Assessing the effects of land use change on the hydrologic regime by RS and GIS

A case study in the Minab catchment, Hormozgan province, Iran

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In the name of GOD

...Dedication to
My Wife and Our Parents

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Abstract

Watershed analysis provides a framework for ecosystem management, which is currently the best option for conservation and management of natural resources. The water cycle regulates and reflects the natural variability of the physical processes which impact on ecosystems. Considering the constraints associated with presently available techniques for evaluating land use impacts on the water cycle, such as paired catchment method and modelling (*Elkaduwa, 1998)*, this study provides an alternative approach to ascertain the actual changes in hydrologic response of a particular watershed to land use transformations made in the past. The alternative rapid approach, as applied here to the Minab catchment (ca. 1.10^6 ha) in the South of Iran, includes the analysis of long-term historical time series of data on rainfall, land use and streamflow, to discern changes in the watershed and their effects on the hydrologic regime. The analysis also takes into account the hydrologically relevant changes and effects at the landscape level, as a guide to identify appropriate options for land and water management. Such management practises largely depend on the degree of variation in the hydrologic response of the watershed to recent land use changes (1975-2000). Therefore, this research project intends to map land use (e.g. overgrazing and deforestation) changes by means of satellite remote sensing and to assess the effect of land use changes on the hydrologic regime (high flow and low flow) of the Minab catchment.

In 1976, about 45 percent of the watershed area was covered by rangeland and natural forest (referred to as medium rangeland, good rangeland and forest). Due to continued overgrazing, rangeland cover decreased to 10 percent in 1988 and to 8 percent in 2002. During a period of ca. 25 years, three main land use classes at a large scale have replaced these fertile rangelands. These are characterized by: poor natural cover (e.g. poor rangeland, bare soil and rock out crop), agriculture area (e.g. irrigated agriculture, rainfed agriculture and orchard) and residential area. This destruction of natural vegetation covers have resulted in a decrease in the annual total water yield by 3.4 mm, with a decrease in the base flow during the low-flow period (May-November) and an increase in the storm runoff during the high-flow period (December to April). Also, the evaluation of flow duration curves shows a reduction in flow duration in the 1984-1990 and 1991-2000 periods in comparison with the 1975-1983 period. Flow duration during 1984-1990 is more related to climate change. However, regarding to the increasing annual rainfall in 1991-2000, the flow duration of the river has been reduced. This is related to the shortening of the low flow period of the river. That is the reason why the percentages of low and medium discharges have decreased. It can be concluded that most of the runoff is discharged from the catchment by floods that take place during high flow periods. The results also show that average base flow discharge, during low flow periods, decreased.

It can be concluded that climatic variability and land use change are the most important factors affecting the (changes in the) hydrologic regime of the Minab catchment. For a return period of

more than 10 years, (high) rainfall intensity as a climatic factor is considered dominant. Other factors such as land use change are considered less important then. For a return period of less than 10 years and in combination with a low flow period, land use change is clearly the dominant factor determining the flow regime. Therefore, an active management strategy aimed at the conservation and regeneration of the natural vegetation is recommended, in order to improve the distribution of water throughout the entire Minab catchment, during both dry and wet periods.

Key words
Land use change, climatic variability, catchment hydrology, floods, droughts, remote sensing, GIS

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Chapter 1 Introduction

1.1 Background and problem

Since the 1950's the country of Iran has faced an increasing number of flood events. This means an annual increase in the number of flood events between 1952 and 1991 of about 4%, and an annual growth of financial damages of about 6%. On the other hand, the growth rates of flood events during three decades (1960-1990) amount to 131%, 175% and 229% respectively (Sadeghi, 1995).

One of the main hydrological problems in the Minab catchment (situated East of Hormozgan Province in the South of Iran) is flow regime change from the major river (e.g. peak flow, base-flow). Deforestation and overgrazing of rangelands, development of orchards, irrigated areas and residential areas, seem to be the most important factors causing this problem. Reported at increasing frequencies is storm runoff, which results from three different types of weather conditions. These are: (i) short duration of high intensity rainfall; (ii) long duration of low intensity rainfall; and (iii) a combination of these conditions.

This research project intends to determine and map land use changes, and assess the effect of land use changes on the hydrologic regime (high flow and low flow) of the Minab catchment.

1.2 Objectives

More specifically, the purpose of the research is to determine whether or not land use changes have affected the hydrologic response of the Minab catchment. This includes two major tasks:

• providing insight on how land use and land cover have changed (e.g. orchard, agriculture, urban development, rangeland, etc) in the Minab catchment over the past 25 years.

• Demonstrating the effect of land use change on selected hydrologic parameters in the Minab catchment., e.g.: high flow, low flows, , dry and wet periods and water budget.

1.3 Previous work in the study area

Two study projects with similar objectives have previously been carried out in the research area. One project comprises a water resources survey for reservoir dam construction in the downstream part of the catchment. This project has been done by the Setiran consulting engineering company in 1971. During that period, there were not enough stations operated inside the Minab catchment to provide the necessary climatological and hydrometeorological data. Therefore these data have been taken from nearby stations at Bandar Abbas, Kerman and Yazd. The second project comprised a watershed management study. This study was done in the so-called semi-detailed phase. It used information from inside and outside the Minab catchment. This resulted in a estimation of the catchment parameters for practical use in watershed management, by the Abvarzan consulting engineering company in 1994.

1.4 Research questions

In view of the research objectives and the work previously done in the research area, the above has been elaborated into two research questions. These are:

1-How is the trend of land use changes from 1975 to 2002 in the study catchment?

2-How have the land use changes affected the hydrologic regime?

1.5 Methodology

Geographic Information System Application

1-GIS has mostly been used in this research for: Digitizing base maps (geology, drainage...)

2-Derivation of catchment physiographic characteristics (sub basins, main river length, DEM, slope,) using spatial overlaying techniques and thematic database queries.

Remote Sensing Application

Landsat MSS and TM satellite imagery have been used for:

1-Producion of land use/land cover map using satellite image data from 1976,1988 and 2002, based on supervised classification methods and (field) checking, interviewing local people and visual interpretation of aerial photos.

2- Determination of land use changes from 1976 to 1988 and 1988 to 2002.

Hydrological Methods

In line with the present state-of-the-art in the assessment of hydrologic impacts of land use transformation at the watershed scale, a hydrological catchment approach based on earth observation data has been tested in an arid tropical region, with the objective of evaluating its use as a guide to identify appropriate land use transformations and land use policy interventions at the watershed scale.

An attempt has been made to analyse changes in the hydrologic regime of the Minab catchment in relation to changes in land use and climate, which have taken place in the passed 25 years.

Historical time series data on streamflow, rainfall, and land use have been used in the analysis. The variability in the hydrologic regime brought about by the year-to-year variation in weather conditions has been removed by establishing correlational relationships among hydrologic variables based on long-term time series data. Moreover, instead of annual data, 5-year moving averages have been used in a trend analysis of hydrologic data to minimize the effect of interannual variations. This is expected to be a useful approach to compare the hydrologic behaviour of a catchment before and after land use transformation.

1.6 Materials

The following spatial (image) data and historic time series of hydrometeorological data have been used in this project.

Satellite and airborne image data and maps:
- Landsat MSS (1976); Landsat TM (1988); Landsat ETM (2002).
- Black and white aerial photographs, at the scale of 1:55000
- Topographic maps, 1974 &1986, at scale 1:50000.
- Topographic maps, 2000, at scale 1:250000.

Time series of hydrometeorological data:
- Mean daily and monthly discharge data of three stations (Minab, Rudan, Jaghin).
- Mean annual precipitation data of 8 stations.
- Mean monthly temperature and mean annual evaporation data of 3 stations.

A selection of scientific reports on the study area has been used as a reference (see Reference).

1.7 Literature review

A simple method to assess hydrologic impacts of different land uses is to compare streamflow characteristics of different catchment areas with contrasting land use types. This would enable comparison of the hydrologic response of a catchment consisting of degraded lands where watershed management is to be introduced with catchments that already have the desired land use characteristics anticipated to be achieved. Such a comparison may lead to wrong conclusions as shown by Bruijnzeel (1990) after reviewing the catchment water balance studies related to land use transformation in the tropics. This is mainly because of the possibility of differences in catchment leakage through bedrock-underlying valley fills or weathering mantles. In many small headwater catchment areas, streams have not cut through the entire weathering mantle that may reach considerable depths in tropics leading to large volumes of leakage (Burnham, 1989). Also larger streams may lose substantial amounts of water to their floodplains. For example, in measuring water yield in small catchments, Richardson (1982) has reported considerable differences in total water yield in Madagascar suggesting catchment leakage. Qian (1983) and Dyhr-Nielsen (1986) have shown that in the tropics, another factor complicating the evaluation of hydrologic effects of land cover transformation is the strong interannual variability of weather.

An effective method evolved to overcome the above problems encountered in catchment water balance studies is the "paired catchment method," where hydrologic comparison is made between two (or more) catchments of similar size, geology, slopes, exposure, and vegetation, and situated close to one another. Here the "control" is left unchanged while land use changes are effected in the "experimental" or "treatment" catchment (Roche, 1981& Hewlett and Fortson, 1983). In addition to the comparison made after treatment, a comparison is also made during the initial calibration phase of several years (depending on rainfall variability) before changes in land use are effected in the control catchment. The degree to which linear regression equations or double mass curves correlating the streamflows of the two catchments change after the treatment compared to that during the calibration period is a measure of the hydrologic effect of land use change (Hsia and Koh, 1983). The total duration of experiments with the paired catchment method may easily span a decade (Bruijnzeel 1990). Moreover, the results may be rather site-specific due to an area's geological or pedological setting (Fritsch, 1987 & Dano, 1990). Therefore, in recent years there has been an increasing trend to predict hydrologic changes brought about by land cover transformations in the tropics by robust models employing data obtained during relatively short but intensive measuring periods (Shuttleworth, 1990& Institute of Hydrology ,1990).

For watershed development projects in the developing countries, the application of the paired catchment method to identify the suitable land use interventions has practical limitations. Several years of watershed calibration prior to actual implementation of the project is not practical in many instances as such projects are implemented mostly with donor funding soon after their appraisal. Even if calibration of catchments is accomplished successfully prior to effecting land use changes in the treated catchment, it takes time to evaluate the actual hydrologic changes brought about by land use transformations. If the evaluation reveals that desired results are not achieved, it is too late to correct the already introduced land use transformation. In other words, this technique does not predict the hydrologic impacts of any set of anticipated land use transformations in a given locality unless the paired catchment method has been applied in the past to evaluate land use transformations in the areas with similar physio-geographical conditions. Such an accumulated knowledge with previous studies is either scanty or not available in most of the tropical countries. Under these circumstances, one can expect to overcome these constraints by the application of suitable models.

Effects of land use changes on runoff characteristics of a watershed have been studied using several types of models, which varied from strictly empirical to physical-based distributed models. Reciprocity in hydrologic processes and the mosaic landscape are scale-dependent and nonlinear, and due to such relations the success of both physical and empirical cause-effect modeling is increasingly questioned (e.g., Beven, 1989). Investigating natural, potential, and human-induced impacts on hydrologic systems commonly requires complex modeling with evolving data requirements, plus massive amounts of one to four dimensional data at multiple scales and formats (Hay and Knapp, 1996). Most hydrologic models are traditionally based on deductionistic cause-effect relationships developed for the temperate region but the sustainable management of vulnerable and extreme regions, such as the tropics, demands a new holistic and transparent approach relying on first principles and integration of processes and landscape patterns (Gumbricht, 1997). Considering the requirements of various models and their limitations in the application to predict hydrologic changes with land use transformations, it is reasonable to conclude that dependence on models is not feasible in developing countries of the tropics, at least in the near future. The major constraints are the knowledge gap in hydrology-related processes and parameter values, the cost involved and time consumed even if minimum data requirements are to be achieved, and the problems in calibration and validation of such models with reliable historical data.

Many research projects have been done on land use change and land use effects on hydrologic regime in Iran. In some cases, they are similar to the present research, so their results can be compared to envisaged project results for the Minab catchment. Relevant observations:

-In order to review the causes of flood increasing in Tehran, some morphometric characteristics and surface runoff of studies basins have been done. Furthermore, ultimately a review was carried out regarding the relation between urban development and the increasing trend of flood water, taking into consideration the SCS and Rational methods (Saberi and Ghoddusi, 1997).

-Many factors including climatic, geometrical and land use characteristics have influenced the discharge of precipitation through the watershed. In comparison with other watershed characteristics, precipitation variation has a greater effect on runoff generation and is the main cause for runoff differences in regions (Mahdavi, 1993).

-The value of the runoff coefficient in the Kasilian watershed in Iran has increased in a period of 15-20 years with 10-15% as a result of clearing the forest cover (Sadeghi, 1995).

Chapter 2 General description of the study area

2.1. Topography

The Minab River consists of two main branches, the Rudan River in the north and the Jaghin River in the east. The combined runoff of these two rivers reaches to the Minab dam reservoir. The location of the study area is about 100 km north east of Bandar Abbas, the provincial capital of Hormozgan province in Iran. The two sub catchments of the Minab River are shown in figure1.1.

The Minab catchment area covers 10.100 km^2 that is formed by the Jaghin (32%) and Rudan (67%) sub catchments. Table 2.1 shows some statistics of the Minab catchment and the sub catchments physiographic parameters.

Table 2.1 the summary of physiographic information of the study area

Catchment name	A (Km^2)	P (Km)	LR (Km)	Hmax (m)	Hmin (m)
Rudan	6750	437.5	183.5	2731	135
Jaghin	3250	285	129.5	2125	135
Minab	10100	654.5	241.5	2731	130

A: Catchment area (km^2)

P: Catchment perimeter (km)

LR: Main river length (km)

H max: The highest elevation (m +MSL)

H min: The lowest elevation (m +MSL)

2.2 climate

2.2.1 Relative Humidity

Based on three Relative Humidity gage data in the study area, the percentage of Relative Humidity is high in the months October and June and low in September and March. With an increasing distance from the sea, a decreasing Relative Humidity is observed. The monthly Relative Humidity in the Minab catchment is shown in Figure 2.2.

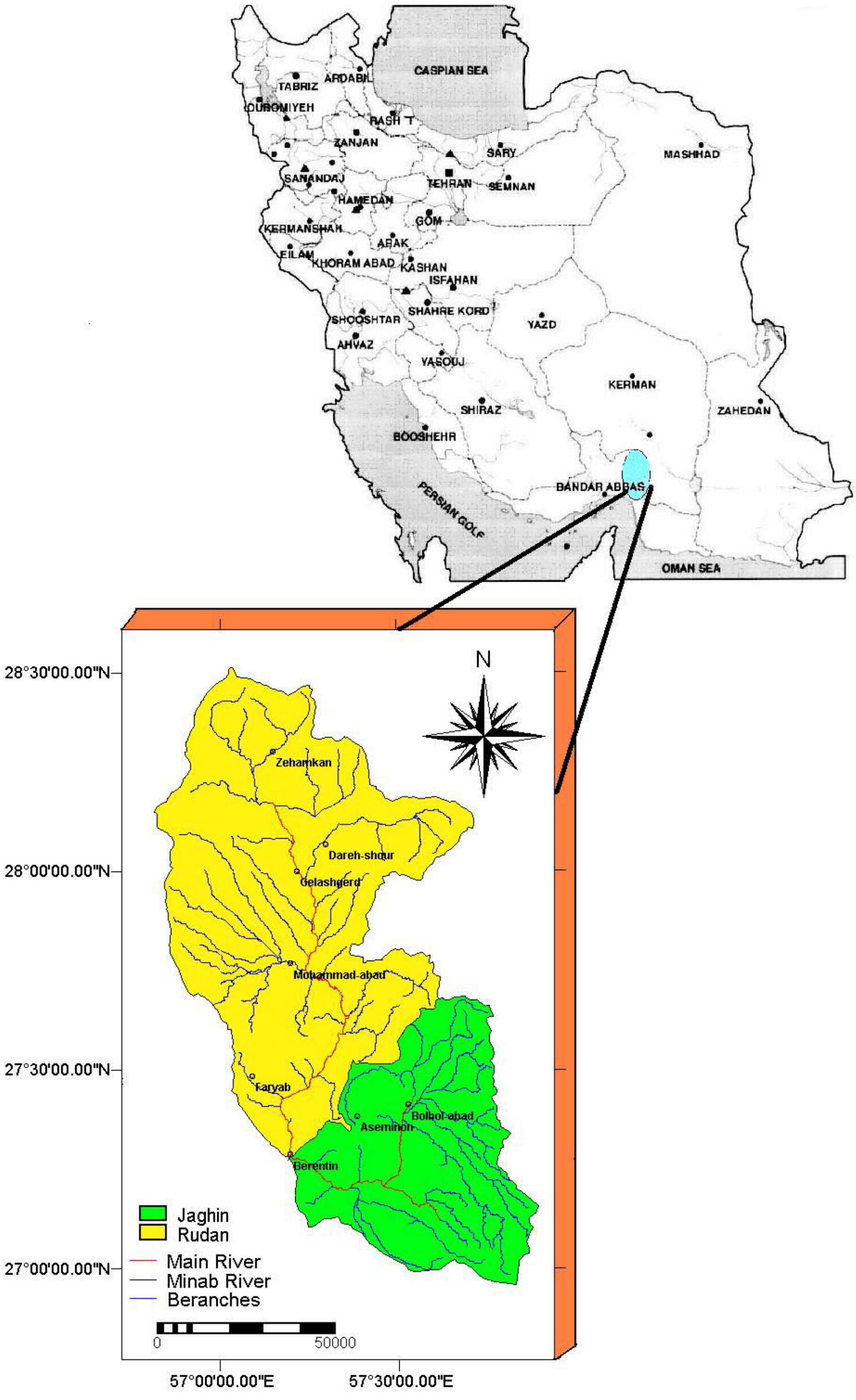


Figure 1.1 Location of the two sub catchments of the Minab catchment.

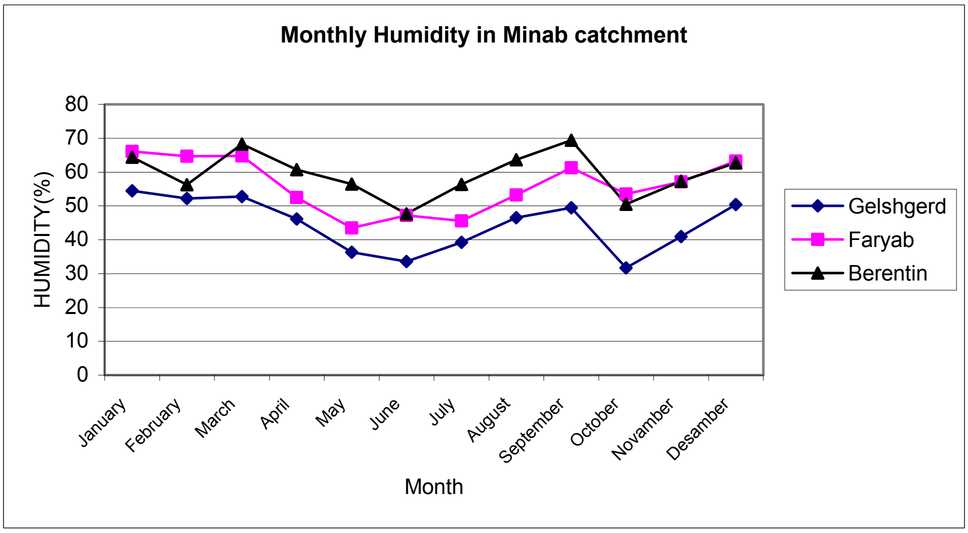


Figure 2.2 Mean monthly Relative Humidity in the Minab catchment

2.2.2 Temperature

Based on three Temperature gage data, an increase in the mean temperature is observed from March to July. Also, from July on the mean temperature decreases. It is to be noted that July and January have the highest and the lowest mean temperature respectively.

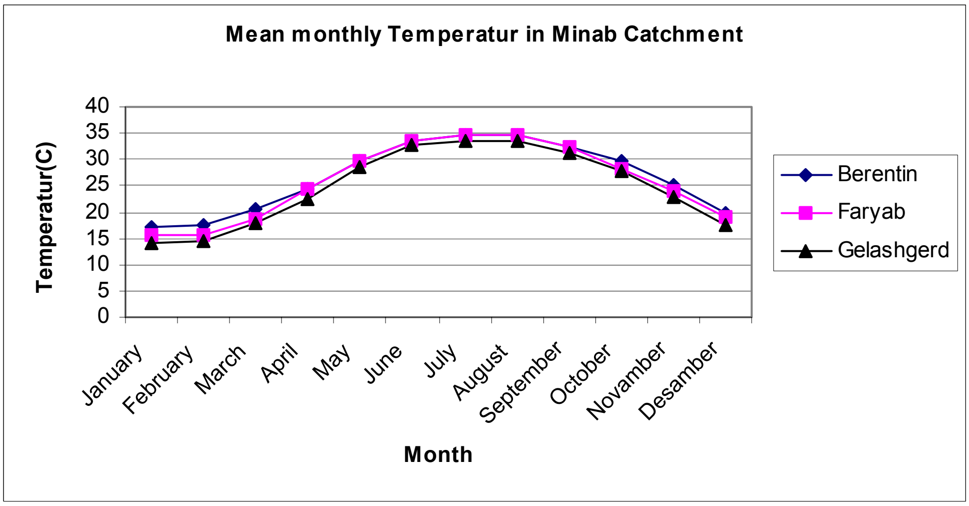


Figure 2.3 Mean monthly temperature in the Minab catchment

2.2.3 Rainfall regime

Precipitation in the Minab catchment consists only of rainfall. There is no snow, as in many other areas in Iran. Most of the rainfall in the study area (65%) is in winter. There is also a little rainfall (8%) in summer that is related to the monsoon mass effect, which comes from the Indian Ocean. Figure 2.4 shows the respective rainfall percentages of the Minab stations. The catchment has high-density rainfall during short periods in most of the months, especially during the summer season. This is illustrative for the arid tropical rainfall regime.

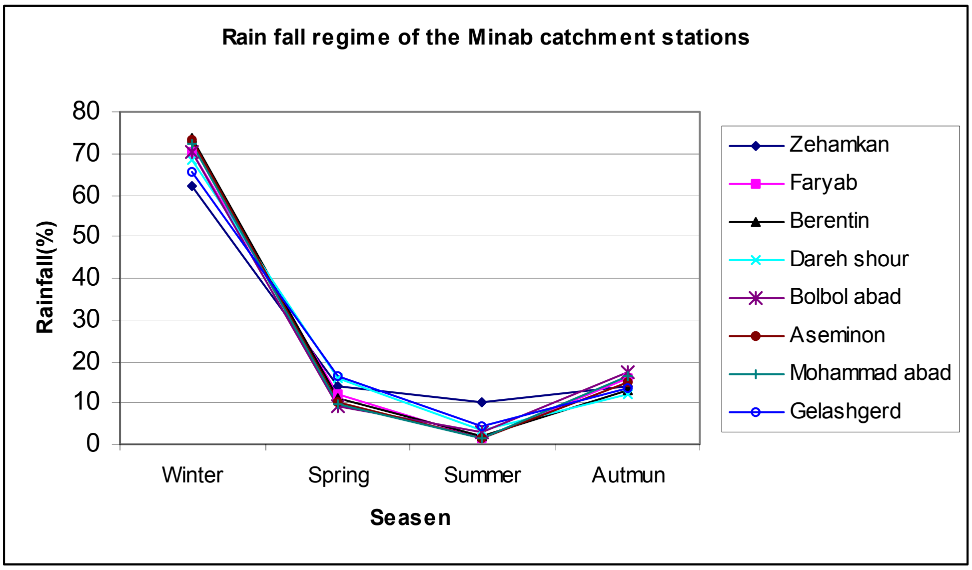


Figure 2.4 Rainfall percentages of the Minab catchment stations.

2.2.4 Evaporation

The average monthly evaporation of 3 stations is shown in figure 2.5. A relatively wet period is observed from April - October.

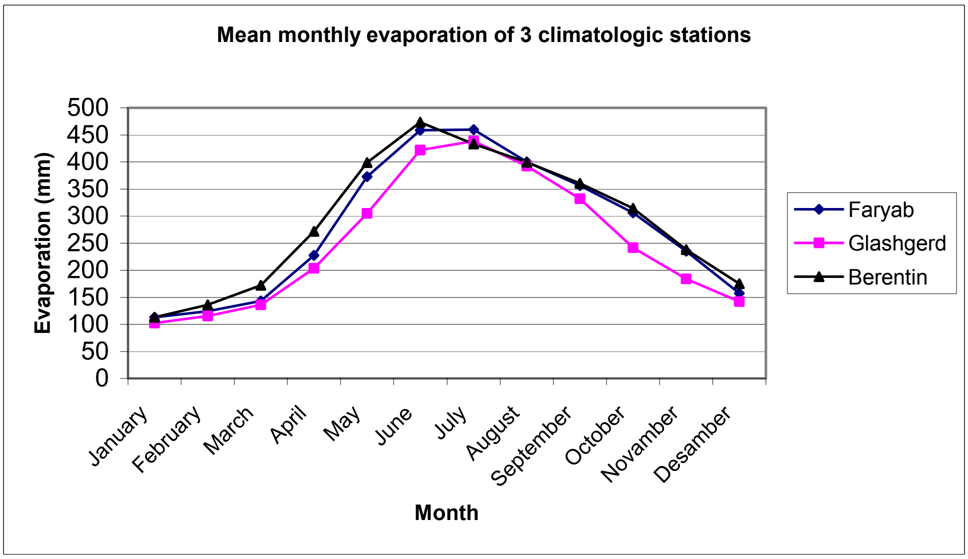


Figure 2.5 Mean monthly evaporation of 3 stations in study area

2.3 Soil

Based on the F.A.O international classification method the soils in the study area have been classified in six major groups. These include:

1-Leptosols

2- Fluvisols (alluvial fans, flood plains).

3- Solonchaks (playas).

4- Arenosols (wind blown deposits).

5- Regosols (hills, denudatinal units, texture, drainage classes, etc)

6- Cambisols (Abvaezan.1994)

The depth of the soil in the mountainous area varies from shallow (d< 5 cm) to bare soil with a light texture. The depth of the soil in the (lower lying) hills is mainly moderately deep to shallow(100 cm> d>5cm). In the alluvial parts in the north and centre of the catchment the texture varies from sandy loam to loam. In the upland parts patches of stone and gravel are found. Soils nearby the river beds range between very gravely in the apical part of the fans with excessive drainage and a medium coarse texture, and deep and well-drained soils at more distance from the fan.

2.4 Natural vegetation cover

Natural vegetation coverage in Minab is poor (<30%). This is the result of a combination of factors, such as climate, geology and man. Natural vegetation of the Minab catchment can be divided in 3 parts, as follows:

1. Rangeland: seems to have expanded across most of the area, especially in the hilly areas and at the foot of a mountain in the central and northeast of the catchment. Species include: Astragalus (shrub), Cymopogon (grass), Convolvolus (shrub) and partly in north of catchment is Artemisia genius (shrub).

2. Dry forest: on plain margins, hilly parts, foot slopes and stream margins in the southeast and northwest of the catchment. Most tree species are drought resistance, such as Ziziphus, Acacia, Prosopis, Proplica, Pistachio.

3. Sub forestlands: in mountains in the northwest and east at ca. 1500 m +MSL, small trees such as Olea, Cupresus and Amingdalus.

2.5 Geology

Geological formations in the Minab catchment are directly related to the Zagros fold and the Makran mountains string, which is located in the southeast of Iran. These consist of the oldest Kertasa formations (Kcm, Kmt, Kvs; see Table 2.2) that include: complex sedimentary, metamorphic & color complex. Eosen formations (Els, Eshl & Evs). Rock types include limestone, shale, sandstone, tuff, conglomerate and some volcanic rocks in the western part of the area.

Also, Peleosen formations (Psc, Pzmt) expanded in the western and central part of the Minab catchment. Miocene conglomerate with red color is seen in the southwest near the outlet of the catchment. Quaternary sediments expand in most of the plains and at the feet of mountains.

All of those formations can be classified based on Table 2.1 in 4 classes, i.e.: 1. High; 2. Medium to high; 3. Low to medium; and 4. Low for relative permeability. Figure 2.6 shows the areal percentage of relative permeability in the Minab catchment. Figure A.2 (in appendix B) shows the map with the distribution of relative permeability in the Minab catchment.
The relative permeability has a reverse ratio with surface runoff. Therefore, the area of low relative permeability has a high runoff potential and vice versa. On the basis of the geological map it can already been concluded that the northern and eastern part of the area are very important in producing surface runoff and floods.

Table 2.2 Classified geology formations based on relative permeability

Symbol	Litology	Age	Permeability
d	Durit	Meseozoic	Low
Els	Limestone, shale, sandstone, tuff & conglomerate	Eocene	Low to medium
Eshl	Shail, silt rock & sandstone	Eocene	Medium to high
Evs	Complex metamorphic & volcanic	Eocene	Low to medium
Kcm	Color complex	Jurassic-cretaceous	Low
Kmt	Complex sedimentary & metamorphic	Jurassic-cretaceous	Medium to high
Kvs	Complex sedimentary &volcanic	Jurassic-cretaceous	Low to medium
Ms	Clay rock, silt rock & shale	Oligocen-miocene	Low to medium
Psc	Sandstone and conglomerate with silt rock &	Pliocene-quarternairy	Medium to high
PZmt	Complex metamorphic	Paleozoic	Low to medium
Qal	River bed sediments	Pliocene-quarternairy	High
Qsc	Clay salty plain	Pliocene-quarternairy	Medium to high
Qt1	Old alluvial & river terrace	Pliocene-quarternairy	Medium to high
Qt2	Young alluvial (not compact)	Pliocene-quarternairy	High

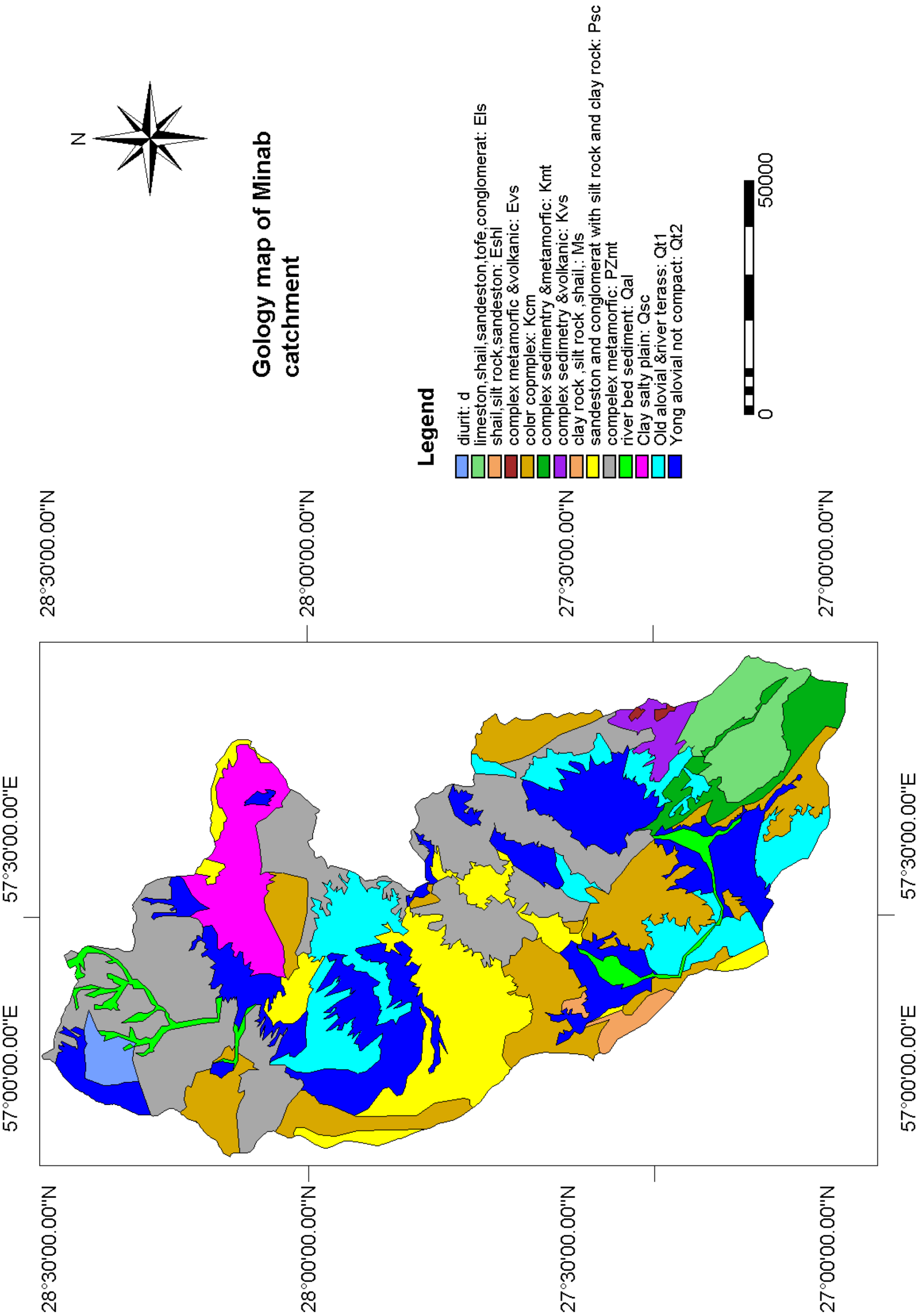


Figure 2.6 Geology map of Minab catchment

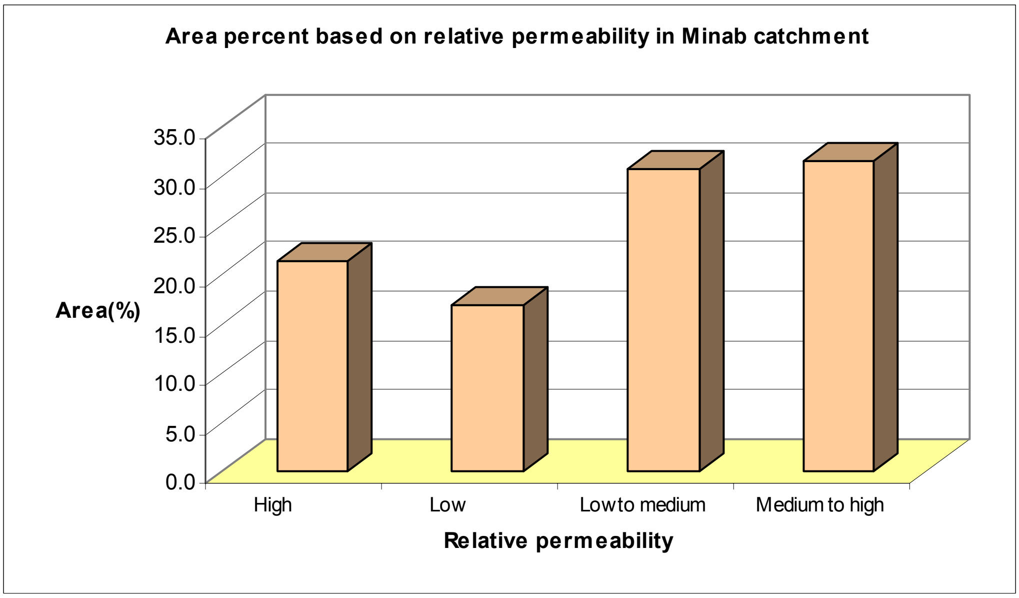


Figure 2.7 Percent of relative permeability in the Minab catchment

Figure 2.8 Orchards location in Berentin village (Southern part of the catchment, July 2002)

2.6 Social and economic aspects

Most inhabitants of the Minab catchment live in villages near rivers, because of the presence of flat alluvial lands and base flow used for irrigation of orchards. Before 1980, only the river base flow has been used for irrigation of orchards. The remaining agricultural activities were more rainfed oriented. Then after 1980, groundwater wells have started to be used for agricultural development. This marked the change from rainfed agriculture to irrigated agriculture. The most important agricultural products from the Minab catchment are: Citrus, Date and Cereals.

2.7 Conclusion

The Minab catchment is a big catchment in the south of Iran. Its runoff depletes to the Minab dam reservoir and to the Persian Golf. Due to primary studies based on topographical conditions, it can be found that these do not have any influence on the observed increase of flood events.

Based on climatological conditions, the Minab catchment is located in an arid tropical regime. Temporal distribution of rainfall is irregular. This causes poor vegetation cover and high rainfall in short time and eventually flood occurrence. As a result of the shallow and young soils in Minab catchment, runoff depletion is quick and the geological conditions in some of the northern and eastern parts with low relative permeability cause a high percentage of surface runoff.

Chapter 3 Land use analysis

3.1 Introduction

Many types of remote sensing images are routinely recorded in digital form and are processed by computers to produce images for interpreters to study. The characteristics of the images used in this research are shown in table 3.1. Figure 3.1 shows the spectral ranges and the relative reflection in the six TM bands in the visible and infrared parts of the electromagnetic spectrum. The spectral reflectance curves correspond with vegetation, hydrothermally altered rocks and unaltered rocks respectively. Spectral ranges of the four MSS bands are also shown in figure 3.1. Band 6 of TM (10.4 to 12.5 µm) lies in the thermal IR region, beyond the range shown in figure 1.3. Land cover refers to different features covering the earth's surface including vegetation cover, water bodies, rock outcrops etc. The land use term refers to man's use of the land and its cover (FAO; 1990). Although land use and land cover are conceptually different, they are used synonymously in many cases (as in this thesis).

The fact that land use/land cover changes with time is commonly known, because of many factors like land-ownership, population pressure etc. The major procedure in achieving the temporal figure of land use is through the application of remote sensing data, which provide an aid in the rapid assessment of the land use in a GIS environment.

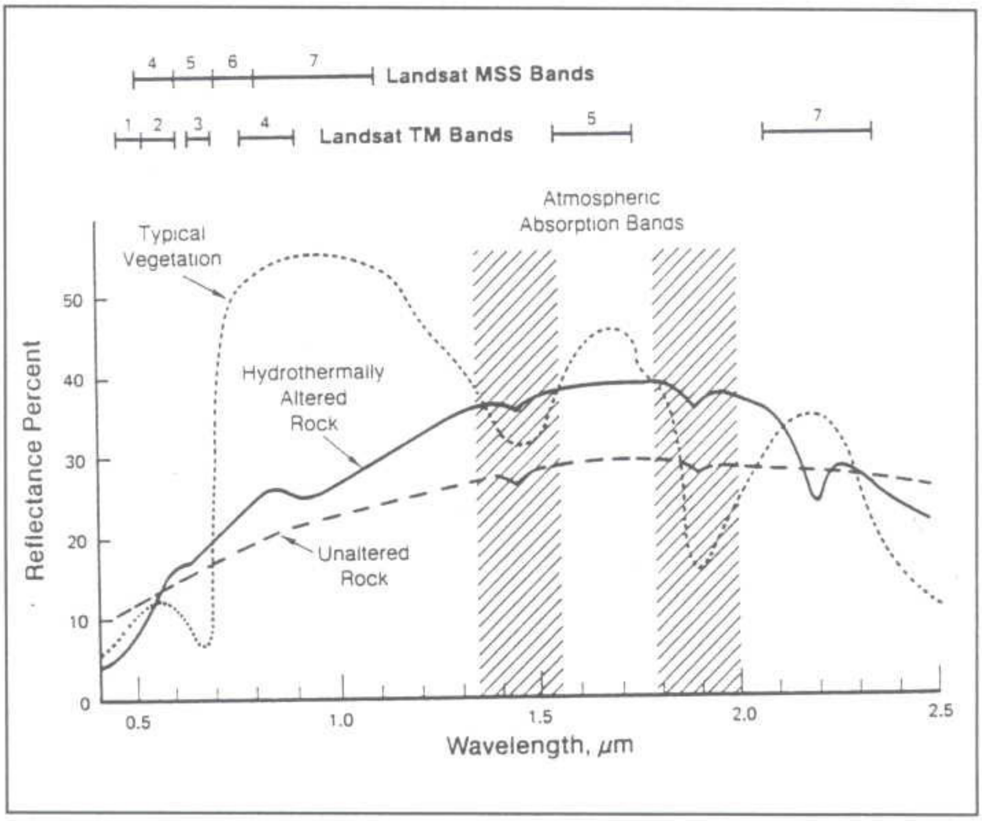


Figure 3.1 Spectral bands of TM and MSS systems (from Sabin, 1983)

Table 3.1 Characteristics of the used satellite images

Satellite image	Bands	Ground resolution (m)	Scene No.	Date
MSS	1 to 4	82m	171/41 170/41	Jul 1976
TM	1 to 7 6	30m 120m	159/41 159/40	Feb. 1988
ETM+	1 to 5, 7 6 Pan	30m 120m 15m	159/41 159/40	Feb.2002

3.2 Methods of land use classification

Different methods and techniques have been used in the procedure for image restoration, enhancement and classification in this study. These steps are described in the following (Fig.3.2).

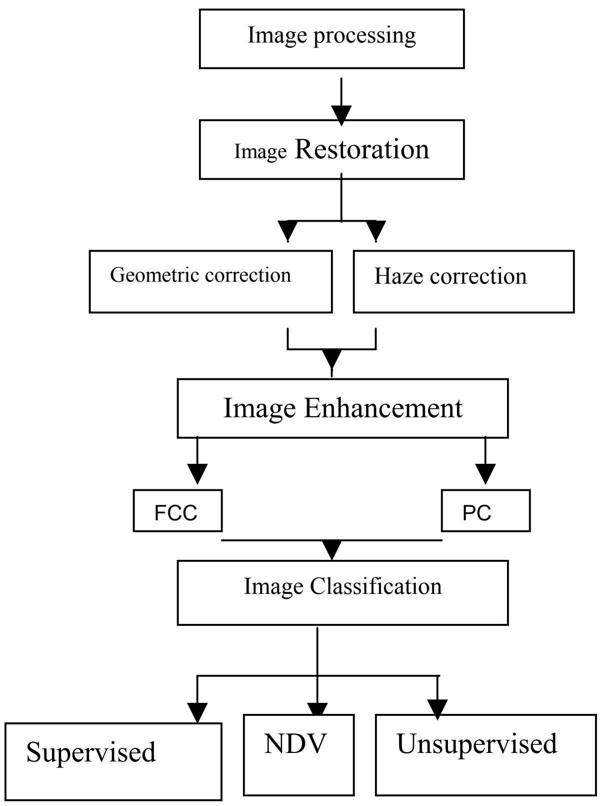


Figure 3.2: image processing (Gudarzi , 2000)

3.2.1 Image Restoration

Data received from satellites need to be corrected before use. Prior to any image classification atmosphere effects and geometric distortions should be removed or corrected for. Radiometric correction has already been done on the applied images by the Remote Sensing Center of Iran before submitting the data to users.

A. Geometric correction

When the images are obtained from the receiving station these are not georeferenced. In order to be able to work in a GIS environment (e.g.; Overlaying maps) the images must be linked to a co-ordinate system and a projection of the earth's globe.

In this study the images (MSS 1976,TM 1988 and ETM 2002) have been georeferenced using the available topographic map to a Universal Transverse Mercator projection using 50 control points for each image. The points have been identified on the topographic map as accurate as possible. An affined transformation was then used to match the geometry of the satellite images with the UTM geometry of map (ITC;ILWIS user manual, 1999).

B. Haze correction

Earth surface and suspended particles in the atmosphere affect the image brightness in the visible and the near infrared TM bands causing low image contrast. Haze correction proceeds through the following steps (ILWIS user Manual, 1999):

-Preparation of the histogram of all bands,

-Subtraction of the minimum value of each band (and all bands) from the minimum value of band 7.

$$Brc=Bx- (Bx\_min - B7\_min)$$

Where:

Brc = haze corrected image.

Bx_min = the minimum value of corresponding image.

B7_min= is the minimum value of band 7 of image.

In this research a simple haze correction has been applied, following the menu of Ilwis 3.1. In the ILWIS operation list, such a script for haze correction of different bands is available.

3.2.1 Image enhancement

Enhancement technique concerns the modification of an image to improve its quality as perceived by a viewer (Mulders, 1987). A number of methods can be applied to perform image enhancement. The most suitable must be selected to achieve the best colour of images for visual interpretation. In this study, the following spatial enhancements have been applied:

-False colour compositing (FCC)

-Principle component analysis (PCA)

False colour compositing (FCC)

A colour composite that is usually composed of three bands is assigned to one of the basic colures: Red, Green, and Blue. Two types of colour composites i.e. a false colour composite (FCC) and a natural colour composite (NCC) are distinguished here. In order to create a clear feature on the Landsat TM images, it is necessary to know the reflection characteristics of the basic cover types of the earth surface.

The best FCC depends on the purpose of the study. From several FCC produced for visual interpretation the best combination was 742 (RGB). In this band combination, 4 different types of area can be distinguished as shown in Table 3.2.

Table 3.2 colures of surface feature in FCC 742

Surface feature	Colour
Irrigated agriculture and orchard	Green to yellow
Water	Red
Rangeland	Dark green
Residential	Blue to dark green

Principle component analysis (PCA)

Principle component analysis is a statistical method used for compressing the original data set without loosing too much information. PCA is collecting the information of the spectral bands used in a cloud of points in a multidimensional space and calculates a new optimum set of axis through this cloud of data points. The number of principal components is equal to the number of bands. The first PC is defined by maximum variance of the original data set; the last PC defines the leftover variance (Meijerink et.al, 1994). In this research from several PCA produced for visual interpretation the best combination was 1.3.4 (RGB) that showed clearly the difference between bare soil and irrigated area and geology.

3.2.3 Image classification

NDVI

The Normalized Difference Vegetation Index (NDVI) is calculated from a TM-scene by taking the ratio of the difference of the near infrared and red reflection and the sum between these two bands using following formula (Dejoing, 1994):

$$NDVI=(TM4-TM3)/(TM4+TM3)$$

NDVI: Normalized Difference Vegetation Index

TM4: TM spectral band 4

TM3: TM spectral band 3

On a NDVI image, vegetated areas will generally yield high values because of their relatively high near –infrared reflectance and low visible reflectance. In contrast, water, clouds, and snow have larger visible reflectance than near-infrared reflectance. Thus, these features yield negative index values. Rock and bare soil areas have similar reflectance in the two bands and result in vegetation indices near zero.

In this study, a NDVI map has been produced (figure 3.3), and then classified in a map with four-land use/land cover classes, i.e.: Poor range; moderate range; good range; forest and agriculture (figure 3.2). A problem that occurred was that it appeared to be not possible to distinguish between land farming and forest, as the reflectance between agriculture and forest in the up of mountains are the same. However, the NDVI classification was useful for discriminating between dry forestland and rangeland, and assigning these to different classes.

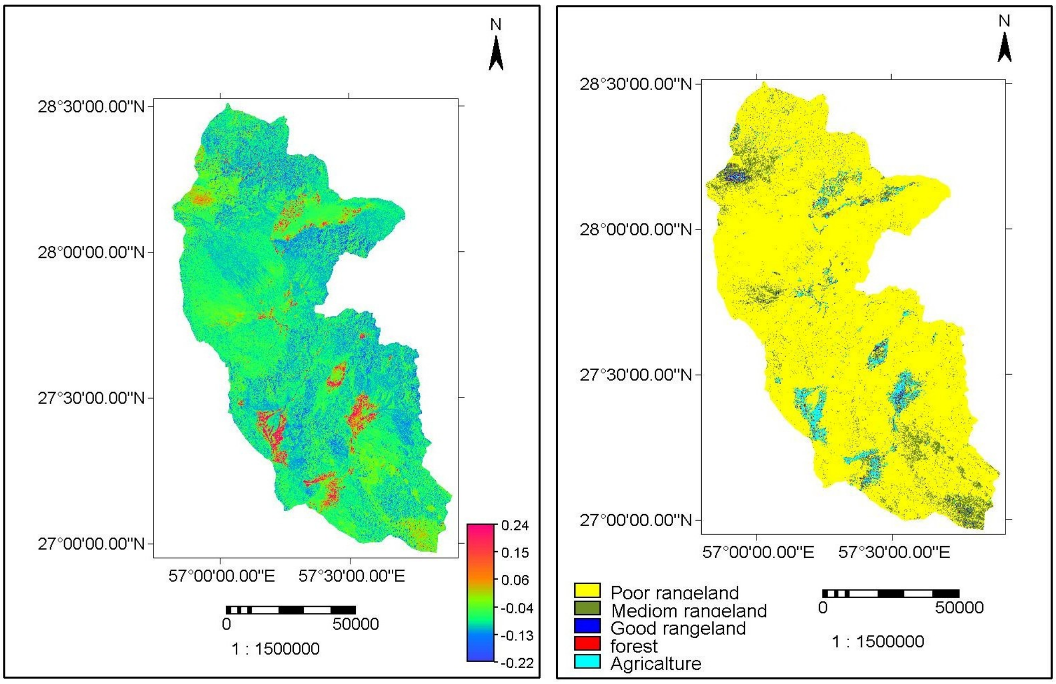


Figure 3.2 and 3.3 NDVI and NDVI classification maps of Minab catchment(TM, 1988)

<u>Unsupervised classification</u>

In this type of classification, the computer produces spectral classes based on the digital numbers (DN) without any direction from the user. It gives preliminary information on the potential spectral clusters to be assigned to thematic classes. Therefore, subsets of the satellite data were first classified using unsupervised classification. All together 8 classes were used. This classification has been used as a guide in the selection of training sites for input into the supervised classification.

Supervised classification

Supervised classification is based on ground data collected in the field from training- sample sites. For visual interpretation of land cover, band combinations 432 and 742 showed to be the best. Selecting individual pixels rather than areas has done sampling. Two dimensional feature space diagrams illustrated the validity of the samples. In these diagrams classes have been checked for any combination of two bands. In other words, the training-sample sites have been used to define the decision space of the eight different classes of land cover. In order to determine the necessary samples for each image the following strategy has been used:

ETM image 20002: samples for this image were only based on field observations incl. GPS positioning, providing more than 300 samples for different land use types;

TM image 1988: samples for this image were based on field interviews and old maps, providing more than 250 samples for different land use types;

MSS image 1975: samples for this image were based on field interviews, old maps and aerial photo interpretation, providing more than 150 samples for different land use types.

Finally, 7 classes were extracted, namely: Irrigated agriculture, Orchard, Rainfed crops, Poor rangeland, Moderate rangeland, Good rangeland and Residential area. The box classifier was recognized as the most meaningful algorithm, due to big size of the Minab catchment and they have limitation samples others method (maximum likelihood) couldn't do it, the image was then classified. The result of which is shown in figure 6.4.

The result of a supervised classification usually has some percentage of misclassification, due to noise and unknown pixels. For example, in this study farmland was misclassified as forest. After classification, it was necessary to test the accuracy of the classification by using field knowledge and other ancillary data.

Due to the big size of the Minab catchment and the variation distribution of the native vegetation (rangeland and forest), it was necessary to apply a stratified approach on the land classification process for the whole area. For instance, some of the forest areas on steep mountains were classified as agriculture. This is inevitably wrong. Therefore, before the supervised land classification of the study area, agriculture and orchard land have been separated from the native vegetation (rangeland and forest) by on-screen digitizing from a colour composite of the area. Then both individual parts were separately classified using supervises classification. Then it appeared that the prepared land classification was not suitable for rangeland and forest area. In addition, a slicing procedure was applied to the NDVI in order to discriminate between rangeland and forest area. Finally, the classified maps of both the low-lying agricultural area (orchard, irrigated agriculture, rainfed and residential) and the higher elevated native vegetated area (rangeland and forest) have been joined. This was done for three images taken in 1976,1988 and 2002, respectively.

3.2.4 Analysis of spectral response curves of land cover classes

All materials exhibit a unique spectral response to electromagnetic radiation, due to variations in their physical state or chemical composition. As the response to the radiation varies across the electromagnetic spectrum (EMS), the resulting spectral signatures can be used to identify features within the satellite data. Fig. 3.1 shows typical spectral signatures for vegetation, soil and water. Comparison of the typical spectral signatures for vegetation, soil, and water to the pseudo-spectra corresponding to the land cover classes identified on the TM and ETM images of the Minab catchment allow for a more complete interpretation of the characteristics of the classes in the images.

In contrast to the problems with separating agricultural area with forest and good rangelands, I faced with mixing them on the images, somehow the very high slope mountains were determined as agricultural lands; These types included residential, rangeland, orchard, irrigated agriculture and forest class representing dense irrigated agriculture. Detailed analysis of the pseudo-spectra for these land cover classes demonstrate the potential of separating these vegetation classes on their spectral characteristics, with breaking the whole area to the less extent sub areas that with this method we would have restricted areas with different DNs.

Although these types are distinguishable as different land cover types, they all demonstrate the typical characteristics of a vegetation-like spectral signature with the dramatic increase in brightness coming from band 4 (infrared). This is being referred to as the ‘red edge’.

Looking in detail at the pseudo-spectra of the rangeland classes, the effect of the presence of different amounts of exposed soil can also be observed. As shown in figure 3.4, a rangeland signature is overall brighter than agriculture, and generally increases in brightness from the visible through the infrared wavelengths. The pseudo-spectrum of rangeland resembles that of the agriculture though the brightness values are generally higher. The contrast of bare soils between rangelands is very high and in fact the rangelands are not well integrated, that makes the classification invaluable, because of this NDVI indices were used for rangelands classifying.

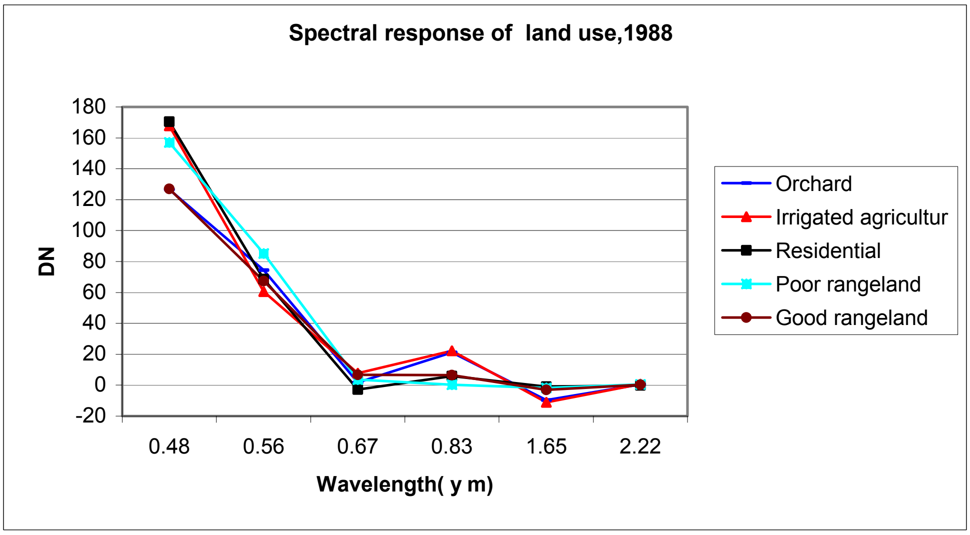


Figure 3.4 Spectral response of land use, 1988. (TM)

The two classes are also expected to be similar in the significant contribution of the soil to the spectral signatures, due to the sparse vegetation cover of both classes. The higher brightness values of the rangeland (appendix A.4 and A.5 tables) probably result from a higher soil to vegetation ratio relative to the agriculture class. An extreme case of bare soil is a very high brightness value in all bands.

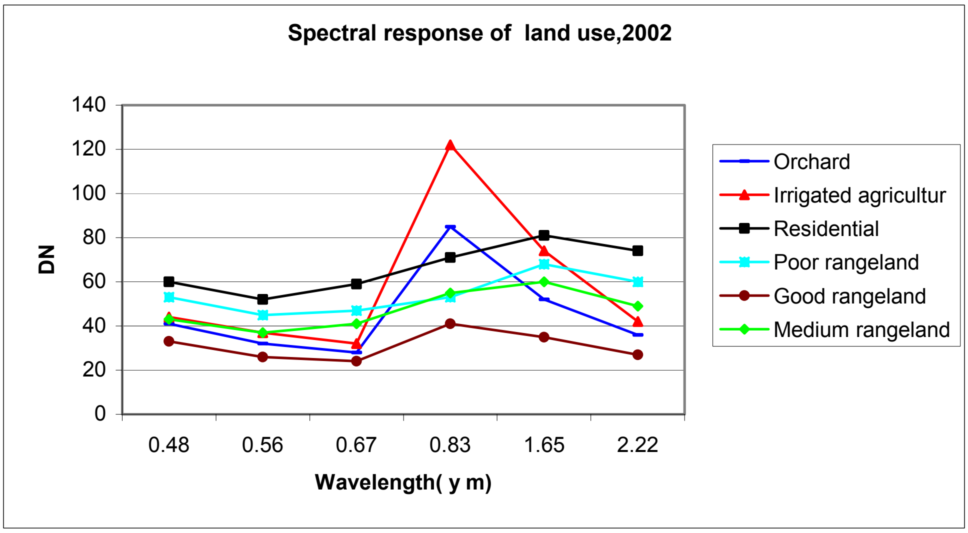


Figure 3.5 Spectral response of land use, 2002. (ETM^+)

3.3 Accuracy of classification result

The applied empirical approach requires an accuracy assessment of the results of the spectral classifications. This may be done by using various methods. A relatively simple one is described below, expressing overall and category accuracies. (Meijerink et al., 1994)

To access the accuracy of an image classification result, it is common practice to create a confusion matrix or error matrix. In a confusion matrix, classification results are compared to additional ground truth information. To obtain a confusion matrix, a raster map with ground truth information is required (which has not been used to train the classifier). This map is then crossed with the classification result, and displays the cross table. This can be done by choosing the confusion matrix command from the View menu in the ILWIS table window. (Ilwis help. version 3.11). The accuracy of the 1976, 1988 and 2002 land cover maps are showed in the related error matrices (tables 3.3, 3.4 and 3.5). The overall accuracy refers to the number of correctly classified pixels. The overall accuracies obtained are 83.8%, 84.4% and 83.65% for the 1976, 1988 and 2002 maps respectively. The user accuracy is the probability that a reference pixel has been correctly classified, and it is calculated by dividing the diagonal values of each class by the column total. The producer accuracy is the probability that a pixel classified on the map represents that class on the ground (Anderson, 1976). The values obtained for the producer are 80.95%, 75.07% and 81.13%. The user accuracies are 83.8%, 84.4% and 82.72%. These all apply to the 1976,1988 and 2002 land use maps respectively.

Table3.3. Error matrix of 1976 land use map

Land use type	**Re**	**Or**	**Fo**	**G.R**	**I.A**	**P.A**	**M.R**	**Ra**	Producer Accuracy
Re	5	1	0	0	0	0	1	0	0.71
Or	0	24	0	0	1	0	0	0	0.96
Fo	0	1	26	0	3	0	0	0	0.87
G.R	0	0	2	21	1	2	3	1	0.70
I.A	0	0	2	1	16	0	0	0	0.84
P.A	0	0	2	1	1	20	2	0	0.77
M.R	0	0	1	2	1	4	35	0	0.81
Ra	0	0	1	1	2	0	0	17	0.81
User Accuracy	1.00	0.92	0.76	0.81	0.64	0.77	0.85	0.94	201.00

Average accuracy= 80.95%   Average reliability= 83.79%

Overall accuracy= 81.59%

Table3.4. Error matrix of 1988 land use map

Land use type	Re	Or	Fo	G.R	I.A	P.A	M.R	Ra	Producer Accuracy
Re	25	1	0	0	0	0	0	0	0.96
Or	1	56	0	0	1	0	0	0	0.97
Fo	0	1	16	2	0	0	0	0	0.84
G.R	0	1	2	18	0	0	2	0	0.78
I.A	1	4	1	3	64	0	0	0	0.88
P.A	1	1	0	2	1	29	4	0	0.76
M.R	2	3	2	0	1	0	35	0	0.81
Ra	0	0	0	2	0	0	0	0	0.00
User Accuracy	0.83	0.84	0.76	0.67	0.96	1.00	0.85		282.00

Average accuracy= 75.07% Average reliability= 84.38%

Overall accuracy= 86.17%

Table 3.5 Error matrix of 2002 land use map

Land use type	Re	Or	Fo	G.R	I.A	P.A	M.R	Ra	Producer Accuracy
Re	15	7	0	0	0	1	1	0	0.63
Or	1	85	0	2	4	1	3	0	0.89
Fo	0	2	33	2	1	0	0	0	0.87
G.R	0	0	2	20	0	1	3	0	0.77
I.A	0	3	2	2	49	1	1	0	0.84
P.A	0	0	1	1	1	29	2	0	0.85
M.R	1	1	1	0	1	2	30	0	0.83
Ra	0	0	0	0	0	0	0	0	
User Accuracy	0.88	0.87	0.85	0.74	0.88	0.83	0.75		312.00

Average accuracy= 81.13% Average reliability= 82.72%

Overall accuracy= 83.65%

Where

Re: Residential

I.A: Irrigated agriculture

P.R: Poor rangeland

M.R: Medium rangeland

Ra: Rainfed

Or: Orchard

Fo: Forest

G.R: Good rangeland

3.4 Land use maps

Three land use maps have been prepared using the available satellite images, aerial photos and other field data for the years 1976,1988, 2002 (table 3.6 and figure 3.7). The eight different types of land use that have been distinguished in these maps are described in the following.

1. Forest: this land cover type includes dry forestland, located in hilly areas and at high altitudes, containing species such as Acacia and Prosopis. It also includes sub forestland, mostly observed at altitudes higher than 1500 m +MSL, including Amingdalus and Cupresus. The entire area here is considered as forest (fig.3.10).

2. Good rangelands: this type includes dense rangeland and vegetation, covering more than 15%.

3. Medium rangelands: this type contains moderately dense rangeland and vegetation, covering 5-15%.

4. Poor rangelands: this type includes poor range, low dense vegetation, covering less than 5% and bare soil.

5. Orchard: it includes a mixture of palm and citrus trees (fig.2.4and3.8).

6. Irrigated agriculture: these lands are mostly cultivated under vegetables and cereal.

7. Rainfed agriculture: these lands are cultivated under cereals, which only occur in the land use map of 1976. Due to the extension of the agricultural wells, this type has been irrigated or left as fallow.

8. Residential area: this land cover type contains the urban area, villages and towns situated within the catchment. The buildings were constructed from wood, stone and mud. Two basic styles of construction can be distinguished, in the period before 1978 (national revolution) and afterwards.

3.4.1 Land use map, 1976

In 1976, about 90 % of the study area of the Minab catchment was still covered with forest and rangeland. These classes consisted of 50% poor rangeland, 38% medium rangeland and 3% forest (table 3.6). Only in this year the agricultural lands are characterized as rainfed.

3.4.2 Land use map, 1988

In this year, the poor rangeland, medium rangeland, good rangeland and forest covered 87%, 8.5%, 1% and 0.5% respectively. The extent of orchard, irrigated agriculture land and settlements covered 1%, 2% and 0.2%. In this year the extent of rainfed agriculture was zero (table 3.6). In comparison with land u se map of 1976,severe reduction of good, medium rangeland and forest has been noticed. Increase of agriculture lands and residential also have been observed.

3.4.3 Land use map, 2002

In this year, the extent of poor rangeland, medium rangeland, good rangeland and forest land covered 87%, 5%, 1.5% and 1.33%. Orchard, irrigated agriculture and settlements covered 3%, 1.4% and 0.3% respectively (table 3.6). In comparison with land use map of 1988, the most important change is due to cultivated land change to orchard.

Table 3.6: land use types of the Minab catchment, 1976,1988 and 2002

Land use type	*1976*		*1988*		*2002*	
Unit	*KM^2*	*%*	*KM^2*	*%*	*KM^2*	*%*
Forest	259.07	2.59	44.89	0.45	132.44	1.33
Good rangeland	441.17	4.41	90.78	0.91	149.53	1.50
Irrigated agriculture	75.55	0.75	190.81	1.91	137.12	1.37
Medium rangeland	3828.54	38.25	851.58	8.53	500.74	5.01
Orchard	38.3	0.38	93.43	0.94	300.77	3.01
Poor rangeland	5258.05	52.54	8696.84	87.07	8741.41	87.49
Rainfed	102.55	1.02	0	0.00	0	0.00
Residential	4.96	0.05	20.02	0.20	29.32	0.29
Total	***10100***	***100***	***10100***	***100***	***10100***	***100***

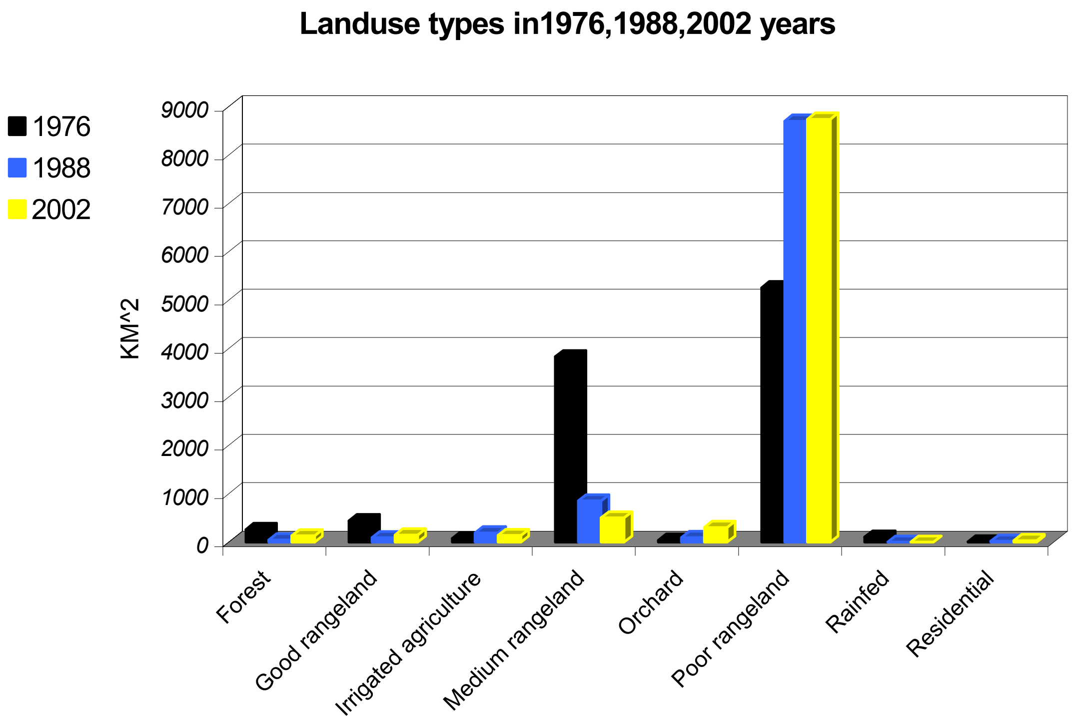


Figure 3.6 land use types of the Minab catchment, 1976,1988 and 2002

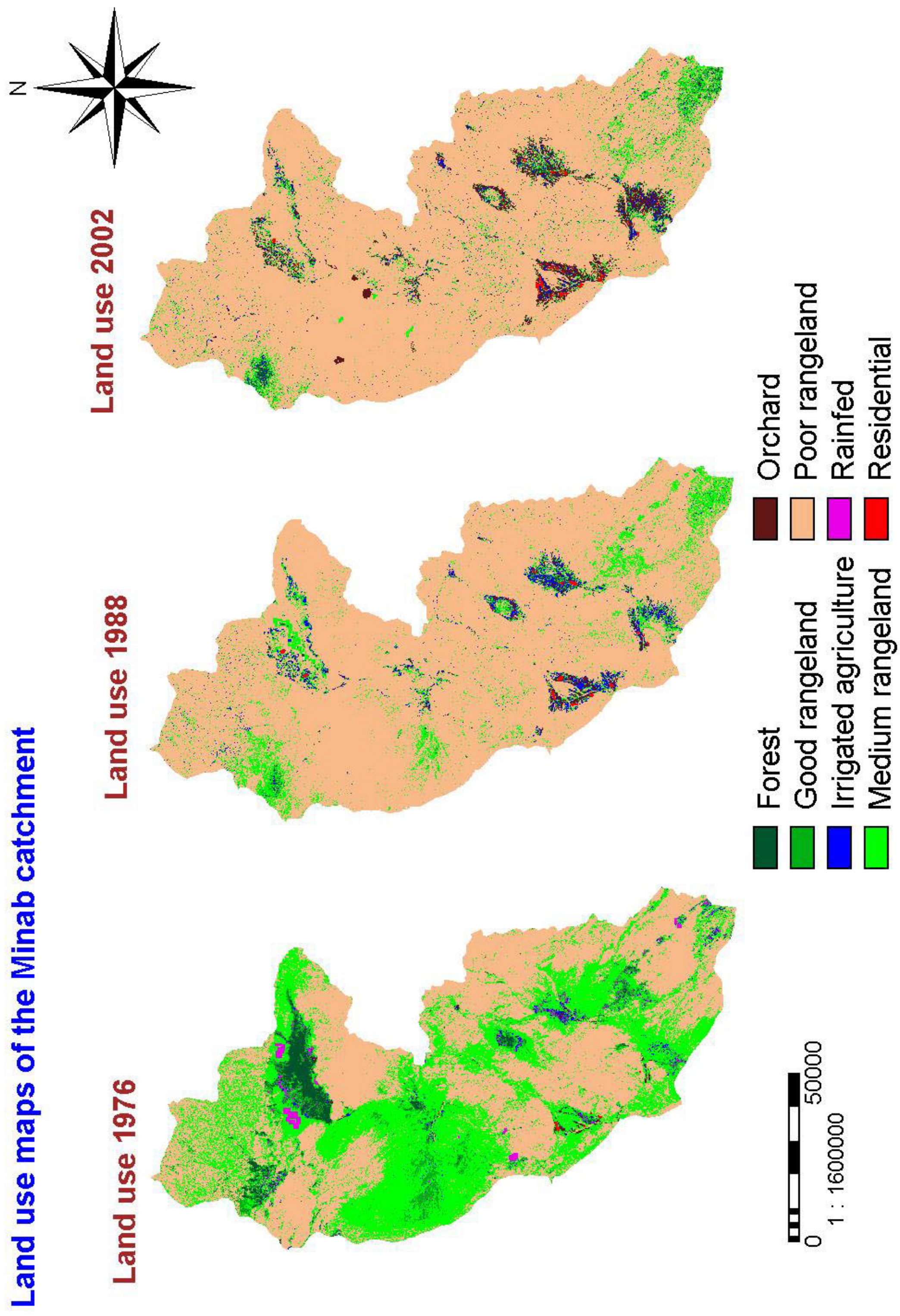


Figure 3.7. Land use maps of the Minab catchment, 1976, 1988 and 2002

Figure3.8 Development of agriculture lands and orchards, 2002

Figure3.9.   Poor rangeland type of Minab catchment, 2002

Figure3.10 Dry forest land of Minab catchment, 2002

3.5 Land use changes

3.5.1. 1976-1988 period:

In this period, the maximum change is related to a decrease in the extent of medium rangelands and an increase in poor rangelands, 30% and 34% respectively. This change shows the disappearance of the natural vegetation cover in the catchment. There are different factors accounting for this, such as drought and mismanagement of rangelands. This is based on interviews with local villagers in the catchment and experts of the Natural Resources Office. It was observed that after 1978, the protective programs and exploitation system in the region did not have any follow-up, and a negative trend without any care for natural vegetation was initiated. Also, with the carry-out of agricultural development programs and digging of deep wells, the coverage of irrigated lands in this period has increased (1.2%). The change was from rainfed lands to irrigated lands (table 3.8 and fig.3.6).

3.5.2. 1988-2002 period:

In this period, despite the slight increase in rainfall, the natural vegetation cover did not recover to the situation in the late seventies. Only the extent of the orchards increased with about 3%, as an effect of long duration of a drought period combined with mismanagement of the exploitation of the rangelands. These are the two main factors that reduced the probability of natural reclamation of rangeland during these relatively wet years (table 3.7).

Table 3.7. Land use changes in 1976-1988 and 1988- 2002 periods

Land use types	1976-1988 period		1988-2002 period	
Unit	KM^2	%	KM^2	%
Forest	-214.18	-2.14	87.55	0.88
Good rangeland	-350.39	-3.50	58.75	0.59
Irrigated agriculture	115.26	1.16	-53.69	-0.54
Medium rangeland	-2976.96	-29.73	-350.84	-3.51
Orchard	55.13	0.55	207.34	2.07
Poor rangeland	3438.79	34.53	44.57	0.42
Rainfed	-102.55	-1.02	0.00	0.00
Residential	15.06	0.15	9.30	0.09

3.6 Conclusion

In the Minab catchment land use types can be grouped in to three major groups, namely agriculture area (irrigated agriculture, rainfed agriculture and orchard), rang and forest land (medium rangeland, good rangeland and forest) and poor natural cover area (poor rangeland, bare soil and rock out crop).

Considering of the aim of this study the percent of changes area was determined for total of the study area (mountain, alluvial. and hilly area) and just for hilly area.

The hilly and mountain area are very important due to type of geology of this area (low permeability) so it has more runoff (appendix, fig. B.2). According to the figure 3.6 (total of study area) the sequence of land cover changes including:

-Decreasing rang and forest land (medium rangeland, good rangeland and forest).

-Increasing poor natural cover area (poor rangeland, bare soil and rock out crop).

-Increasing residential area.

Before 1978(The change time of policies of natural resource management in Iran) basin’s vegetation cover especially medium rangeland had a relatively good condition because climatological condition and management were suitable.

After 1978 because of changing in control structures on natural resources that was the beginning of drought period the vegetation cover starts reducing and in the years after drought period, the natural important was not possible. These changes have an important effect on hydrologic regime of the basin in this period.

Chapter 4 Climatologic data analysis

Introduction

The climatologic data analysis (Ch.4) is including analysis of rainfall, temperature and evaporation characteristics of Minab catchment. Since rainfall is source of runoff and evaporation and temperature effect on runoff.

4.1 Meteorological Data

There are three climatologic stations and five rain gage stations in the study area. Table 4.1 shows the stations and the period for which data are available. All of the stations are located inside the Minab catchment. In this study a data set for daily rainfall is available for all stations in a 25 years period (1975-2000). Some stations have been operated since 1966 already. The location of the stations is shown in figure 1.1

Table 4.1 Meteorological stations distribution and recording periods in the Minab catchment

Name of Station	Location	Station Type	Altitude (m)	Average annual rainfall (mm)	Recording period (Years)	Data available for analysis
Faryab	27° 29′ 0″ 57° 5′ 30″	Climatologic	290	317.40	1966-2000	Daily, monthly (rainfall)
					1975-200	Monthly (tepertur, evaporation)
Zehamkan	28° 18′ 0″ 57° 9′ 0″	Rain gage	1320	187.70	1966-2000	Daily, monthly (rainfall)
Mohammad abad	27° 46′ 0″ 57° 12′ 0″	Rain gage	480	210.31	1966-2000	Daily, monthly (rainfall)
Berentin	27° 16′ 0″ 57° 11′ 0″	Climatologic	128	257.25	1966-2000	Daily, monthly (rainfall)
					1975-200	Monthly (temperature, evaporation)
Bolbol- abad	27° 24′ 45″ 57° 31′ 34″	Rain gage	310	218.66	1966-2000	Daily, monthly (rainfall)
Dareh-shour	28° 4′ 0″ 57° 18′ 0″	Rain gage	640	199.76	1966-2000	Daily, monthly (rainfall)
Glashgerd	28° 0′ 0″ 57° 13′ 0″	Climatologic	640	181.27	1966-2000	Daily, monthly (rainfall)
					1975-200	Monthly (temperature, evaporation)
Aseminon	27° 23′ 0″ 57° 23′ 0″	Rain gage	750	263.32	1966-2000	Daily, monthly (rainfall)

4.2 Catchment Rainfall

4.2.1 Density of rain gage stations

An issue that should be noted in most hydrological studies is how many observation stations are necessary for a particular analysis. In order to determine the optimum numbers of rain gage stations regarding the accuracy assessment, the following simple statistical equation (4.1) can be used. (Alizadeh, 2001)

$$N=(Cv/E)^2 \qquad (4.1)$$

Where

Cv**:** Coefficient variable rainfall area based on available stations and data

E: Percentage of permissible error in area average rainfall estimation

N: Numbers of required rain gage stations

P: Average rainfall of area

Based on information from the 8 rain gages stations in the Minab catchment (3 climatic, 3 rain gage), the following statistical parameters on rainfall have been calculated:

$\overline{P}=\Sigma\ \overline{P}/n = 228.44$

$\overline{P}^2=\Sigma\ \overline{P}^2/n = 53822.12$

$S=\sqrt{}\Sigma(P-\ \overline{P})^2/n\text{-}1=43.3$

$Cv=100S/\ \overline{P}=100*43.3/228.44=18.95$

$N=(Cv/E)^2=(18.95/10)^2=3.59$

Based on a 10 % permissible error and rainfall data of available stations, the minimum required number of stations is four, which is half of the existing number of stations.

4.2.2 Checking of rainfall data

To check the reliability of the rainfall data, the mass curve method has been applied. The accumulated rainfall data was plotted against time (years). The result is shown in figure 4.1. It can be concluded that there is no systematic discontinuity between the stations, and the data can be used in the further analysis.

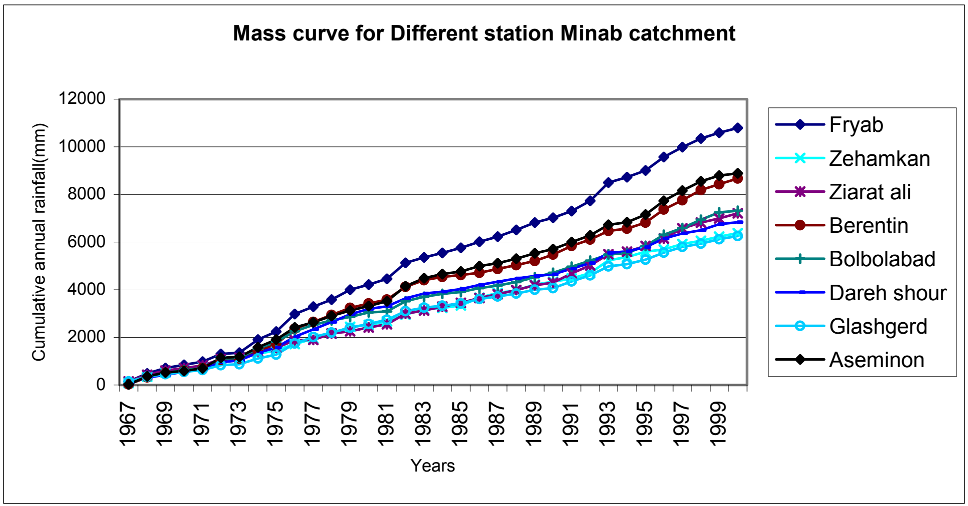


Figure 4.1 Mass curves of rainfall stations

4.2.3 Monthly course of rainfall

The average monthly rainfall of 8 stations is shown in figure 4.2. There is a relatively wet period from December until April. Also there is a relatively dry period from May to November. This is associated with climate of area.

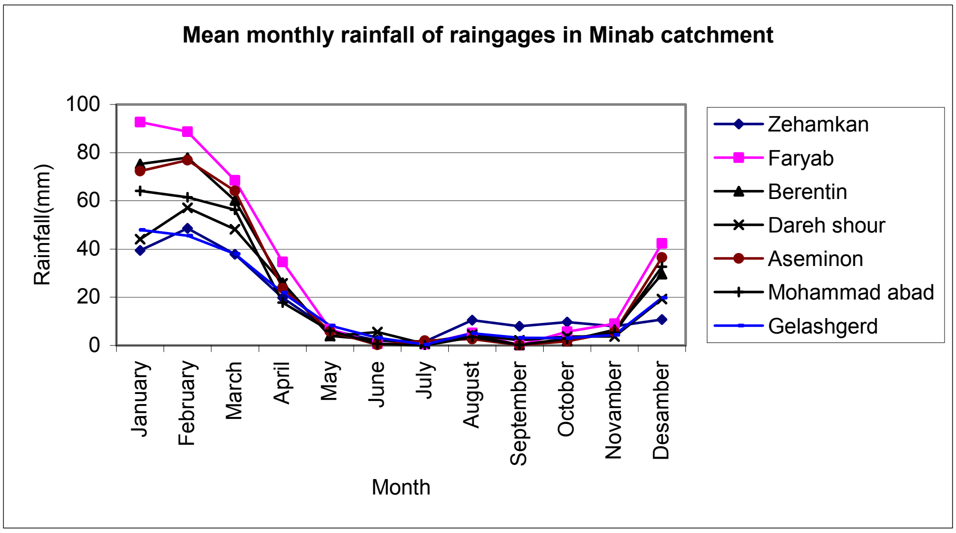
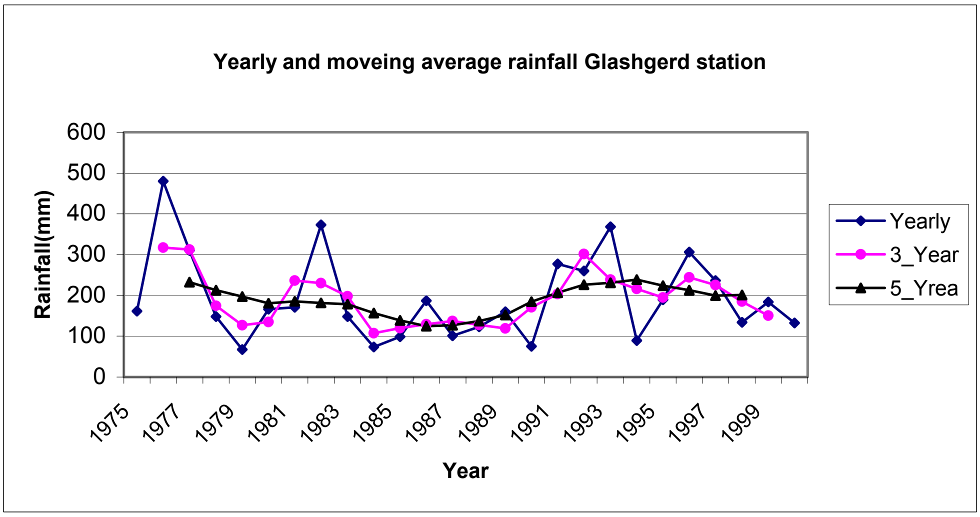


Figure 4.2 Mean monthly rainfall of rain gages in Minab catchment

4.2.4 Annual rainfall

For the period 1975 to 2000, the annual rainfall, 3-years and 5-years moving averages are shown for one station in the Minab catchment in figure 4.3. The full time series for all 8 stations are enclosed in Appendix B.5. All stations show a decreasing trend in rainfall during the period 1985 to 1991. The presented times series for 8 stations particularly illustrates (Appendix A.1).



Figures 4.3 Yearly and moveing average rainfall of rain gages in Minab catchment

4.2.5 Correlation between rainfall and altitude

It can be conclude that no clear correlation exists between the altitude and the annual average rainfall for the available 26 years of the 8 stations in the Minab catchment (see for the situation of the stations figure 3.7). The correlation index of altitude and rainfall is about R= -0.52 (negative trend). This has also been concluded from a previous studies carried out in the south of Iran (Movahed danesh, 1991 and Abvarzan, 1994).

Figure 4.4 shows the relatively low correlation between rainfall and altitude in the Minab catchment. The reason may be the nearby existence of the sea, because there is a relatively moderate correlation between longitude and rainfall. This is indicated by the slightly higher mean annual rainfall of the Berentin and Faryab stations, that are both closer to the sea, compared to the Zehamkan and Gelashgerd stations, that are in the mountainous part in the north of the catchment.

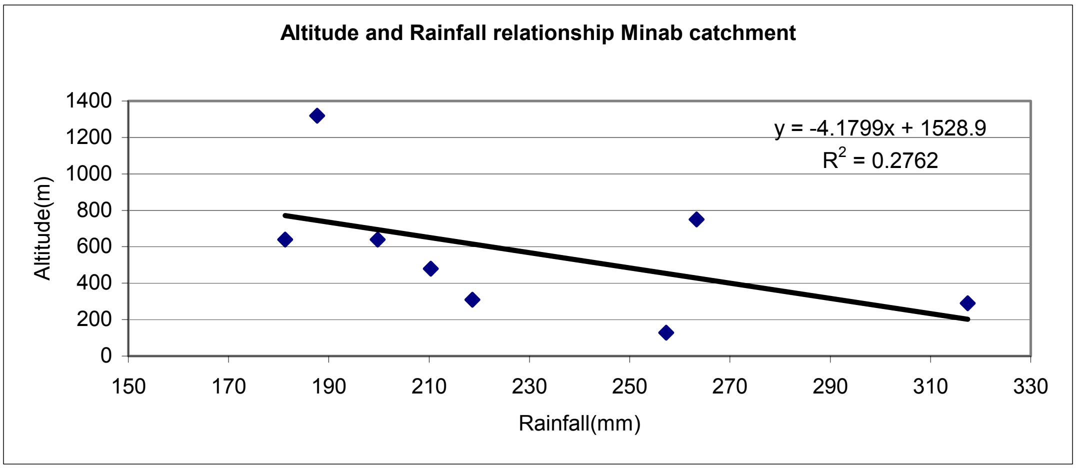


Figure 4.4 Relation between altitude and precipitation

4.2.6 Areal rainfall

To calculate the spatially distributed rainfall for an area, the point rainfall needs to be converted to an area depth of rainfall. There are various methods to do this. In the present study two methods have been used. These are explained in the following.

Thiessen polygon method

The first step in the Thiessen polygon method is to connect all the rain gages by straight lines so that no lines form an angle greater than 90 degrees. Next, we construct perpendicular bisectors of the first lines. The bisectors should intersect with in the triangular areas. The area of each polygon within the catchment is divided by the total area and expressed as a percentage. The area percent multiplied by the rainfall amount for each polygon gives an estimation of the rainfall over the watershed. The relative area weight for eighth polygons enclosing the corresponding stations in percentages is shown in Table 4.3. Figure 4.5 shows the constructed Thiessen polygons in the study area.

Table 4.3 Areal rainfall using the Thiessen polygon method

Name of station	Polygon area (Km^2)	Weight%	Rainfall (mm)	Weighted rainfall (mm)
Aseminon	1114.8	0.11	263.32	29.2
Berentin	1224.8	0.12	257.25	31.4
Bolbol-abad	1912.8	0.19	218.66	41.6
Dareh-shour	807	0.08	199.76	16.0
Faryab	1148.6	0.11	317.4	36.3
Gelashgerd	1367.6	0.14	181.27	24.7
Mohammad-abad	1804.4	0.18	210.31	37.8
Zehamkan	666.6	0.07	187.7	12.5
TOTAL	10046.6	1.00		229.4

Isohytal method

The Isohytal method is based on interpolation between gauges. The following approach is used to make such a map. The first stage is to plot the location of the rainfall station on the map with the amount of rainfall in each gauge. Next, the best interpolation method between gauges is determined. Applying the moving average method to rainfall amounts in the study catchment does this. Then, by the slicing method, the identical depths from each interpolation are connected to form Isohytal lines of equal rainfall depth. The areal average is the weighted average of depth between the isohyets, that is, the mean value between the isohyets. In table 4.4 the yearly amount of rainfall in the area closed and average rainfall of Minab catchment by Isohytal method.

Figure 4.5 shows the spatial distribution of mean annual rainfall using the Isohytal method.

Table 4.4 Areal rainfall using the Isohytal method

Value of Isohytal (mm)	Area enclosed (Km^2)	Amount of rainfall (mm)
200	479.1	9.5
210	1456.4	30.4
220	1926.6	42.2
230	2078.9	47.6
240	2436.9	58.2
250	1668.6	41.5
TOTAL RAINFALL		229.5

4.2.7 Correlation analysis between stations

There are a series of factors affecting rainfall. Among them, topography and distance between rain gage stations are the most influencing factors that affect this relationship. Correlation analysis has been applied to determine the degree of association of rainfall from the different stations. The results of the correlation analysis based on annual rainfall are shown in table 4.5. The linear regression analysis results indicate that there is only a low association between the stations. In Minab catchment correlation between Zehamkan and Mohammad abad stations with other stations are low and correlation between other stations are good.

Table 4.5 Correlation matrix based on annual rainfall data of Minab catchment stations

Stations	Fryab	Zehamkan	Mohammad abad	Berentin	Bolbolabad	Dareh shour	Glashgerd	Aseminon
Fryab	1.00							
Zehamkan	0.65	1.00						
Mohammad abad	0.72	0.50	1.00					
Berentin	0.83	0.39	0.65	1.00				
Bolbolabad	0.75	0.36	0.62	0.88	1.00			
Dareh shour	0.84	0.62	0.57	0.77	0.76	1.00		
Glashgerd	0.89	0.60	0.72	0.81	0.74	0.88	1.00	
Aseminon	0.85	0.48	0.75	0.90	0.91	0.77	0.80	1.00

4.3 Catchment evapotranspiration

There are three climatologic stations in the Minab catchment that have good recorded data. These include: Berentin, Faryab and Gelashgerd. That is used for calculation of potential evapotranspiration by Pan method.

Evapotranspiration involves both processes of water evaporation from soil surface and transpiration by growing plants. To measure evaporation and transpiration separately is very difficult. Therefore, these are generally grouped together in one term. Transpiration is the process where by water is brought up through the plant root, circulated throughout the plant structure and finally returned (transpirated) to the atmosphere.

4.3.1 Potential Evapotranspiration

ETP is the maximum amount of water that could be evaporated by vegetation assuming an unlimited supply of water in the ground. There are several method for calculation of potential evapotranspiration such as: Blaney–Craiddle, Penman, etc. In this study Belany-crridle and Pan method are used for calculation of ETP. (Maidment, 1996)

<u>Pan method</u>

This method relates the potential evapotranspiration to the evaporation from the free water surface from a standard US class A evaporation pan used by the National Weather Service through dimensionless pan coefficient K_p.

$ET_o = K_p * E_{pan}$

Pan coefficient varies with pan exposure, wind velocity, humidity, and placement within the field. Regarding to previous studies, it was used 0.6 coefficients for this project. (Alizadeh, 2001)

<u>Blaney-Craiddle method</u>

This method is commonly used in the semi-arid region and requires temperature and mean day time percentage of annual day time hours. The following formula is used for calculating the ETP:

$ETP=P\ (0.46T+8)$

Where

ETP: Potential evapotranspiration (mm/day)

T: Mean daily temperature (°C)

P: Mean day time percentage of annual day time hours

Table 4.6 shows that the results of the Pan and Blaney-Craiddle methods are almost the same. (Fig.4.6)

Table 4.6 variation of mean annual ETP, 175-2000 period

Year	Pan method	Blaney-Craiddle method
1975	2212.65	1765.03
1976	1960.92	1710.26
1977	2180.02	1823.51

1978	2125.21	1760.29
1979	2202.44	1795.24
1980	2084.41	1696.36
1981	2191.88	1691.89
1982	1812.03	1750.31
1983	1836.23	2088.72
1984	2017.81	1816.51
1985	2150.48	1819.25
1986	1967.79	1780.88
1987	2021.49	1822.41
1988	1875.39	1823.56
1989	1894.65	1766.18
1990	1957.05	1802.45
1991	1811.59	1748.58
1992	1729.38	1696.67
1993	1891.20	1772.25
1994	1816.75	1780.90
1995	1898.09	1772.87
1996	1778.29	1770.79
1997	1872.46	1758.37
1998	1840.17	1814.20
1999	1734.05	1792.36
2000	2150.84	1807.60

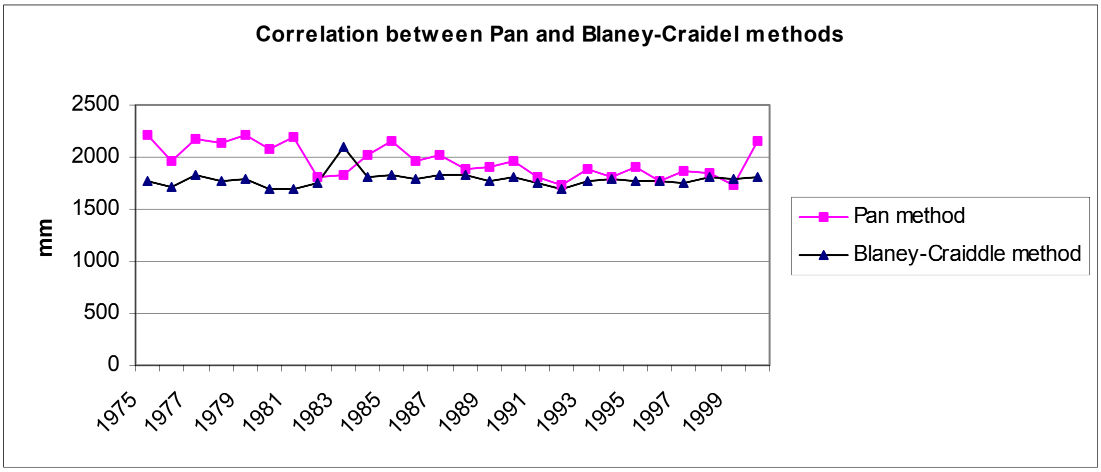


Figure 4.6 Correlation between Pan and Blaney-Craiddle methods

4.4 Correlation between mean annual climatologic data

Climatological studies show a reliable relation between mean precipitation, temperature and evapotranspiration in the Minab catchment. As shown in figure.4.7, the amount of annual precipitation is increasing and temperatures are rising with decreasing rates of evapotranspiration, and vise versa. This shows the effect of evapotranspiration on hydrologic variations and low flow in dry years.

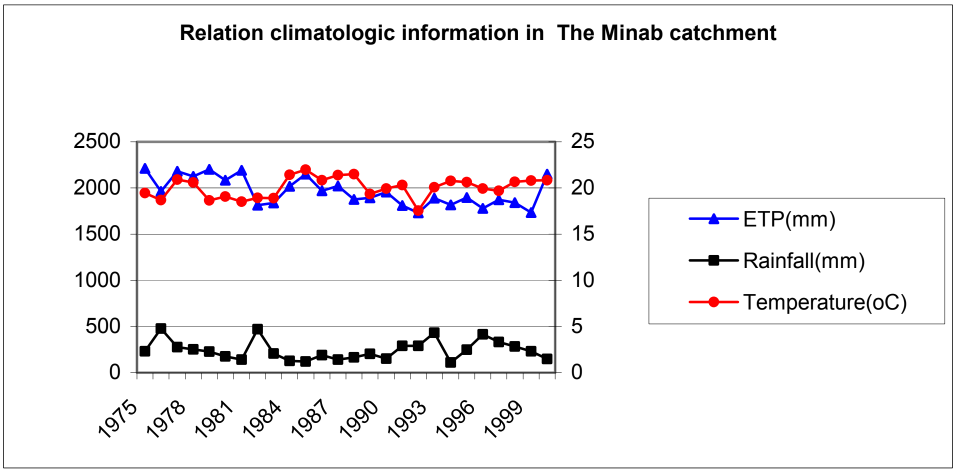


Figure 4.7 Relation between climatologic data, 1975-2000 period

4.5 Conclusion

There is a relatively wet and dry periods from December till April and May to November respectively in the Minab catchment. All of stations in the same period (1984 to 1990) have shown decreasing rainfall. A climatological study shows a reliable relation between mean precipitation, temperature and evapotranspiration in Minab catchment. When the amount of precipitation is high, temperature is below and the amount of evapotranspiration is less too in some years and vise versa. This shows the effect of evapotranspiration on hydrologic variations and low flow in dry years.

Chapter 5 Runoff analysis

Introduction

Runoff is the most important factor in surveying the hydrologic regime of a catchment, that is affected by climatic variation (rainfall, evapotranspiration) and land use changes. These factors change due to flow regime and different periods. The following shows the study of effect of each factor during different runoff:

5.1 Runoff data

There are three hydrometric stations including Minab, Rudan and Jaghin in the catchment outlet. The Minab River consists of two branches referred to as Rudan and Jaghin. However, in this project only the hydrometric data from the Minab station have been used for analysing runoff and peak flows. This is due to a lack of precise data for the Jaghin and Rudan stations.

5.2 Dry and Wet Period analysis

Investigation of the variation in trends of annual rainfall and discharge in the 1975-2000 period shows the existence of three different periods. This is particularly illustrated by the 5 years moving averages of rainfall and discharge (fig.5.1, 5.2). The three periods are:

1) **1975-1983**: this period is the first relatively wet period, with annual rainfall and discharge of 267 mm and 6.9 m^3/ s respectively;
2) **1984-1990**: this period is a dry period with decreasing mean annual rainfall and runoff to 158.1 mm and 2.25 m^3/s respectively;
3) **1991-2000**: this period is again a relatively wet period with increased mean annual rainfall and discharge to 289.2 mm and 4.4 m^3/s respectively.

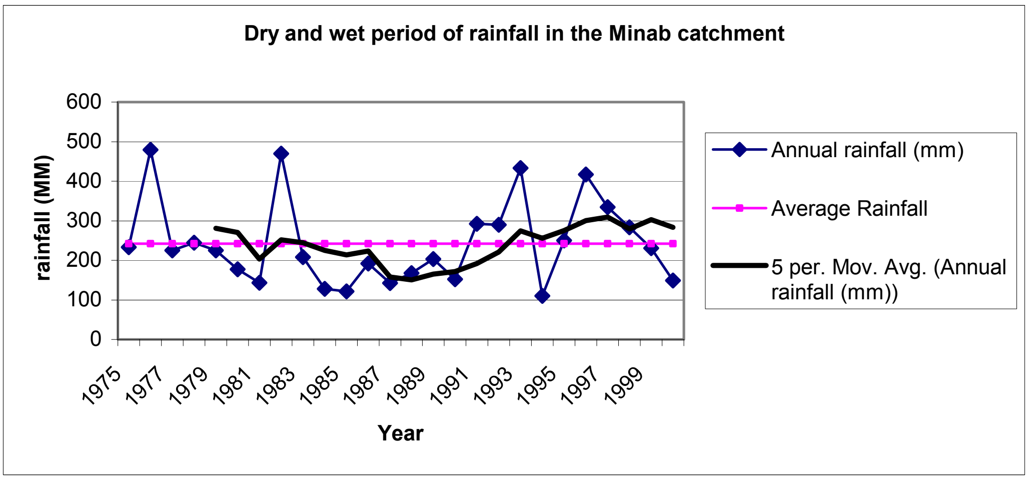


Figure 5.1. Dry and wet period of annual rainfall in the Minab river

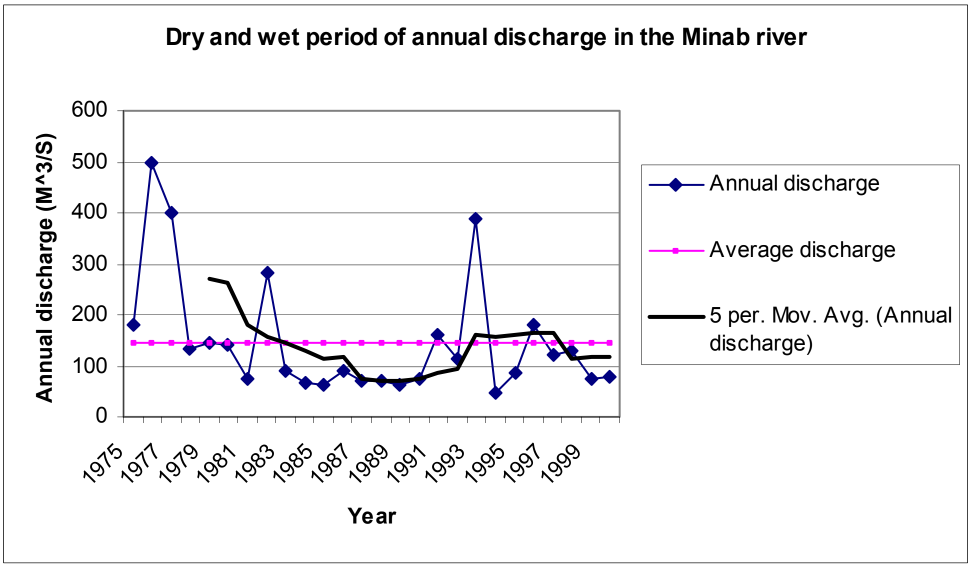


Figure 5.2. Dry and wet period of annual discharge in the Minab river

5.3 Flow Duration Curve

The flow duration curve is the empirical cumulative frequency distribution function of the entire daily stream recorded at a site. A flow duration curve describes the fraction of the time over the entire record that different daily flow levels were exceeded. It provides a compact graphical summary of stream flow variability (Maidment, 1993).

Daily flow duration data for three time periods that are available for the Minab River have been compared in order to determine the flooding and drying trends for the entire river catchment. Figure 5.3 shows the duration of flows from 1975-1983, 1983-1991 and 1992-2000 on the Minab river. The flow duration curve from the latter time period shows a downward shift to higher discharges (Fig. 5.3). The downward shift of the flow duration curve reflects an overall decrease in discharge in the latter time period. The observed changes in the flow duration curve and discharge rates are an indication of possible hydrologically relevant changes in the watershed. These are e.g.: land use change; change in rainfall intensity; change in seasonal distribution of rainfall; and change in rainfall duration. As stated previously, the area of the watershed has experienced an overall decrease in the average annual precipitation in the 1984-1990 period. Then it increased again in the 1991-2000 period. In addition, the seasonal distribution of this precipitation has shifted between the three time periods.

Land use changes within the watershed are also likely to have had an effect on the flow duration. As stated previously, many factors exert influences on the hydrologic cycle. Analyses of all factors are beyond the scope of this document. However, further data collection and analysis of the most relevant hydrologic data were considered to be important for determining long-term trends within the watershed. These factors are described in the following.

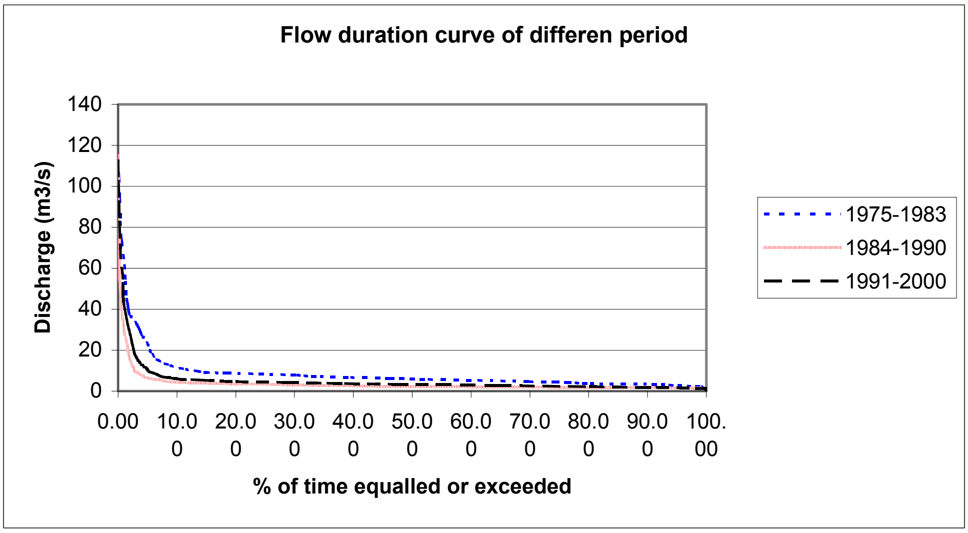


Figure 5.3 Flow duration curve of Minab River (1975-2000)

5.4 Maximum daily rainfall and peak discharge frequency analysis

Figure 5.4. clearly shows that with an increasing return period, the annual peak flow and the maximum of 24 hrs of rainfall are increased to a similar extent (upper green curve). However, for the return period of 10 years with increasing maximum 24 hrs of rainfall, the annual peak flow increases logarithmically (lower magenta curve). From this it can be concluded, that for a 10 return period and longer high intensity of rainfalls is the dominant factor determining peak discharge. The interaction of other factors such as land use would then be of less importance. Only for return periods less than 10 years, land use should be considered as a significant factor on peak runoff.

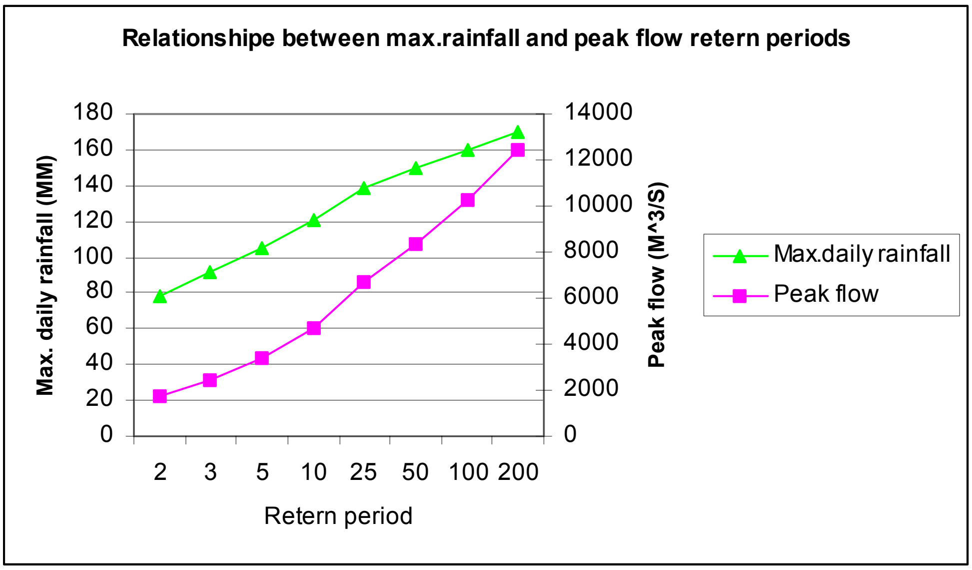


Figure 5.4. Relationship between maximum 24 hr. rainfall and peak flow return period

5.5 Hydrograph separations

The total runoff can be divided into surface runoff and base flow. In hydrograph analysis, the separation of these components is usually made in an arbitrary manner and both parts may contain a certain amount of the interflow. Different techniques for the separation of the base flow from the total hydrograph have been developed. These are:

A-The straight-line method

B-The fixed base length method

C- The variable slope method

The three methods are shortly introduced in the following. The third method has been applied in this study and is therefore described more thoroughly using data from the Minab catchment.

Ad A-The straight-line method: involves drawing a horizontal line from the point where surface runoff begins to the intersection with the recession limb. This method is applicable to ephemeral streams.

Ad B-The fixed base length method: the direct runoff is assumed to end at a fixed time N after the hydrograph peak. The base flow before the direct runoff is projected ahead to the time of the peak. A straight line is used to connect this projection at the peak of the point of the recession limb at time N after the peak. N=A^0.2

Ad C- The variable slope method: the base flow curve before the direct runoff began is extrapolated forward to the time of the peak discharge, and the base flow curve after the direct straight line is used to connect the end points of the extrapolated curves (Chow, 1987)

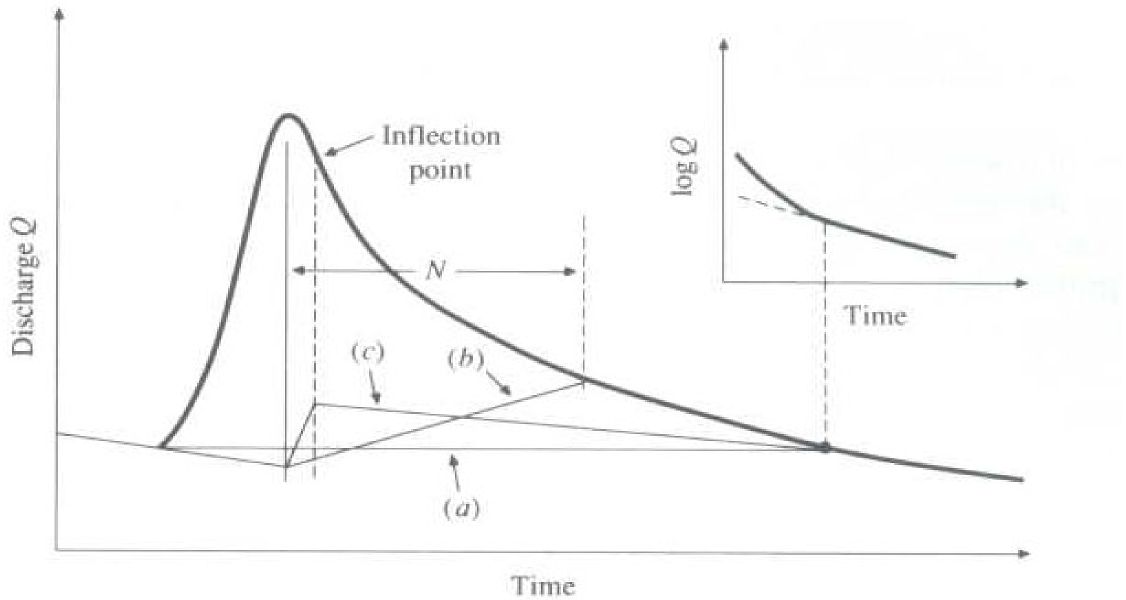


Figure5.5 Baseflow separation techniques.

(a) Straight line method (c) Variable slope method

(b) Fixed base method

In this research project hydrograph separation has been done using the AWBM model (Analysis of Water Balance Model; W.Boughton, 2002), which follows the variable slope method (Sharifi, 2000). At the start of the program, the value of the base flow index (BFI) is determined by trial and error (and expert opinion). The BFI is the ratio of the amount of base flow to the total amount of stream flow. For the Minab river it was calibrated on BFI=0.02. Base flow and direct runoff for the 1975-2000 period are shown in table 5.1 .

Table 5.1. Variation in runoff parameters, 1975-2000 period

Year	Annual rainfall (mm)	Changes (%)	Base flow (MM)	Changes (%)	Direct runoff (MM)	Changes (%)	BFI index	Changes (%)
1975	233.29	-3.77	40.69	181.69	46.94	142.29	0.46	-4.45
1976	479.00	97.57	31.39	117.31	46.15	138.22	0.40	-16.70
1977	224.90	-7.24	36.13	150.12	68.18	251.95	0.35	-28.73
1978	244.32	0.77	21.75	50.57	11.27	-41.82	0.66	35.54
1979	224.95	-7.22	16.64	15.20	17.26	-10.90	0.49	1.00
1980	177.35	-26.85	10.21	-29.32	8.28	-57.26	0.55	13.63
1981	143.53	-40.80	23.40	61.99	24.93	28.69	0.48	-0.37
1982	470.01	93.86	21.26	47.18	28.92	49.29	0.42	-12.82
1983	207.84	-14.27	14.24	-1.42	2.99	-84.57	0.83	70.06
1984	127.56	-47.38	10.56	-26.89	6.27	-67.63	0.63	29.11
1985	121.14	-50.04	8.25	-42.89	8.80	-54.57	0.48	-0.43
1986	192.31	-20.68	9.41	-34.86	23.79	22.81	0.28	-41.68
1987	142.34	-41.29	8.68	-39.91	21.09	8.87	0.29	-40.00
1988	167.85	-30.77	5.32	-63.17	1.46	-92.46	0.78	61.46
1989	203.13	-16.21	6.52	-54.86	9.01	-53.49	0.42	-13.61
1990	152.26	-37.20	7.82	-45.86	12.60	-34.96	0.38	-21.20
1991	292.51	20.65	10.96	-24.13	44.79	131.21	0.20	-59.55
1992	290.10	19.66	5.44	-62.33	0.67	-96.53	0.89	83.15
1993	433.56	78.83	8.87	-38.61	5.41	-72.06	0.62	27.79
1994	110.22	-54.54	7.74	-46.40	4.50	-76.79	0.63	30.17
1995	250.28	3.23	11.76	-18.56	16.90	-12.75	0.41	-15.56
1996	417.11	72.04	16.67	15.38	29.67	53.17	0.36	-25.99
1997	334.30	37.89	12.13	-16.04	20.12	3.86	0.38	-22.61
1998	283.73	17.03	13.31	-7.88	20.35	5.06	0.40	-18.65
1999	230.73	-4.83	8.90	-38.39	10.55	-45.54	0.46	-5.85
2000	149.19	-38.46	7.52	-47.93	12.77	-34.07	0.37	-23.73
Average	242.44183	0	14.44495	0	19.37209	0	0.48597	0

5.5.1 Trend analysis of direct runoff and base flow

Comparison between the runoff parameters base flow and direct runoff shows that the variation trends in both base flow and direct runoff have decreased since 1975 (fig. 5.7; blew and magenta curves respectively). This decrease is largely related to a decrease in rainfall during the

1984-1990 period. During the 1991-2000 period, mean rainfall increased but the baseflow and direct runoff did not increase to a similar extent. This can be due to the effect of other factors such as land use changes. Another observation is that the ratio of base flow to direct runoff has decreased during the years. This is probably due to a significant decrease in rainfall during the 1984-1990 period. However, this ratio did not returned to the initial condition during the 1990-2000 (second wet) period. From this it can be concluded that other factors than rainfall had an impact on changes in runoff characteristics.

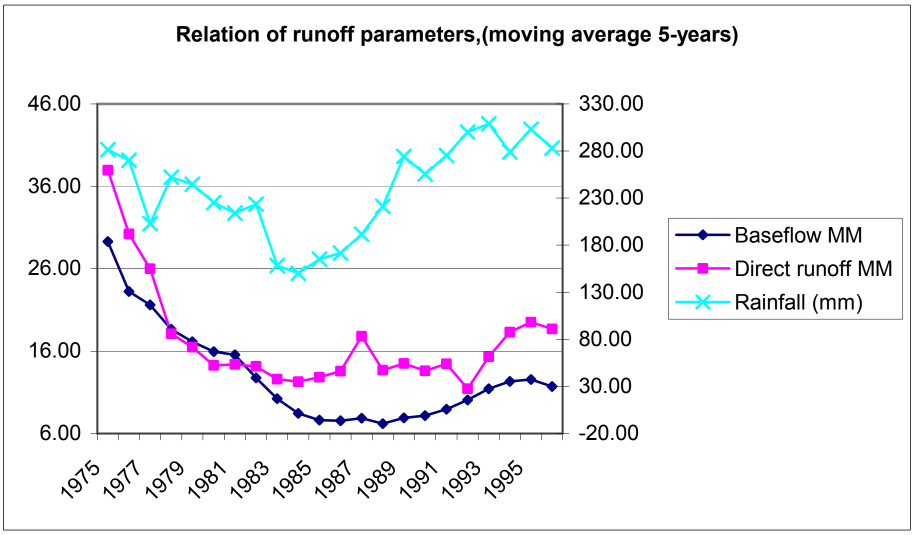


Figure 5.7 Relation of runoff parameters, (moving average 5-years)

5.6 Water budget Changes (annual rainfall and runoff)

The long-term trends of variations in annual runoff (water yield), rainfall, and their ratios based on 5-year moving averages during 1975-2000 are shown in figure 5.8. Linear regression models for the entire period show an increasing trend of rainfall, while runoff and runoff-to-rainfall-ratio are decreasing. However, these estimated annual changes are non-significant. These explain only 18 percent of the variation in rainfall, 14 percent of the variation in runoff, and 55 percent of the variation in runoff-to-rainfall-ratio. This is indicated by the coefficient of determination (R^2) estimated for the 5-year moving averages. There are substantial differences in rates and directions of short-term deviations. To discern these short-term trends, the rainfall-runoff relations for the three different time periods, i.e. 1975-1983; 1984-1990; and 1991-2000, have been analysed separately. The results of the analyses show distinct changes in hydrologic processes, as depicted in figures 5.9, 5.10, and 5.11.

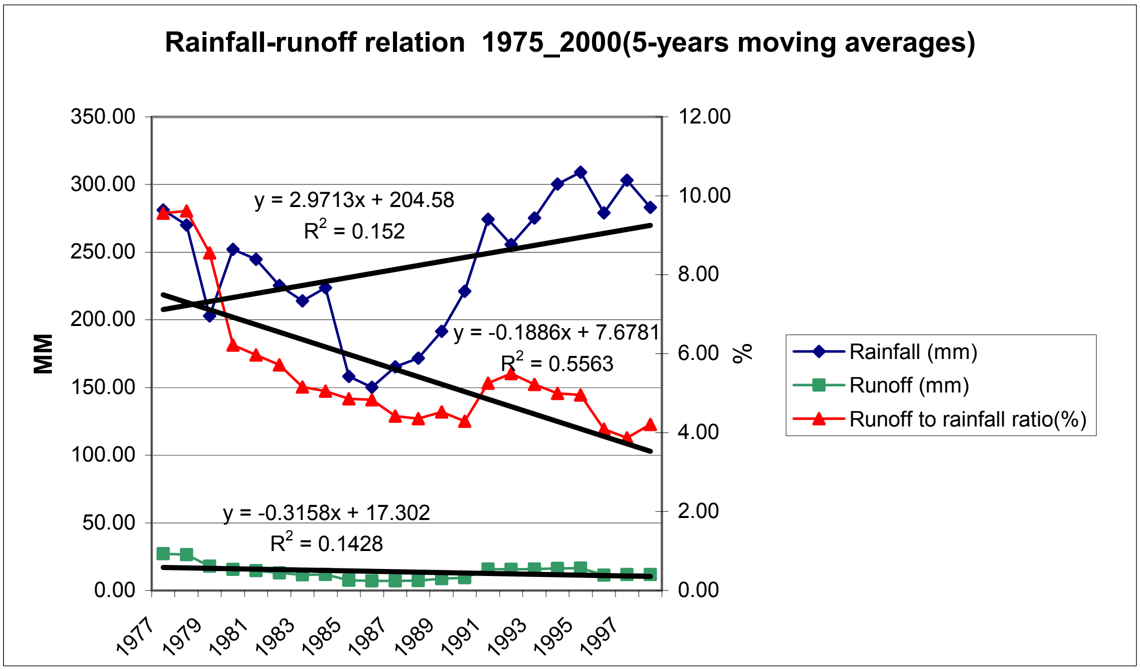


Figure 5.8. Rainfall-runoff relation 1975_2000 (5-years moving average)

5.6.1 The 1975-1983 Period

In this period, annual rainfall is decreasing, runoff and runoff-to-rainfall-ratio are 8 mm, 0.3 mm, and 0.84 mm respectively (fig.5.9). Also, values of the coefficient of determination (R^2; 44% and 90% respectively) indicate that, due to the healthy state of the vegetation cover, this relates in a relatively high baseflow.

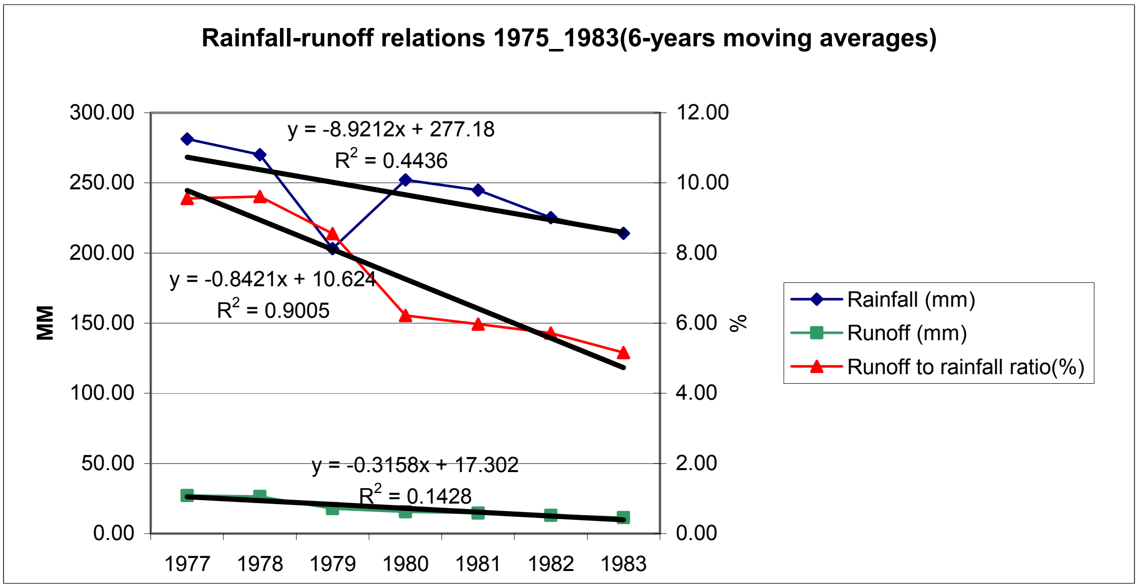


Figure 5.9.Rainfall-runoff relation 1975_1983 (5-years moving average)

5.6.2 The 1984-1990 Period

In this period, which is in fact a drought period, the rainfall increases following a smooth trend by 2.9 mm per year (fig.5.10). The runoff and runoff-to-rainfall-ratio show a decreasing trend. Also, the values of the coefficient of determination (R^2) indicate that rainfall has increased by 4%. But runoff and runoff-to-rainfall-ratio have decreased by 14% and 81% respectively. The probable cause for this is an increase in the low amount of annual average rainfall and evaporation in this period.

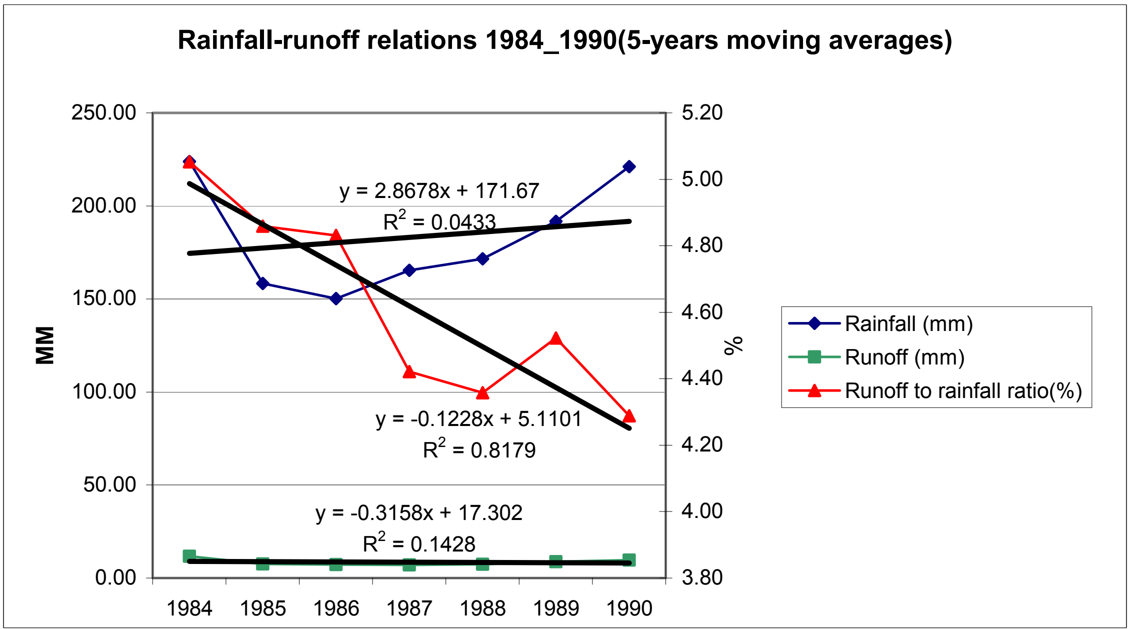


Figure 5.10. Rainfall-runoff relation 1984_1990 (5-years moving average)

5.6.3 The 1991-2000 Period

Figure 5.11 shows that during 1991-2000 rainfall increases annually by 3.8 mm. But runoff decreased at 0.7 mm per year, due to the annually decreasing runoff-to-rainfall-ratio to 0.22 percent. The linear trend accounts for only 26 percent of the variation in rainfall, whereas the estimated trend explains 60 percent and 80 percent of the respective variations in runoff and runoff-to-rainfall-ratio. This is a clear indication that a decrease in runoff is not merely due to change in rainfall. Therefore, the downward trend in runoff during 1992-2000, with a reduced baseflow and flooding taking place, is attributed to changes in land use.

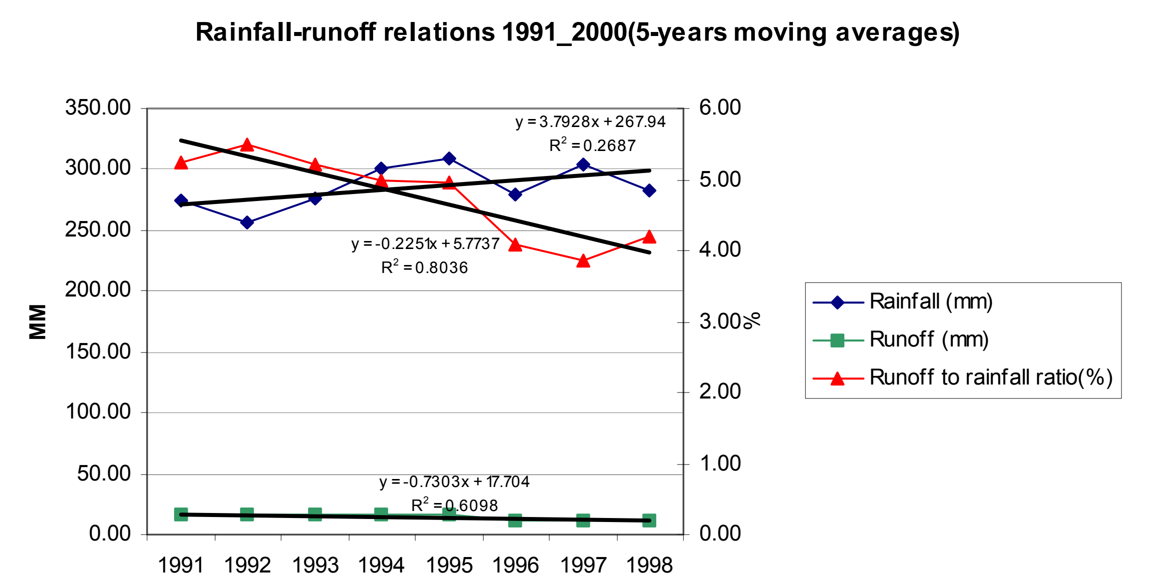


Figure 5.11. Rainfall-runoff relation 1991_2000 (5-years moving average)

Table 5. 2 Five –years moving averages of rainfall, runoff and runoff-to-rainfall-ratio

Year	Rainfall (mm)	Annual discharge m^3/s	Runoff (mm)	Runoff to rainfall ratio (%)
1975	-	-	-	-
1976	-	-	-	-
1977	281.29	8.61	27.14	9.56
1978	270.10	8.37	26.38	9.61
1979	203.01	5.66	17.86	8.56
1980	252.03	4.93	15.55	6.22
1981	244.74	4.64	14.63	5.97
1982	225.26	4.14	13.05	5.71
1983	214.02	3.64	11.48	5.16
1984	223.77	3.74	11.78	5.05
1985	158.24	2.40	7.56	4.86
1986	150.24	2.27	7.17	4.83
1987	165.35	2.26	7.12	4.42
1988	171.58	2.33	7.35	4.36
1989	191.62	2.78	8.76	4.52
1990	221.17	3.03	9.57	4.29
1991	274.31	5.05	15.93	5.25
1992	255.73	4.96	15.63	5.50
1993	275.33	5.04	15.89	5.22
1994	300.25	5.17	16.32	5.00
1995	309.09	5.24	16.53	4.96
1996	279.13	3.61	11.38	4.09
1997	303.23	3.78	11.93	3.87
1998	283.01	3.72	11.72	4.21
1999	-	-	-	-
2000	-	-	-	-

5.7 Changes in Flow Regimes

In dealing with effects of land use changes, it is important to distinguish between effects on water yield (i.e. total stream flow or total runoff) and on flow regimes (i.e. the seasonal distribution pattern of streamflow or runoff). Annual values of runoff and runoff-to-rainfall-ratio give the combined effect of storm runoff and base flow, and thereby they may conceal the actual changes that occurred in the runoff pattern during the relatively wet and dry periods. To discern such seasonal changes within the annual cycle, changes in flow regimes were first investigated. Figure 5.12 shows the variations in flow regimes, based on mean monthly runoff, during the three time periods. Each shows a different trend in annual total runoff. Mean monthly rainfall given in figure 5.13 shows that the distribution of rainfall is bimodal with convectional cyclonic activities peaking in December to April. Indian Ocean monsoonal rains peak in August. Table 5.3 gives the variations in mean monthly flow as calculated for the 1975-1983, 1984-1990, and 1991-2000 periods. The results are compared in terms of percentages of flow and depth (mm).

In the context of rainfall pattern as shown in figure 5.13, it can be concluded that during the most prominent low flow period between May and November, stream flow develops differently for the three periods. It increases during 1975-1983, but decreases during 1984-1991, compared to the 1975-1983 and 1984-2000 periods. During the low flow period of May to November as well as during the one high flow period of August, streamflow decreases during both the 1984-1991 and the 1991-2000 periods, in comparison to that of the 1975-1983 period. During the 1992-2000 period, compared to the 1975-2000 period, water yield is almost stable with changes in flow regimes despite the high rainfall. Moreover, high flow and low flow periods have shifted compared to those observed during the rest of the years (fig.5.12). Compared to the 1975-1983 period, mean monthly runoff is reduced in all months, especially in June, April and August.

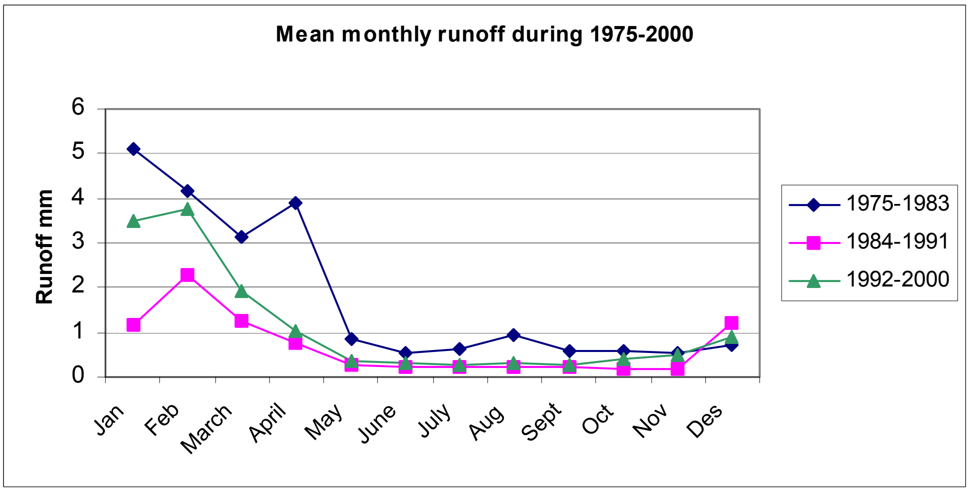


Figure 5.12. Changes in flow regime

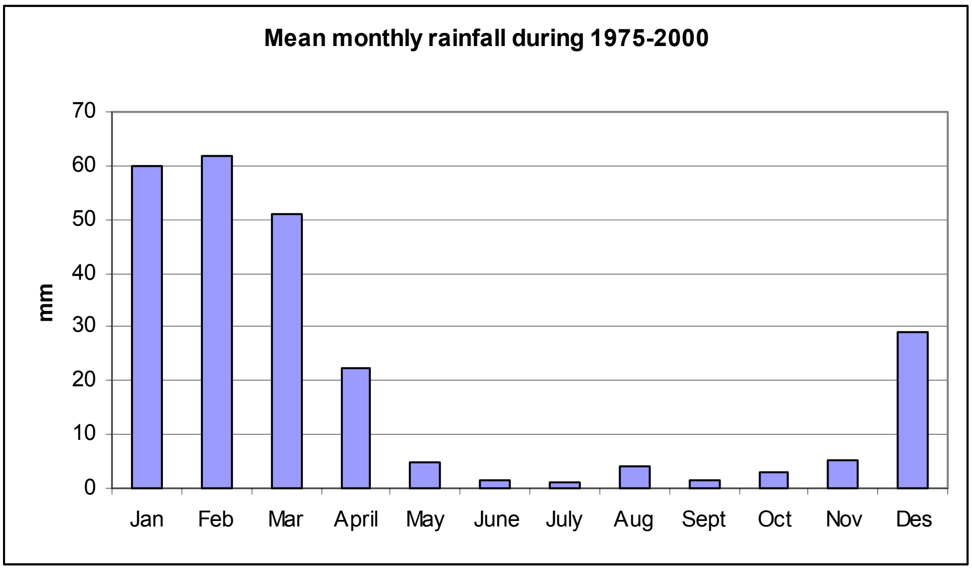


Figure 5.13. Mean monthly rainfall during 1975-2000

The shifts in flow regimes during 1975-2000 have resulted from changes in rainfall regimes as shown in figure 5.14. To understand the underlying causes of changing flow regimes, monthly rainfall-runoff relations, based on 5-year moving averages of runoff, have been analysed separately and subsequently, consecutive months with a similar pattern of change have been plotted, taking the cumulative values of rainfall and runoff for such consecutive months.

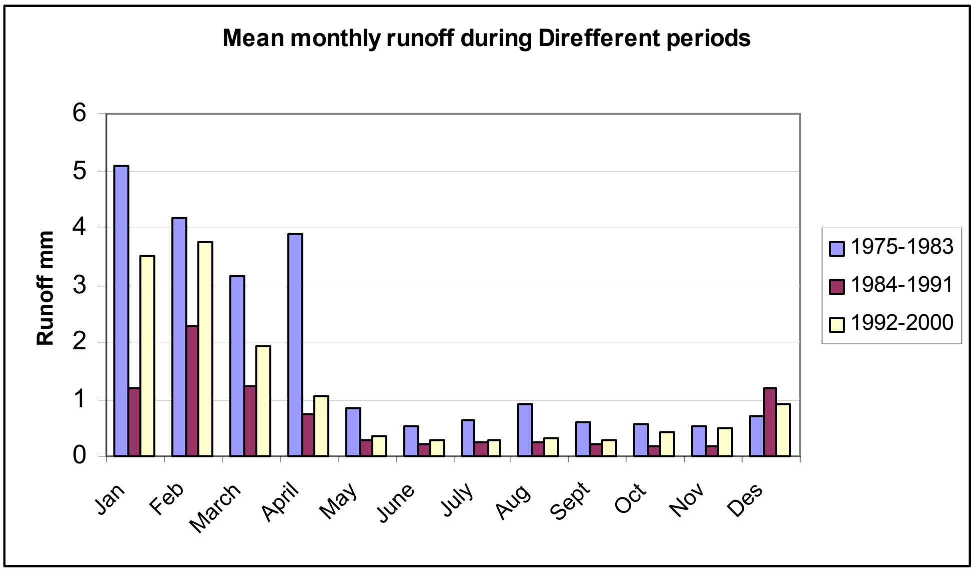


Figure 5.14. Mean monthly runoff during 1975-1983,1984-1991 and 1992-2000 periods

5.7.1 May - November—Low Flow Period

1975-1983 period

In this period during May to November, rainfall increases 0.5 mm annually, but runoff and runoff-to-rainfall-ratio annually decrease by 0.4 mm and 0.02 respectively. R^2 values indicate 39% increase in rainfall and 90% and 62% decrease in runoff and runoff-to-rainfall ratio in this period (fig.5.15).

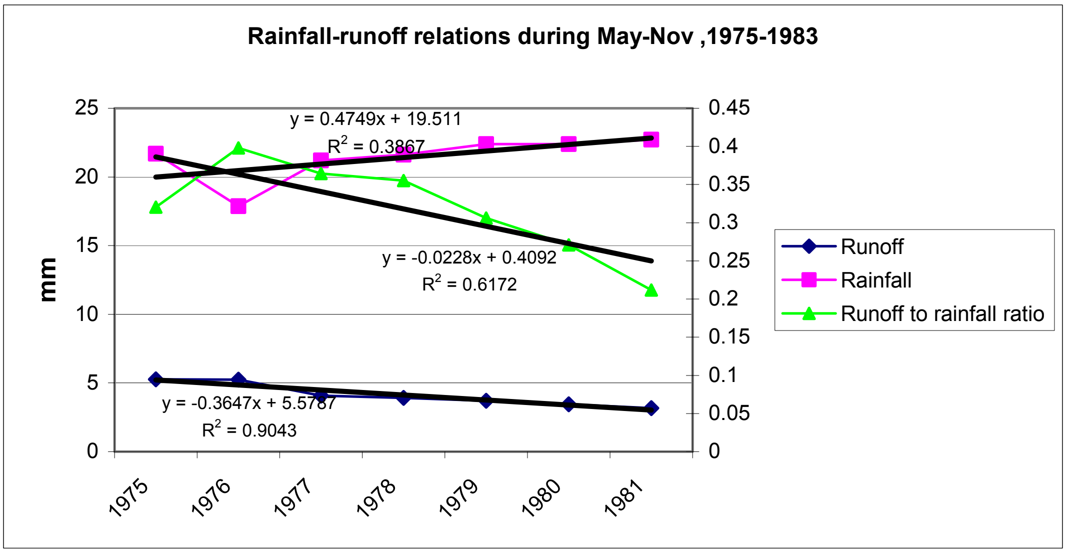


Figure 5.15. Rainfall-runoff relations during May -Nov (1975-1983)

1984-1990 period

In this period during May to November, rainfall and runoff decrease by 0.3 mm and 0.2 mm annually, but the runoff-to-rainfall-ratio shows a slight increase by 0.06 annually. (fig.5.16).

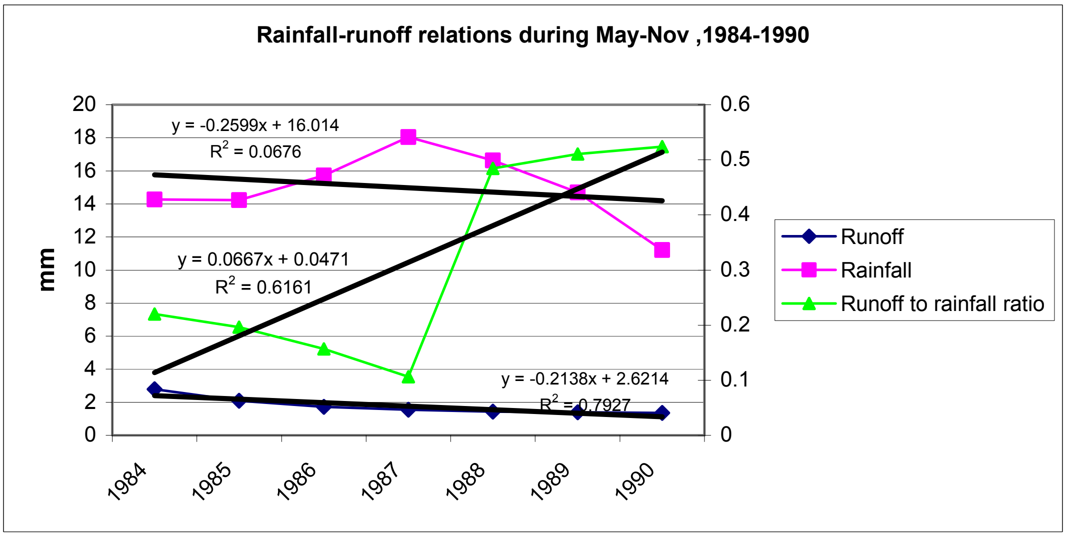


Figure 5.16.Rainfall-runoff relations during May -Nov (1984-1991)

1991-2000 period

In this period during May to November, the average rainfall and runoff increase annually by 3.5 mm and 0.16 respectively. The runoff-to-rainfall-ratio shows a severe decreasing trend with 0.2 per year. (Fig.5.17).

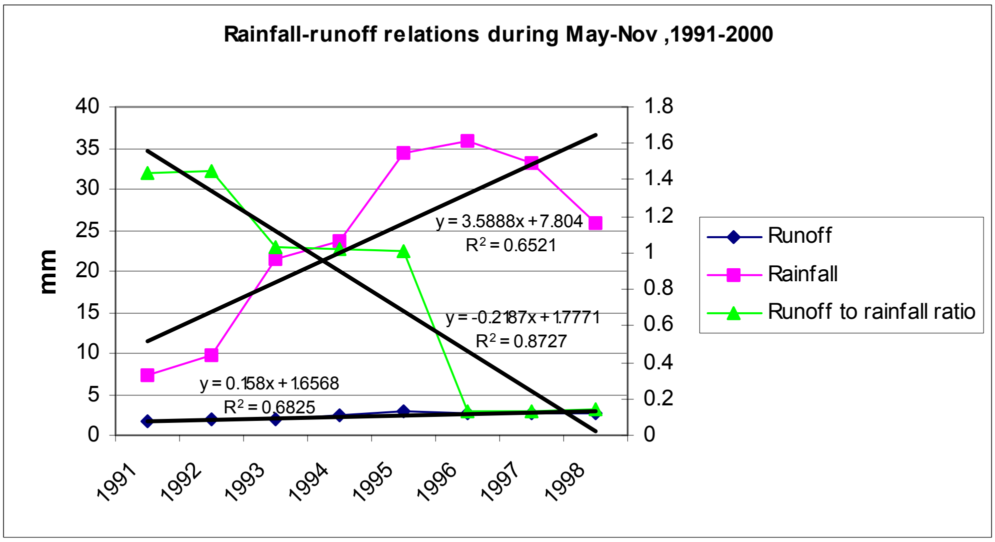


Figure 5.17.Rainfall-runoff relations during May -Nov (1991-2000)

Changes in rainfall and runoff and their ratios during 1984-1991 are reduced for both precipitation and drought. But a comparison of two wet periods 1975-1983 and 1991-2000 shows that the rainfall averages is almost equal. While the average runoff in 1975-1983 is two times that of 1991-2000 (table.5.4) this illustrates again the effect of other factors on runoff in this period, e.g. land use change (at low flow).

5.7.2 December- April — High-Flow Period

<u>1975-1983 period</u>

In this period during December to April, rainfall, runoff and runoff-to-rainfall-ratio, decreases by 12.4 mm, 2.4 mm and 0.007 respectively (fig. 5.18). Important observations in this period are the severe decreasing trend in rainfall and the smooth decreasing trend in runoff and runoff-to-rainfall-ratio. These can be related to the good condition of the vegetation cover.

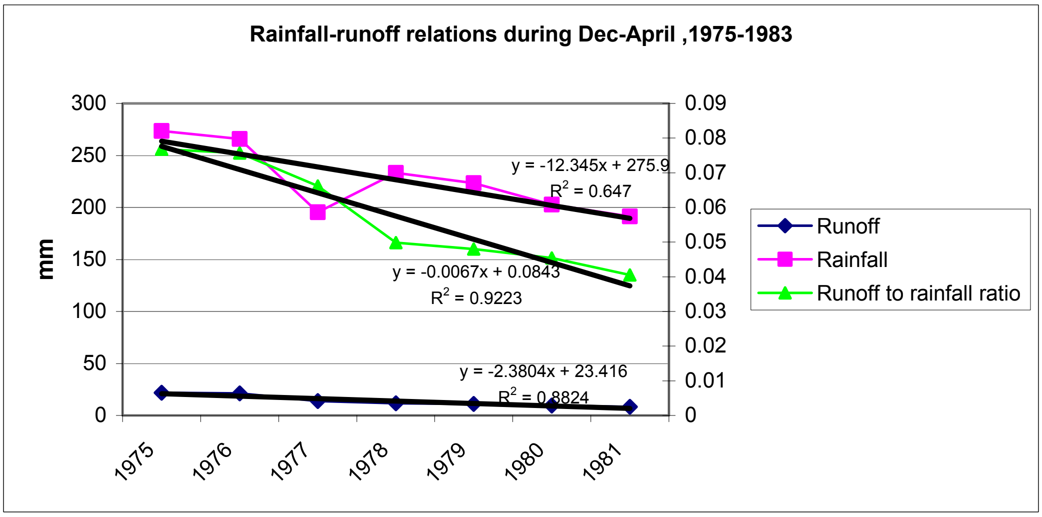


Figure5.18.Rainfall-runoff relations during Dec -April (1975-1983)

1984-1990 period

In this period during December to April, the amount of rainfall and runoff increases following a smooth trend. Runoff-to-rainfall-ratio also shows a decreasing trend because of drought and a reduced base flow (fig.5.19)

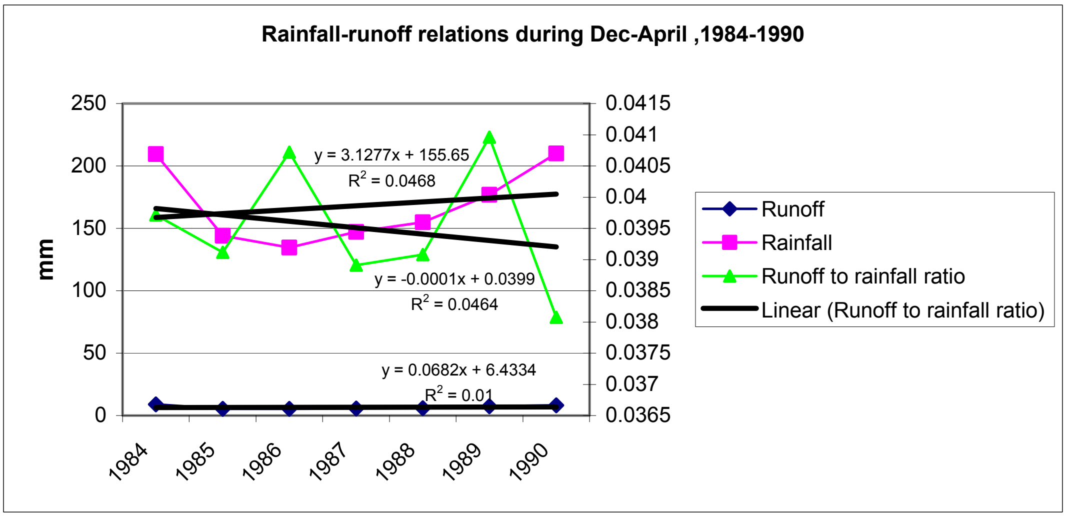


Figure5.19. Rainfall-runoff relations during Dec -April (1984-1990)

1991-2000 period

In this period during December to April, there is a small increasing trend in rainfall of 0.2 mm per year. Runoff and runoff-to-rainfall-ratio decrease by 0.9 mm and 0.002 annually respectively (fig.5.20). Comparison between the wet periods in 1975-1983 and 1984-2000 shows that the average annual runoff has decreased ever since (with reduced baseflow; Table 5.4). During high flow months in the 1991-2000 period, most of the runoff is discharged from the catchment by flooding. The cause lies in the observed land use changes from 1976 to 2000.

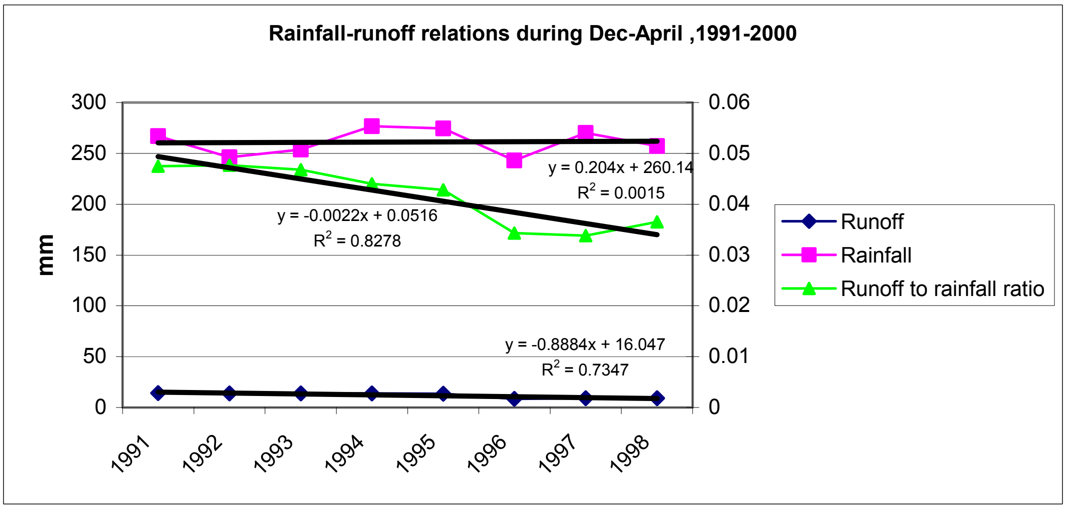


Figure 5.20. Rainfall-runoff relations during Dec -April (1991-2000)

Table 5.3.rainfall and runoff relations in high flow and low flow periods

	December-April (High flow)			*May-November (Low flow)*		
Year	Rainfall mm	Runoff mm	Runoff to rainfall ratio	Rainfall m m	Runoff mm	Runoff to rainfall ratio
1975	-	-	-	-	-	-
1976	-	-	-	-	-	-
1977	273.55	21.87	0.08	21.69	5.27	0.32
1978	265.97	21.14	0.08	17.87	5.24	0.40
1979	195.54	13.78	0.07	21.21	4.08	0.36
1980	233.38	11.65	0.05	21.61	3.90	0.36
1981	223.24	10.92	0.05	22.40	3.70	0.31
1982	202.65	9.60	0.05	22.39	3.46	0.27
1983	191.30	8.30	0.04	22.71	3.18	0.21
1984	209.51	8.99	0.04	14.26	2.79	0.22
1985	144.00	5.46	0.04	14.23	2.10	0.20
1986	134.51	5.44	0.04	15.73	1.73	0.16
1987	147.31	5.57	0.04	18.05	1.55	0.11
1988	154.94	5.91	0.04	16.63	1.44	0.48
1989	176.92	7.36	0.04	14.70	1.39	0.51
1990	209.95	8.20	0.04	11.22	1.36	0.52
1991	266.96	14.28	0.05	7.36	1.65	1.44
1992	246.06	13.73	0.05	9.67	1.90	1.44
1993	253.84	13.88	0.05	21.49	2.01	1.03
1994	276.65	13.94	0.04	23.61	2.38	1.02
1995	274.62	13.55	0.04	34.47	2.98	1.01
1996	243.15	8.61	0.03	35.98	2.77	0.13
1997	270.05	9.27	0.03	33.18	2.66	0.13
1998	257.13	9.12	0.04	25.88	2.59	0.14
1999	-	-	-	-	-	-
2000	-	-	-	-	-	-

Table 5.4. Variations in mean monthly flow and rainfall

Period	May-November (Low flow)		December-April (High flow)	
	Rainfall mm	Runoff mm	Rainfall mm	Runoff mm
1975-1983	23.73	4.6	251.14	16.99
1984-1990	13.94	1.5	144.5	5.5
1991-2000	23.67	2.3	255.5	11.5

5.8 Conclusion

The evaluation of wet and drought periods in the Minab catchment shows that the 1975-2000 period can be divided into two periods. The first relatively wet period is from 1975 to 1983, and the second wet period is from 1991-2000. The in between drought period is from 1984 to 1990.

For evaluating the effect of land use changes on the hydrologic regime of the catchment, subsequent periods should have the same climatological conditions. It can be concluded that the 1984-1990 period is more affected by climatological changes. Because in this period in comparison with wet periods (1976-1983 & 1991-2000), the average annual rainfall has been decreased up to 50% and most of discharge is related to base flow and runoff decreasing especially direct runoff are related to climatic changes. (rainfall reducing and evapotranspiration increasing).

Plotting of flow duration curve of the Minab river in three periods show a decrease of high and medium runoff percents in drought period of 1984-1991. It is predictable in respect to climatic changes but comparison of two wet periods (1975-1983 & 1991-2000) shows that Minab river has been slightly good flow duration. In 1975-1983 while this duration in 1991-2000 has been decreased more, with taking into consideration relative constancy of climatic factors, the effects of other factors like land use changes would be cleared.

During high flow months (December to April) in the 1991-2000 period, most of the runoff is discharged from the catchment by flooding. The cause lies in the observed land use changes from 1976 to 2000.

Of course, in the upper 10 years return periods the role of rainfall intensity is clear. This is because of the logarithmic increase of flood in plot with maximum 24 hr of rainfall. Other factors, such as land use changes do not have a distinct effect on the occurrences of floods.

Chapter 6 Conclusions and recommendations

The applied RS and GIS based methodology for assessment of the effects of land use change on the hydrologic regime of the Minab catchment, in Hormozgan province, Iran, has led to the following conclusions.

6.1 Conclusions

The multitemporal analysis of satellite image data clearly indicate, that in 1976 about 45 percent of the Minab catchment was under range and forest natural cover (medium rangeland, good rangeland and forest). Due to continued overgrazing, rangeland cover decreased to 10 percent in 1988 and to 8 percent in 2002. Between 1976 and 2002, the overgrazed area has largely been replaced by: large-scale poor natural cover (poor rangeland, bare soil and rock out crop); agricultural area (irrigated agriculture, rainfed agriculture and orchard); and residential area. These land use changes, particularly the conversion of natural cover, must be responsible for the decrease runoff generation process during 1991-2000, as revealed by the analysis of annual rainfall – runoff relations.

However, in spite of increasing rainfall the increase in runoff generation is not reflected in the annual runoff (water yield), during 1991-2000, as shown in the hydrological analysis. Though the runoff-to-rainfall-ratio decreased in the low-flow period (May-November). This increasing rainfall was accompanied with a substantial increase in storm flow during the high-flow period (December to April). A decrease in runoff generation has, therefore, taken place due to the decrease in the low flow period (base flow). This is strongly related to the reduction of natural range and forest cover from 45 percent to 8 percent in the entire watershed area.

An analysis of seasonal runoff revealed that during the 1975-1983 period, both base flow and storm runoff have increased. This conclusion has been brought by a higher runoff-to-rainfall-ratio during the prominent low-flow period of May to November compared to that of 1991-2000. The cumulative effects of these changes are a decrease in mean annual runoff by 3.4 mm during 1991-2000, in comparison to the 1975-1983 period. About 80 percent of this decrease in annual runoff (water yield) is due to the decrease of base flow during low flow periods (i.e., May-November). The decrease in base flow during low flow periods is due to a reduced infiltration rate which is in turn caused by the reduction of range land and forest after conversion to other land uses (large-scale poor natural cover).

These changes in the runoff generation pattern are in agreement with the state of knowledge on the prospective role of rangelands, that reduced range and forest covers and decreased the water yield in the Minab catchment. A more conspicuous decrease in water yield during 1984-1990 compared to that of 1975-1983 and 1991-2000 have mainly resulted from the impact of decreased rainfall and increased evapotranspiration during 1984-1990. The range land and forest covers have decreased from 45 to 10 percent in 1983-1991 period, in case of climatic severe changes. On the other hand, because of lacking the same drought period information for comparison, an exact opinion can not be formulated on the effect of land use change on the hydrologic regime in this period. This is because the effect of this land use change in the wet period (1991-2000) are clearly observed.

Nortcliff, Ross, and Thornes (1990) have demonstrated that it is evident that major changes in runoff occur between 0 percent and 30 percent vegetation cover, with changes of cover above this having a relatively small impact. Observations in the study catchment, particularly flow regimes, agree very closely with such behaviour. The observed decrease in base flow during 1991-2000, with clearance of range land and forests cover from 45 percent to 8 percent (in comparison with the 1975-1983 period), can be attributed to the distribution of poor natural cover in a substantial area of overgrazing and deforested lands. In fact, the water storage capability of the soil has decreased during the low flow period, because of changing land use.

The geological conditions in the Minab catchment indicate that the layer of alluvial sediments is thin (< 2 m). There are no main aquifers in the area to potentially store high volumes of runoff. The deepest alluvial deposits (> 2 m) are found around rivers, which is also the main factor for agricultural development around rivers.

As a result, in the 1991-2000 period, where range land and forest covered less than 8 percent of the watershed area, changes in flow regimes were at their peaks, compared to the 1975-1983 initial conditions. The observed reduction in base flow after 1965, during low flow periods, is accompanied by increased storm runoff during high rainfall months compared to that observed with a low percentage of range and forest cover. This has reduced infiltration of water to the subsoil.

Also, the evaluation of the flow duration curves shows the reduce in flow duration in the 1984-1990 and 1991-2000 periods in comparison with the 1975-1983 period. Flow duration in 1984-1990 is more related to climate variability. Regarding to the increasing annual rainfall in 1991-2000, river flow was reduced compared to normal low flow. That is why most of the average and low discharges have decreased and the larger part of runoff in high flow periods have gone out of the catchment. Also, the average base flow decreased in the low flow period.

Climate change and land use change are the effective factors for (changes in) the hydrologic regime of the Minab catchment. In rainfall with high intensity (with a return period of more than 10 years), land use changes have less importance because of the effectiveness of climatic factors (e.g. rainfall intensity). For rainfall with a return period of less than 10 years, in combination with a low flow period, the importance and effectiveness of land use changes on the flow regime is considerable.

6.2 Recommendations

An active management strategy aimed at the conservation and regeneration of the natural vegetation is recommended, in order to improve the distribution of water throughout the entire Minab catchment, during both dry and wet periods. These measures should be directed towards the buffering of scarce water during droughts and towards effective discharge of excess water during floods.

It is recommended to set up suitable conservation programs specifically aiming at the functioning of rangelands and forests in the catchment, particularly in drought periods.

It is also recommended to start the reclamation of poor rangelands and poor forests in the catchment, particularly in the northern and eastern hilly areas. These play an important role in the generation of runoff due to low permeability of the soil. This is expected to significantly increase base flow and decrease flood events.

6.3 Future research

Rainfall runoff relationships derived in this study do not display any deviations from the stationary process. However, this study needs to be continued to include more time series data. The next stages of development should focus on a GIS modelling approach in order to simulate the catchment dynamics for different land use scenarios. Assessing the effect of land use changes on water quality and sediment yield is another need for sustainable management of the Minab catchment.

Reference

Abvarzan consulting engineering co.1994, climatologic, geologic& soil parts of watershed management studies of Minab catchment, the semi-detail phase, Hormozgan province

Alizadeh, A., 2001,Principels of Applied Hydrology, publication Cultural Razavi Fundation, Mashhad, Iran

Beven, K. 1989. Changing ideas in hydrology- the case of physically based models. Journal of Hydrology 105.

Bruijnzeel, L. A. 1990. Hydrology of moist tropical forests and effects of conversion: A state of knowledge review. UNESCO International Hydrologic Programme, Amsterdam: Humid Tropics Programme, Free University.

Boughton, 2002, AWBM catchment water balance model manual ,version 4

Choow/Midment/Mays,1987, Hydrologic Measurement Ch.6"Applid hydrology", Mcgraw-Hill, various paging

Dano, A. M, 1990. Effects of burning and reforestation on grassland watersheds in the Philippines. Publication 192. International Association of Hydrologic Sciences. Wallingford, UK.

Dyhr-Nielsen, M, 1986. Hydrologic effects of deforestation in the Chao Phraya basin in Thailand. Paper presented at the International Symposium on Tropical Forest Hydrology and Application. Chiang Mai, Thailand, 11-14 June, 1986.

Elkaduwa and Sakthivadivel. 1998. Use of historical data as a decision support tool in watershed management: A case study of the Upper Nilwala basin in Sri Lanka. Research Report 26. Colombo, Sri Lanka: International Water Management Institute.

Fritsch, J. M. 1987. Ecoulements et erosion sous prairies artifielles apres defrichement de la forest tropicale humide. Publication 167. International Association of Hydrologic Sciences. Wallingford, UK.

Gumbricht, T., H. Lindholm, A. Akre, R. Szczepanek, M. Hessling, and J. McCarthy. 1997. GIS integrated modelling of a Himalayan landscape. International Journal of Water Resources Development 13 (1). (March)

Gudarzi .m,2000,Land evaluation for land use planning in the namrood area in Iran, with special attention to sustainable fodder production, ITC MSC thesis,65 pp.

Hay, L. E., and L. K. Knapp. 1996. Integrating a geographic information system, a scientific visualization system, and a precipitation model. Water Resources Bulletin, Journal of the American Water Resources Association 32 (2). (April)

Hewlett, J. D., and J. C. Fortson. 1983. The paired catchment experiment. In Forest water quality, ed. J. D. Hewlett. Athens, Georgia, USA: School of Forest Resources, University of Georgia

Hsia, Y. A., and C. C. Koh. 1983. Water yield resulting from clear cutting a small hardwood basin in Central Taiwan. Publication 140. International Association of Hydrologic Sciences. Wallingford, UK.

Hudson Jr., H. E., and R. Hazen. 1964. Droughts and low streamflow. In Handbook of applied hydrology, ed. Van Te Chow. New York: MaGrow-Hill Book Company.

Hudson Jr., H. E., and R. Hazen. 1964. Droughts and low streamflow. In Handbook of applied hydrology, ed. Van Te Chow. New York: MaGrow-Hill Book Company.

Institute of Hydrology. 1990. Eucalyptus: Forest friend or foe ? In Report of the Institute of Hydrology for 1988/89. Wallingford, UK.

Nortcliff, S., S. M. Ross, and J. B. Thornes. 1990. Soil moisture, runoff and sediment yield from differentially cleared tropical rainforest plots. In Vegetation and erosion, ed. J. B. Thornes. London: John Wiley & Sons Ltd.

Qian, W. E. 1983. Effects of deforestation on flood characteristics with particular reference to Hainan island, China. Publication 140. International Association of Hydrologic Sciences. Wallingford, UK.

Richardson, J. H. 1982. Some implications of tropical forest replacement in Jamaica. Zeitschrift fur Geomorphologie Neue Folge, Supplement Band 44.

Meijerink et.al, 1994, Introduction to the use of GIS for practical hydrology,243 pp, Public ITC

Meijerink, A., Valenzuela, C.R., Stewart, A., eds., 1988 ILWIS: Integrated Land and Watershed Management Project; Geo Information System for Land Use Zoning and Watershed Management, International Institute for Aerospace Survey and Earth Sciences, Enschede, Netherlands,

Shuttleworth, W.J. 1993. Evaporation, Ch.4, In D.R. Maidment (ed.), Handbook of Hydrology, Mcgraw-Hill, various pagings

Roche, M. A. 1981. "Watershed investigations for development of forest resources of the Amazon region in French Guiana." In Tropical agricultural hydrology pp. 75-82. See Lal and Russell 1981.

Madduma Bandara, C. M. 1997. Land-use changes and tropical stream hydrology: Some observations from the upper Mahaweli Basin of Sri Lanka. In Process and forms in geomorphology, ed. D. R. Stoddart. London and New York: Rutledge.

Sadeghi.H, 1995, Investigation of effect parameters on floods occur in Iran, Forest and rangeland journal, No.26

Appendix

A. Data

A.1 Mean annual rainfall stations of Minab catchment

Year	Faryab	Zehamkan	Mohammad abad	Berentin	Bolbolabad	Dareh shour	Glashgerd	Aseminon
1975	325.0	133.5	154.0	282.5	275.0	206.0	161.6	320.2
1976	739.0	271.0	317.0	645.0	445.0	465.6	480.0	502.6
1977	315.0	226.0	17.0	284.0	271.0	308.0	261.0	223.8
1978	289.0	204.0	267.0	292.2	185.0	307.0	187.6	265.0
1979	423.0	295.0	88.0	292.6	150.0	326.8	196.7	224.0
1980	211.0	73.0	171.0	188.4	180.0	222.5	166.0	185.5
1981	243.0	147.0	124.0	166.1	50.0	109.0	170.5	201.5
1982	678.0	281.0	450.0	541.9	426.0	330.0	373.0	637.9
1983	224.5	227.5	132.0	282.8	185.0	201.0	148.0	341.6
1984	180.0	65.0	157.0	133.6	120.0	82.5	74.0	174.2
1985	226.0	100.5	161.0	70.3	90.0	113.0	99.0	107.5
1986	249.0	328.8	212.0	95.2	150.0	170.0	187.0	218.5
1987	211.0	192.0	152.0	160.4	110.0	135.5	101.0	120.0
1988	292.0	117.0	173.0	163.2	151.0	128.5	123.0	187.5
1989	297.0	232.0	206.0	181.6	203.0	113.5	160.0	230.0
1990	212.0	121.0	102.5	269.5	182.0	60.0	75.0	180.0
1991	282.0	138.0	390.0	349.9	255.0	244.0	277.0	299.0
1992	421.4	223.0	345.0	276.9	253.0	233.0	260.0	270.0
1993	771.0	540.0	459.0	361.3	261.0	433.0	368.0	447.5
1994	227.0	137.0	117.5	94.8	71.0	64.0	89.5	109.0
1995	274.9	225.5	231.5	258.4	292.0	172.0	189.9	325.0
1996	573.2	90.0	318.0	549.7	468.0	366.0	306.3	577.0
1997	406.8	231.0	427.5	380.5	283.0	212.0	236.2	427.0
1998	372.4	141.0	234.0	435.6	350.0	140.0	133.8	382.5
1999	235.0	173.0	184.0	234.8	309.0	246.0	183.9	248.5
2000	202.5	151.0	210.5	245.0	72.0	80.0	132.7	94.5
Average	317.4	187.7	212.0	255.2	216.0	200.8	183.8	262.8

A.2. Mean annual Temperature stations of Minab catchment

Year	Berentin	Glashgerd	Faryab
1975	1841.0	1693.1	1754.1
1976	1810.9	1725.2	1512.1
1977	1884.7	1755.1	1832.3
1978	1826.5	1670.2	1796.6
1979	1851.6	1787.1	1711.9
1980	1884.6	1405.0	1858.2
1981	1887.7	1391.8	1855.5
1982	1830.9	1639.7	1795.9
1983	2618.1	1716.2	1798.8
1984	1867.6	1746.2	1845.8
1985	1862.4	1766.4	1833.1
1986	1836.1	1705.2	1811.9
1987	1872.6	1762.7	1835.5
1988	1855.7	1793.7	1818.1
1989	1784.7	1763.4	1738.9
1990	1839.3	1791.4	1757.4
1991	1738.8	1739.1	1781.2
1992	1706.2	1707.0	1663.1
1993	1775.9	1770.1	1769.5
1994	1787.5	1765.1	1796.0
1995	1785.7	1759.0	1774.0
1996	1788.5	1744.1	1784.8
1997	1773.0	1731.2	1778.5
1998	1824.3	1783.9	1847.4
1999	1826.8	1754.1	1796.9
2000	1800.3	1813.0	1811.3
Average	1852.4	1718.4	1783.0

A.3. Mean monthly discharge of Hydrometric Minab station

Year	January	February	March	April	May	June	July	August	September	October	November	December
1963	3.61	3.6	3.61	10.23	3.13	2.76	2.67	2.87	2.78	3.02	4.46	3.51
1964	6.4	4.26	5.89	3.91	3.48	2.91	2.72	2.69	2.7	2.97	3.04	3.63
1965	32.77	3.53	19.75	5.24	6.28	3.09	3.3	2.62	2.52	3.3	3.67	3.36
1966	3.54	12.9	3.24	6.7	3.4	3.8	3.3	3.3	3.3	2.4	8.9	3.2
1967	3.5	38.19	4.6	2.9	2.6	2.5	2.2	2.5	2.6	2.6	3	5.9
1968	5.9	58.7	11.8	3.6	6.6	2.8	2.7	2.5	2.6	2.8	2.7	59.3
1969	32.5	24.8	4.9	4	3.8	3.3	3.3	3.5	3.1	6.53	6.63	6.39
1970	19.46	10.54	13.65	6.22	5.5	5.09	4.94	4.84	9.98	3.3	3.26	3.25
1971	3.36	5.37	4	3	2.8	2.66	2.58	2.58	3.46	2.43	3.88	2.74
1972	6	9.85	35.66	7.26	5.55	3.18	2.85	2.6	2.78	4.23	5.06	4.35
1973	5.66	3.76	3.57	3.21	2.88	2.63	4.62	2.84	3.12	2.47	2.58	3.18
1974	17.44	119.78	10.29	4.49	3.34	2.87	2.86	2.76	2.7	2.89	3.28	33.89
1975	41.01	88.83	6.51	4.36	4.27	4.07	3.4	7.35	4.75	4.32	4.2	6.96
1976	5.24	52.23	153.3	188.9	12.6	7.54	10.8	35.53	8.69	9.42	7.99	7.77
1977	289.07	23.93	9.36	10.36	8.25	7.09	15.3	6.86	8.3	6.43	6.49	6.7
1978	51.19	8.72	11.87	8.91	6.78	5.17	5.71	6.12	5.77	8.19	8.04	8.27
1979	9.89	75.02	9.98	5.64	5.24	5.11	4.93	4.92	4.93	4.23	4.72	9.59
1980	30.69	34.5	23.6	20	6.14	4.14	4.71	5.77	4.6	3.22	2.28	2.3
1981	13.69	14.14	3.9	2.87	15.1	3.11	3.25	2.85	3.24	3.94	3.17	4.67
1982	10.24	66.5	56.1	92.93	11.3	6.79	5.84	5.7	7.42	6.45	6.31	7.09
1983	7.33	12.28	8.48	15.36	5.04	4.77	4.21	8.35	4.5	4.53	4.36	9.45
1984	10.84	6.35	11.8	4.57	3.31	3.11	3.01	3.08	3.23	3.03	3.09	10.1
1985	17.36	3.87	3.8	3.52	2.49	2.18	2.07	3.42	2.25	2.08	2.41	17.94
1986	3.68	14.85	4.43	3.23	2.33	2.27	1.94	2.18	2.12	2.2	2.1	47.45
1987	3.63	2.41	13.49	35.12	1.94	2.57	1.8	3.09	1.98	1.97	1.98	1.79
1988	10.93	30.18	6.91	2.29	3.3	1.91	4.96	2.19	1.87	1.56	1.56	1.57
1989	24.25	3.18	6.74	4.11	3.73	1.56	1.47	1.44	1.55	1.5	1.49	11.8
1990	4.15	48.04	5.76	2.19	1.83	1.8	1.75	1.66	1.66	1.36	1.35	3.26
1991	20.05	73.65	46.02	4.68	2.26	2.03	1.82	1.82	1.87	1.51	1.45	1.98
1992	24.78	48.11	4.27	17.1	2.58	2.12	1.82	1.8	1.78	1.9	1.85	4.24
1993	139.49	191.12	13.84	7.06	5.37	4.92	4.14	3.97	4.46	4.7	4.22	4.25
1994	4.95	4.5	4.97	3.82	3.31	2.84	2.7	2.98	2.07	3.71	7.68	4.23
1995	2.6	2.66	9.66	3.77	2.31	1.51	2.36	5.06	1.79	1.32	2.43	52.38
1996	23.6	15.9	89.63	16.31	5.4	4.74	4.2	3.99	3.95	5.12	3.68	3.92
1997	13.21	10.37	13.17	36.02	4.28	2.81	3.02	3.04	3.31	13.11	14.68	6.06
1998	37.64	37	26.73	4.66	3.57	3.12	3	2.82	2.87	2.76	3	2.88
1999	16.43	23.06	10.06	3.37	2.92	2.56	2.3	2.34	2.32	2.03	5.2	2.31
2000	51.88	4.86	2.92	2.43	2.3	1.92	1.86	1.94	1.86	2.5	2.1	2.2

A.4 DNs for each land cover type,TM,1988

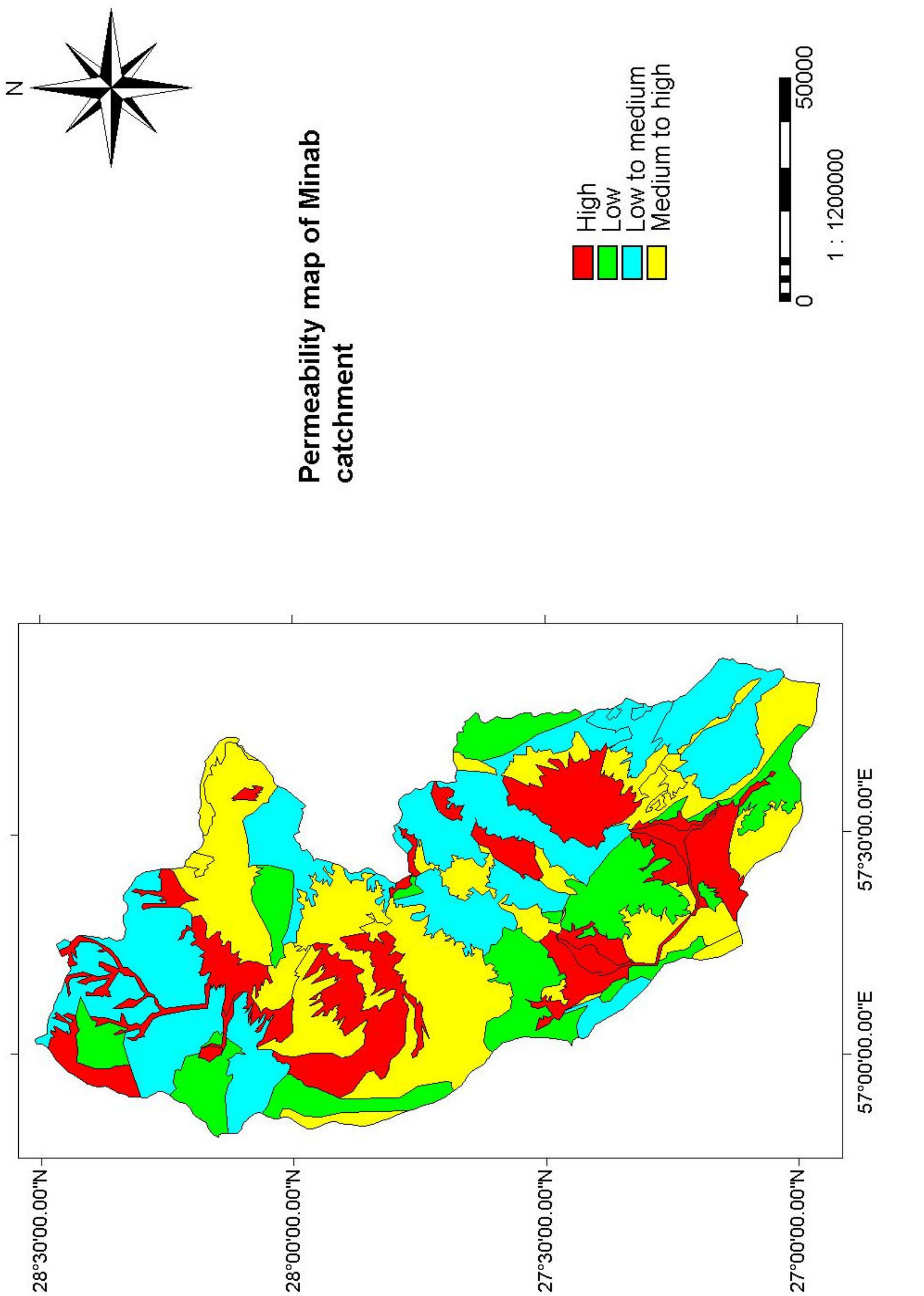
	Band 1	Band 2	Band 3	Band 4	Band 5	Band 7
Orchard	126.6	74.5	1.7	21.2	-9.7	0.4
Irrigated agricultur	167.7	60.5	7.7	22.3	-11.1	0.7
Residential	170.4	68.6	-2.8	5.8	-0.9	-0.2
Poor rangeland	157.1	85.1	3.7	0.3	-1.7	0.6
Moderat rangeland	136	66	7.1	2.4	-4.5	-0.3
Good rangeland	127.1	67.4	6.8	6.4	-3.1	0.2

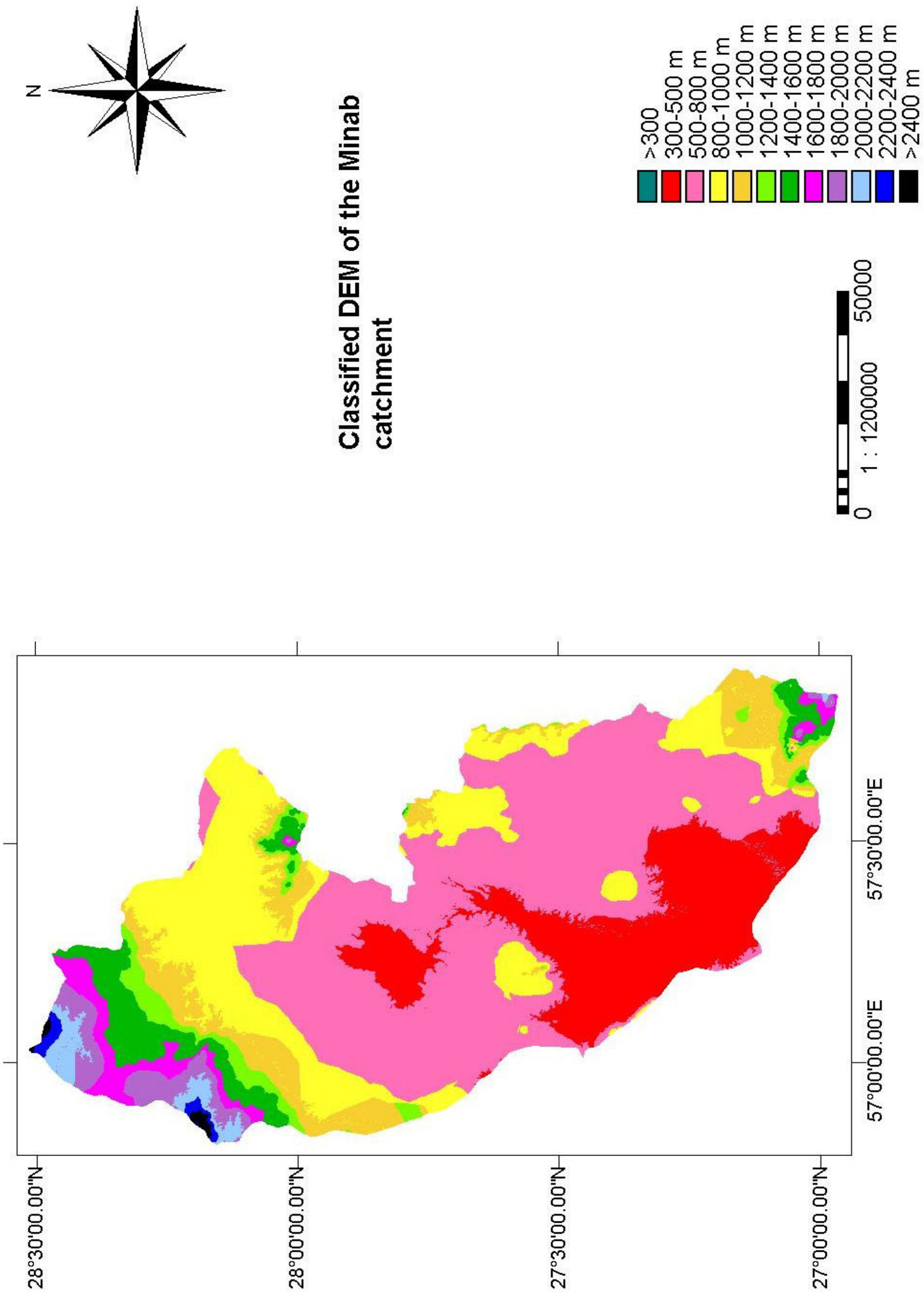
A.5 DNs for each land cover type,ETM$^+$,2002

	Band 1	Band 2	Band 3	Band 4	Band 5	Band 7
Orchard	41	32	28	85	52	36
Irrigated agricultur	44	37	32	122	74	42
Residential	60	52	59	71	81	74
Poor rangeland	53	45	47	53	68	60
Medium rangeland	43	37	41	55	60	49
Good rangeland	33	26	24	41	35	27

B. Figures

B.1. Permeability map of Minab catchment


N
Permeability map of Minab catchment
High
Low
Low to medium
Medium to high
0
50000
1 : 1200000
57°00'00.00"E
57°30'00.00"E
28°30'00.00"N
28°00'00.00"N
27°30'00.00"N
27°00'00.00"N



B.2 Classification map of DEM

B.3 Return period analysis of peak flow of Minab River by Smada program

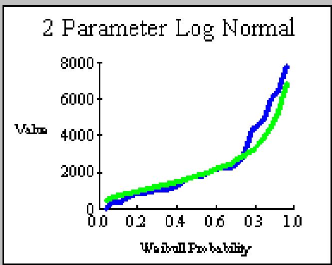
DISTRIB 2.13 - Distribution Analysis

File Edit Statistics Calculators Help

Select Distribution

- ○ Normal
- ◉ 2 Parameter Log Normal
- ○ 3 Parameter Log Normal
- ○ Pearson Type III
- ○ Log Pearson Type III
- ○ Gumbel Type I Extremal

	Weibull	Data	Prediction	Std. Dev.
1	0.04	16.02	462.61	756.3503
2	0.07	376.00	597.85	695.1406
3	0.11	376.00	708.69	645.9423
4	0.15	595.00	809.47	602.1599
5	0.19	786.00	905.53	561.4690
6	0.22	835.00	999.66	522.8162
7	0.26	891.00	1093.63	485.7236
8	0.30	988.00	1188.74	450.0777
9	0.33	1019.00	1286.08	416.0845
10	0.37	1070.00	1386.64	384.3126
11	0.41	1332.00	1491.40	355.7992
12	0.44	1554.00	1601.42	332.1956
13	0.48	1771.00	1717.85	315.8724
14	0.52	1805.00	1842.11	309.8084



	Prob	R Period	Prediction	Std. Dev.
1	0.995	200.0	12405.92	5298.0690
2	0.990	100.0	10279.15	4235.6570
3	0.980	50.0	8369.65	3283.0380
4	0.960	25.0	6659.88	2432.2630
5	0.900	10.0	4675.19	1452.3140
6	0.800	5.0	3354.68	818.7020
7	0.667	3.0	2462.26	439.0211
8	0.500	2.0	1778.90	311.3584
9				

Print

Help

Use CTRL-INSERT to copy highlighted data from spreadsheet. SHIFT-INSERT to paste data into spreadsheet

Mean
2363.5392

2nd M
4.275e06

Skew
1.123e+00

Click to Fit Data to Normal Distribution

B.4 Return period analysis of Maximum daily rainfall of Minab River by Smada program

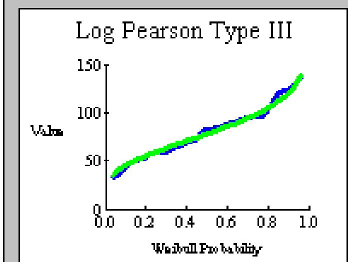
DISTRIB 2.13 - Distribution Analysis

File Edit Statistics Calculators Help

Select Distribution

- ○ Normal
- ○ 2 Parameter Log Normal
- ○ 3 Parameter Log Normal
- ○ Pearson Type III
- ◉ Log Pearson Type III
- ○ Gumbel Type I Extremal

	California	Data	Prediction	Std. Dev.
1	0.04	33.05	35.07	6.7623
2	0.07	36.81	41.62	6.1368
3	0.11	46.38	46.40	5.8222
4	0.15	50.49	50.37	5.6709
5	0.19	52.61	53.88	5.6219
6	0.22	57.27	57.11	5.6414
7	0.26	59.61	60.14	5.7079
8	0.30	60.20	63.03	5.8069
9	0.33	62.28	65.84	5.9280
10	0.37	65.63	68.59	6.0635
11	0.41	70.95	71.32	6.2082
12	0.44	71.14	74.04	6.3579
13	0.48	81.91	76.77	6.5097
14	0.52	82.51	79.55	6.6617



	Prob	R Period	Prediction	Std. Dev.
1	0.995	200.0	169.66	32.8903
2	0.990	100.0	160.11	25.9507
3	0.980	50.0	149.71	19.7741
4	0.960	25.0	138.25	14.5906
5	0.900	10.0	120.92	9.8219
6	0.800	5.0	105.35	8.0153
7	0.667	3.0	91.61	7.2703
8	0.500	2.0	78.15	6.5858
9				

Print

Help

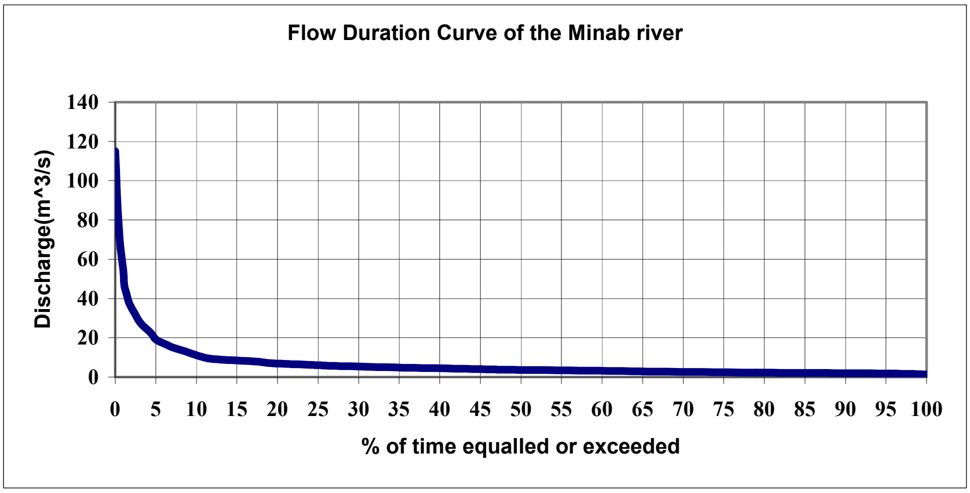
Use CTRL-INSERT to copy highlighted data from spreadsheet. SHIFT-INSERT to paste data into spreadsheet

Mean
80.4635

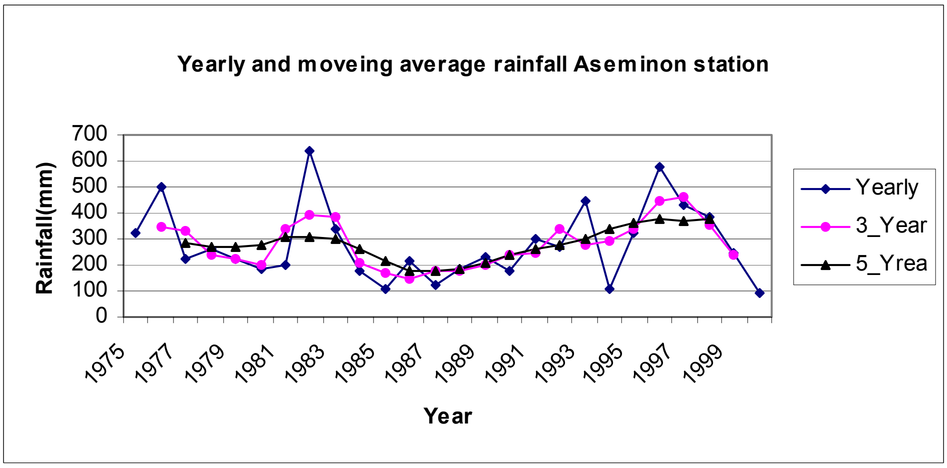
2nd M
7.97e02

Skew
2.604e-01

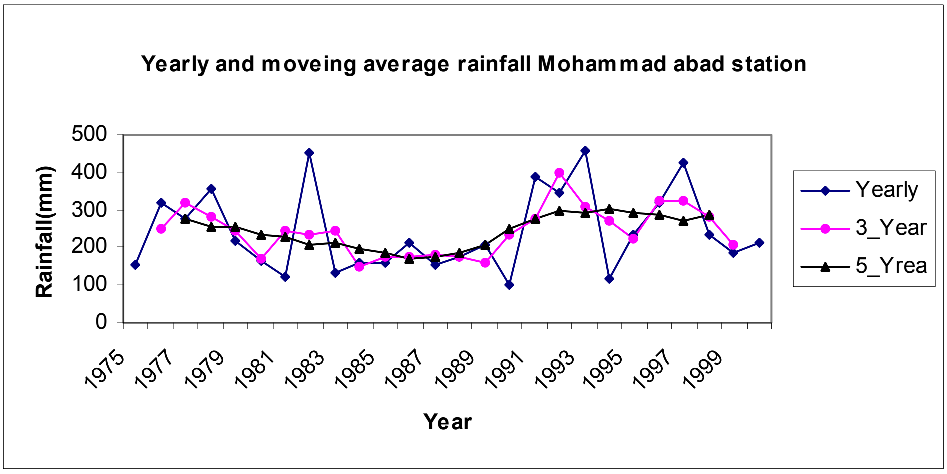
Click to Fit Data to 3 Parameter Log Normal Distribution



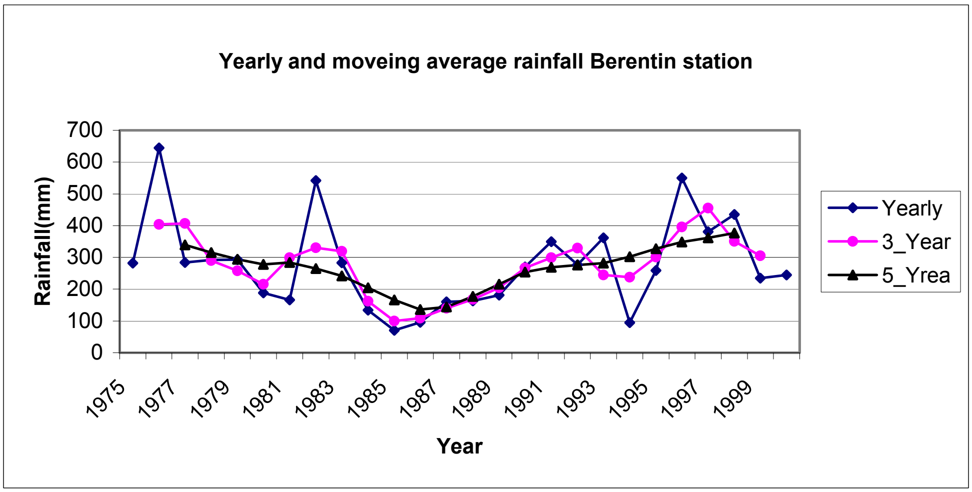
B.5 Flow duration curve of Minab River (1975-2000)



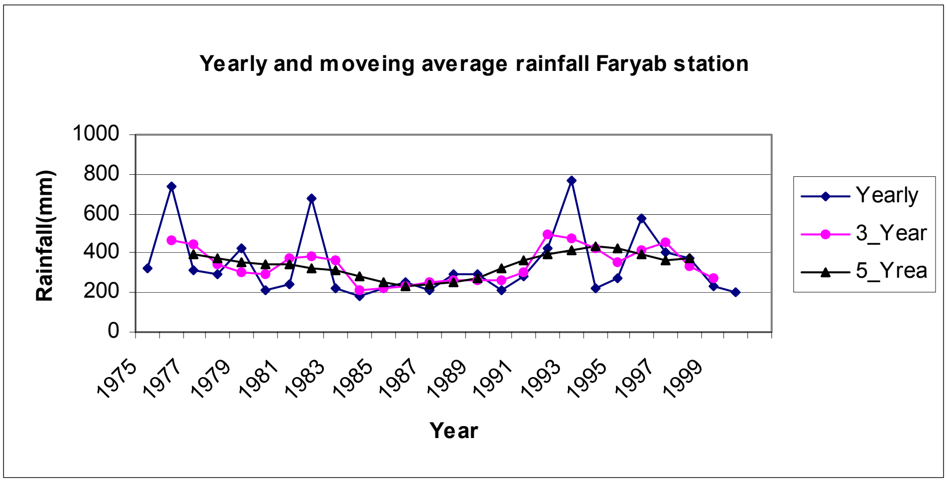
B.6 Annual and moving average rainfall of Aseminon station



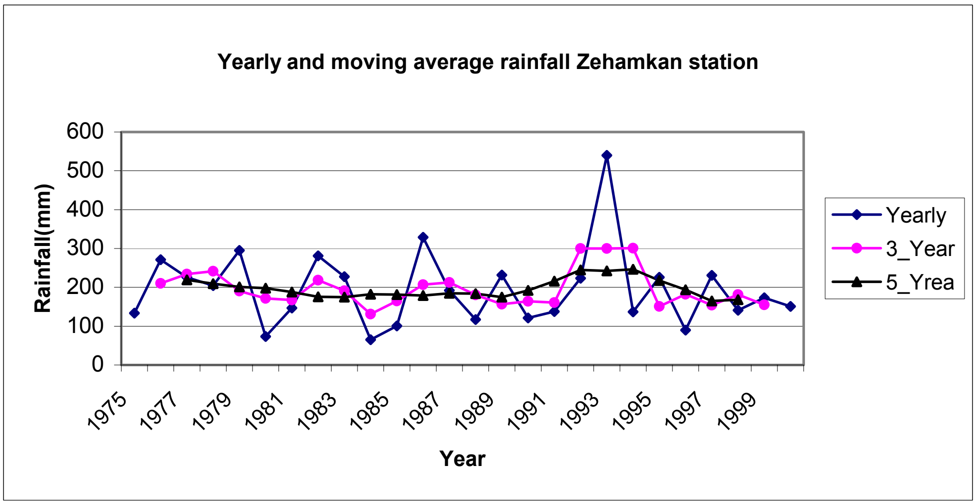
B.7 Annual and moving average rainfall of Mohammad abad station



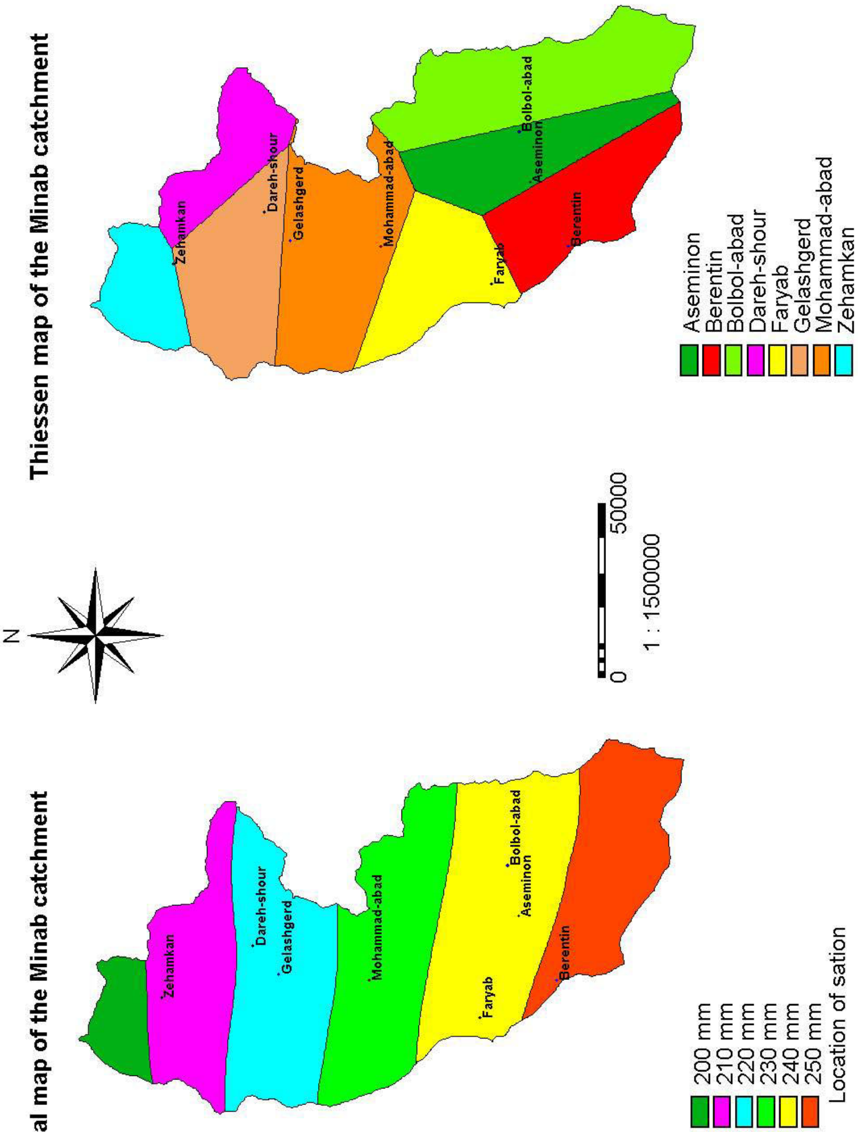
B.8 Annual and moving average rainfall of Berentin station



B.9 Annual and moving average rainfall of Faryab station



B.10 Annual and moving average rainfall of Zehamkan station



B.11 the Thiessen polygon and Isohytal maps of the study area.