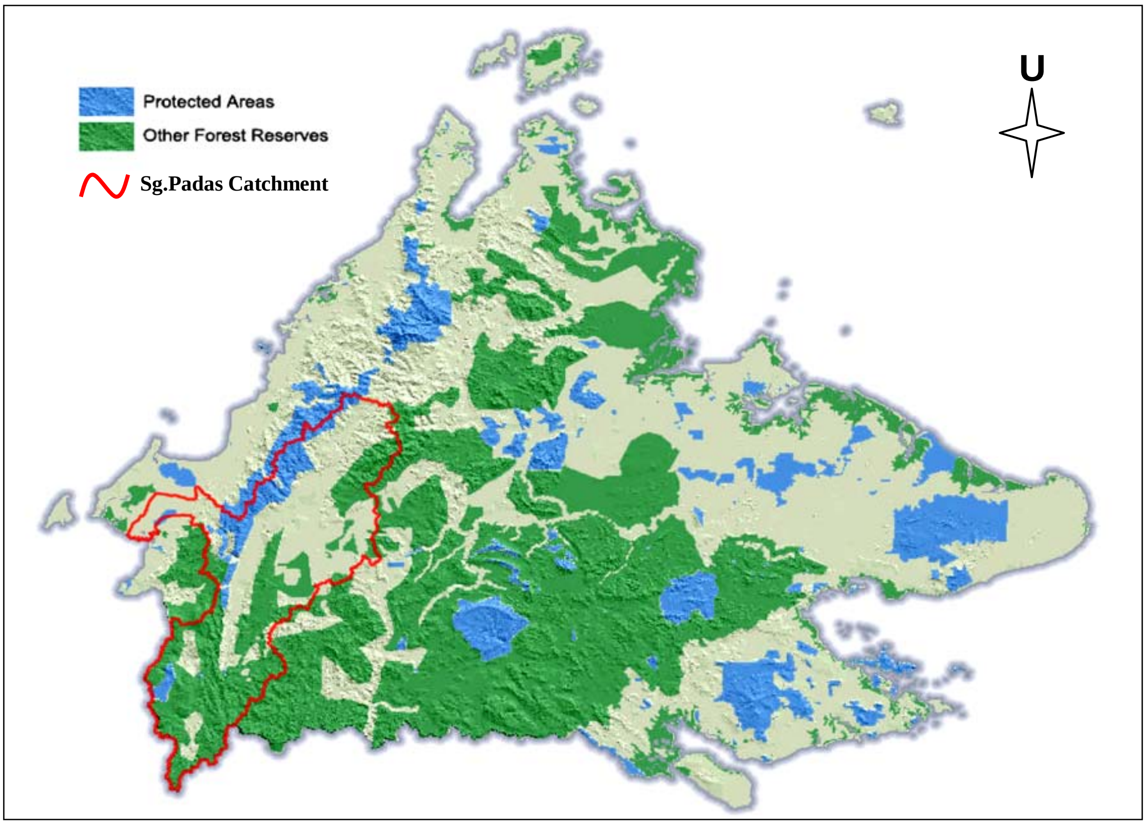

Figure 1.2: Protected and Reserved Forest in Sungai Padas Catchment
(Adapted from EPD, 2003)

The area enclosed within the red boundary line (Figure 1.2) represents the Sungai Padas catchment area. As shown in Figure 1.2, the forest protected areas are much smaller than the forest reserved areas, and this indicates that there was a rapid change of primary forest for many purposes such as commercial logging and agriculture within this catchment.

1.3 Research Objectives

The main objectives of the research are as follows:

a) To find out the effect of land cover changes due to deforestation activities on the runoff hydrograph at Sungai Padas based on available data.

b) To identify the magnitude of deforestation and its effect on the runoff hydrograph magnitude changes based on landcover information.

c) To investigate the effect of large scale agriculture plantation (e.g. rubber and palm oil plantation) on the deforested area to the runoff hydrograph of Sungai Padas.

d) To identify the magnitude of runoff hydrograph changes resulting from the large scale agriculture plantation (e.g rubber and palm oil plantation).

1.4 The Study's Aim

The aim of the study is to identify the cause of runoff increase which is inundating the downstream area during heavy rains through hydrologic modelling, based on landcover changes especially from deforestation activities.

1.5 Scope of Study

The scopes of the study are described as follows:

1. All raw data are acquired based on availability of data from relevant departments in Sabah, for instance; rainfall data, discharge data and Sungai Padas catchment maps are acquired from Department of Irrigation and Drainage; landuses and soilmap acquired from Department of Agricultue; topographic maps acquired from the Land and Survey Department. Whereas, other catchment characteristics such as river's length and slope, catchments slope and landcover are determined from available topographic maps which are dated from 1984 to 1995.

2. Hydrologic modelling is performed by employing the HEC-HMS, a free domain software, which is downloadable from the USACE website. For this purpose, the HEC-HMS version 2.2.2 is used.
3. The study is only focused on the water quantity (rainfall-runoff model) and does not include the water quality analysis.
4. The method of determination of the rainfall temporal distribution within the study area are refer to the DID Hydrological Procedure No.1 (HP-1).
5. The design rainfall for the study area are from the DID data, a readily calculated in the TIDEDA system for 2, 5, 10, 25, and 100 ARI within 72-hr period.
6. The simulations of the HEC-HMS model are based on the available information of rainfall and discharge data ranging from 1969 to 2004.
7. Analysis of the catchments responses are performed based on the changes of landcover which is focused on forest area only. This is according to the topographic maps between 1984 and 1995. Whereas, other types of vegetation are beyond the scope of the study. For the future estimation of runoff, the large scale of vegetation such as rubber and palm oil tree are considered.

1.6 The Importance of the Study

The impact of the deforestation activities on the flood hydrograph peak discharge from the catchment, due to the changes of the forest area is the main finding from the study. The information can be used to enhance the future catchment planning and management in the area.

1.7 Related Issues

Generally, deforestation activity increase when the population growth rate increases, because population always foster for agriculture development, which leads to the forest alteration. There are some examples of deforestation issues which had been experienced in other countries such as in Ethiopia, Indonesia, and United States.

In Ethiopia (located at Eastern Africa), the high population growth rate causes the vast forest area changed into non-forest mainly for shifting agriculture, livestock production and fuel wood, especially in the drier areas (Sucoff, 2003). At the beginning of the Twentieth century, around 42 million hectares (or 35% of Ethiopia land) was covered by forest which provides a vast area for biodiversity. However, the country has badly affected by deforestation causes the losses of 141,000 hectares of its natural forest every year. Between the year 1991 and 2005, the deforestation increased about 10.4% causes the losses 14% of its forest (or 2,100,000 hectares). In 2003, the remaining forest area in this country is only about 11.9% (13,000,000 hactares) of Ethiopia land (Parry, 2003). The country has been hit by famine frequently because of the severe deforestation, and depletion of natural resource. During the 1970’s and 1980’s, a horrific famine has occurred in Ethiopia, where thousands of people died. Only then the government of Ethiopia has started to aware of the effect of environment degradation.

In Indonesia, there were large areas of native forest have been cleared by large multi-national pulp companies and being replaced by plantations. Million of hectares of forest have been cleared in Sumatra for the country economic improvement purposes. In Kalimantan, between the year 1997 and 1998, large areas of forest were burned due to uncontrolled fire causing the pollution into the atmosphere.

In the United States, prior to the arrival of European-Americans, about one half of the country was covered by forest (400 million hectares). The deforestation has been commenced for the agriculture purpose until 1920s when the amount of crop land stabilized in spite of continued population growth. As abandoned farm land reverted to forest, the amount of forest land has increased from the year 1952 to 1963, where the forestland area reached to 308 million hectares. Taking into account the development pace in the United States, it is projected that, in the year 2050, about 9.3 million hectares of forest will be lost.

1.8 Thesis Summary

The thesis comprises of five (5) chapters. Chapter 1, provides a brief introduction of the definition of deforestation, related deforestation issues from other countries, and summaries the essential subject of the thesis. Chapter 2, discusses some literature reviews of deforestation. The discussion of catchment hydrology, hydrologic models, design rainfall and result analysis are also pointed out. Chapter 3, describes the research methodology approaches, in which how the research would be carried out. The methodology framework has been summarized in the flow chart which includes all procedures from the start to the end of the study. Chapter 3 also describes the Sungai Padas catchment characteristics includes available rainfall stations, discharge stations, weighted rainfall average calculation using Thiessen Polygon Method of the catchment, land cover, and soil types. Chapter 4, describes the result of the analysis which includes the design rainfall, hydrologic modelling, calibration and validation process of the HEC-HMS model. This chapter also covers the sensitivity analysis of the HEC-HMS model parameters. Chapter 5, summarizes the conclusions and suggestions or recommendations for the future study. References and appendices are enclosed at the end of the thesis.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter covers related literature review of the deforestation effects on the catchment response. Some of the hydrologic concepts are shown and described such as hydrologic cycle, hydrologic budget, the precipitation measurements techniques and the classification of soil. Overview of some hydrologic models and description of design rainfall is also discussed. Some examples from various studies from other countries were also contributing to the knowledge regarding to the land use changes effects to the runoff hydrograph such as Keppeler (1998), Hewlett and Hibbert (1961), Stednick (1995), Sun and Li (2005), and Costa et al. (2003).

2.2 Catchment Hydrology

The word “hydrology” is a combination of the Greek word “hudor” (water) and the term “logy” (a study of) (McCuen, 1989). More specifically, the general word “hydrology” refers to the scientific study of water and its properties. Therefore, catchment hydrology refers to the study of water and its properties within a catchment or watershed area. According to the New Zealand Environmental Code of Practice for Plantation Forestry (2008), catchment hydrology is defined as a term describing the measurable patterns of water flow from a catchment including water yield, flood flows, flood response and other characteristics. Also, Chow (1988) has pointed out that the hydrology of a region is determined by its weather patterns and by physical factors such as topography, geology and vegetation. Catchment hydrology comprises an interconnected system in hydrologic cycle, hydrologic budget, precipitation and soil characteristic within a catchment area.

2.2.1 Hydrologic Cycle

The hydrologic cycle is the central focus of catchment hydrology (Chow, 1988). Hydrologic cycle (Figure 2.1) involves some process of movement of water vapour from surface water, groundwater, and vegetation to the atmosphere and back to the earth in the form of precipitation. The sun's heat evaporates water from the stored surface water as such as lakes, ponds, streams and oceans. The water raises as invisible vapour through the process called evaporation. Moisture in the air comes mostly from evaporation, which largely comes from the ocean. Water rises to atmosphere also occur through the process known as evapotranspiration in plants or vegetations. Evapotranspiration process occurs when water transfer from plant tissues to the atmosphere. The water vapour then condenses forming clouds of liquids droplets. Some of the droplets may freeze, forming particles of ice. The droplets and particles then undergo a variety of changes in the clouds. They fall to the surface in the form of rain, snow or some form of moisture. Raindrops form in clouds when microscopic droplets of water grow or when particles of ice melt before reaching the ground.

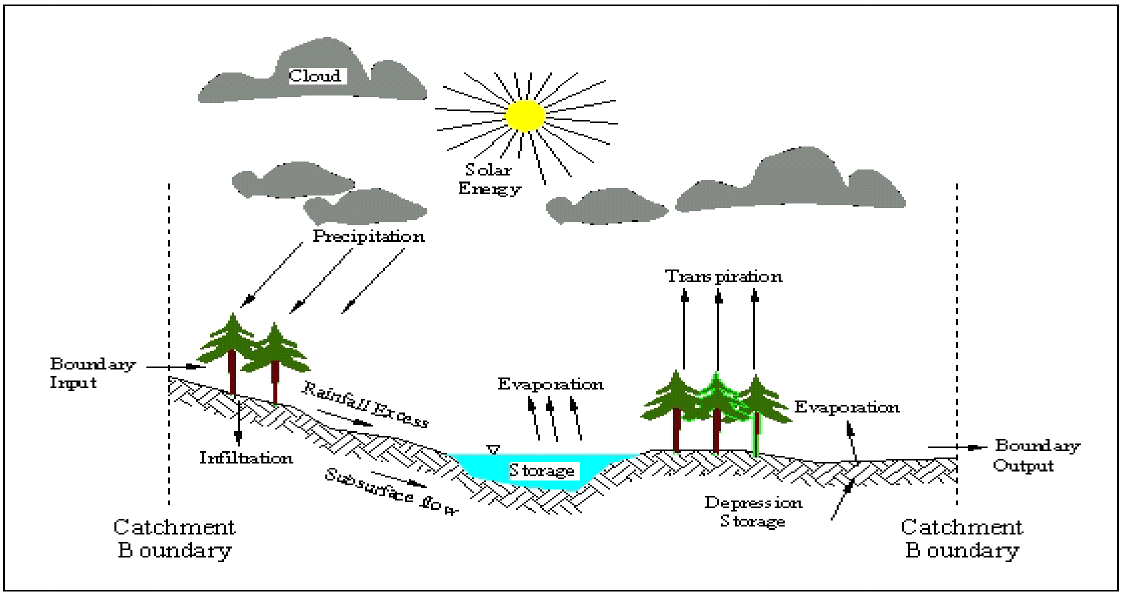

Figure 2.1: Hydrologic Cycle

Rainfall can be abstracted onto vegetation, intentionally stored in ponds, be abstracted by depression storage (unintentional small volumes), infiltrated into the soil, or be available for discharge as rainfall excess. Rainfall that infiltrates into the soil moves or percolates to the water table. Some of this groundwater may help recharge the aquifers. Some infiltrated waters may evaporate or flow in the direction of surface waters. However, most precipitation drops back directly into the ocean, and the remainder falls on the rest of the earth. In time, this water return to the surface water storage and the cycle starts again. Plants absorb water from the soil through the root system. After plants have drawn water from the ground through their roots, they pass it through their leaves as vapour and evapotranspiration process incorporated with the evaporation process from the surface water will continue the hydrologic cycle.

2.2.2 Hydrologic Budget

The determination of hydrologic budget is based on the hydrologic cycle concept on how the water cycle works by accounting the various transport phases of the hydrologic cycle within a catchment area. Hydrologic budget calculation is considering both surface water and groundwater. Hydrologic budget that considers both surface and groundwater is described by equation as follows (Wanielista et.al.,1997):

$$\Delta S = P - (E + T + G + Q) \tag{2.1}$$

whereby,

ΔS = change of storage

P = precipitation

E = evaporation

T = evapotranspiration

G = groundwater flow (baseflow)

Q = surface runoff

Hydrologic budget that considers only for surface water is described by equation as follows (Wanielista et.al., 1997):

$$\Delta S = P - (E + T + I + Q) \quad (2.2)$$

whereby,

I = infiltration

By assuming ΔS = 0, means no change in storage within a given time span, equation 2.2 becomes,

$$Q = P - L \quad (2.3)$$

whereby,

L = Hydrologic losses or (E+T+G+I)

2.2.3 Precipitation

Precipitation is the process in which water return back onto the earth. Precipitation occurs primarily in the form of drizzle, rain, snow, or hail. Each types of the precipitation form have its own characteristic in their water droplet sizes. Table 2.1 shows the description of precipitation by types.

Table 2.1: Types of Precipitation (Chow, 1988)

PRECIPITATION TYPES	DIAMETER (mm)	DESCRIPTION
Drizzle	0.1-0.6	Consists of tiny liquid water droplets which are falling at intensities rarely exceeding 1mm/hr.
Rain	>0.5	Consists of liquid water droplets of the intensities which can be classified into: Light (3 mm/hr), Moderate (3-10 mm/hr), Heavy (>10 mm/hr).
Snow	Several mm	Composed of ice crystals, primarily in complex hexagonal form.
Hail	5-125	Composed of solid ice stones or hailstones, may be spheroidal, conical or irregular in shape.

Precipitation pattern is highly governed by the temporal and spatial distribution precipitation.

i) Temporal Rainfall Distribution

The temporal rainfall distribution describes the variation of rainfall depth within a storm or rainfall duration, either expressed by discrete or continuous form. The discrete form is referred to as a hyetograph, a histogram of rainfall depth (or rainfall intensity) with time increments as abscissas and rainfall depth (or rainfall intensity) as ordinates. The continuous form is the temporal rainfall distribution, a function describing the rate of rainfall accumulation with time where the rainfall duration (abscissas) and rainfall depth (ordinates) can be expressed in percentage of total value (Ponce, 1989).

ii) Spatial Rainfall Distribution

Generally, spatial variation of rainfall is depicted by Isohyets (a contour line showing the loci of equal rainfall depth). Individual storms may have a spatial distribution or pattern in the form of concentric isohyets of approximately elliptic shape and gives rise to the term ‘storm eyes’ to depict the centre of the storm. For regional rainfall mapping, isohyets are commonly referred to as isopluvials (Ponce, 1989).

Precipitation average within a catchment can be estimated either by applying the Thiessen method, Isohyetal method or the Arithmetic Average method.

a) Thiessen method

Theissen Method is used when the location of gauging station in a catchment is non-uniform. This method is attempting to determine the area of influence. The ratio of the area of influence of a station in the topographic catchment to the total area in the topographic catchment is a weighting factor to be applied for the calculation of the average value. Figure 2.2 illustrated the procedure. The procedure involves connecting each rainfall station with straight lines, constructing perpendicular bisectors of the connecting lines and forming polygons with these bisectors. The area of the polygon is determined, and a weighted area is calculated.

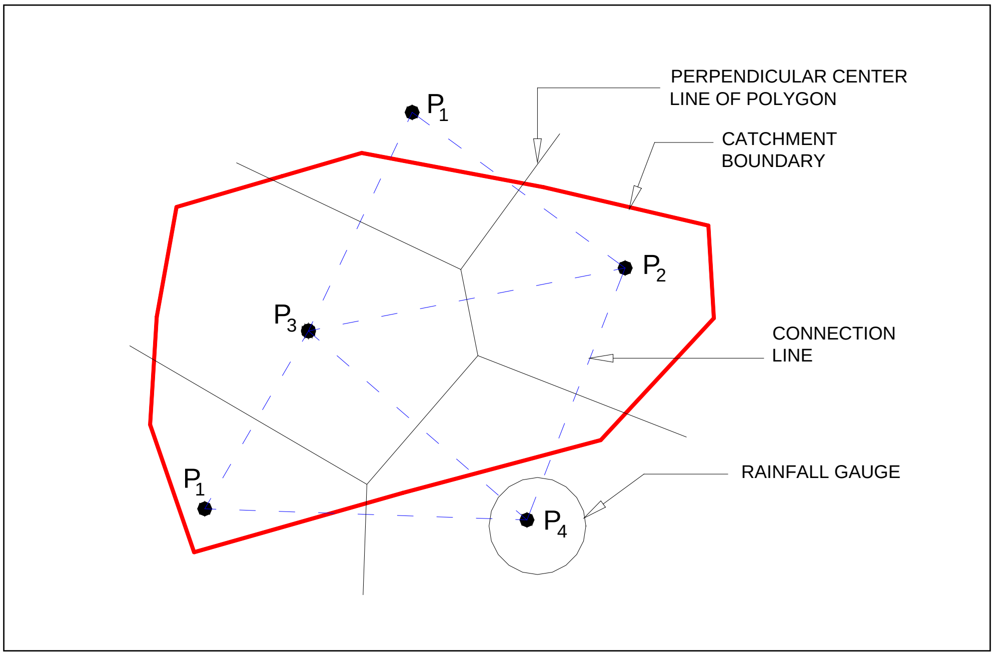

Figure 2.2: Precipitation Average Using Thiessen Method

The average precipitation by Thiessen method (Wanielista et.al, 1997),

$$\overline{P} = \sum_{i=1}^{n} W_i P_i \qquad (2.4)$$

whereby,

$\overline{P}$ = precipitation average (mm)

P_i = gage precipitation for polygon i

n = total number of polygons

which,

$$W_i = \frac{A_p}{A} \qquad (2.5)$$

whereby,

W_i = weighted area, dimensionless

A_p = area of the polygon within the topographic catchment (km^2)

A = total area of a catchment (km^2)

b) Isohyetal method

The Isohyetal method (Figure 2.3) for estimating the average precipitation for a catchment is a reliable method, but the average is difficult to reproduce by others because of the subjective nature or knowledge of storm morphology of drawing isohyets. The precipitation values between the precipitation station locations are determined by linear interpolation. The isohyetal calculations are well adapted for visual display. The area between each isohyet within the watershed is determined, and an average precipitation value is calculated.

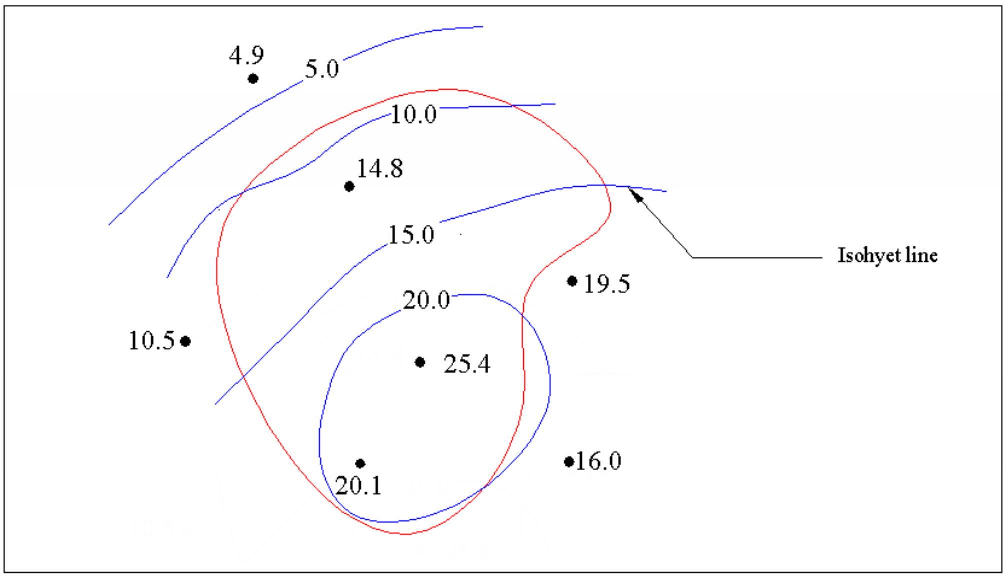

Figure 2.3: Precipitation Average Using Isohyetal Method

The average precipitation by using isohyetal method (Wanielista et.al,1997),

$$\overline{P} = \sum_{i=1}^{n} W_i P_i \tag{2.6}$$

whereby,

$\overline{P}$ = isohyetal average precipitation (mm)

P_i = isohyetal cell average precipitation (mm)

W_i = A_i/A (A_i is the area of cell (km^2))

A = total area (km^2)

n = total number of cells

c) Arithmetic Average method

The arithmetic average method calculates the average precipitation by taking only the gauging stations within the catchment area. This is the simplest method of calculation the average precipitation. The average precipitation by arithmetic method (Wanielista et.al,1997);

$$\overline{P} = \sum_{i=1}^{n} \frac{P_i}{n} \tag{2.7}$$

whereby,

$\overline{P}$ = average precipitation depth (mm or in)

P_i = precipitation depth at gage (*i*) within the topographic catchment (mm or in)

n = total number of gauging stations within the topographic catchment

The isohyetal method is more accurate than the Thiessen method, whereas the Thiessen method is more accurate than the arithmetic average method (Ponce, 1989).

2.2.4 Soil Classifications

Soil can be classified into three (3) major soil textures viz.; sand, silt and clay. Decaying materials are also the primary particle in soil. The soil types can be used to determine the infiltration factor. Infiltration has been related to soil texture. Soil characteristics are influenced by several factors such as climate, slope, biological activity, parent material, and age. According to the Natural Resources Conservation Service (NRCS) (USACE, 2000), every soil types have the minimum infiltration rates as shown in Table 2.2.

Table 2.2: Hydrologic Soil Properties Classified by Soil Texture
(Wanielista et.al., 1997; USACE, 2000)

TEXTURE CLASS	EFFECTIVE WATER CAPACITY (in/in)	MINIMUM INFILTRATION RATE (f_c) (in/hr)	POROSITY Φ (cm^3/cm)	WETTING FRONT SUCTION (cm)	SCS HYDROLOGIC SOIL GROUPING
Sand	0.35	8.27	0.437	10.6	A
Loamy sand	0.31	2.41	0.437	14.2	A
Sandy loam	0.25	1.02	0.453	22.2	B
Loam	0.19	0.52	0.463	31.5	B
Silt loam	0.17	0.27	0.501	40.4	C
Sandy clay loam	0.14	0.17	0.398	44.9	C
Clay loam	0.14	0.09	0.464	44.6	D
Silty clay loam	0.11	0.06	0.471	58.1	D
Sandy clay	0.09	0.05	0.430	63.6	D
Silty clay	0.09	0.04	0.479	64.7	D
Clay	0.08	0.02	0.475	71.4	D

Soils are grouped into four types; A, B, C and D, according to the U.S Department of Agriculture (USDA), as shown in Table 2.3.

Table 2.3: SCS Hydrologic Soil Groups (Wanielista et.al., 1997)

SOIL GROUP	DESCRIPTION
A	Lowest runoff potential. Includes deep sands with very little silt and clay; also, deep, rapidly permeable gravel.
B	Moderately low runoff potential. Mostly sandy soils less deep and less aggregated than A, but the group as a whole has above average infiltration after thorough wetting.
C	Moderately high runoff potential. Comprises shallow soils and soils containing considerable clay and colloids, though less than those of group D. The group has below average infiltration after saturation.
D	Highest runoff potential. Includes mostly clays of high swelling percentage, but the group also includes some shallow soils with nearly impermeable subhorizons near the surface.

The classification of soil by texture, according to the United State Department of Agriculture (USDA), is shown in Figure 2.4.

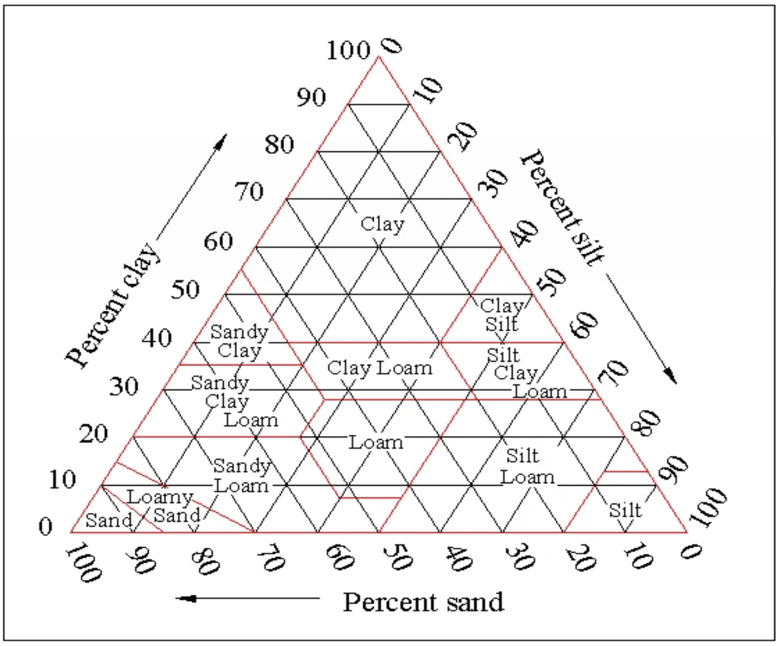

Figure 2.4: Textural Soil Classification (Wanielista et.al., 1997)

2.3 Hydrologic Models

There are numerous types of hydrologic software tools for hydrologic modelling purposes such as URBS, RAFTS, XAJ, API, HEC-HMS etc. Most hydrologic software required to be purchased with licence where some are too expensive for individual use (e.g Infoworks CS). The reliability and accuracy of each software depends on the project or scope of works in hydrologic modelling, besides it also depends on what condition of area to be modelled. Hydrologic model for urban area and rural catchment are different in catchment characteristics, therefore the selection of hydrologic tool must be relevant.

Markar et al. (2004) had evaluated five (5) well established software they are; URBS, RAFTS, XAJ, API and HEC-HMS in China during the Yangtze River Flood Control and Management project. The evaluation on these hydrologic models was carried out based on two (2) key performance indicators specified in Chinese Standard viz.; the Coefficient of Determination (CD) (or known as R^2), which is a measure of goodness-of-fit between the predicted and recorded discharged time series data, and the Qualifying Rate (QR) of predicted individual flood event peak discharges and volumes. The result indicated that the average CD values obtained from the different models do not vary significantly, where HEC-HMS showed among the highest measure of goodness-of-fit. The QR result indicated that the HEC-HMS showed a reliable consistent of measure in terms of peak and volume of hydrograph, while the rest also showed reliable results but inconsistent.

2.4 Design Rainfall

Design rainfall (or usually specified as “design storm” in engineering practice) is defined as a value for precipitation depth at a point, by a design hyetograph specifying the time distribution of precipitation during a storm, or by an isohyetal map specifying the spatial pattern of the precipitation (Chow, 1988). Design rainfall can be based upon historical precipitation data at a site or can be constructed using the general characteristics of precipitation in the surrounding region. The design rainfall depth is determined based on the point precipitation which is occurring at a single point in space as opposed to areal precipitation over a region. For point precipitation frequency analysis, the annual maximum precipitation for a given duration is selected to all storms in a year, for each year of historical record. This process is repeated for each of a series of durations. For each duration, frequency analysis is performed on the data to derive the design precipitation depths for various return periods; then the design depths are converted to intensities by dividing by the precipitation duration (Chow, 1988).

The most common approach in the design rainfall is involving a relationship between rainfall intensity (depth), duration and the frequency or return period appropriate for the facility and site location. The relationship between intensity-duration-frequency is therefore presented in IDF curve. For larger catchment the rainfall spatial characteristics are very important to be considered (MSMA, 2000). In general, the larger the catchment and the shorter the rainfall duration, the less uniformly the rainfall is distributed over the catchment and for any specified ARI and duration, the average rainfall depth over an area is less than the point rainfall depth. The ratio of the areal average rainfall with a specified duration and ARI to the point rainfall with the same duration and ARI is termed the areal reduction factor. The urban stormwater management manual (MSMA) has specified values of rainfall areal reduction factor for urban area up to 200 km^2. For natural catchment larger than 200 km^2, the rainfall distribution method viz., arithmetic average, Thiessen method or isohyetal method as discussed in paragraph 2.2.3 can be applied.

IDF values for some major towns in Malaysia had been identified in MSMA between the periods from 20 to 100 ARI. However, ARI information in Sabah (East Malaysia) has been outdated and some reviews and updated historical rainfall data are necessary to generate new IDF. Also, the listed IDF curves in MSMA are only showed for major town. In rural catchment area the generation of IDF curve has to be carried out according to the available rainfall gauges within the catchment.

2.5 Related Deforestation Case Study

Many studies regarding to the deforestation effects to the runoff were conducted at other countries. All findings from the studies conclude that the disturbance or alteration of forest area into non-forest area resulted to increase in the runoff besides contribute additional sedimentation effects into the river system.

Costa et. al. (2003) have conducted a study to the Tocantins River at Porto Nacional (area of 175,360 km^2) to investigate effect of catchment response to the rainfall with the land cover changes. They analysed a 50-year long time series of streamflow, and precipitation over the drainage area during a period where substantial changes in land cover occurred in the basin between the year from 1949 to 1998. In their study, they separated the period into two periods (Period-1 and Period-2). Period-1 (1949-1968) was the period in which the catchment has little changes in land cover, while Period-2 (1979-1998) was the period in which the catchment has more intense changes in land cover. The rainfall used for both periods was not statistically different. The result indicates that, the annual mean discharge in Period-2 was 24% greater than in Period-1, and the high-flow season discharge is greater by 28%. They also indicated that, in large river basin, the two most likely drivers of long-term discharge modification are precipitation variability and changes in landuse or land cover in the upstream catchment. They have also indicated that the hydrograph peak from the catchment which has various landuses occurs earlier than that from the catchment which has limited types of landuses.

Another study has been conducted by Costa and Foley in 1998 at Amazonia, Brazil to determine the combined effects of large-scale deforestation and increased of CO_2. This area has been undergone by highest deforestation rates, which occurred in the late 1970s and early 1980s due to the high migration of people into Amazonia. As a consequence, in 1991, about 10.5% of the original forest area had been deforested. In the study, they used the National Center for Atmospheric Research GENESIS atmospheric general circulation model for modelling purpose. The results from this study indicate that the deforestation decreases basin-average precipitation by 0.73 mm/day over the basin as a consequence of the general reduction in vertical motion above the deforested area. The combined effect of deforestation and doubled in CO_2 concentration, result into a decrease in the basin-average precipitation of 0.42 mm/day. The effect of deforestation and increased in CO_2 concentration both tend to increase surface temperature, mainly because of decreases in evapotranspiration and the radiative effect of CO_2, which has caused the temperature to increase by roughly 3.5^{o}C.

Stednick (1995) conducted a study in the United State to assess the effect of timber harvesting on annual water yield (runoff) including lowflows and peakflows using 95 paired catchments. Paired catchment defined as a catchment that has two treatment conditions includes pre-treatment and postreatment. Pretreatment condition is where deforestation activity has yet to be carried out, while postreatment is where deforestation activity has been carried out in the catchment. The outcome from the studies have shown that changes in annual water yield from forest cover reduction (or catchment area harvested) of less than 20% could not be determined by hydrometric or streamflow measurement methods. The catchment studies were discriminated by hydrologic region, defined by temperature and precipitation regimes. The regionalization suggested that as little as 15% of the catchment area (or basal area) could be harvested for a measurable increase in annual water yield at the catchment level in the Rocky Mountain region as compared with 50% in the Central Plains, although system responses are variable. The study also summarized that the maximum increase in water yield was due to land clearance, and the effect of deforestation on precipitation and runoff depend on the recovering process of forest vegetation.

A study was carried out by Sun and Li (2005) from 28 catchments in China to access the deforestation effect on the annual water yield by considered several influencing factors such as the type of vegetation cover, climate and catchment sizes. The linear regression analysis was applied to determine the influence of vegetation cover types and precipitation (climate factor) on annual water yield. The results from the study deduced that;

a) The differences of impact on water yield among different forest types were somewhat different with those from the other countries.
b) There is a higher water yield changes in humid regions compared to that of drier regions.
c) The water yield is consistent in both small and large catchments due to the deforestation effect, but there is a big fluctuation in streamflow responses to forest cover changes in smaller catchments.

A study to evaluate the effects of two harvesting methods (by selection and clear cutting method) on summer flow and annual yield was conducted by Keppeler (1998) at Casper Creek, Northwestern California. The objective of the study was to compare the effects of selection cutting and tractor yarding on the South Fork (SFC) streamflow with those of clearcutting and cable yarding on the North Fork (NFC) streamflow. Regression analysis was used to evaluate differences in annual water yield before and after timber harvesting activities on NFC and SFC. For summer low flow analysis, similar regression approach was used to analyzed changes in minimum