SUPPORTING REPORT I (MASTER PLAN)

PAPER III

Basin Topography, Land Use and Geology

THE STUDY ON FLOOD AND DEBRIS FLOW IN THE CASPIAN COASTAL AREA FOCUSING ON THE FLOOD-HIT REGION IN GOLESTAN PROVINCE

SUPPORTING REPORT I (MASTER PLAN)

PAPER III BASIN TOPOGRAPHY, LAND USE AND GEOLOGY

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CHAPTER 1 TOPOGRAPHY

1.1 Topographic Classification

The main regional topography in the Study Area is summarized below.

Alluvial Plain to Inundation Region

The Alluvial plain and inundation area are evidenced by a flat feature with a regular seaward slope and widely distributed in Nardin basin (sub-basin S-1) with an elevation of about 1,415 - 1,430 m, Cheshmeh Nay to Sefid Daly basin (sub-basin S-1) with 1,300 – 1,400 m, Cheshmeh Khan to Robat Gharabil basin (sub-basin S-2) with 1,200 – 1,500 m, Dasht basin (sub-basin S-3) with 1,000 – 1,200 m, and downstream from Tangrah (sub-basins S-6 to S-8) with 65 – 500 m.

It consists of various topographical elements of riverbed, floodplain, fan, and natural levee. This region has been widely utilizing for farming.

Hilly Region (and Undulating Region)

Hilly region extends between alluvial plain to mountainous region, and at the middle western part of drainage border near Sudaran, Goldin, Kolanke, Dastshad, where talus deposit, Tertiary formation, and heavily weathered rocks are distributed.

This topography is characterized as a gentle and smooth relief on river terrace and old age topography. The drainage pattern is parallel and it forms a gentle valley with a riverbed gradient of 1/10 to 1/20. Gully erosion is dominant in this region because of soft or fragile characteristics of these rocks.

This region has been utilizing for dry farming and grazing.

Mountainous Region

It is distributed mainly in the middle stream reaches from Dasht to Terjenly (sub-basin S-5) with an elevation of about 500 m in the riverbed to the border of the study area with an elevation of about 1,700 to 2,300 m. It shows a rugged and forms very steep slope with cliff in the distribution area of Cretaceous limestone. Small traces of collapse are distributed here and there.

The drainage pattern is dendritic and it forms a steep to very steep valley. The vegetation coverage is generally low excluding “Golestan National Park”, especially in the headwaters of Nardein basin and Robat Gharabil basin. The Golestan National Park is located in the middle stream reaches of the Madarsoo River with natural forest.

1.2 Basin Topography

The topography is classified in detail on the basis of the interpretation through satellite images (2004) and aerial photos (scale: 1/40,000, in 1976) and field reconnaissance.

Riverbed

The riverbed is divided into two of before flooding of 2001 and after. Almost old riverbeds were covered by the 2001 flooding in the middle reaches passing through the Golestan National Park.

Alluvial Fan (Alluvial Fan New, Alluvial Fan Old, Alluvial Cone)

Alluvial fan is mainly divided into two of New, Old with an attendant topography of Alluvial Cone. These are widely distributed at the stream mouth and most of Old Alluvial fans are covered by New one.

Colluvial Slope and Pediment

These are distributed at the mountain foot having gentle slope. It might change over from talus with comparatively steep slope. So it may lump together with talus deposit in geology.

Floodplain (Floodplain 1, 2 and Flood Terrace)

It is also classified as younger and older Floodplain and Flood Terrace reflecting its formative period. But Flood Terrace is sometimes difficult to distinguish from Lower Terrace. They are distributed along the Madarsoo River and main tributaries of Cheshmeh-Khan River, Ghiz Ghaleh River and Gelman Darreh River.

Talus

Talus topography is widely distributed at the foot of steep slope with comparatively steep slope (repose angle: 35 degree in maximum). Talus deposit becomes sources of debris flow at steep streams that are distributed at the right bank of middle reaches in the Madarsoo River.

Terrace (Terrace 1, 2, 3)

It is recognized three Terraces of Lower, Middle, and High. The lower terrace is distributed 5 to 10 meters height from the recent riverbed and the middle terrace is 30 to 50 meters. High terrace is rare. The lower terrace is widely distributed around Dasht village, at Cheshmehnik village and Nardin village in the upper reaches of the Madarsoo River, and in the upper reaches of Ghiz Galeh River and Cheshmeh-Khan River basins. The middle terrace is also distributed adjacent to the lower terrace.

Landslide

Landslide is mainly distributed on the gentle slope of weathered Paleozoic formations, soft Tertiary formations, Mesozoic shale, Mesozoic bedded marl, and along crashed zones. Collapses are dominant in the distribution area of fresh Mesozoic limestone located at the right bank of middle stream reach of the Madarsoo River.

1.3 Slope Condition

Slope condition is one of the essential factors for debris flow occurrence in topography. It is well known debris flow may occur in the steep slope stream.

Slope and Sediments

The steep slope, which is composed of rocks, yields mainly rock and sand by gravity fall and rainfall. They will accumulate at the mountain foot of gentle slope and will be named “talus deposit”. On the other hand, the gentle slope, which is dominantly composed of clay with sand, will mainly yield soil. The slope condition and sediments is presented in the following table.

Table 1.1 Slope Condition and Sediment Transport

Slope	Main Lithology	Yielding	Cause of movement	Topography	Debris flow
Steep	Sound with loosened rocks	Rocks & sand	Gravity, rainfall		
Medium	Soft rocks Weathered rocks Loosened rocks	Rocks and sand with clay	Gravity, rainfall	Talus	Rain
Gentle	Heavily weathered & loosened rocks, Gravel, Sand, Clay	Gravel, sand, clay	Rainfall	Talus, Terrace, Fan	Debris Deposit
Plain	Gravel, sand with clay			Fan	Debris Deposit
Plain	Gravel, sand, clay			Flood plain	

<u>Slope Classification</u>

The slope coverage will be estimated as the following table on the basis of GIS topographical database with a scale of 1/50,000 in the Study Area. Figure 1.1 shows the slope classification.

Table 1.2 Slope Coverage in the Study Area

Description	Degree (^{o})	Area (Km^2)	Ratio (%)
1 Level to nearly level	0-3	560	24
2 Gently sloping to undulating	3-10	766	32
3 Moderately sloping to rolling	10-15	405	17
4 Strongly sloping to moderately sloping	15-20	286	12
5 Steep mountains	20-30	271	12
6 Very steep mountains	>30	76	3
Total		2,364	100

It is also classified in the each sub-basin area in the following tables.

Table 1.3 Slope Coverage by Sub-Basin

Description	Gradient (Degree)	Sub-Basin Area (Km^2)								Total
		S-1	S-2	S-3	S-4	S-5	S-6	S-7	S-8	
1.Level	0-3^o	227	135	27	15	6	47	22	80	560
2.Gentle	3-10	319	163	61	59	44	70	40	9	766
3.Moderate	10-15	124	70	23	22	63	66	34	3	405
4.Strong	15-20	67	45	9	13	81	46	21	1	286
5.Steep	20-30	42	35	3	15	119	40	16	0	271
6.Very steep	>30	8	3	0	2	50	11	2	0	76
Total	-	787	452	125	126	362	281	136	95	2,364

Table 1.4 Slope Coverage Ratio by Sub-Basin

Description	Gradient	Slope Coverage Ratio in the Sub-Basin Area (%)							
	(Degree)	S-1	S-2	S-3	S-4	S-5	S-6	S-7	S-8
1.Level	0-3^o	28.8	30.0	22.0	12.0	1.6	16.7	16.3	85.0
2.Gentle	3-10	40.6	36.1	49.1	46.9	1.3	25.0	29.2	10.0
3.Moderate	10-15	15.7	15.4	18.5	17.6	17.3	23.5	25.1	3.6
4.Strong	15-20	8.5	10.0	7.6	10.6	22.8	16.5	15.7	1.3
5.Steep	20-30	5.4	7.8	2.8	11.6	32.8	14.4	12.0	0.2
6.Very steep	>30	1.0	0.7	0.0	1.3	13.8	3.9	1.8	0.0
Total		100	100	100	100	100	100	100	100

Sub-basins S-1, S-2 and S-3 are located in the headwaters of the Madarsoo River. Gentle slopes are dominant and almost 70% of slope will be level to gentle in these basins.

Sub-basin S-5, which covers the middle stream of Madarsoo River and Golestan National Park is located in, has the most steep and very steep slope with a ratio of 46.6% while their slope gradient in the whole Study Area are about 14.7%. If streams had riverbed deposits and slope covered by the talus deposit and other unconsolidated materials, strong rainfall will triggers off debris flow at streams in the sub-basin S-5 area.

<u>Stream Gradient and Debris Flow</u>

According to the result of the debris flow investigation in Japan, debris flow will occur in the slope gradient with more than 15 degree and will be piled up at the place with a gradient of less than 15 degrees in general. Of course, it depends on the rainfall intensity with accumulated rainfall, and other natural condition of geology, vegetation, and land use.

The relation between stream gradient and debris flow is applied in the following classification based on the experimental works in Japan. In this case, drainage area will be required more than 5 hectares with a slope gradient of more than 15 degrees.

Table 1.5 Relationship between Stream Gradients and Debris Flow

Gradient	Classification of debris flow
$\theta \geq 20^o$	Location of debris occurrence
$20^o > \theta \geq 15^o$	Location of debris occurrence and passing area
$15^o > \theta \geq 10^o$	1. Piled-up area of debris flow. 2. Passing area of mudflow.
$10^o > \theta \geq 3^o$	Piled-up area of both debris flow and mud flow
$3^o < \theta$	Piled-up area of both debris flow and mud flow

Source: Experimental Classification in Japan

<u>Collapse and Landslide</u>

Collapses are distributed here and there that were confirmed by the field reconnaissance and aerial photo interpretation. But most of them are marks of old collapse in the middle to lower reaches on the basis of aerial photo taken in 1966. New collapses are distributed only in mountain streams. Large-scale collapses and landslides were formed in the sub-basin S-1 to S-4 in the headwaters of the Madarsoo River where unconsolidated deposit and soft rocks are widely distributed. They are easily eroded and have supplied the soil and rocks to the riverbed.

Most of debris flow in 2001 or 2002 might occur eroding the riverbed deposits that had been transported by old collapse and deposited the riverbed in Tangrah and Terjenly villages in the middle reaches with steep and very steep slope.

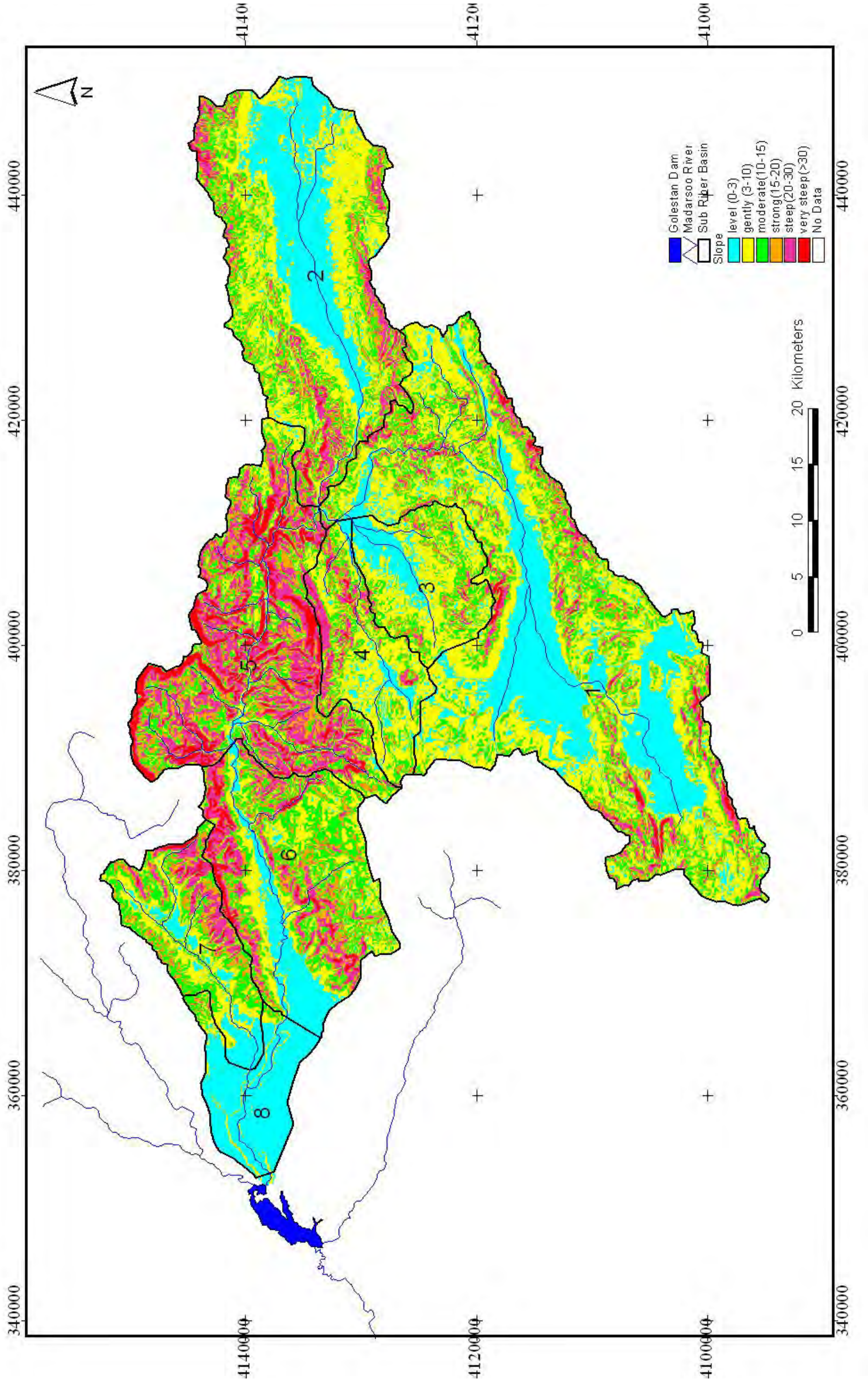

Figure 1.1 Slope Classification

1.4 Fan

Rainfall erodes loose materials such as loosened rocks, heavily weathered rocks, Tertiary soft rocks, and unconsolidated sediments of talus deposits, terrace deposit, and river deposit. Loosened rocks also fall down to the mountain foot. They will be deposited at the riverbed and the gentle slope located at the mountain foot (river side) and the plain. The strong rainfall will make the river discharge increase, and it will erode the riverbed and riverbank and transport the materials of rocks, sand, clay, and others which deposited at riverbed and riverbank to more downstream comparing with a ordinary river discharge. Transported materials will deposit again on the area with gentle stream slope.

These transported materials make fan topography as shown in the left photo below.

Fan is the historical marks of debris flows. The debris flow changes sometime the river course. The main river course may flow in the center of the valley, but the debris flow deposits forces the main river course to the opposite side. But, flooding water of the main river might erode again the foot of fan deposit “R.1” as shown by a solid arrow “G” in Figure 1.2.

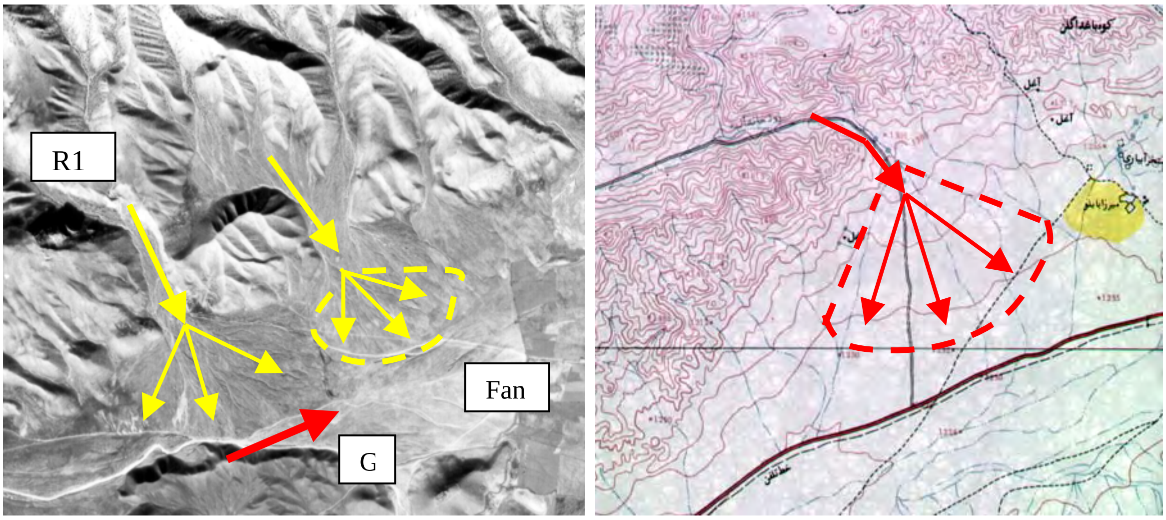

Figure 1.2 GhyzGaleh River near Dasht Village

Fan is also recognized on the topographical map as shown in the right map. Contour line shapes like a fan. Fan is formed at many stream mouths all around the Study Area. This fan is located at the opposite side of Cheshmeh Khan village in the sub-basin “S-2”.

CHAPTER 2 LAND USE

2.1 General

Land

Land is a delineated area of earth surface embracing all attributes of biosphere above and below it, including climate, soil, geological materials, flora, fauna, as well results of human activity, such as pond/reservoir and afforestation.

Land Resources

Land Resources are of two categories: 1) Natural land- constitutes natural elements such as climate, soil and vegetation. 2) Artificial land- includes products of human activity such as dam/dike, roads, canal and terraces.

Land Use

Land Use is any kind of permanent or cyclic human intervention to satisfy human needs, either material or spiritual or both, from the complex of natural (climate, soil, vegetation) and artificial (dike, road, canal) resources, which together are called land.

Land Use Planning

Land Use Planning is the development of plans for uses of land that will, over a long period, best serve the general welfare, together with the formulation of means/measures for achieving such uses. Land use planning is important in enhancing the living condition of people, by increasing productivity of resources, and preserving natural assets for future generations through proper management and sustainable utilization.

Land Use Plan

Land Use Plan for Study Area has been formulated based on the following concept/ assumption:

(1) Target year for the project is 2025, and its implementation is commenced just after completion of feasibility study and submission of relevant reports by JICA(Japan International Cooperation Agency) study team.

(2) Average annual population growth rate is fixed at 1.8 % per year, assuming all factors on population growth remain constant. This figure has been estimated by Iranian experts, based on growth rate for the last 10 years, and mentioned in Reports provided by MOJA (Ministry of Jihad-e-Agriculture).

(3) Area (space) expansion for residential purposes is set at 119 m^2 per person, including spaces for road network, commercial, educational, sanitary and other facilities, in line with figures provided by Housing Foundation of Islamic Revolution, Golestan province.

(4) Desert area is vegetated at a rate of 2% per year, considering water scarcity and harassed climate, more than this is not expected.

(5) Only 40% of bare land is converted to agricultural and pasture lands at an average rate of 2% per year, due to limitations such as presence of rocks/gravel, and scarcity of water.

(6) Structures such as dam/dike and relevant facilities to be constructed for flood/debris flow control are of small scale and require limited space.

(7) About 85% of scattered, small and unproductive dry farms established in rangelands are abolished, and 15 % remain for self-subsistence of persons associated with livestock pens.

(8) Area of existing lake/pond is kept unchanged, since the study team does not purpose construction of any reservoirs.

(9) Afforestation (artificial forest) is not significantly expanded, but existing natural forestlands are rehabilitated/improved and properly managed. Natural forest area is expanded by about 4%, to bring the situation back to that of 1960s.

(10) Rangeland area is rehabilitated/improved and expanded by about 4.5% over the next 20 years, to get a situation somewhat near to that of 1960s.

(11) Area for irrigated agriculture is not expanded, but farms are modernized and properly managed to attain higher yield in unit area, in accordance with MOJA policy.

(12) To avoid overgrazing and ensure sustainable utilization of natural resources, reduction in number of livestock (even up to 50 %) is carried out, and domestic animals are dismissed from forest, as stressed in 3rd and 4th development plans of the country, and emphasized by the Ministry of Jihad-e-Agriculture (MOJA).

(13) Sufficient and timely fuel is made available to inhabitants to discourage illegal harvest of forest resources, as stipulated in 3rd and 4th development plans of the country.

(14) Inhabitants are educated on importance of natural resources and concept of sustainable utilization, as well encouraged to participate in development activities (MOJA policy).

2.2 Guidelines/Procedures for Execution of Land Use Plan

However this land use plan is spatial in nature, it should be implemented by referring to the following maps/materials inserted in the report of the JICA study team or available with MOJA.

Table 2.1 Map Utilized for Land Use Planning

Thematic Map	Available Data/Information/Map
Map of present land use	Precipitation isohyets map/material
Map of land capability classification	Long-term climatic data/information
Map of slope classification	Map showing location of historical and cultural assets
Geology map	Map showing location of existing and proposed structural measures
Soil map	Soil classification map/materials

The plan should be implemented by paying attention to the following points:

(1) Area allocated for afforestation is gradually planted by fast growing trees in localities susceptible to (massive/gully) erosion, and subjected to frequent flood/debris flow. Forestry experts of MOJA are expected to provide technical details and cooperate in afforestation works.

(2) Bare land shown on present land use map is carefully surveyed and suitable parts (having no rock/gravel limitation) are identified and gradually vegetated. Rangeland experts of MOJA, and staff of NRGO (Natural Resources General Office) of relevant provinces would cooperate on this matter.

(3) Part of desert-land is gradually converted to pasture by introducing drought resistant vegetation, starting from localities with most favorable conditions.

(4) Over the past 30 years area of dry farming has largely increased by being expanded in rangeland and on slopes nearby villages. Most of expanded farms are unproductive, and cause soil erosion. To prevent further land degradation, gradual reduction in dry farming is recommended. Farms on slopes are converted to olive/nut yards. Soil and Water Research Division of Golestan Provincial Jihad-e-Agriculture Organization has good field experiences and is expected to cooperate in execution tasks.

(5) In last decades, the area of irrigated farming has doubled, thus no further expansion of irrigated area is proposed. Instead improvement in irrigation facility/method and proper utilization of water and management of water resources are recommended.

2.3 Past Land use

To grasp land use situation in the past decades, the available data/materials were thoroughly examined, result of which is briefly presented below.

Data for land use in 1960s indicates that larger areas have been under rangeland and forest, and lesser areas under irrigated and dry farming (Table 2.2). This could be attributed to lower population, and biological densities in the area, and thus less pressure on natural resources. Area of bare land was significantly high, indicating less competition for land occupation, and more choices in selecting favorable location for economic activities. Large area of forest occurred in territory of Golestan province, while rangelands were distributed mostly in Khorasan and Semnan province. Irrigated farming was mainly practiced in lower reaches of Madarsoo river basin in plains of Golestan province.

Table 2.2 Past (1960s) Land Use in the Madarsoo River Basin

Land Use	Area (ha)	% of Total
Afforestation	1,814	0.77
Bare Lands	5,502	2.33
Desert	1,067	0.45
Dry Farming	30,748	13.01
Forest	67,473	28.54
Irrigated Farming	14,865	6.29
Lake	115	0.05
Rangeland	114,552	48.45
Mixed Dry Farming and Rangeland	10	0.00
Residential (Urban)	254	0.11
Others (limits of sites for structures, roads, observatory stations, etc)	-	-
Total	236,400	100.00

Source: Ministry of Jihad-e-Agriculture (MOJA), GIS Division.

2.4 Present Land Use

Present land use map (2005) was prepared based on the latest (2002) satellite imagery of the area, checked through field survey and revised based on experience and knowledge of MOJA experts, with collaboration of the JICA study team. Final output of this work is presented in Table 2.3 as well as shown in Figure 2.1.

Careful examination of present land use and comparing it to that of 1990s, as shown in Figure 2.2 as reference, reveal that:

- The area of bare land has decreased by about 51%, and mainly converted to dry farms.

- Area of dry farming has increased by about 22 %, and the increment is more significant in those parts of the basin occurring in Semnan and Khorasan provinces.
- Forest area has decreased by about 4%, particularly in less elevated area nearby villages.
- Area of irrigated farming has increased by 51%, and the increment is more pronounced in those parts of the basin occurring in Khorasan and Semnan provinces.
- Area of rangeland has reduced by 21%, and mostly converted to dry farms.

Table 2.3 Present (2005) Land Use in the Madarsoo River Basin

Land Use	Area (ha)	% of Total
Afforestation	1,830	0.77
Bare Lands	2,693	1.14
Desert	1,078	0.46
Dry Farming	39,276	16.61
Forest	64,781	27.40
Irrigated Farming	30,703	12.99
Lake	126	0.05
Rangeland	94,709	40.06
Mixed Dry Farming and Rangeland	938	0.41
Residential (Urban)	266	0.11
Others (limits of sites for structures, roads, observatory stations, etc)	-	-
Total	236,400	100.00

Source: Golestan Provincial Jihad-e-Agriculture Organization, GIS Section, with collaboration of JICA Study Team- September 2005.

2.5 Future Land Use

In formulating the future land use plan by paying attention to following points:

(1) Noting chronic changes in land use during the past decades by examining relevant documents and materials

(2) Predicting the future population till target year of 2025

(3) Realizing the biological capability and environmental condition of the area

(4) Paying attention to concept of sustainable development and wise/efficient utilization of natural resources

(5) Avoiding any harm to national natural reserves or historical/cultural heritages

(6) The plan is a *back to future* approach, means attempt is made to bring the status of natural resources more or less near to that of 1960s, which reflects the biological capability of the area on that period. And in planning biological capability should be highly considered.

(7) Emphasizing on crop yield increment in existing irrigated fields by enhancing water use efficiency and improvement in farm practice, rather area expansion

Table 2.4 Future (2025) Land use in the Madarsoo River Basin

Land Use	Area (ha)	% of Total
Afforestation	1,840	0.79
Bare Lands	1,616	0.68
Desert	647	0.27
Dry Farming	34,095	14.42
Forest	67,371	28.50
Irrigated Farming	30,703	12.99
Lake	126	0.05
Rangeland	98,970	41.87
Mixed Dry Farming and Rangeland	141	0.06
Residential (Urban)	741	0.31
Others (limits of sites for structures, roads, observatory stations, etc)	150	0.06
Total	236,400	100.00

Source: Golestan Provincial Jihad-e-Agriculture Organization, GIS Section, with collaboration of JICA Study Team- September 2005.

Land Capability is the capacity/fitness of a piece of land for a defined use. In expressing land capability two terms are used:

(1) Current capability refers to land capability for a defined use at its present condition (without improvement measures).

(2) Potential capability is capability of land for a defined use at some future date (after completion of improvement measures).

Data/information on land capability in the Madarsoo River basin is presented in Table 2.5, as well as shown in Figure 2.3. MOJA experts may refer to these materials while executing the land use plan.

Table 2.5 Land Capability in the Madarsoo River Basin

Land Capability in the Madarsoo River Basin

Code	Area (ha)	% of Total	Present Situation	Improvement Measures needed	Situation after Improvement
12	7,012	3.0	Mountainous area with shallow soils, pastural vegetation and woody plants. Used for seasonal grazing. Prone to erosion and degradation.	Erosion and runoff control, care for rangeland (control grazing and re-vegetation)	Rangeland with better soil condition and higher production. Land with more reliability and higher value
13	17,906	7.6	Mountains with 30 to 60% slope, moderately deep soils with rock outcrops, prone to erosion and landslide. Poor rangeland, with forest trees in some localities.	Prohibition of grazing and tree cutting, forest and rangeland rehabilitation, countermeasure for erosion and landslide.	Can be used for grazing with proper management. Contribute in enhancement of ecosystem of the basin
15	117,526	49.7	Mountains with sharp slope (50 to 100%), Moderate to deep and relatively heavy soils, forest land, prone to debris flow/ erosion and subject to landslide in some localities. Dry farming is practiced in some flat patches.	Measures for erosion, debris flow and landslide control. Abandon of dry farming and introduction of woody plants. Forest maintenance works.	Proper site for promotion of Eco-tourism, and conservation of bio-diversity. Wood production under proper management.
22	4,432	1.9	Hills with20 to 40% slope, deep heavy soils, poor pastural vegetation, subjected to severe erosion. Low-density forest with dry farming.	Abandon of dry farming. Introduction of commercial trees. Measures for erosion and runoff control.	Suitable place for wood and fruit production, such as olive and nuts.
32	4,234	1.8	Alluvium terraces with gravelly soils, prone to flood and sediments. Presently are under irrigated farming	Measures for flood and sediment control.	Land with better quality and higher reliability for grain production.
42	81,708	34.5	Piedmont plains with 1 to 3% slope, deep heavy soils, high groundwater table in most parts, subjected to flood/debris. Largely occupied by irrigated farms.	Measures for flood/debris flow control. Provision of drainage, proper farming practices.	Land with higher value and more productivity. Suitable for introducing variety of crops in irrigated fields.
53	3,582	1.5	Alluvial (sedimentary) plains with gentle slope, deep heavy soils, high water table, prone to flood, and salinity. Presently most parts are occupied by dry farms.	Measures for flood and erosion control, provision of irrigation and drainage facilities.	Creation of suitable arable lands, expansion of in irrigated area and increment in agricultural production. Suitable place for producing forage
Total	236,400	100.00			

Sources: Golestan Provincial Jihad-e-Agriculture Organization, GIS Section; Soil and Water Research Section. JICA Study Team, Field Survey on Land use- October 2004～June 2005.

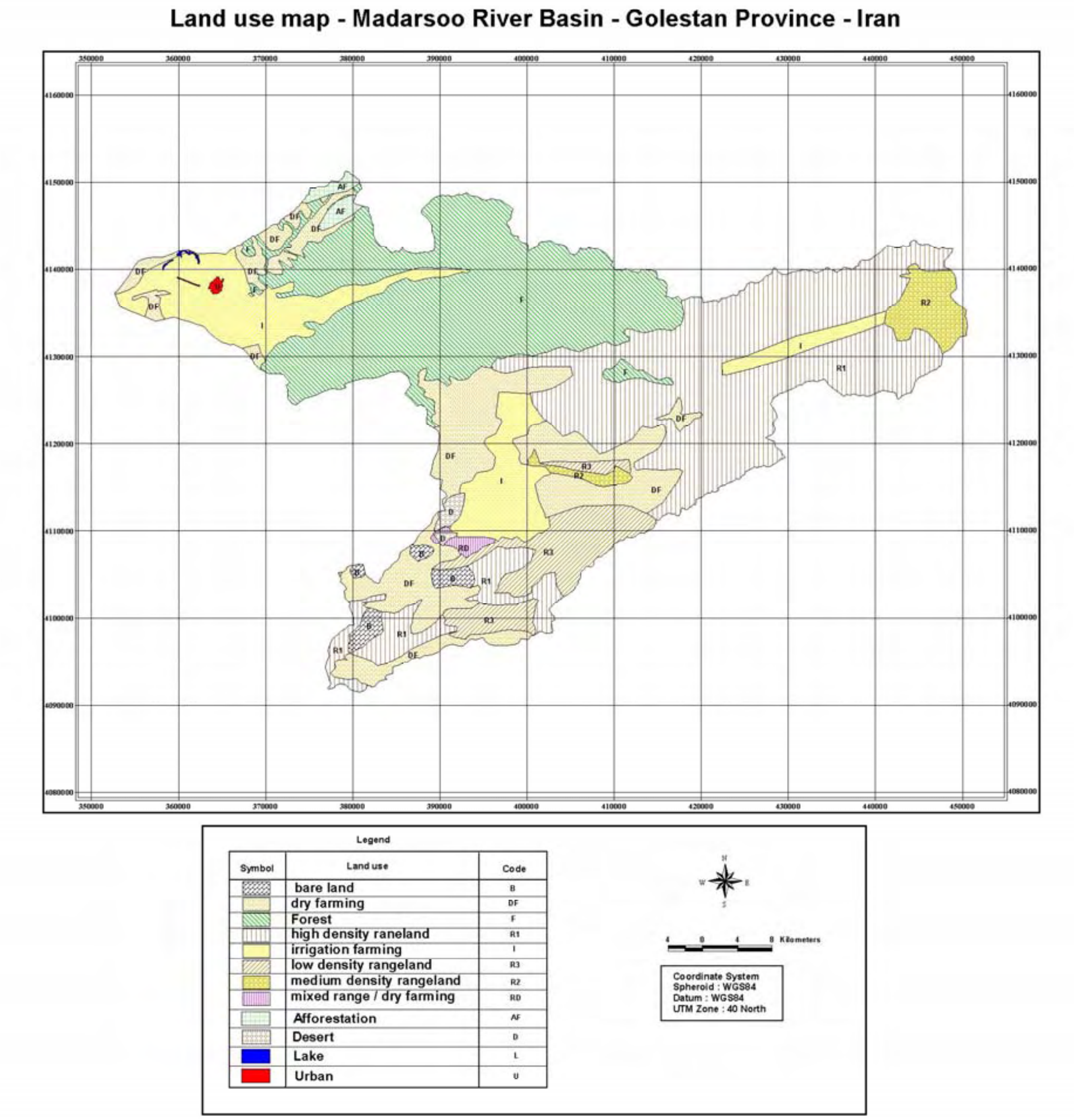

Figure 2.1 Present Land Use Map in 2005

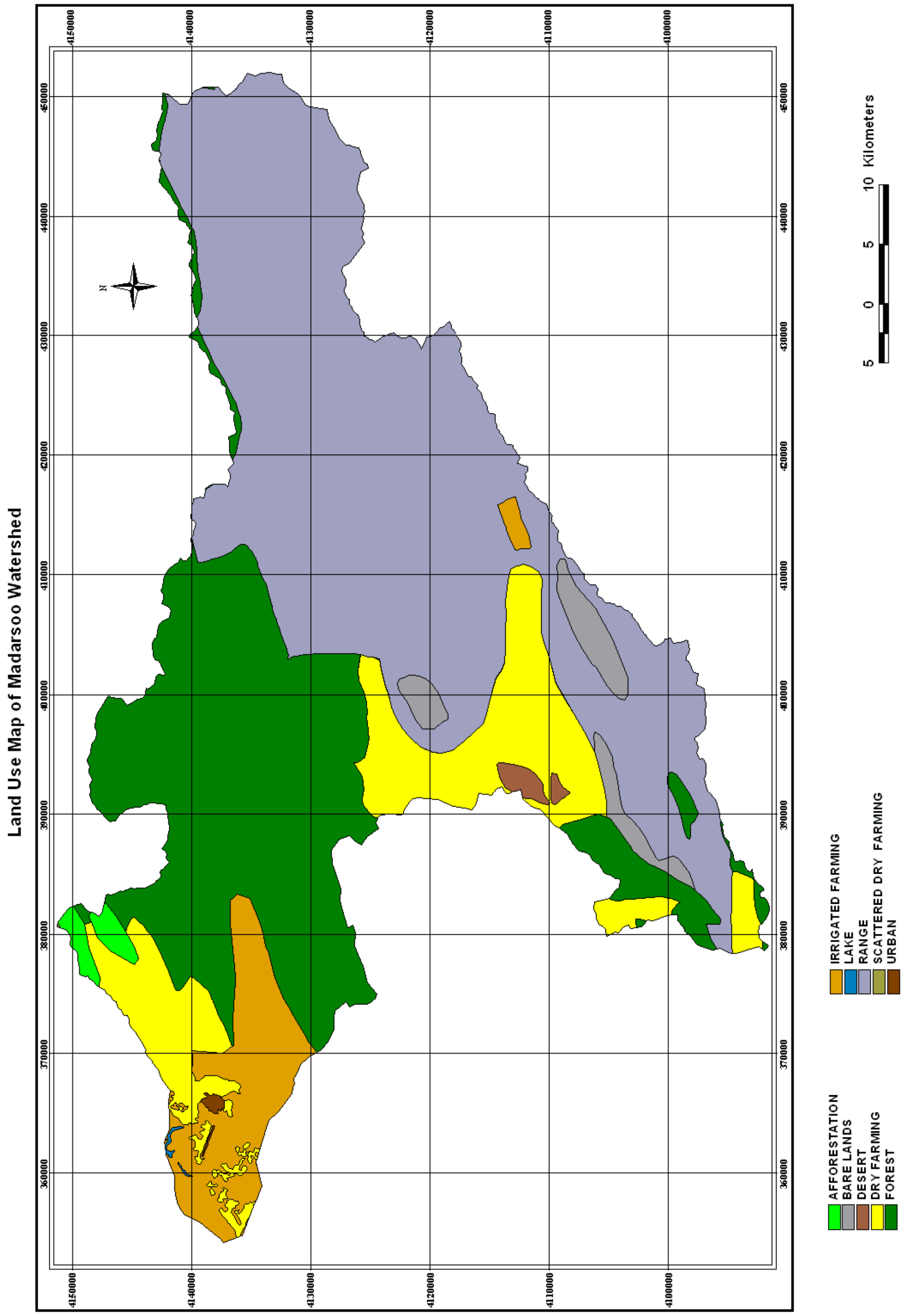

Figure 2.2 Past Land Use Map in 1990s

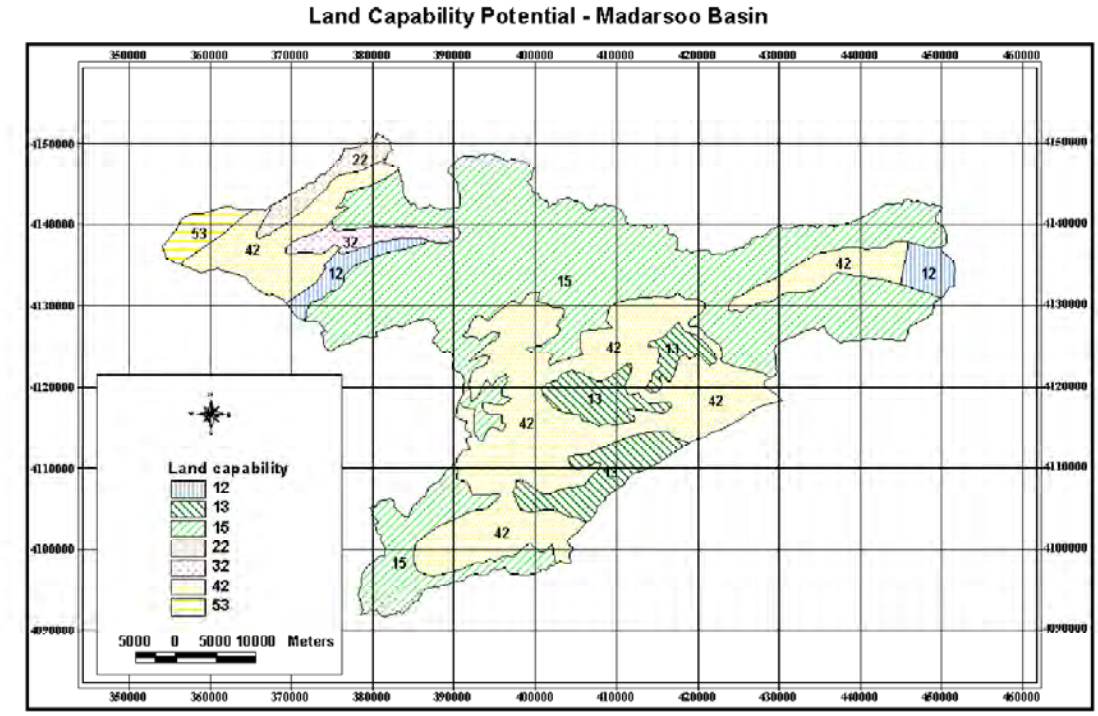

Figure 2.3 Land Capability Map in the Madarsoo River Basin

CHAPTER 3 GEOLOGY

3.1 General

The Study Area is located in the Alborz Mountains that is the continuum of Anatolia Mountains in Turkey that is characterized by seismic activities.

The Study Area is located in the transition zoon of East Albolz Tectonic Zone and Koppeh Dagh Tectonic Zone. These two tectonic zones meet around from Tangrah to Robat Gharabil. Proterozoic to present sedimentary rocks are distributed with a few igneous rocks in the study area and they are heavily folded and faulted. These basement rocks are covered by Quaternary deposit of river, talus, terrace, fan, and loess. The Quaternary deposits are widely distributed in the Nardein-Sefid Dali basin(S-1), Cheshmeh Khan basin(S-2), Dasht-e-Sheikh basin(S-3), Ghiz Galeh basin (S-4), and the lower reaches of the Madarsoo River (S-6 to S-8).

The stratigraphy and lithology (same meaning as petrology) is shown in Tables 3.1 and 3.2, and geological map is presented in Figure 3.1. Major formations are described below.

3.2 Tectonics

3.2.1 Alborz Zone

Alborz Mountains has not monotonous stratigraphical specification and geological structure and also the length of geological periods.

The most area of northern slope in Alborz Mountains is lack of Palaeocene sediments and green tuff of Eocene epoch in Tertiary period. It shows that northern slope of Alborz went out of water because of orogeny in the beginning of Cenozoic era and also Alborz region separated from central Iran because of Aral-Caspian depression. General trend of east to west of Alborz is ancient extension and related to Alps stage.

The folding movement occurred in Palaeocene epoch and changed environmental condition that depression in north changed to dry and formed Alborz Mountains. Southern depression in Alborz Mountains developed quickly and resulted in vast depression of central Iran and generated the volcanic activity in the sea that formed volcanic formation in southern slope of Alborz. But volcanic formation was not distributed in northern slope of Alborz. The central part of southern Caspian block has subsided and is known as south Caspian depression at present. The second stage of orogeny happened in the beginning or middle of Eocene epoch. It causes to height and later erosion of central part of Alborz that quickly subsided and continuously deposited thick sediments of Molasses. Formation of Molasses in north of Alborz slope started in Vindobonian age of Miocene epoch. It is reported that thousands meter of marine molasses are related to Miocene to Pliocene epoch and Quaternary period. Marine sediments are also distributed in southern Caspian after orogeny (post-orogeny).

The last movements of Alborz orogeny occurred in late Pliocene or early Pleistocene epoch. These movements resulted in fault and gentle erosion. It can be defined that northern border of Alborz is between small hills of northern slope and coastal field of the Caspian Sea which are the part of relatively stable region of southern Caspian block. The east border between Alborz and Koppeh Dagh did not specified.

3.2.2 Koppeh Dagh Zone

Ineshtoklin reported in 1968, Koppeh Dagh Zone is one of geological units that are located in the eastern part of the study area. Koppeh Dagh zone was formed by the uplift at the south of the Caspian Sea in Precambrian period. Accomplished studies shows that Koppeh Dagh basin had been distributed up to the end of Triassic and after late Jurassic period sediments had changed to marine sediments. The most part of Koppeh Dagh basin went out from water in Paleogene of Tertiary period because of sea regression. Accordingly, Koppeh Dagh zone has no sediments after Paleogene epoch. Folds have the trend of northwest to southeast formed by Alps orogeny. On the other hand, faults have the trend of northeast to southwest that had been active in the Cretaceous period. Volcanic activity is rare. Border of Alborz and Koppeh Dagh zone will be the Korkhord Fault located in the northern part of middle to headwaters of the Madarsoo River.

3.3 Stratigraphy

3.3.1 Alluvial Deposits (Qal)

Alluvial Deposits include recent river deposit, talus deposit, and fan deposit.

These deposits are widely distributed in alluvial plain at Cheshmeh Khan to Robat Gharabil (S-2), Dasht (S-3), Cheshmeh Nay to Hagholkhajeh (S-1), Nardein (S-1), and the lower reaches of the Madarsoo River (S-6 to S-8). Main compositions are sediments of the numerous watercourses that flow in the plain and mountain foot.

Recent river deposit and floodplain deposit (rd)

Recent river deposits are distributed along the permanent and seasonal mainstream, floodway, its tributaries, and mountain stream. It generally consists of well-sorted silt, sand, and sand with rounded gravel layers in mainstream, floodway, and its tributaries. The thickness of this deposit is estimated a few ten meters in the headwaters to more than 50 meters in the lower reaches of the Madarsoo River.

It mainly consists of sand and gravel with fine materials of silt and clay in the steep middle stream reaches of the Madarsoo River, floodway, and steep mountain stream. They are eroded and transported again and again by floods to downward.

Talus deposit (td)

It is distributed at mountain foot caused by the gravity fall and rainfall. It consists of all materials of clay, silt, sand, and gravel depending on the geology of the slope. Gravel and sand are dominant at the mountain foot of steep slope with sound rocks. But sand and fine materials are distributed at the mountain foot of middle to gentle slope with heavily weathered rocks and or soft rocks.

Fan deposit (fd)

It is distributed at the mouth of mountain stream here and there, and mainly consists of sand and gravel. The fan deposit will play an important role in the debris flow investigation that it is the trace of debris flow in the past.

Almost stream mouths at the mountain foot have the fan deposit. It is supposed to have occurred in any number of times in the past on the basis of depth of deposit and its stratigraphy. The thickness of one debris deposit may be a few meters in an average and 5 to 6 meters in maximum on the data of Japan. The river discharge or flooding scale may regulate transported gravel size.

Terrace deposit (Q1)

Terrace deposit is distributed bordering the sub-basin of Cheshmeh Khan to Robat Gharabil (S-2), Dasht (S-3), Cheshmeh Nay to Hagholkhajeh (S-1), Nardein (S-1), and the lower reaches of the Madarsoo River. Main compositions are sediments of the old river courses or old floodplain that flow in the plain. It generally consists of well-sorted silt, sand, or sand and rounded gravel with silt. The thickness of this deposit is estimated a few ten meters.

3.3.2 Loess Formation (Q_{le})

Loess is widely distributed in hilly region at the lower reaches of the Madarsoo River and scattered here and there in the study area. Loess is the terrestrial sediment formed by the wind transportation and lack of layer deferring from aqueous and marine sediments. It is mainly composed of silt with a little clay and sand. It also consists of a kind of minerals such as quartz, feldspar, calcite, dolomite, mica, and iron. Its color is yellow to brown because of chemical weathering of iron and iron oxide. It is classified into “ML” or “ML-CL” and “ML-SP” in the Unified Soil Classification.

3.3.3 Basal Conglomerate Formation (Qpl)

This formation is the basal conglomerate in Quaternary period. The conglomerate is weak in consolidation because of a few cementations and easily weathered and broken. It is distributed around Cheshmeh Khan to Robat Gharabil village, north of Hagholkhajeh village, and southwest of Nardein village. These distributions are utilized for pasture land or leave devastated land.

3.3.4 Neogene Formation

Ngc

This is conglomerate of the Late Neogene epoch and distributed in Cheshmeh Khan to Robat Gharabil village, west of Dasht village, southern ridge of Hagholkhajeh village, and southwest of Nardein village. It is weak in consolidation and easily broken and eroded. It becomes easily the source of debris flow.

Ngm

Ngm is composed of reddish alternation of siltstone, sandstone, and conglomerate and widely distributed on the hilly region of around Dasht to Nardein village, Hagholkhajeh village, and Cheshmeh Khan to Robat Gharabil village. It becomes also the source of debris flow because of weak consolidation and easily broken. It is the bed with a strike and dip of N30^{o}E/80^{o}SE to N50^{o}E50^{o}SE in the Ghiz Galeh River basin.

3.3.5 Paleogene Formation (Pgm)

This formation consists of marl with fossil of nummulites and sandstone. They are not well consolidated and distributed in local at the south of Cheshmeh Nay village and north of Nardein village.

3.3.6 Fajan Formation

It is the formation of reddish conglomerate and sandstone distributed at Peighambar mountains located the north of Hagholkhajeh village and north of Nardein village.

3.3.7 K2 Formation (K2)

It is mainly composed of limestone with a glauconite sandstone and marl in latest Cretaceous period. They are distributed with the direction of south-west to north-east from Nardein to Cheshmeh Khan village, northern to western heights of Nardein village with a strike and dip of N75^{o}E/20^{o}NW, Dasht Shad village in local with a strike and dip of N45^{o}E/40^{o}NW, Peighambar mountains located the north of Haghol Khajeh village with a strike and dip of N45^{o}E/50^{o}NW, and south of Cheshmeh Khan village.

3.3.8 K1 Formation (K1)

It is the sediment of lower Cretaceous period and mainly composed of grey medium-bedded limestone with a fossil of orbitolina. It is distributed locally at west of Cheshmeh Nay village with a strike and dip of N30^{o}E/45^{o}SE.

3.3.9 Lar Formation (Jl) (Jl: East Alborz Zone)

It is the sediment of upper Jurassic period and compared with Mozduran Formation (Jmz) in the Koppeh Grah Tectonic Zone. This formation is composed of hard limestone forming strongly steep slope and cliff and porous dolomitic limestone. It is distributed in the lower to middle reaches of the Madarsoo River with a direction of southwest to northeast covering almost territory of Golestan National Park.

Mozduran Formation (Jmz: Koppeh Gagh Zone)

It is composed of very hard grey limestone and distributed only in the eastern edge of the study area.

3.3.10 Jlm Formation (Jlm: East Alborz Zone)

This formation is composed of grey fine-grained limestone with a fossil of ammonite and marl in the lower part. It is distributed in the southwest of Dasht Shad village with a strike and dip of N45°E/25°NW, Khonbi Mountains located south of Cheshmeh Khan village with a strike and dip of N65°E/25°NE, and west of Dasht village with a strike and dip of N80°W/20°NE.

Chamanbid Formation (Jcb: Koppeh Gagh Zone)

It is the sediment of middle Jurassic period and compared with "Jlm" Formation in the East Alborz Tectonic Zone. It is composed of limestone and marl and widely distributed from the headwaters to lower reaches of the Madarsoo River in the study area, especially in the northern slope of Tangrah village.

3.3.11 Shemshak Formation (Js)

It is the sediment of lower Jurassic period and mainly composed of shale, marl, sandstone, and nodular limestone with a fossil of ammonite and blemnite. It is scattered only in the south of Robat Gharabil village, south of Dasht village, near Dasht Shad village with a strike and dip of N20°W/40°NE, around Cheshmeh Nay village and northwest of Nardein village.

3.3.12 Khoshyeilagh (Dkn)

It is the sediment of Devonian period and mainly composed of limestone and shale with a lot of fossil. It is distributed in the lower reaches of the Madarsoo River at the south of Pasang village with a strike and dip of N70°W/10°NE and locally distributed in the southeast of Sefid Dali village.

3.3.13 Niur Formation (Sn)

It is the sediment of Silurian period and mainly composed of shale, sandstone, and limestone with a lot of fossil in the upper part. It is scattered near Dasht village with a strike and dip of N45°W/25°NE and distributed accompanied by andesite lavas in the north of Robat Gharabil village. Rocks of this formation are weathered in general.

3.3.14 Baruf Formation (P ε)

It is the one of the oldest formation of Pre-Cambrian period in Proterozoic era in the study area. It is composed of dolomite, dolomitic sandstone, shale, and quartzitic sandstone and distributed around the Golestan forest tunnel and around Nardein village in local. Rocks of this formation and other Pre-Cambrian formation (P ε - ε m) are weathered in general.

Table 3.1 Stratigraphy in the Study Area (East Alborz Zone)

Era	Period/Epoch	Formation	Sym.	Lithology*[1]
Cenozoic	Quaternary			
	Holocene	Alluvial	Qal	Sand & gravel with clay
		River deposit	rd	Sand & gravel
		Talus deposit	td	Clay, sand, gravel including debris flow
	0.01*[2]	Fan deposit	fd	Sand & gravel with clay
	Pleistocene	Terrace	Q^1	Sand & gravel with clay
		Loess	Q_{le}	Silt, sand with clay
	2	Basal conglo.	Q_{pl}	Conglomerate
	Tertiary			
	Neogene	-	Ngc	Conglomerate
		-	Ngv	Andesitic basalt, Basalt
		-	Ngr	Reddish shale, Marl, Sandstone, Conglomerate
	25	-	Ngm	Marl, gypsiferous-basal colored conglomerate.
	Paleogene	-	Pgl	Limestone, Sandy limestone with *Nummulites*
65		-	Pgm	*Nummulitic* Marl, Sandstone
	65	Fajan	Pgf	reddish Conglomerate, Sandstone
Mesozoic	Cretaceous	-	K_2	Limestone, detritic glouconitic Sandstone, Marl
		Kartasch	K_1	grey Medium-bedded Limestone, *Orbitolina*
	Jurassic	Lar	J_l	Limestone, oolitic-porous dolomitic Limestone
		-	J_{lm}	fine Limestone, grey, *Ammonite*, with Marl (lower)
		Shemshak	Js	Upper: Shale, Marl, Sandstone, nodular Ls, *Ammonite*, *Blemnite* Lower: Shale, Sandstone with thin-bedded limestone
247	Triassic	Elika	TRe^2	thick-bedded Dolomite
		Elika	TRe^1	Limestone, Marl, Shale, Ss in thin-bedded
Paleozoic	Permian	Ruteh	Pr	grey medium-bedded Limestone, *Fusulinid*
	Carboniferous	Mobarak	Cm	Limestone, medium-bedded massive Dolomite, Lower part: calcareous shale
	Devonian	Khoshyeilagh	Dkn	Undivided sediments
			Dkn^3	Limestone, Shale partly nodular & fossiliferous
			Dkn^2	white & red Gypsum
			Dkn^1	Limestone intercalated with dark Shale
			g	white Gypsum
		Padeha	Dp	white & red Quartzitic sandstone, Upper part: intercalated with red Shale
	Silurian	Niur	Sn	Shale, shaly Sandstone, Limestone. Upper part: nodular & fossiliferous
			Sv^2	Andesite lava
			Sv^1	Andesite lava & shale
	Ordovician	Shirgesht	O	Limestone, Shale, sandy Shale
	Cambrian	Mila	ε m	Limestone, Dolomite with *Brachiopoda & Trilobite*
575		-	ε s	White Quartzitic sandstone. Upper: Quartzite
Proterozoic	Pre-Cambrian	Zaigun-Lalun	P ε zl	Shale, reddish quartzitic Sandstone
		Baruf	P ε	Dolomite, dolomitic Ss, Shale, quartzitic Ss

*[1]: Ss: Sandstone, Ls: Limestone. *Italic word*: fossil name.
*[2]: Geological age (x 10^6)

Source: Geological Quadrangle Map of Iran No.13. 1/250,000. Cartography by IRAN GEOGRAPH Co.

Table 3.2 Stratigraphy in the Study Area (Koppeh Dagh Zone)

Era	Period/Epoch	Formation	Sym.	Lithology
Cenozoic	Quaternary			
	Holocene	Alluvial	Qal	Sand & gravel with clay
		River deposit	rd	Sand & gravel
		Talus deposit	td	Clay, sand, gravel including debris flow
	0.01*	Fan deposit	fd	Sand & gravel with clay
	Pleistocene	Terrace	Q^1	Sand & gravel with clay
		Loess	Q_{le}	Silt, sand with clay
	2			
	Tertiary			
	Neogene	-	N	Red beds
	Paleogene	Khangiran	Pkh	Shales
65		Chehel Kaman	Pch	Limestone
	65	Pestehleigh	Pps	Red beds
Mesozoic	Cretaceous	Kala	Kk	Limestone
		Abtalkh	Kab	Shale, Siltstone
		Abderaz	Kad	cherty Limestone
		Atamir	Kat	Shale
		Sanganeh	Ks	Shale
		Sarcheshmeh	Ksa	Marl
		Tirgan	Kt	Limestone
		Shurigeh	Ksh	Sandstone
		Zard	Kz	Sandstone
	Jurassic	Mozduran	Jmz	Limestone
		Chamanbid	jcb	Limestone and Marl
		Bash-Kalateh	jbk	Shale
247	Triassic	-	-	-
		-	-	-
Paleozoic	Permian	-	-	-
	Carboniferous	-	-	-
	Devonian	-	-	-
	Silurian	-	-	-
	Ordovician	-	-	-
575	Cambrian	-	-	-
Proterozoic	Pre-Cambrian	-	-	-

Ss: Sandstone, Ls: Limestone.
*: Geological age (x 10^6)
Source: Geological Quadrangle Map of Iran No.13. 1/250,000. Cartography by IRAN GEOGRAPH Co.

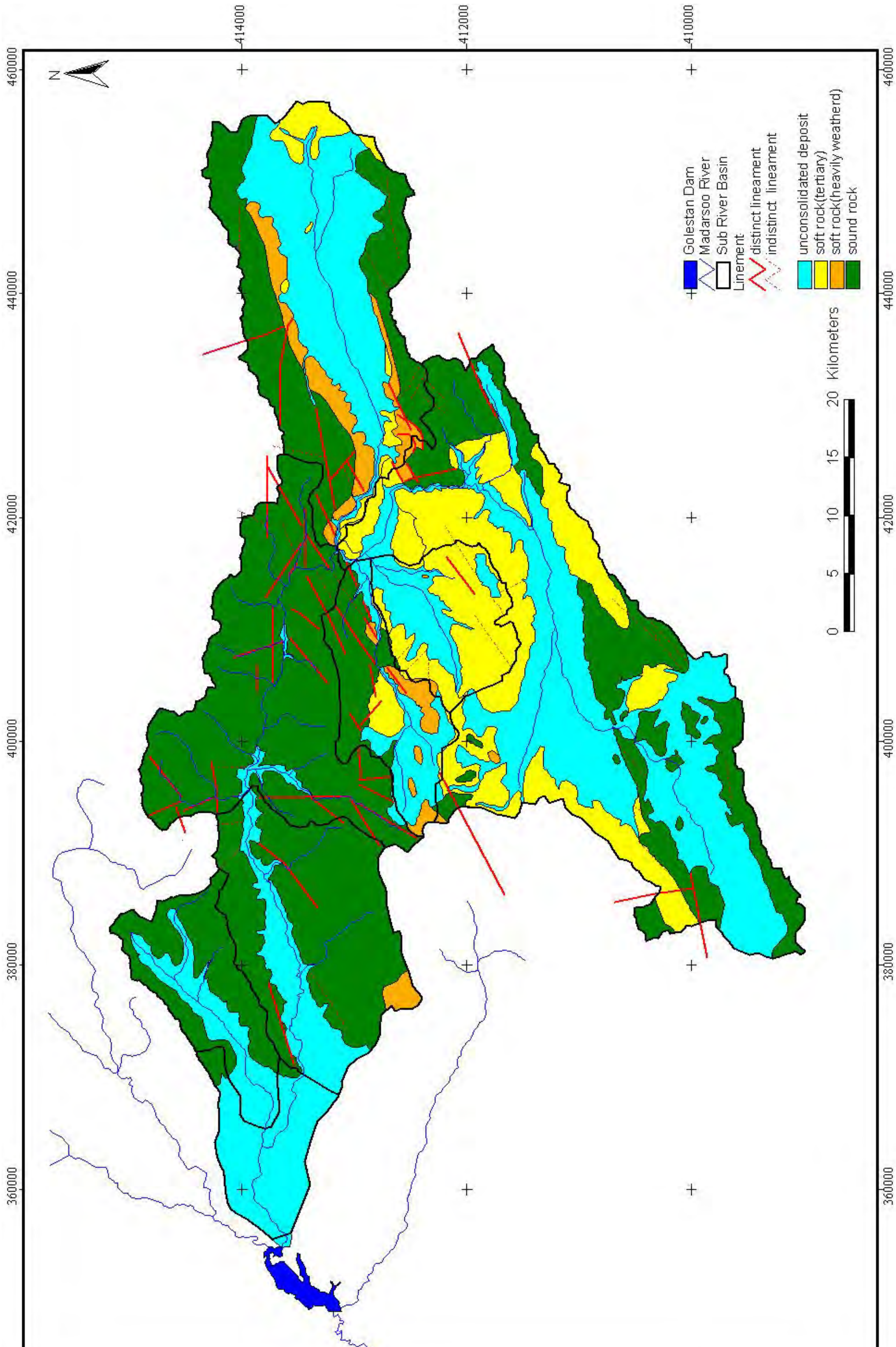

Figure 3. 1 Engineering Geological Map

3.4 Consideration on Debris Flow

3.4.1 Sediment Source

Topographical feature is important information of geological distribution. In other word, topography is a reflection of the geological characteristics. The objectives of this clause are to clarify the sediment sources for debris flow on the basis of topographical and geological conditions in the study area. That is why, geological characteristic, especially unconsolidated deposit and soft rock will be classified by the field survey, aerial and satellite images interpretation. The results are compiled as shown in Figure 3.1.

Table 3.3 Relationship between Topography and Geology

Slope	Lithology
Level – Gentle	Unconsolidated deposits: river, talus, fan, terrace
Moderate	Soft rocks: Tertiary formations, Weathered, sheared, altered rocks Silurian and Pre-Cambrian formations (heavily weathered)
Steep to very steep	Sound rocks

For example, sub-basin S-5, which covers the middle stream of Madarsoo River and Golestan National Park is located in, has the most steep and very steep slope with a ratio of these slope gradient about 47 %. It is composed of sound rocks. On the other hand, sub-basins S-1, S-2, S-3, and S-4 have level to gentle slope with a ratio of these slope gradients about 70 %. They are mainly composed of unconsolidated deposits and soft rocks. They have the possibility of more sediment supply comparing with sub-basin S-5.

3.4.2 Erosion and Deposit

There are some types of erosion by rainfall and river flow as follows:

- Downward and side erosion against river bed deposits by river flow,
- Slope erosion for talus deposit, terrace deposit, soft rocks, and loosened rocks, and
- Sheet erosion for topsoil, terrace deposit, and heavily weathered rocks on dry farm land.

The slope erosion and sheet erosion will constantly supply the materials to the riverbed. The accumulated riverbed materials will be sometimes transported to the downstream by floodwater. The downward erosion in the river or mountain stream is the strongest comparing with other erosion types when floodwater comes out. Then, debris flow investigation should focus on the distribution of riverbed deposit to establish the hazardous area in the first place. Secondly, the distribution of unconsolidated deposits, which have the potential sources of sedimentation to the river, will be investigated.

In the 2001 Flood, downward erosion (channel incision) was remarkable and side erosion (bank erosion) and sheet erosion were not serious in the river basin of Terjenly and Tangrah villages and Ghiz Galeh river basin. In these rivers, river bed deposit might have the thickness of about 2 meters in Terjenly, 5 to 10 meters in Tangrah stream, and more than 20 meters in Ghiz Galeh river. These had deposited on the gentle slope in the stream and river. Ordinary floodflow will not erode this river deposit on gentle sloping area, while it erodes and transports the riverbed materials on only steep slope to the downward. That is why; this 2002 rainfall is unusually heavy. But, the study will be recommended to take measures for next unusual rainfall for streams and rivers, which have thick (more than 2 meters) river deposit.

Figure 3.2 Typical View of Sediment Yielding Area
(Left: Terjenly, Right: Upstream of Ghiz Galeh River Channel)

Left photo is the view of Terjenly mountain stream basin. Tributaries are not devastated. The center-left exposure (brownish) is sound and stable so that does not supply a lot of soil and gravel to the river. Debris flow occurred eroding existing riverbed deposit at Terjenly village.

Right photo shows that slope erosion (gully erosion) for Tertiary soft rocks (Ngm) and downward erosion of riverbed deposit at Ghiz Galeh River basin.

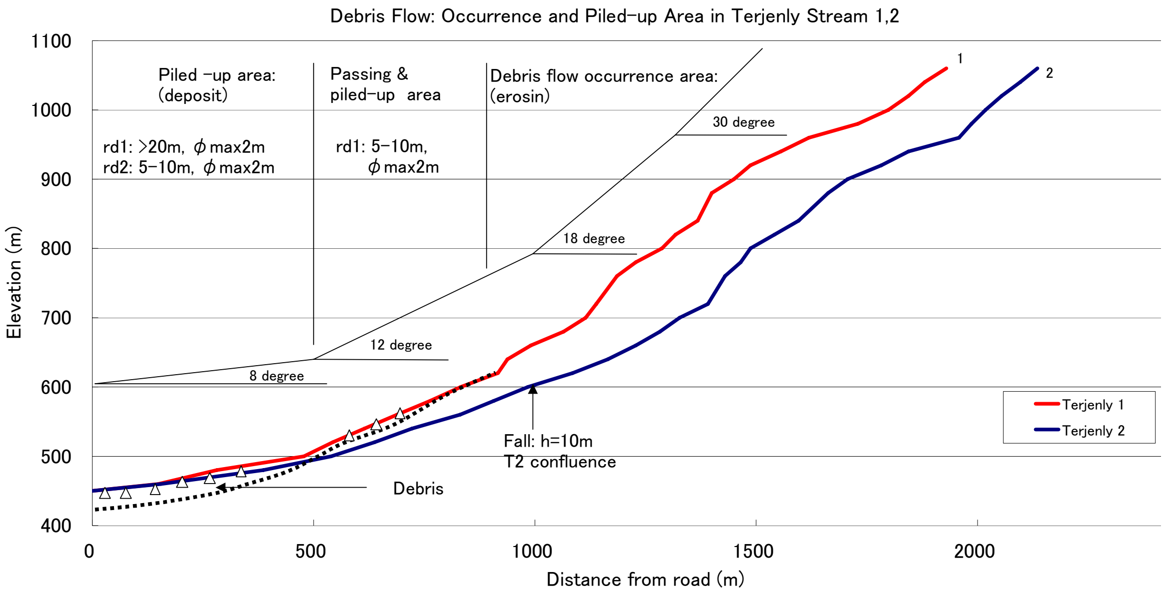

Figure 3.3 Longitudinal Profile of Debris Flow Streams in Terjenly Village

3.4.3 Criteria for Debris Flow Occurrence

The element of occurrence for debris flow consists of various conditions such as rainfall, topography, geology, vegetation, and land use as summarized below.

Table 3.4 Occurrence Factors of Debris Flow

Related Factors	Rank				
	1	2	3	4	5
Vegetation	Bare	Scattered grass	Grass	Shrub	Forest
Land use	Bare	Dry farm	Range	Fruit plant.	Forest
Channel gradient θ	$\geq 20^{o}$	$20^{o} > \theta \geq 15^{o}$	$15^{o} > \theta \geq 10^{o}$	$10^{o} > \theta \geq 3^{o}$	$< 3^{o}$
Slope gradient θ	$\geq 20^{o}$	$20^{o} > \theta \geq 15^{o}$	$15^{o} > \theta \geq 10^{o}$	$10^{o} > \theta \geq 3^{o}$	$< 3^{o}$
Channel deposit thickness	≥2m	2>T≥1m	<1m		
Geology	Volcanic ash, sand (dune)	River, terrace, talus deposits	Weathered, sheared, loosen rocks. Tertiary soft rocks	Jointy rocks	Sound rock
Deposit thickness	>5m	5-2m	2-1m	<1m	-
Fault/Alteration	Large >5m	Medium 5-1m	Small <1m	Non	-
Spring	Yes	Yes in rainy	Wet ground	Non	-
Landslide volume	>1000m^3	1000-500m^3	500-100m^3	<100m^3	Non
Collapse volume	>100m^3	100-10m^3	<10m^3	Non	-
Rainfall	Both Continuous and hourly rainfall are important				
Earthquake	One of the trigger of debris flow				

The above-mentioned related factors could be divided into two causal factors of debris flow: predisposing causes and triggers. The relationship among them could be illustrated in the following figure.

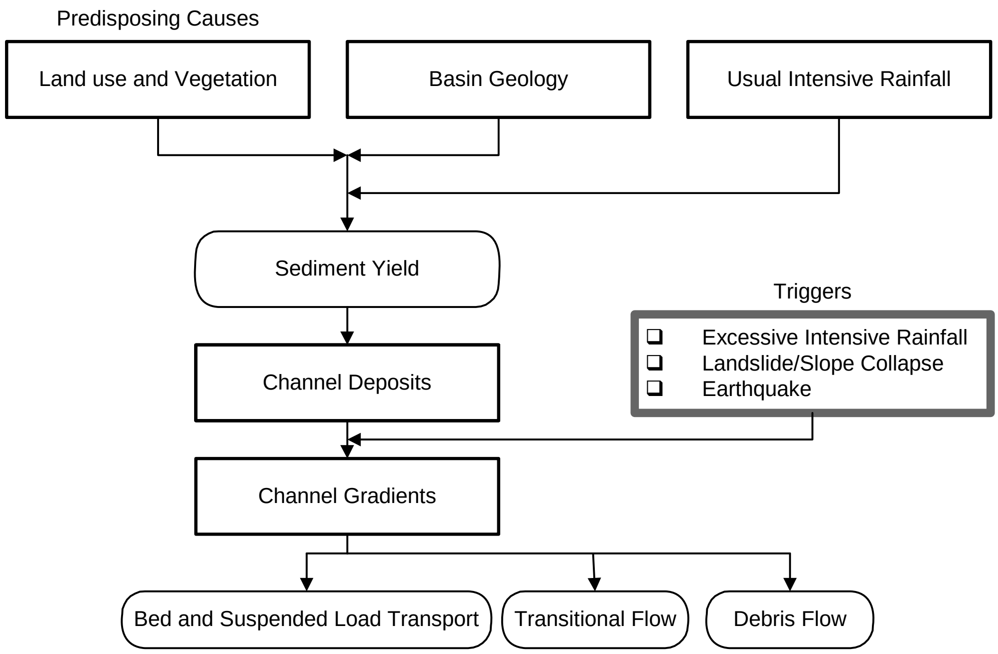

Figure 3.4 Relationship among Causal Factors of Debris Flow

Based on the experiences in Japan, debris flow will be easy to occur empirically at a stream, overlapping with the following conditions:

- Excessive intensive rainfall,

- Steep stream gradient with more than 15 degrees,
- Existence of thick riverbed deposit with more than 2m,
- Drainage area of more than 5 hectares, and
- Thick unconsolidated deposit in the slope (talus deposit, terrace deposit, landslide) with bare land.

On the other hand, debris flow will rarely occur on the combination of gentle stream gradient, a few river deposits, sound rocks on slope, and forest.

3.4.4 Recommendation

It is recommended for the sediment control and debris flow management from the viewpoint of geology as follows.

<u>Sediment Control</u>

"Unconsolidated Deposits", and "Soft Rocks (Tertiary rocks & heavily weathered rocks)" are easy to be eroded and supply a lot of sediments to the downstream. They are widely distributed in sub-basin S-1 to 4 and 8. These deposits and soft rocks will be mainly transported by mudflow type because of the level to gentle slope gradient.

The watershed management of forestation, land use control will be effective in long-term measures. But, these areas are characterized by a few rain, a few vegetation, and heavy rain in sometimes excluding S-8. Therefore sabo facilities are also required to mitigate the damages of mudflow to the village and agricultural field and facilities, especially for Dasht village and its crop field. It is located at the confluence of Ghiz Ghaleh River, Dasht-e-Sheikh River, and Gelman Darreh River where a huge amount of sediment sources are distributed in the sub-basins of S-1, 3 and 4.

<u>Debris Flow Management</u>

The steep to very steep slopes are distributed in the sub-basins of S-5 and 6. There are many small to middle streams are formed and having the streambed deposit at the middle to downstream reaches. When heavy rain comes, debris flows may occur in these streams. Accordingly, measures for the land use limitation and traffic control depending on the rainfall intensity are required. However, in reality, stream mouths are comparatively gentle and easy to develop the residential zone and agricultural fields. Thus some sabo facilities for mitigating the damage of debris flow are required for these developed streams depending on the social and or natural impacts in parallel with the above-mentioned non-structural measures. Subjects to be protected are "trunk road", "villages along the trunk road such as Tangrah, and Terjenly" in sub-basins of S-5 and 6.

SUPPORTING REPORT I (MASTER PLAN)

PAPER IV

Meteo-Hydrology

THE STUDY ON FLOOD AND DEBRIS FLOW IN THE CASPIAN COASTAL AREA FOCUSING ON THE FLOOD-HIT REGION IN GOLESTAN PROVINCE

SUPPORTING REPORT I (MASTER PLAN)

PAPER IV METEO-HYDROLOGY

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CHAPTER 1 METEOROLOGY

1.1 Climate

The study area, Madarsoo River basin, is stretch in-between longitude 55° 21' to 56° 28' E and latitude 36° 58' to 37° 30' N. Rainfall distribution patterns in the basin were analyzed. Study shows semi-arid type of climate is prevalent in the basin. The monthly and annual rainfall amounts at stations in the basin are quite variable. For instance, annual rainfalls are: 695 mm (Tangrah), 357 mm (Dasht Shad) and 198 mm (Robat Gharebil). Similarly, monthly rainfalls in March are: 99 mm (Tangrah), 45 mm (Dasht Shad) and 30 mm (Robat Gharebil). March is the highest rainfall month in the basin. After analyzing the annual and monthly rainfalls at stations in the basin; it shows that November to May are wet months; and June to October are dry months (Figure 1.1). As usual, convectional, orographic, cyclonic and monsoon rains occur in the basin.

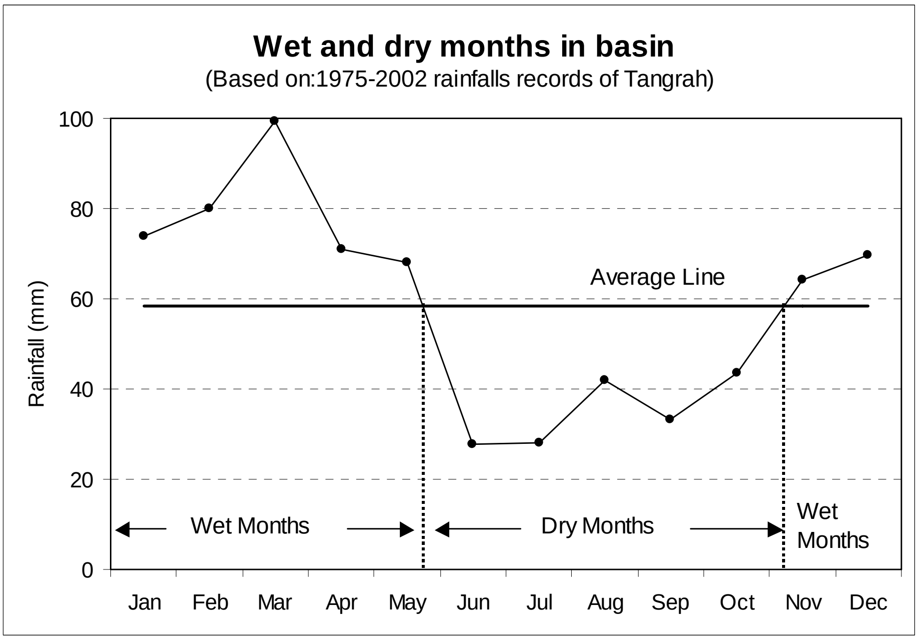

Figure 1.1 Wet and Dry Months in the Madarsoo Basin

(1) Convectional Rain

Clouds developed over the Mediterranean Sea by convection process during hot or summer season are transported to Iran by seasonal winds. Those clouds make rainfalls all over the country during summer season after being condensed as usual.

(2) Orographic Rain

While transporting clouds developed over the Mediterranean Sea and others, cold moist air laden clouds come in contact with warm air layer over the Alborz and Zagros mountains; and the clouds are raised up and make rainfall in and around the mountainous regions because of condensation. Similarly, cold and dry air from Siberia (anti-cyclone) when passes over the Caspian Sea gets moist; and makes rainfalls over the areas along the Sea due to condensation and orographic effect of the Alborz mountains. The orographic effect by the Alborz Mountains is clearly presented in annual rainfall isohyets. Contours of annual rainfall isohyets are developed in the North-South direction as the Alborz Mountains stretches.

(3) Cyclonic Rain

Cyclones or Typhoons developed over the Mediterranean Sea make rainfall in Iran while passing through the country.

(4) Monsoon Rain

The monsoon developed over the Bay of Bengal and Indian Ocean sometimes causes rainfall in Iran. Creation of Sub-Tropical High Pressure (STHP) belt is one of the impeding factors for not getting enough monsoon rainfall. The study of monthly rainfalls distribution in the Madarsoo basin also shows that June to October are dry months, although, monsoon is prevalent during May to September.

1.2 Meteorological Network

Meteorological Organization (MO) of Islamic Republic of Iran mainly manages meteorological network in Iran. However, Ministry of Energy (MOE) has also own rain-gauge station network to measure rainfall.

1.2.1 Meteorological Organization (MO)

This organization is managing meteorological network to observe meteorological parameters like, rainfall, humidity, evaporation, air temperature, air pressure, wind speed and direction, sunshine hours, solar radiation, visibility, etc. For these purposes, there are four types of stations: online, synoptic, climatological and rain-gauge stations. The inventory of meteorological stations is presented in Table A.1 (ANNEX I) and location map is presented in Figure 1.2.

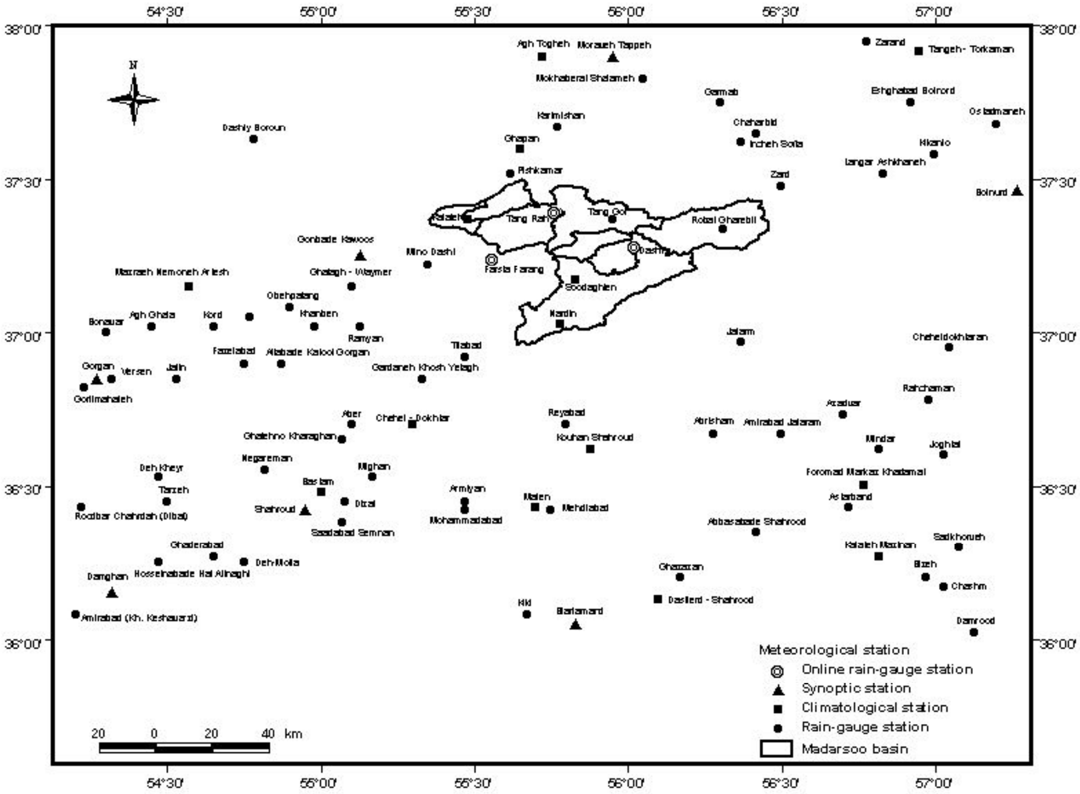

Figure 1.2 Location of Meteorological Stations of Met Organization

(1) Online Stations

The online stations are operating to get real time data on rainfalls, air temperature, humidity, etc. at 10 minutes intervals. At present, there are three online stations that are located at Dasht, Tangrah and Farsian Farang. Meteorological Organization (MO) is planning to install additional four online stations in near future at Hosseinabad Kalpoush, Ghaleh Ghapeh, Bidak and Dasht Shad. According to officials of MO when interviews were made in January 2005, online stations of Dasht and Tangrah are not working well due to problems in radio communication and telephone line. These two online stations lie in the Madarsoo River basin. The MO has installed these online stations for flood warning purpose and setting threshold values as 20 mm/hr of hourly rainfall at stations to warn. Thies Clima Tipping Bucket Type automatic precipitation transmitters, made in Germany, are used for online rainfalls recording. The online system was developed by technical assistance of French Company.

(2) Synoptic Stations

At these stations, meteorological parameters like, wind speed, dry and wet bulb temperatures, relative humidity, amount of cloud, and atmospheric pressures are measured at 0:00, 3:00, 6:00, 9:00, 12:00, 15:00, 18:00 and 21:00 hrs (GMT). But rainfall is measured daily (only one time). There is no any synoptic station in the basin.

(3) Climatological Stations

These stations measure dry and wet bulbs temperatures and humidity at 3:00, 9:00 and 15:00 hrs (GMT), however, rainfall is measured only one time in a day. There are five climatological stations in the basin. They are: Dasht (Kalpoush), Golestan National Park (Tangrah), Kalaleh, Soodaghlene and Nardin.

(4) Rain-gauge Stations

These stations record only daily rainfall amounts. There are some rain-gauge stations in the basin: i.e. Robat Gharebil, Tang Gol, etc.

1.2.2 Ministry of Energy (MOE)

Two types of rain-gauge stations are operated by MOE: online and ordinary. The inventory of rain-gauge stations is presented in Table A.2 (ANNEX III) and location map is presented in Figure 1.3.

(1) Online Stations

The online rain-gauge stations are installed at Dasht Shad, Dasht, Galikesh and Narab. Moreover, Dasht Shad and Dasht online stations lie in the Madarsoo River basin. At Dasht, LAMBRECHT (Type: 00.15183.002200) precipitation transmitter is used for online rainfall recording. The online stations are operating through telephone line and performing well.

(2) Ordinary Stations

The ordinary rain-gauge stations record daily rainfall. There are some rain-gauge stations in the basin. Some of the stations in the basin are: Robat Gharebil, Chesmeh Khan and Tangrah.

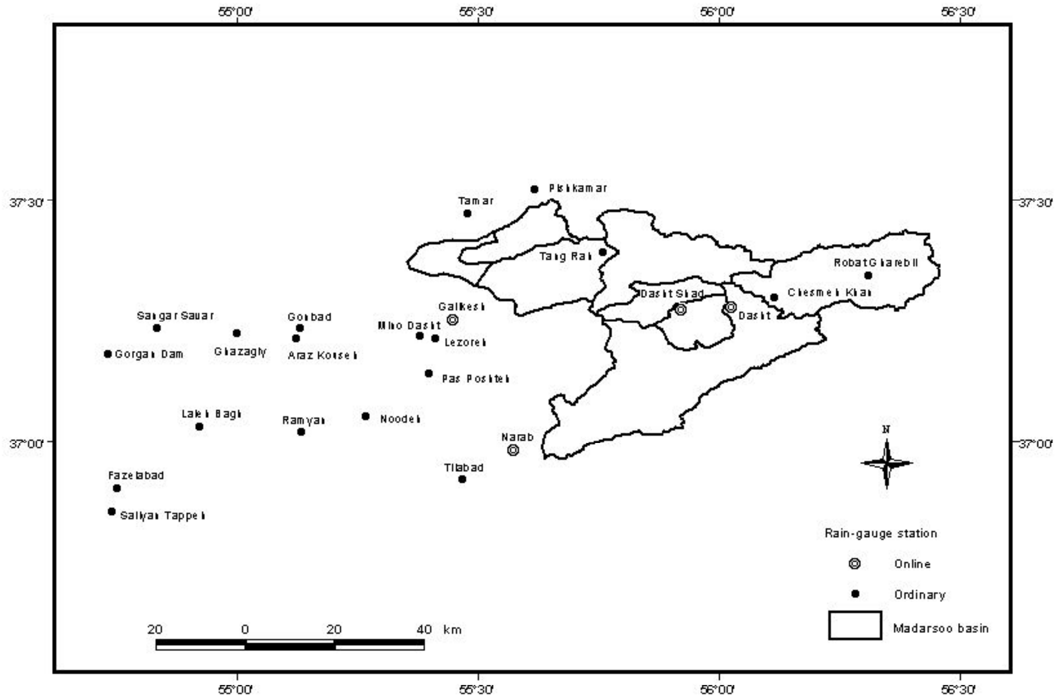

Figure 1.3 Location of Rain-Gauge Stations of MOE

1.2.3 Weather Conditions during 2001 and 2002 Floods

The meteorological parameters like rainfall, relative humidity (RH), air temperature, and wind speed at various stations in the basin were analyzed on the day of flood and a day before during 2001 and 2002 floods.

(1) Rainfall

Daily rainfall isohyets of one day before and on the day of floods in 2001 and 2002 are developed. The isohyets show during 2001 disastrous flood there was considerable amount of rainfall (50 mm) only at Dasht Kalpoush on previous day of flood (10 August) in the basin (Figure 1.4). However, on the day of the flood (11 August), heavy rainfall occurred at Dasht Shad (176 mm), Tangrah (150 mm), Soodaghlene (117 mm), Dasht Kalpoush (100 mm) and Chesmeh Khan (84 mm) as present in isohyets (Figure 1.5). Rainfall isohyets of the flood day show that 80-176 mm rainfall occurred on about 50% of basin area at central part of the basin (with peak rainfall at Dasht Shad). In other areas of the basin, amount of rain was in-between 20–80 mm on the flood day. It has been said that high intensity rain has occurred for sometime which caused the 2001 disastrous flood. The intensity of rainfall could not be analyzed due to not having hourly rainfall data of the stations. Moreover, flood hydrograph of the Madarsoo River at Tangrah also indicates possibility of high intensity rain occurrence in the basin during the 2001 flood, because flood hydrograph is rising sharply. Similarly, debris flow and gully formation at Terjenly also indicates possibility of high intensity rain occurrence during the flood.

During the 2002 flood, on previous day of flood (12 August) there was 24 mm rainfall at Tangrah but no rainfall at other stations in the basin (Figure 1.6). But on the day of the flood (13 August), heavy rainfall occurred at Dasht Shad (108 mm) and Dasht Kalpoush (60 mm). Furthermore, considerable amount of rainfall occurred at other stations like Soodaghlene (33.4 mm), Nardin (25 mm), Chesmeh Khan (16 mm) and Tangrah (30 mm). The rainfall distribution in the basin on the day of flood is presented by isohyets (Figure 1.7). Rainfall isohyets of the flood day show that there was 40–108 mm rain on about 35% of basin area at central part of the basin (with peak rainfall at Dasht Shad). In other parts of the basin, only 10–40 mm rainfall occurred on the day of flood.

(2) Other parameters

Maximum relative humidity (RH), maximum air temperature and maximum wind speed at stations in the basin were analyzed since 2 days before to one day after of the floods. During 2001 flood, values of maximum relative humidity were higher on the day of flood (11 August) than on previous days at Soodaghlene, Nardin and Dasht Kalpoush, however, value of maximum relative humidity was lower than on previous day at Kalaleh station (Figure 1.8). The values of maximum relative humidity on the day of flood were: 94% (Soodaghlene), 96% (Nardin), 81% (Dasht Kalpoush) and 52% (Kalaleh). On the other hand, values of maximum air temperature have dropped gradually since 2 days before and reached the lowest values at all stations in the basin on the day of flood (Figure 1.9). The maximum air temperatures on the day flood at stations were: 20.5 ^{o}C (Soodaghlene), 19.5 ^{o}C (Nardin), 22 ^{o}C (Dasht Kalpoush) and 23 ^{o}C (Kalaleh). Moreover, the values of maximum wind speed of the stations in the basin do not show any trend (Figure 1.10). The maximum wind speeds on the day of flood were: 2.7 m/s (Soodaghlene) and 0.5 m/s (Nardin).

During 2002 flood, values of maximum relative humidity were higher on the day of flood (13 August) than on previous days at Nardin and Kalaleh stations, but the values were lower at Soodaghlene and Dasht Kalpoush stations (Figure 1.8). The values of maximum relative humidity at stations on the day of flood were: 94% (Soodaghlene), 84% (Nardin), 69 % (Dasht Kalpoush) and 82% (Kalaleh). However, values of maximum air temperature at stations in the basin have shown the exactly same trend as in the 2001 flood time (Figure 1.9). The daily maximum air temperature gradually decreased since 2 days before and attained the lowest values of 20 ^{o}C (Soodaghlene), 19.5 ^{o}C (Nardin), 21 ^{o}C (Dasht Kalpoush) and 31 ^{o}C (Kalaleh) on the day of flood. Further, values of maximum wind speed were more or less similar with previous days values on the day of flood at stations (Figure 1.10). The maximum wind speeds at stations were 2.2 m/s (Soodaghlene) and 3.1 m/s (Nardin) on the day of flood.

Note: Although, it is quite difficult to say exactly, due to having complicated atmospheric phenomenon, how such heavy rainfalls occurred in 2001 and 2002 in the basin. However, while analyzing the weather conditions since 2 days before of the 2001 and 2002 floods indicate rainfall at those times might have occurred due to Cold Breeze from the Siberia. Because, the Cold Breeze got moist while passing through the Caspian Sea and made rainfall due to orographic effect of Alborz Mountains over the basin. It is justifiable because daily maximum air temperatures in the basin were gradually decreased since 2 days before of the floods.

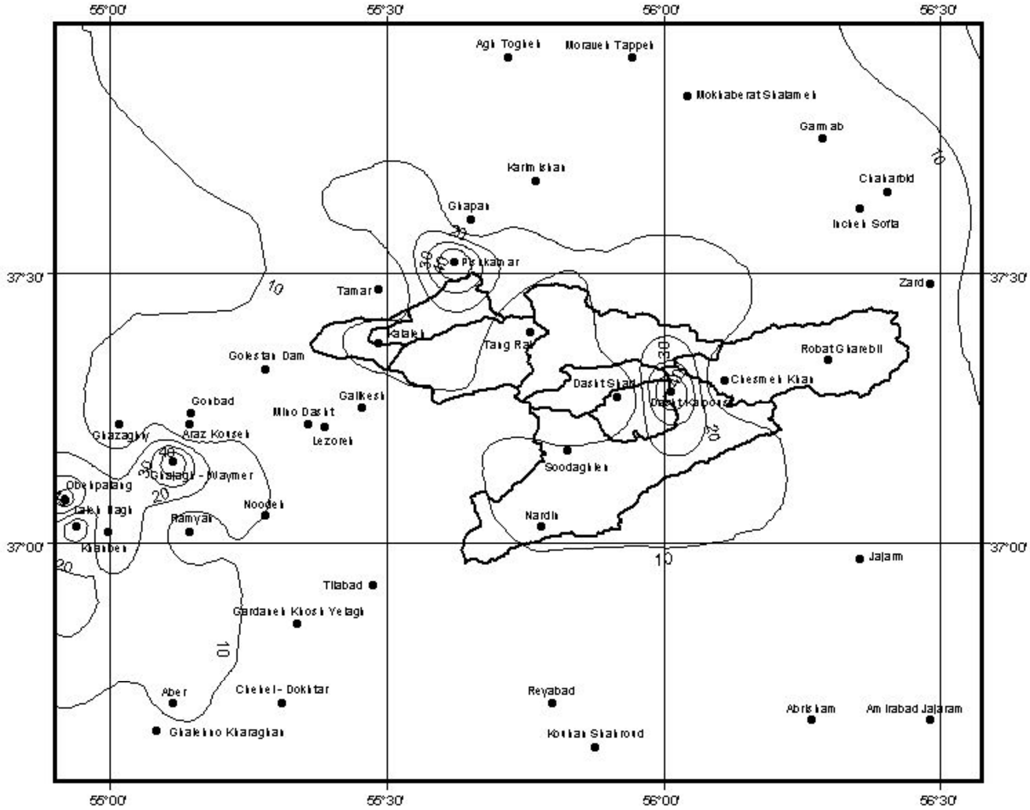

Figure 1.4 Rainfall Isohyets (10 August 2001)

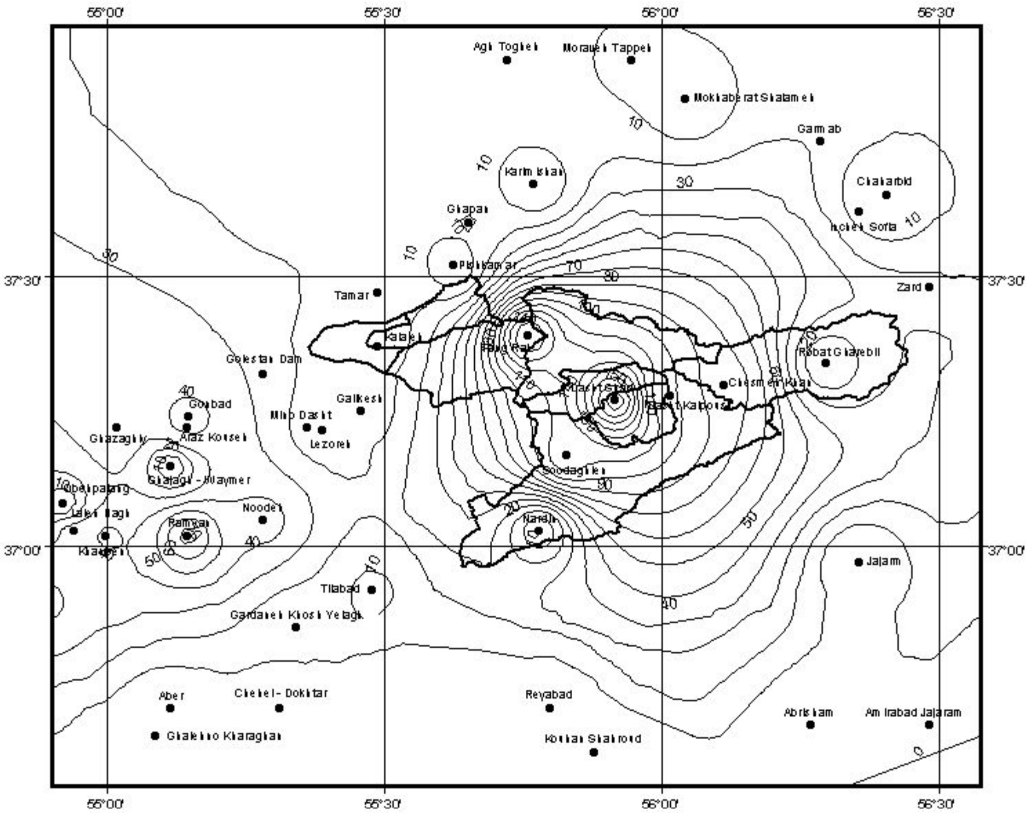

Figure 1.5 Rainfall Isohyets (11 August 2001)

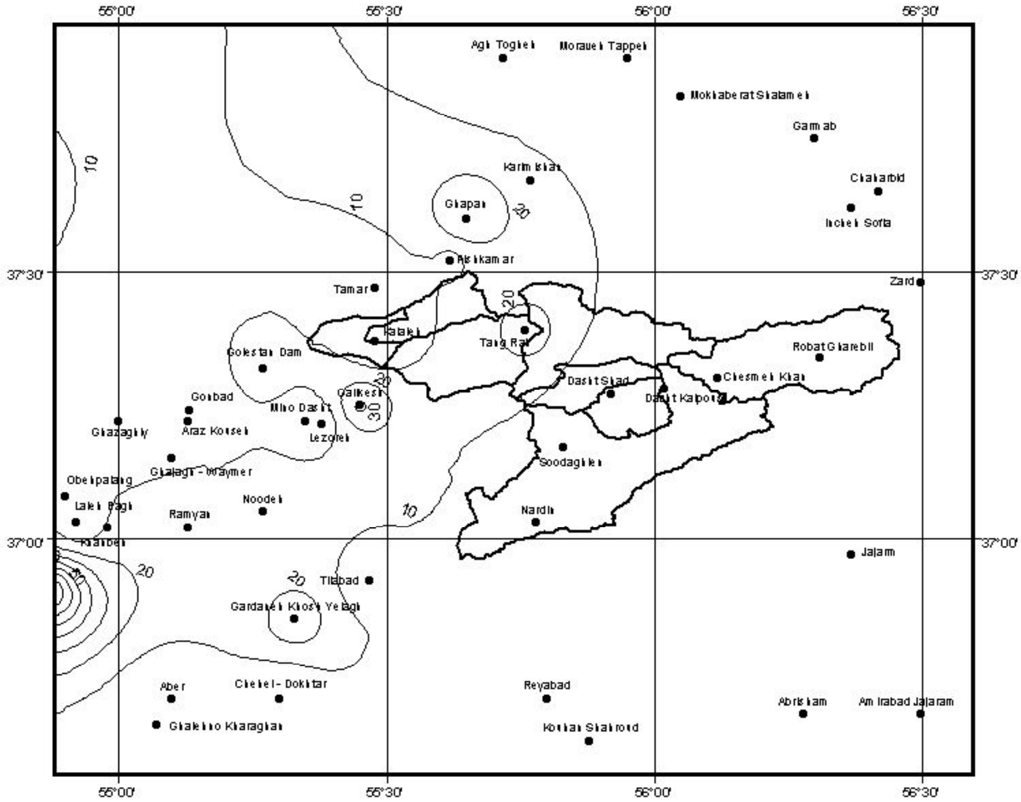

Figure 1.6 Rainfall Isohyets (12 August 2002)

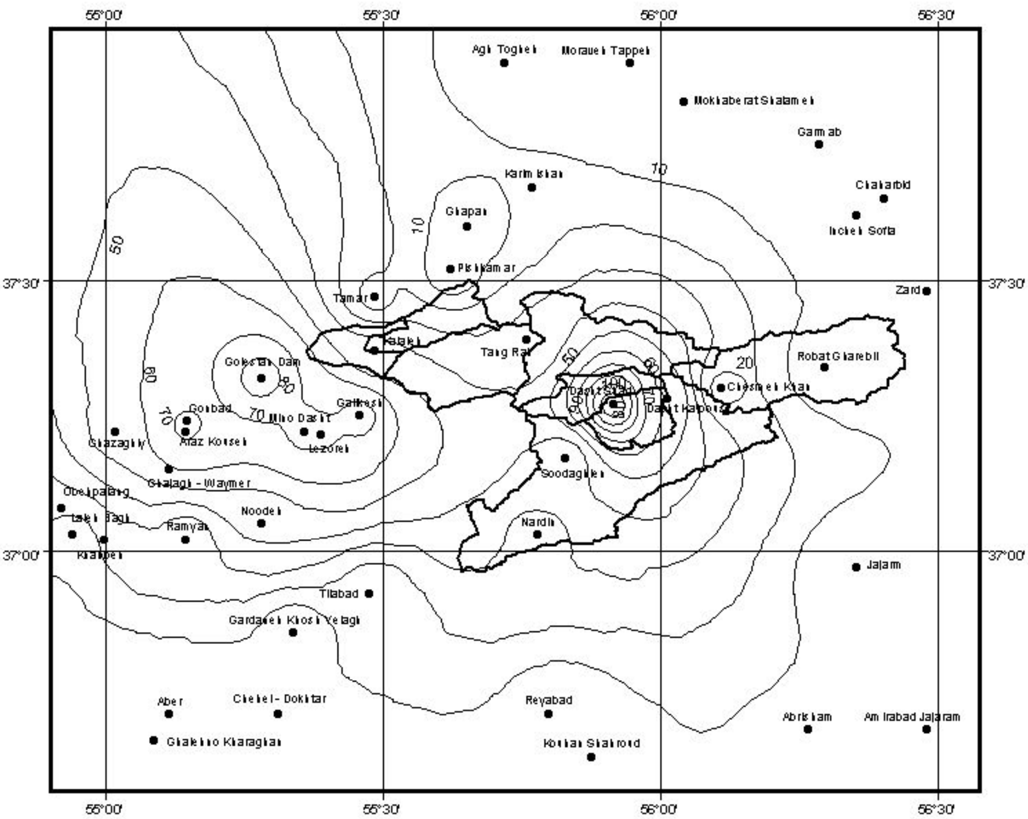

Figure 1.7 Rainfall Isohyets (13 August 2002)

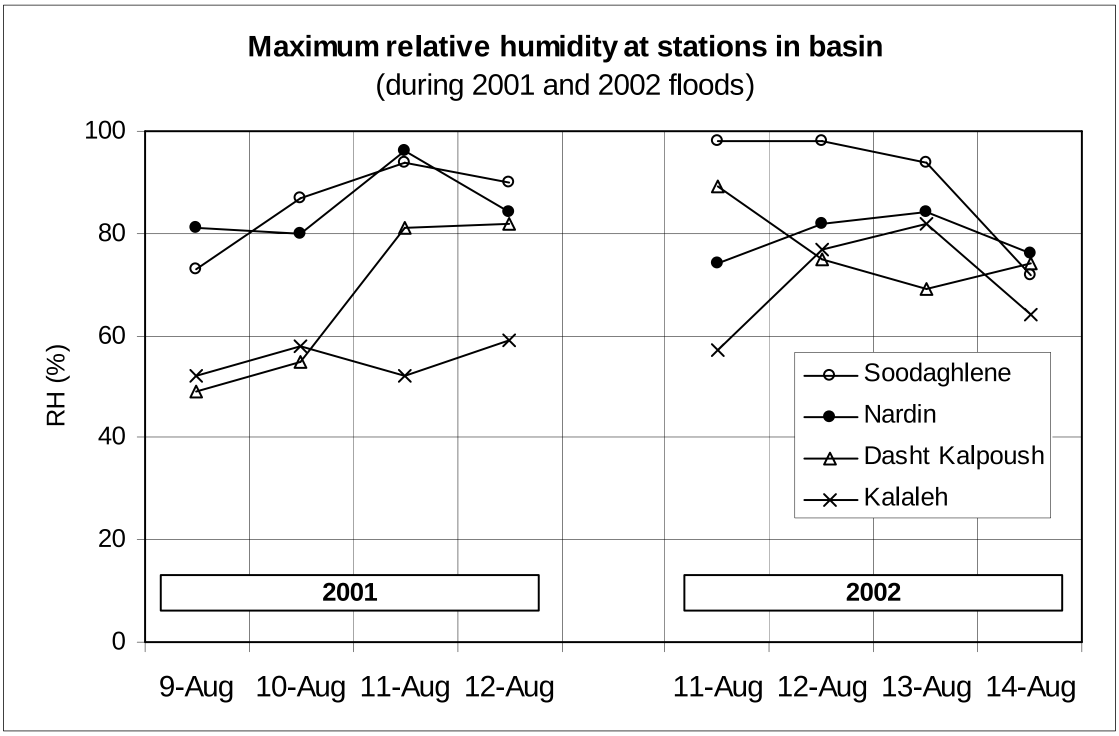

Figure 1.8 Maximum Relative Humidity at Stations in the Basin

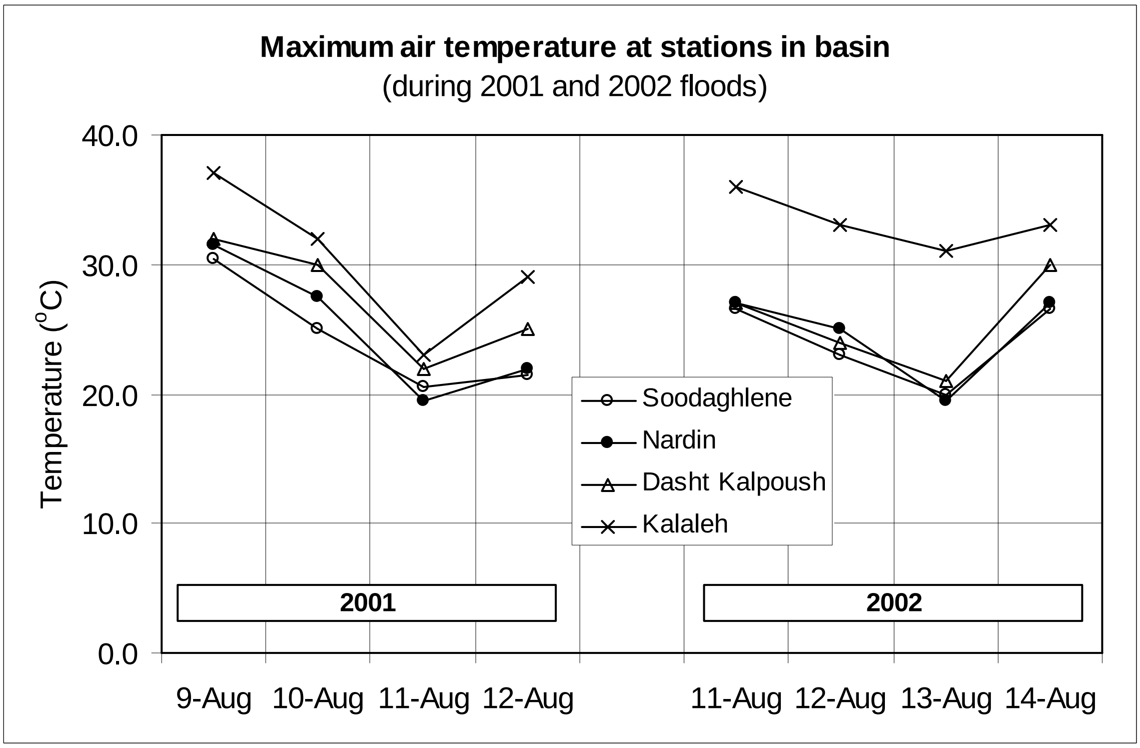

Figure 1.9 Maximum Air Temperature at Stations in the Basin

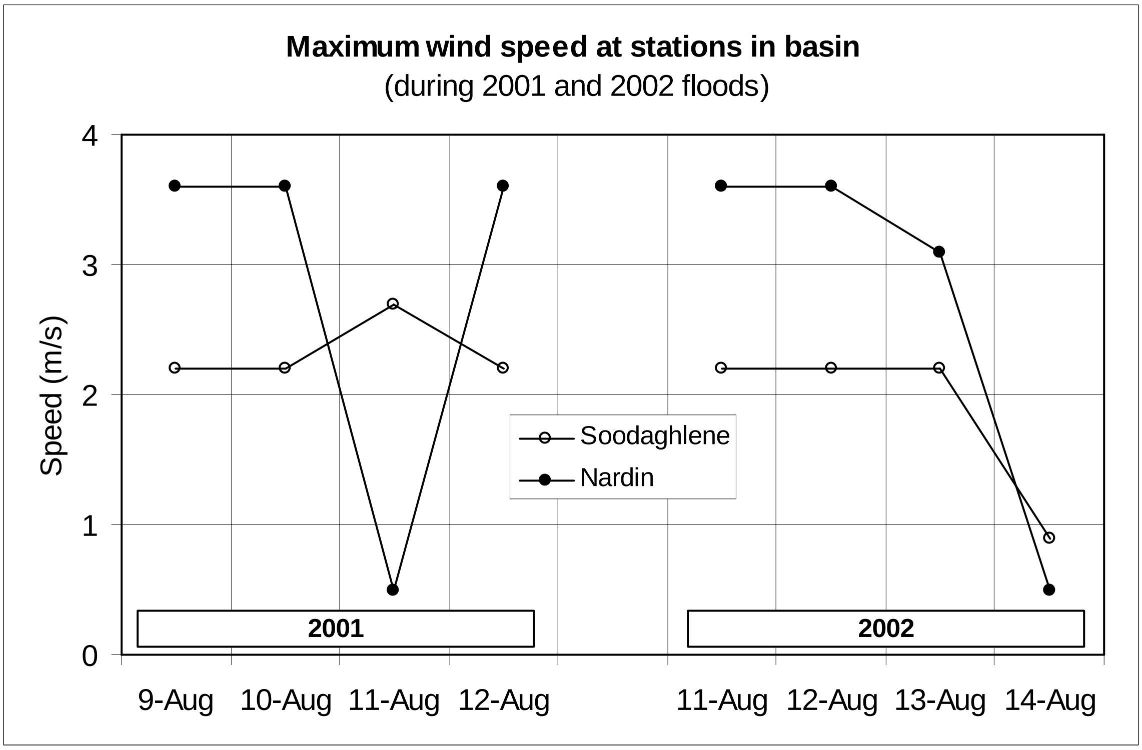

Figure 1.10 Maximum Wind Speed at Stations in the Basin

1.3 Monthly and Annual Rainfall Distribution

Monthly and annual rainfalls are analyzed by developing isohyets as well as at points (stations) in the basin. For developing monthly and annual rainfall isohyets, data of meteorological stations which lie in-between 36^o to 38^o N and 54^o to 58^o E and have more than 10 years daily or monthly rainfall records were used. Mean monthly and mean annual rainfalls for the stations were computed and used for developing rainfall isohyets. Altogether 71 stations mean monthly and mean annual rainfall data are used for developing rainfall isohyets (Figs. 1.11 and 12). Therefore, accuracy of the developed rainfall isohyets is quite high. For instance, rainfall isohyets of Climatic Atlas of Iran published in 1965 shows annual rainfall of Noodeh, Pas Poshteh and Tangrah are within the range of 400 mm, while study results show annual rainfalls of Pas Poshteh (974 mm), Noodeh (822 mm) and Tangrah (695 mm). Monthly and annual rainfalls distributions in the basin are described individually.

(1) Isohyets

Monthly rainfall isohyets show March is the highest rainfall month. In this month, over the lower to middle part of the Madarsoo River basin (Golestan Dam to Tangrah), 80-99 mm rainfall occurs (Figure 1.11(3/12)). The amount of rain decreases as we go to the middle part from the lower part of the basin (from Golestan Dam to Tangrah). The isohyets show on the upper (Nardin and Robat Gharebil) to middle (Tangrah) part of the basin 20-99 mm rain occurs in March. The amount of rain increases as we go to the middle part from the upper most parts of the basin. Furthermore, annual rainfall isohyets indicate Tangrah and its vicinity get the highest rainfall in the basin (Figs. 1.13 and 14). Annual rainfall at the lower most part of the basin is 500 mm and amount gradually increases as we go to the middle part of the basin and reaches 695 mm at Tangrah. When we go further upstream part of the basin from Tangrah then annual rainfall amount declines and reaches up to 198 mm (Robat Gharebil) and 139 mm (Dasht Kalpoush).

(2) Point Rainfalls

Mean monthly rainfalls at various stations in the basin are presented (Figure 1.13). Tangrah gets higher rainfalls in every month and is followed by Kalaleh and Soodaghlene. Moreover, Nardin and Dasht Kalpoush get lower rainfalls in every month. As mentioned in previous section, March is the highest rainfall month in the basin. Therefore, mean monthly rainfalls in March at stations in the basin are discussed. Mean monthly rainfalls in March at stations are: 89 mm (Kalaleh), 99 mm (Tangrah), 33 mm (Chesmeh Khan), 30 mm (Robat Gharebil), 16 mm (Dasht Kalpoush), 58 mm (Soodaghlene) and 29 mm (Nardin). Similarly, mean annual rainfalls at different stations in the basin are also presented for reference (Figure 1.14). Mean annual rainfalls at stations in the basin are: 516 mm (Kalaleh), 695 mm (Tangrah), 406 mm (Soodaghlene), 231 mm (Chesmeh Khan), 198 mm (Robat Gharebil), 148 mm (Nardin) and 139 mm (Dasht Kalpoush). It indicates that Dasht Kalpoush gets the lowest and Tangrah gets the highest rainfalls in the basin.

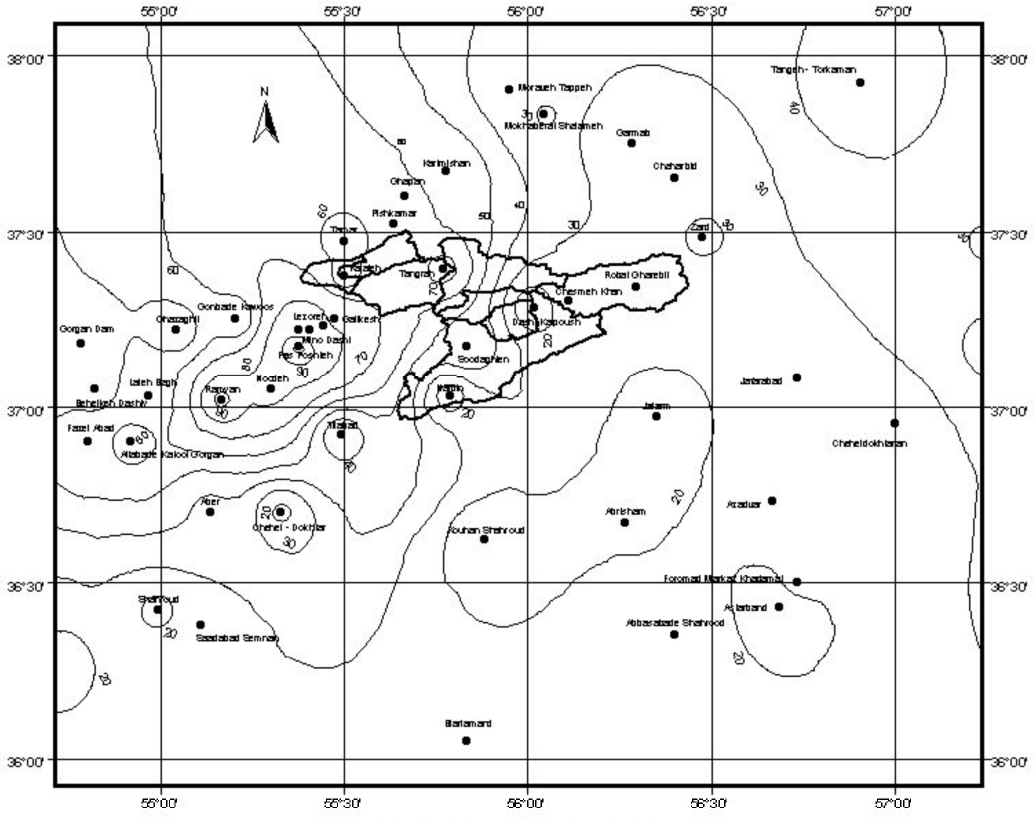

Figure 1.11(1/12) Monthly Rainfall Isohyets (January)

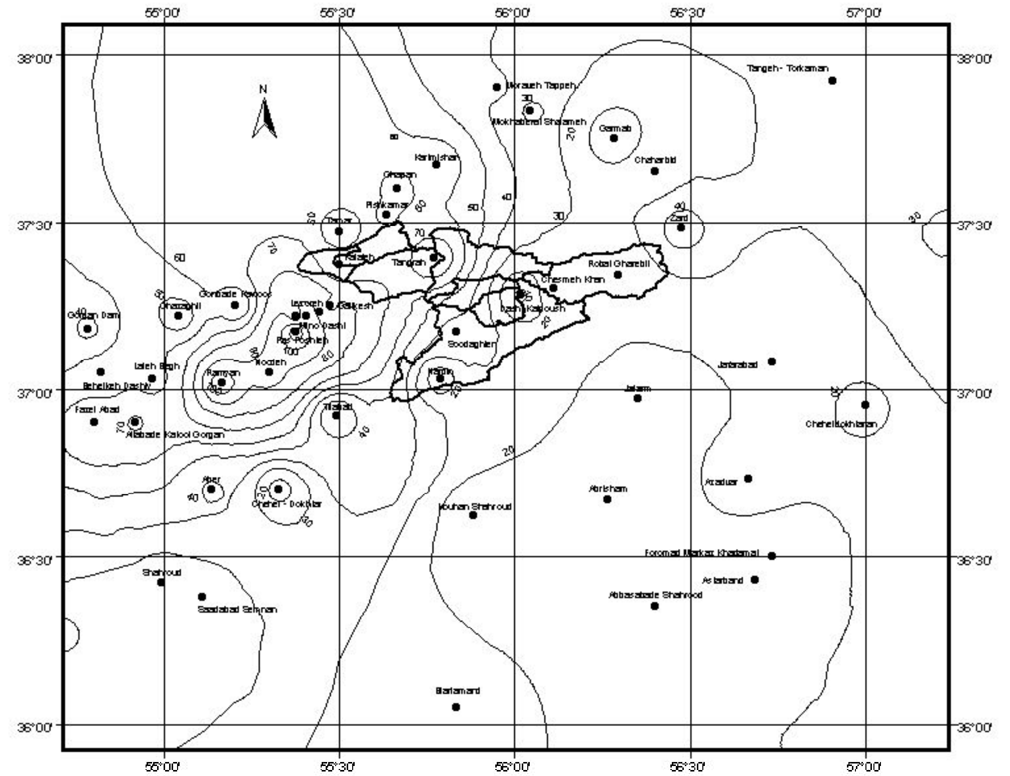

Figure 1.11(2/12) Monthly Rainfall Isohyets (February)

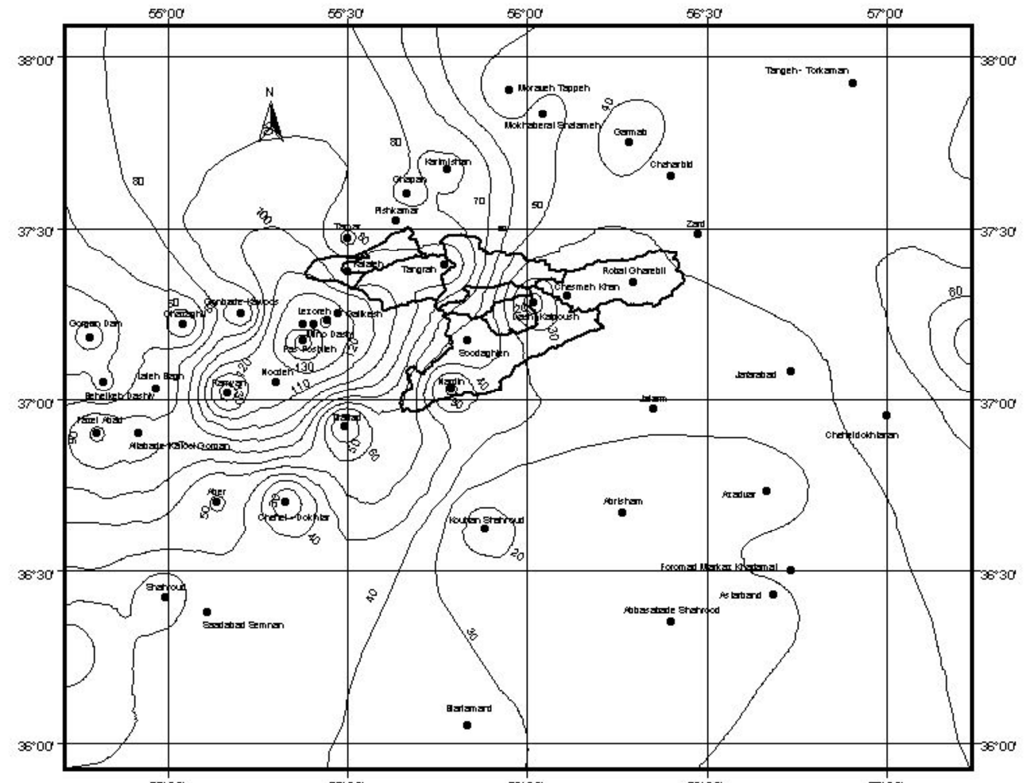

Figure 1.11(3/12) Monthly Rainfall Isohyets (March)

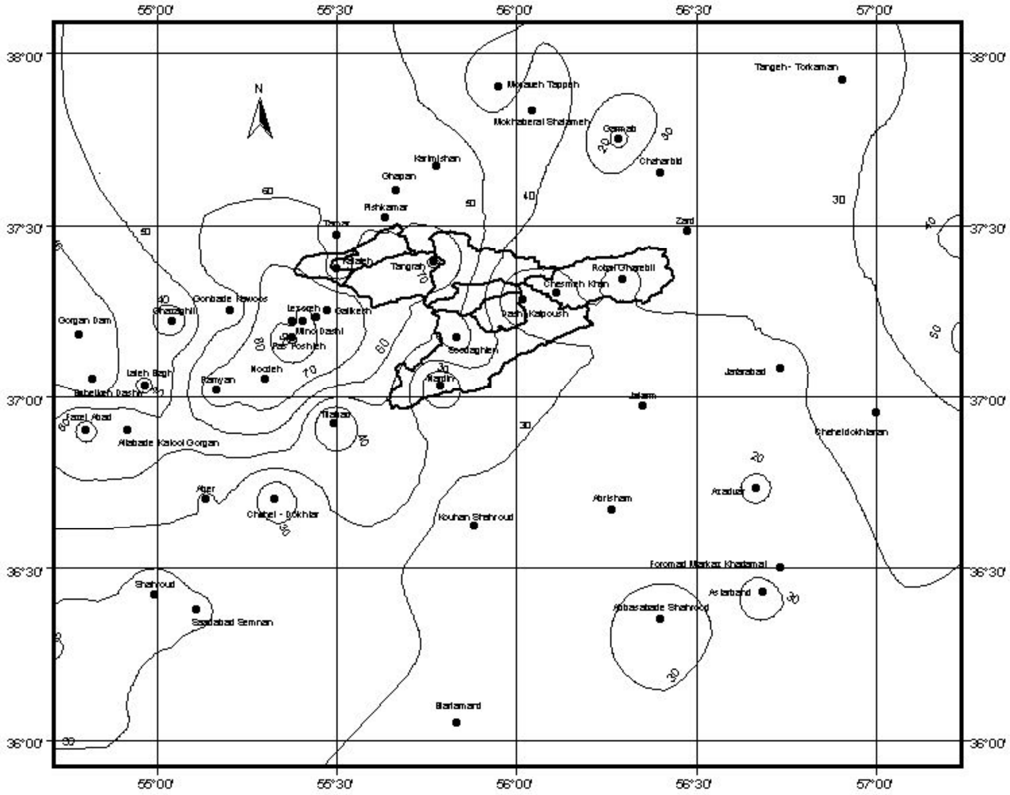

Figure 1.11(4/12) Monthly Rainfall Isohyets (April)

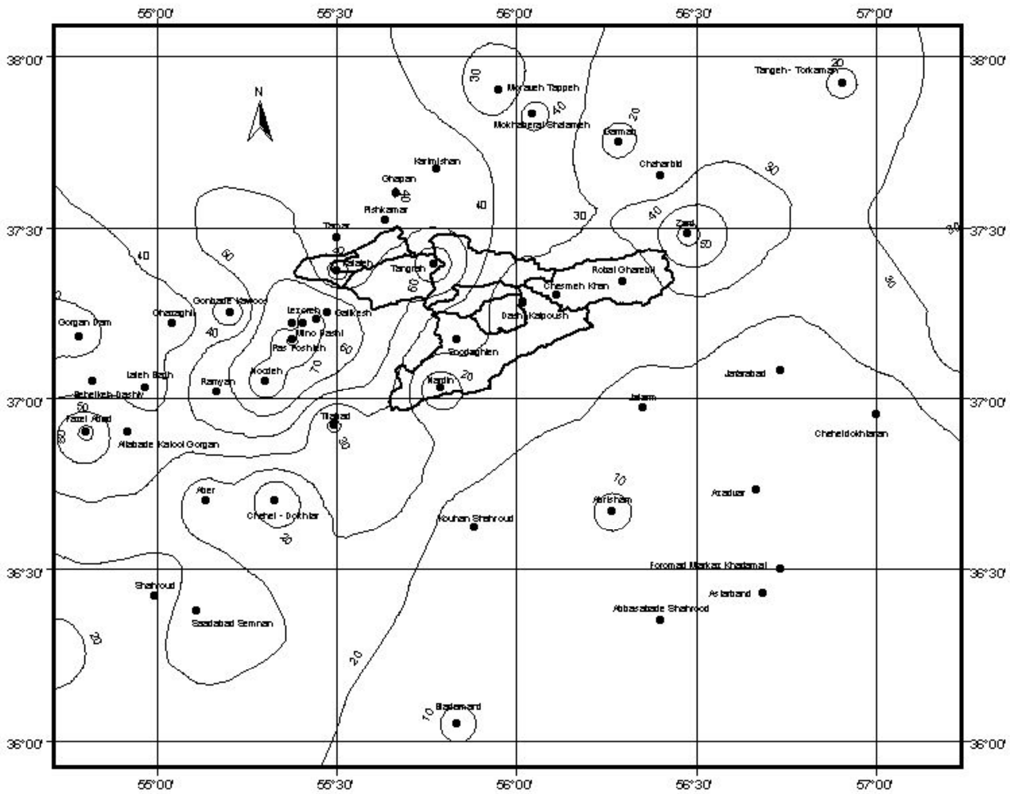

Figure 1.11(5/12) Monthly Rainfall Isohyets (May)

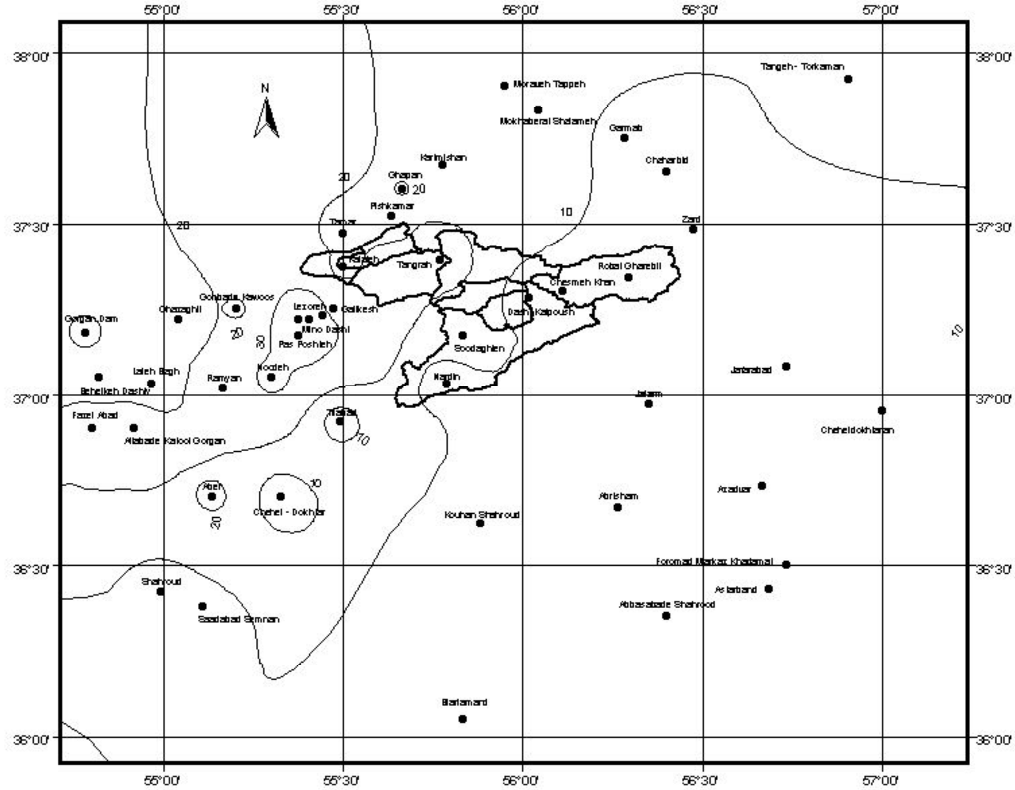

Figure 1.11(6/12) Monthly Rainfall Isohyets (June)

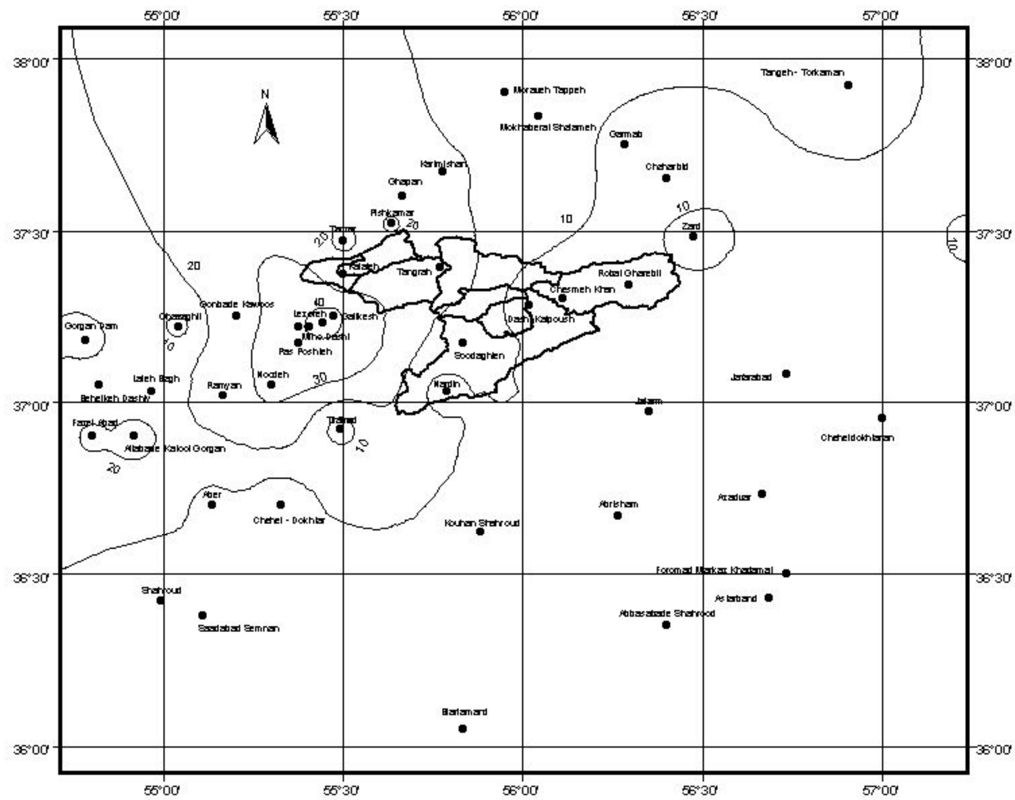

Figure 1.11(7/12) Monthly Rainfall Isohyets (July)

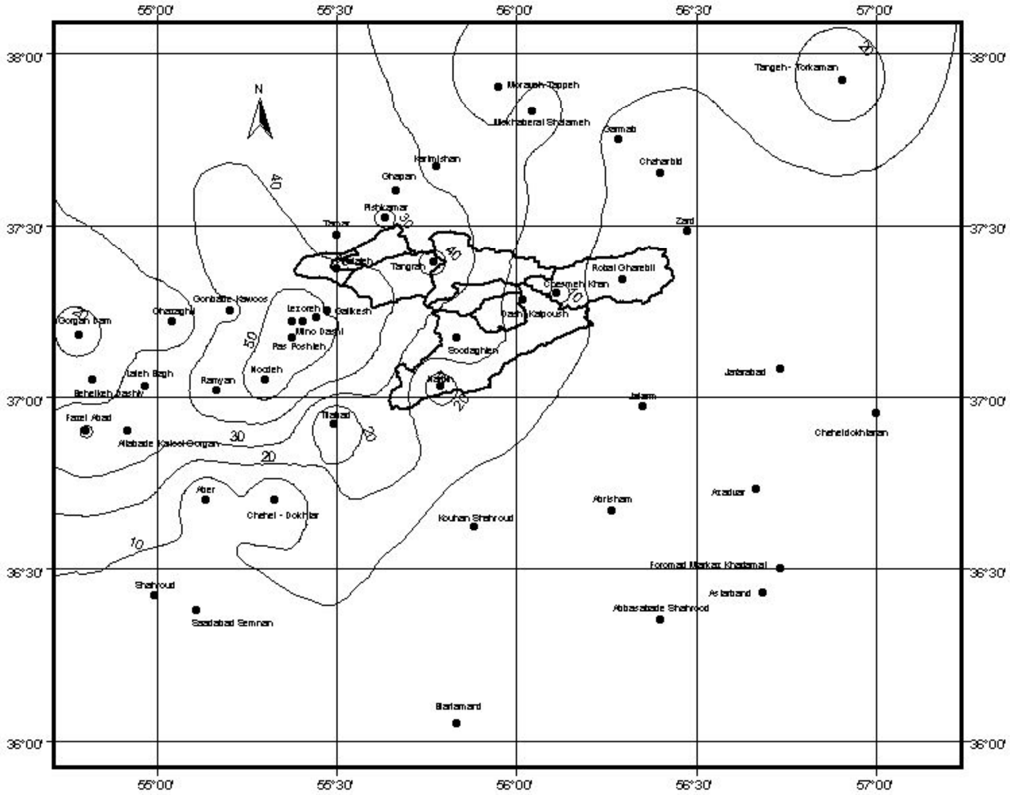

Figure 1.11(8/12) Monthly Rainfall Isohyets (August)

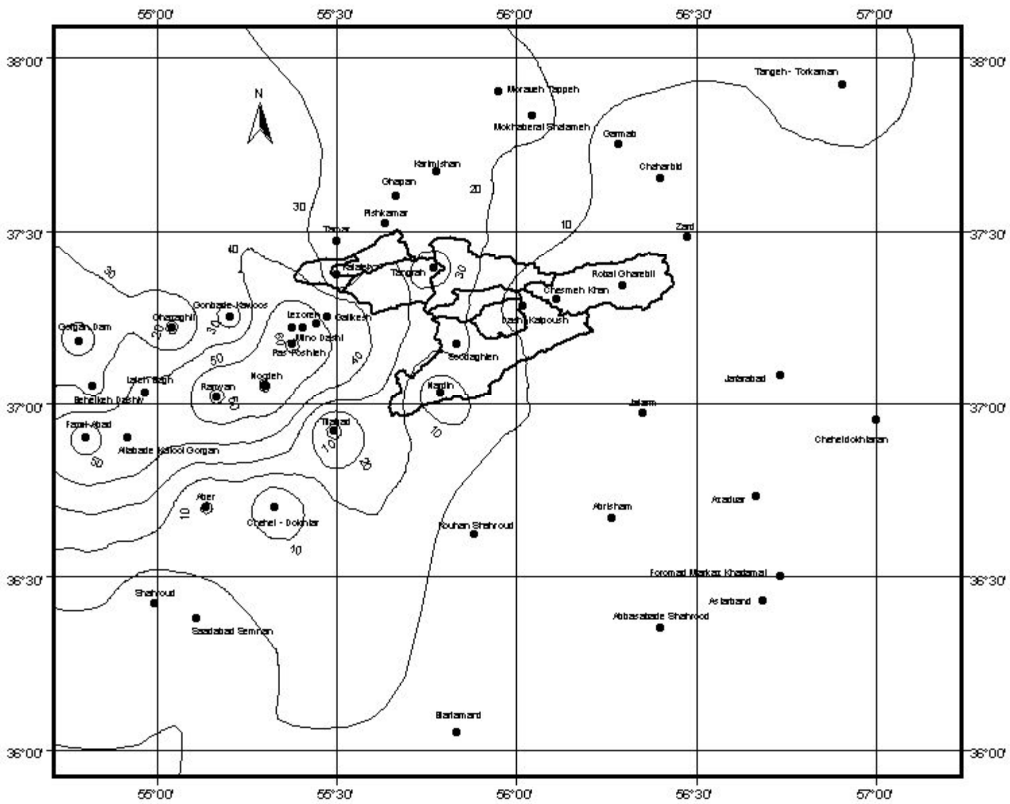

Figure 1.11(9/12) Monthly Rainfall Isohyets (September)

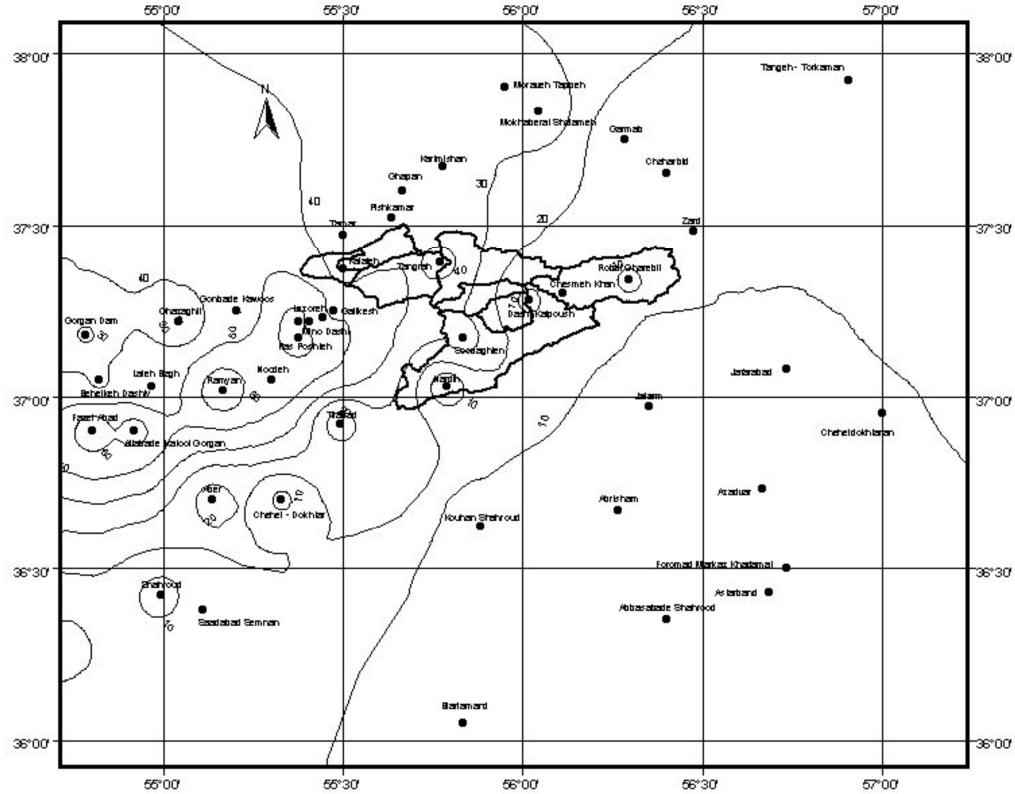

Figure 1.11(10/12) Monthly Rainfall Isohyets (October)

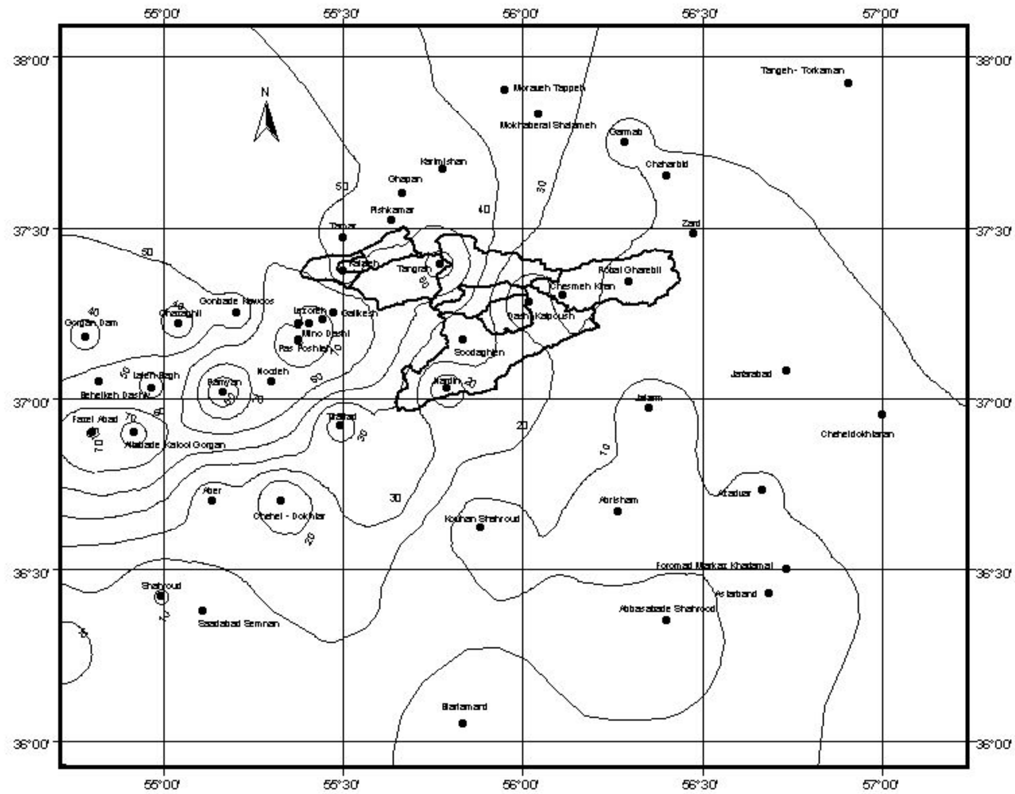

Figure 1.11(11/12) Monthly Rainfall Isohyets (November)

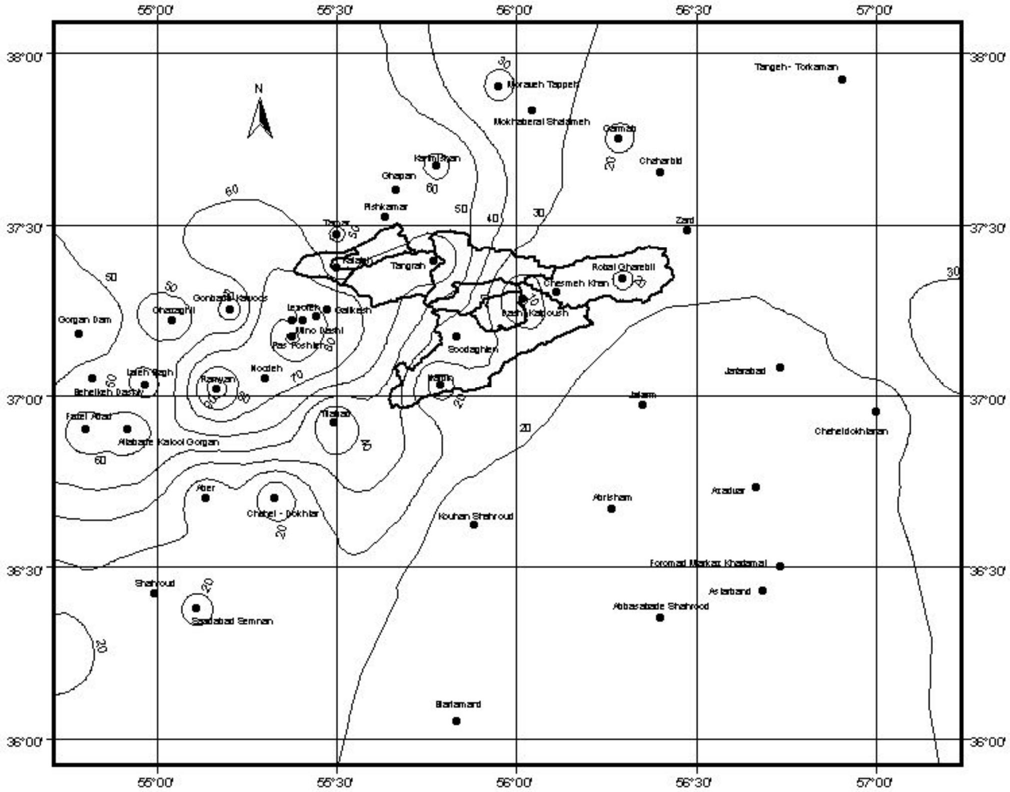

Figure 1.11(12/12) Monthly Rainfall Isohyets (December)

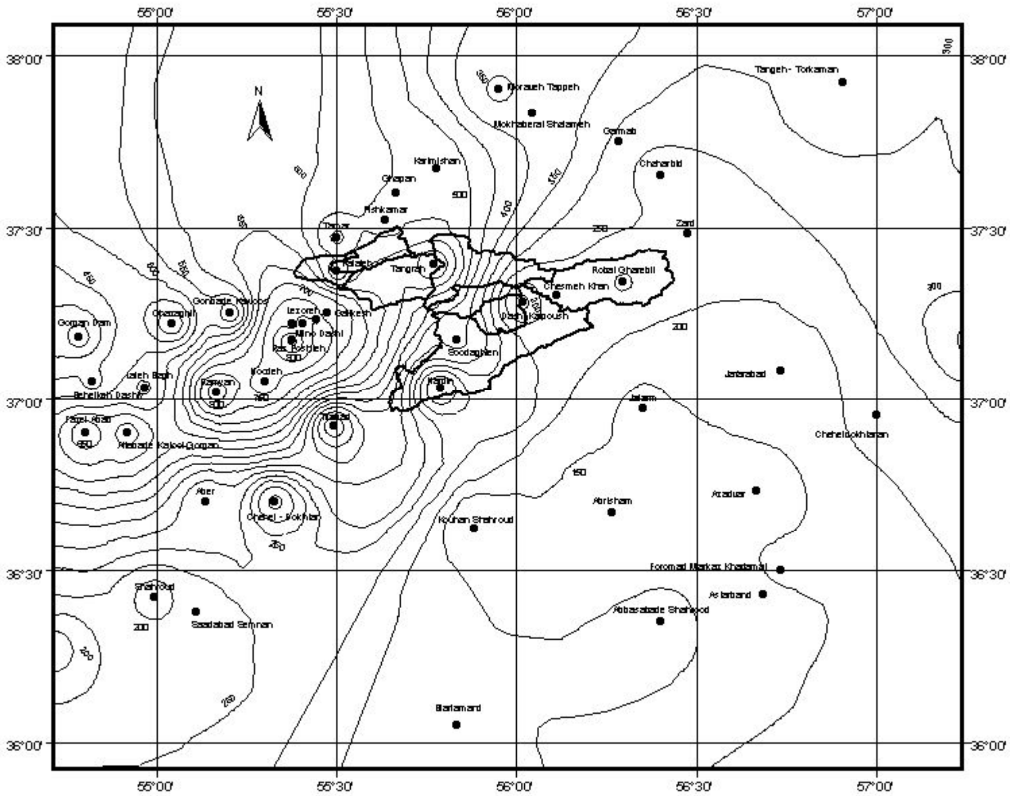

Figure 1.12 Annual Rainfall Isohyets

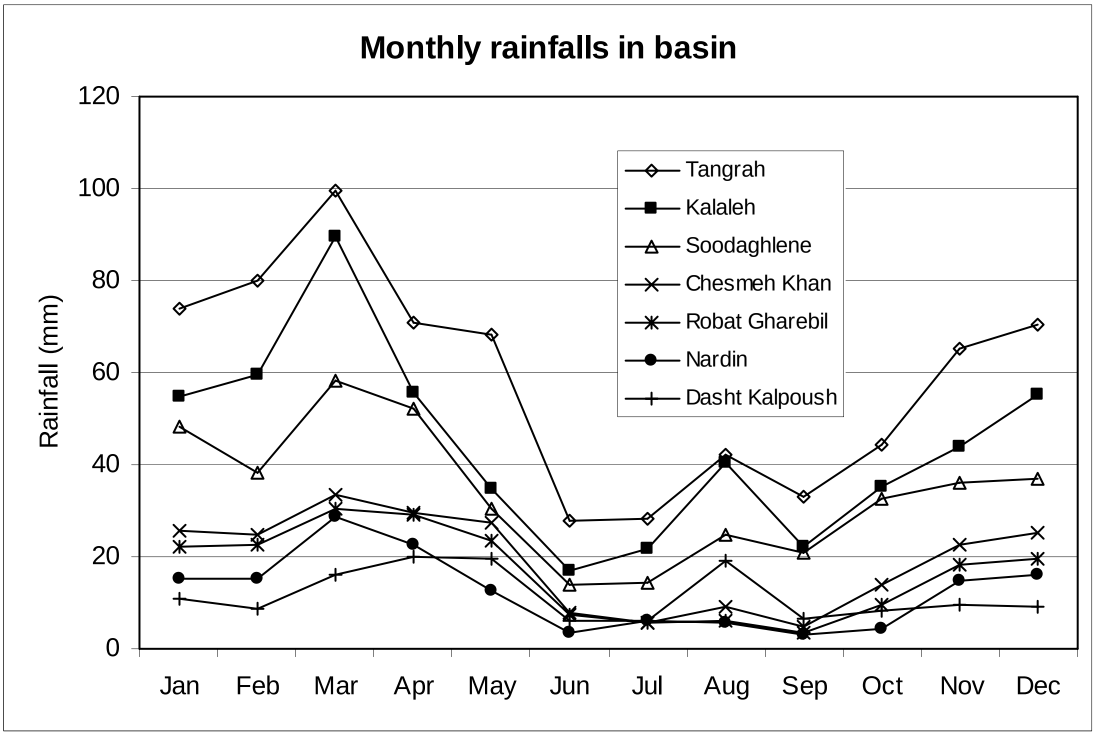

Figure 1.13 Monthly Rainfall Variation of Stations in the Basin

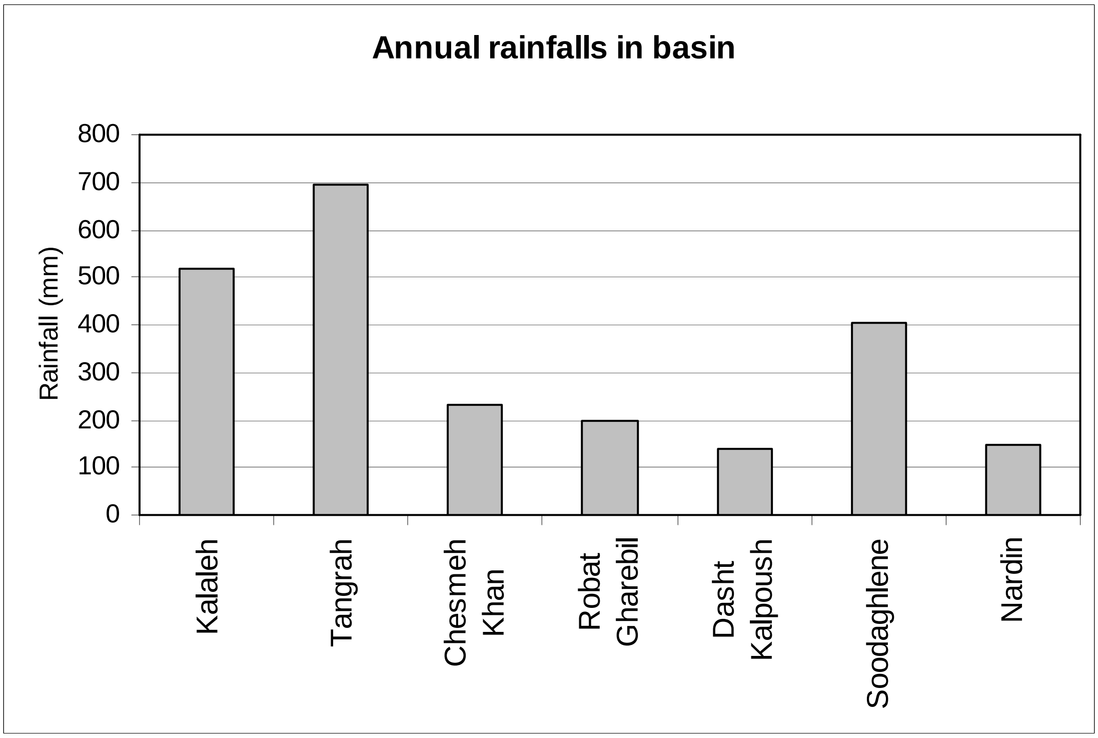

Figure 1.14 Annual Rainfall of Stations in the Basin

CHAPTER 2 HYDROLOGY

2.1 Hydrological Network

There are two hydrological stations in the Madarsoo River basin that are located at Dasht and Tangrah. The station at Dasht is a newly built station after the past two disastrous floods. Station at Tangrah was also destroyed by the 2001 flood and repaired in 2002. However, there are other stations like Galikesh, Tamar and Hoji Ghousan in Golestan Dam basin (Figure 2.1). Ministry of Energy (MOE) manages two types of hydrological stations, namely, online and ordinary. Real time water level data are being recorded through online telecommunication network at intervals of 10 minutes.

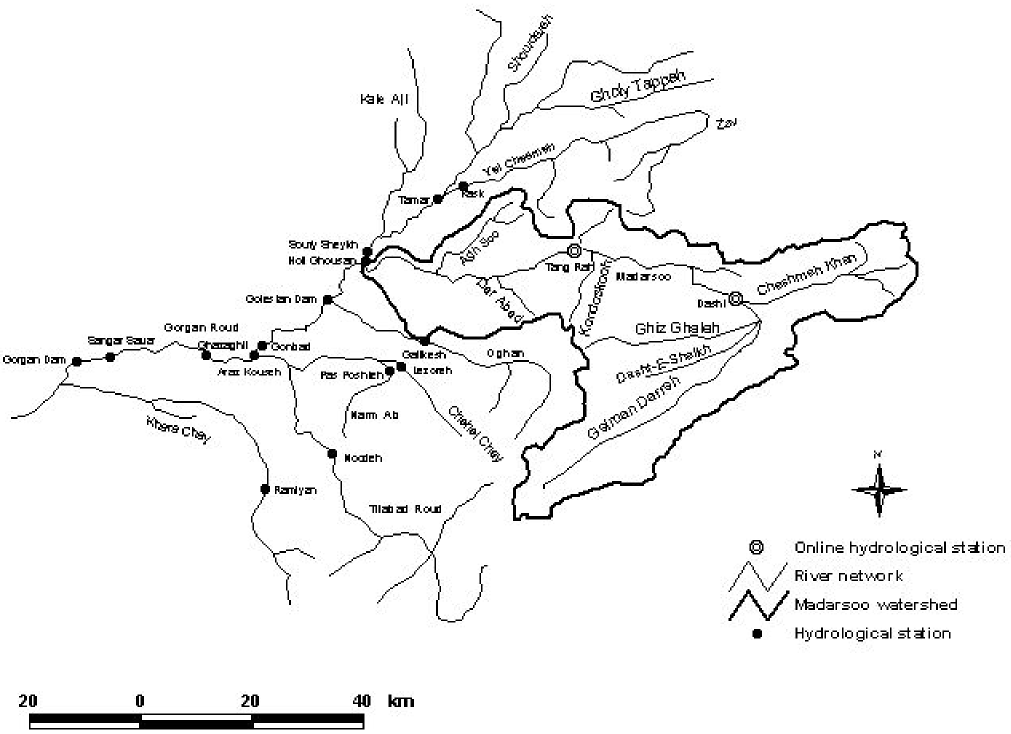

Figure 2.1 Location of Hydrological Stations

(1) Dasht Station

This station was established in 2003; and has staff gauge and water level recorder installed. Station is located downstream of the confluence of Chesmeh Khan and Madarsoo rivers. The location of station is suitable for flow measurement due to having foundation of bridge to converge flows. But it seems, especially during low flow season, proper care should be given to have always river water connected with stilling well to measure water level. Because, the bridge is quite wide so that during low flow season river flow may not be connected with stilling well having very low discharge in the river. At present, Ministry of Energy (MOE) is getting online water level data from this station with automatic water level recorder (Thalimedes OTT, Germany).

(2) Tangrah Station

Station is in the Madarsoo River and was destroyed by the 2001 flood, so that data could not be recorded in 2002. Staff gauge, water level recorder and cable way are installed at the station. Presently, Ministry of Energy (MOE) and Ministry of Road and Transport (MORT) jointly are conducting riverbank protection works, it helps to converge flows in river thereby can record water levels more precisely. At present, MOE is getting online water level data with automatic water level recorder (AKIM Elektronik Lymnygraph PSTN, Turkey).

(3) Galikesh Station

This station is in the Oghan River at gorge. Staff gauge, float type water level recorder and cable way (to measure flow discharge) are installed. The location of the station seems suitable for stream flow measurements. The 2001 disastrous flood did not destroy this station.

(4) Tamar Station

Station is located in the Gorgan River. Staff gauge, float type water level recorder and cable way are installed at the station. The station was destroyed by the 2001 flood and repaired later. River bed seems deepened at site of the station, because base of stilling well was not so much dipped inside river water level, therefore, maintenance of the station is advised.

(5) Hoji Ghousan Station

Station situated at bridge in the Gorgan River just upstream of the Golestan Dam. The location of the station seems good for stream flow measurements. Staff gauge and float type water level recorder are installed, and cable way is under construction for flow measurements. The 2001 flood also destroyed this station.

2.2 Hydrological Data in the Recent Floods

2.2.1 Water Levels in the 2001 and 2002 Floods

Hourly water level of Tangrah (Madarsoo River), Galikesh (Oghan River), Hoji Ghousan (Gorgan River) and Golestan Dam during the 2001 flood were analyzed (Figs. 2.2 to 2.3). The maximum water levels at stations on the day of flood (11 August) were: 4.95 m (Galikesh at 2:00), 5.25 m (Tangrah at 6:00), 8.58 m (Hoji Ghousan at 10:00) and 62.94 m (Golestan Dam at 24:00). However, graph of water levels indicates possibility of occurrence of high intensity rainfalls in the basin, because water levels at Tangrah rose and fell sharply during the flood. Unfortunately, it is not possible to compare the water level differences between stations and Golestan Dam due to unavailability of zero gauge elevations of staff gauges installed at the stations. At Tangrah, water level was at peak level for 4 hours from 4:00 to 8:00 o'clock on flood day. Flow travel time between Tangrah and Golestan Dam will be discussed in the next Section. Similarly, in the 2002 flood, the maximum water levels at stations on the day of flood (13 August) were: 4.80 m (Tamar at 6:00) and 10.00 (Hoji Ghousan at 6:00), however, data of other stations were not available (Figure 2.4).

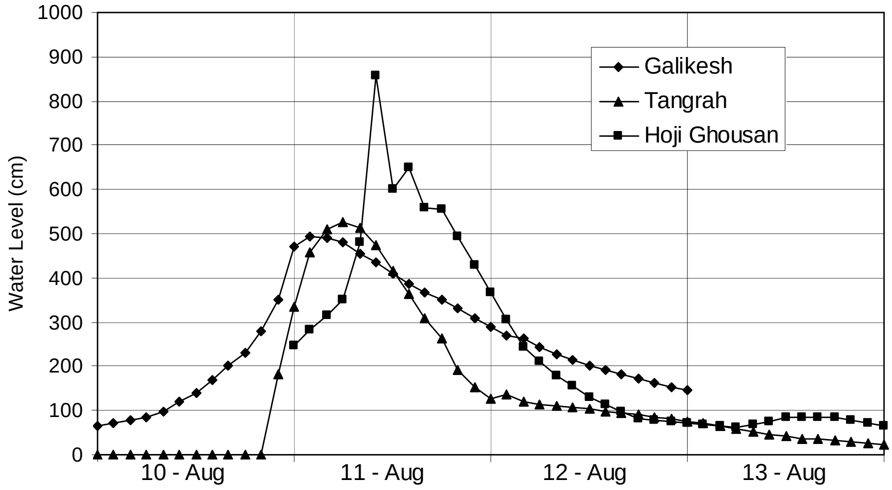

Figure 2.2 Hourly Water Levels at Stations during the 2001 Flood

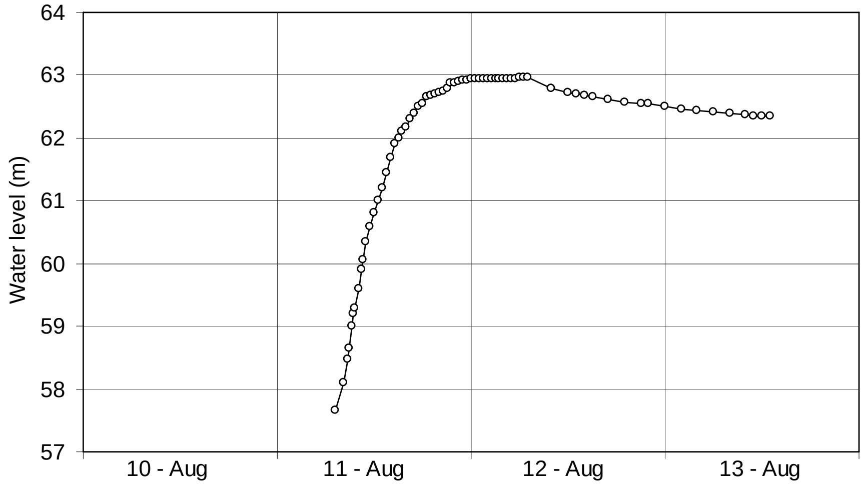

Figure 2.3 Hourly Water Levels of Golestan Reservoir during the 2001 Flood

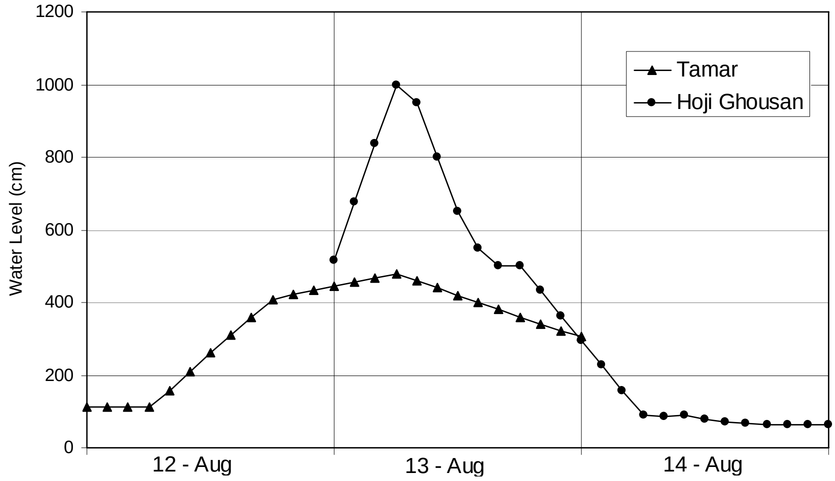

Figure 2.4 Hourly Water Levels at Stations during the 2002 Flood

2.2.2 Discharges in the 2001 and 2002 Floods

During the 2001 flood, the maximum hourly discharges at stations on the day of flood (11 August) were: 468 m^3/s (Galikesh at 2:00), 1,650 m^3/s (Tangrah at 6:00), and 241 m^3/s (Hoji Ghousan at 10:00). Further, the maximum hourly inflow into Golestan Dam was 2,736 m^3/s at 10:00 o'clock (Figure 2.5). Having quite fluctuating values of hourly inflows into the Golestan Dam computed from reservoir storage curve and water levels, moving average of 5 consecutive inflows were taken to minimize error. If we sum up the maximum discharges at stations and compare with the maximum inflow of the Golestan Dam it seems all right. Because, difference between sum of stations maximum discharges and Golestan Dam's maximum inflow is about 400 m^3/s, which is quite reasonable. Because, the less amount in inflow of the Golestan Dam is contributed from the Madarsoo River catchment between Tangrah and Golestan Dam. Moreover, flow travel time between Tangrah and Golestan Dam is about 4 hours.

On the other hand, in the 2002 flood, the maximum hourly discharges at stations on the day of flood (13 August) were: 58 m^3/s (Tamar) and 300 m^3/s (Hoji Ghousan) at 6:00 o'clock (Figure 2.6). Hourly discharges data of other stations were not available.

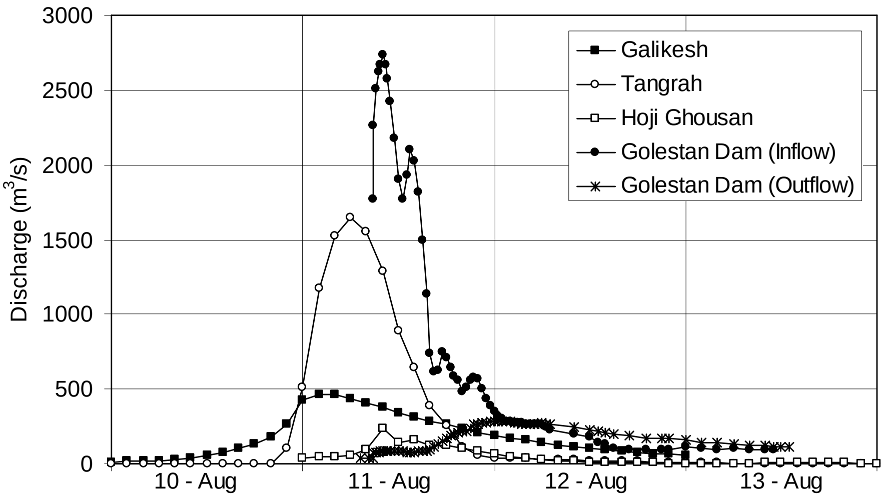

Figure 2.5 Hourly Discharges at Stations Located in the Golestan Reservoir Basin during the 2001 Flood

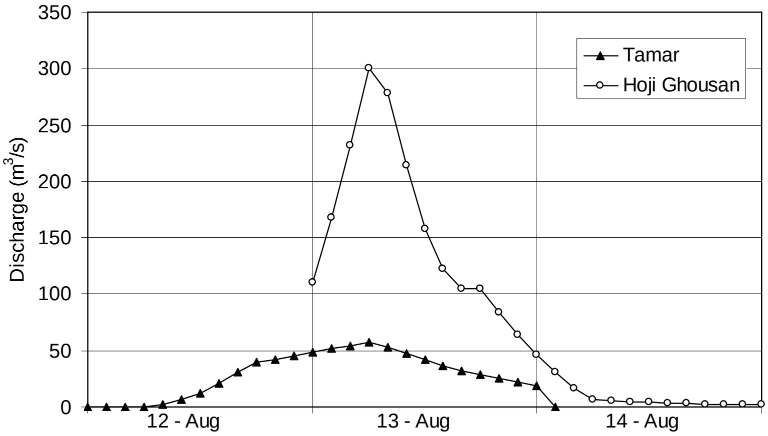

Figure 2.6 Hourly Discharges at Stations Located in the Golestan Reservoir Basin during the 2002 Flood

2.3 Hydrological Study including the 2005 Flood

2.3.1 Meteo-Hydrological Data in the 2005 Flood

Weather Conditions

Meteorological parameters recorded at Tangrah, online station, were studied, since hourly rainfall data was only available at this station. On 9 August, air temperature started to decline gradually from mid-day; and kept on declining until mid-night; air temperatures were: 32.6 °C (at 13:10) and 19.7 °C (at 23:30); and rain started at 20:10. Similarly, relative humidity (RH) started to increase gradually from mid-day; and went on increasing until mid-night (Figure 2.7); RH was: 49.9 % (at 13:10) and 99.7 % (at 23:30).

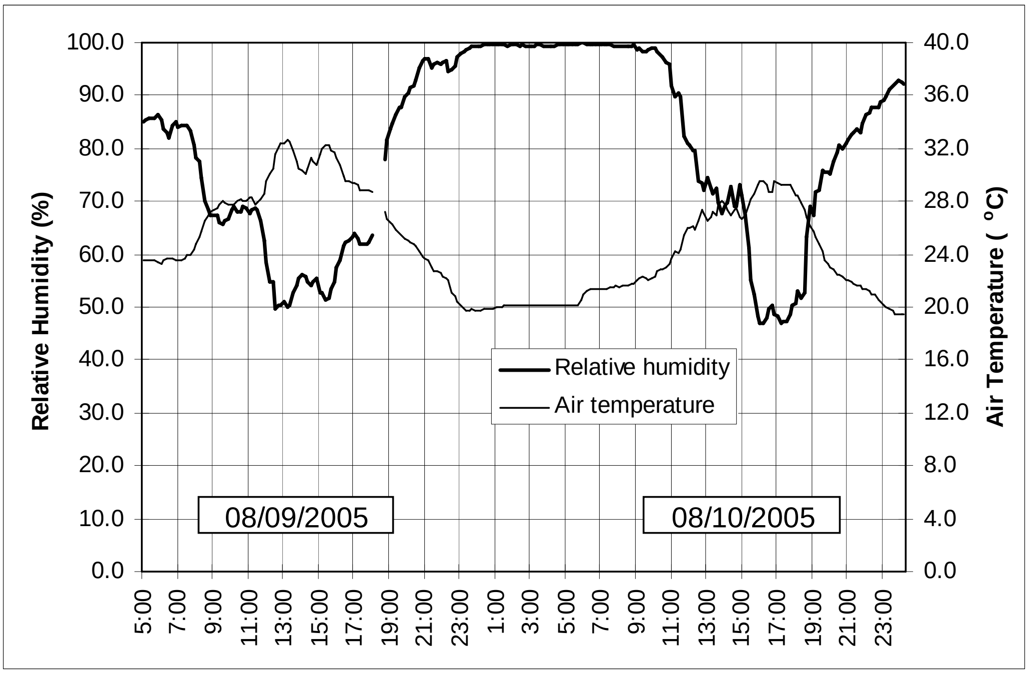

Figure 2.7 Air Temperature and Relative Humidity (RH) at Tangrah

Spatial Distribution of Rain

The point rainfall data at different stations in the basin on the day of the flood (10 August) and on one day before the flood (09 August) were collected. There was no rainfall at any stations in the basin on one day before the flood. But, on the day of the flood heavy rainfall occurred in the basin. The point rainfall amounts in and around the basin on the day of flood (10 August) were: 14 mm (Tilabad), 12 mm (Nardin), 110 mm (Soodaghlene), 113 mm (Dasht Shad), 98 mm (Dasht), 137 mm (Tangrah), 33 mm (Pishkamar), 7 mm (Galikesh), 85 mm (Chesmeh Khan) and 17.5 mm (Robat Gharebil). The spatial distribution of rain over the basin on the day of the flood is presented by developing rainfall isohyets (Figure 2.8). It shows that 80–137 mm of rainfall occurred on about 55% of basin area.

Rainfall Pattern

Rainfall recorded at Tangrah, online station, during the 2005 flood event was analyzed. Rain started at 20:10 (09 August) and continued till 07:10 (10 August). Therefore, rainfall duration was 11 hours, however, in-between 3 hours have nominal rainfall. The total amount of rainfall was 136.8 mm; and the highest intensity rain occurred at 23:00 of 09 August. The maximum 10, 30 and 60 minutes rainfall intensities were 18.5, 46.3 and 80.8 mm, respectively (Figure

2.9). It shows quite high intensity rainfall occurred, which caused violent flash flood in the basin. Moreover, rainfall distribution pattern was analyzed, about 76% of total rainfall occurred within the first 4 hours of rain (Figure 2.10). Similarly, about 43.93% of total rainfall amount was occurred in the third hour of rain; about 20.91% of total rainfall amount was occurred in the fourth hour of rain. The lowest amount of rainfall (0.22% of total rainfall amount) was occurred in the sixth hour of rain (Figure 2.11).

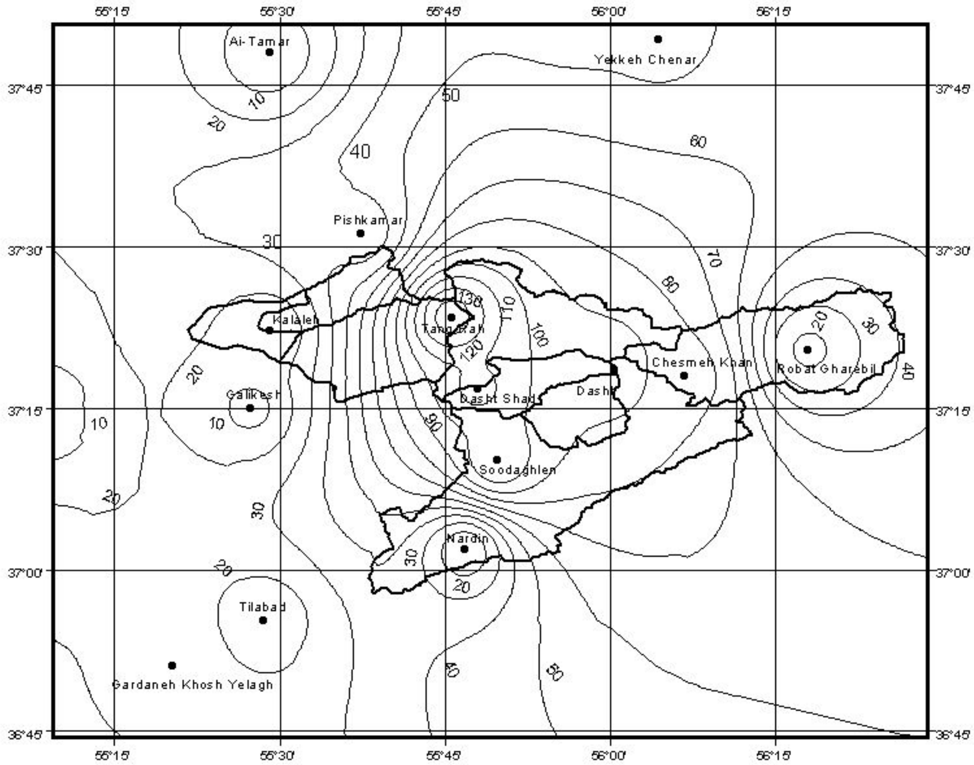

Figure 2.8 Rainfall Isohyets (10 August 2005)

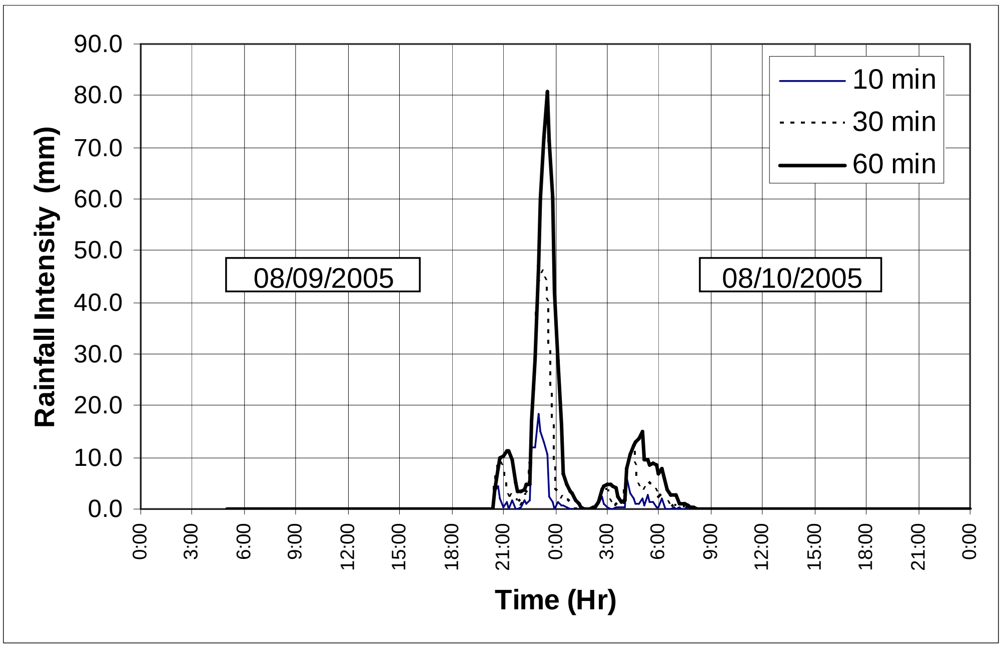

Figure 2.9 Rainfall Intensity at Tangrah

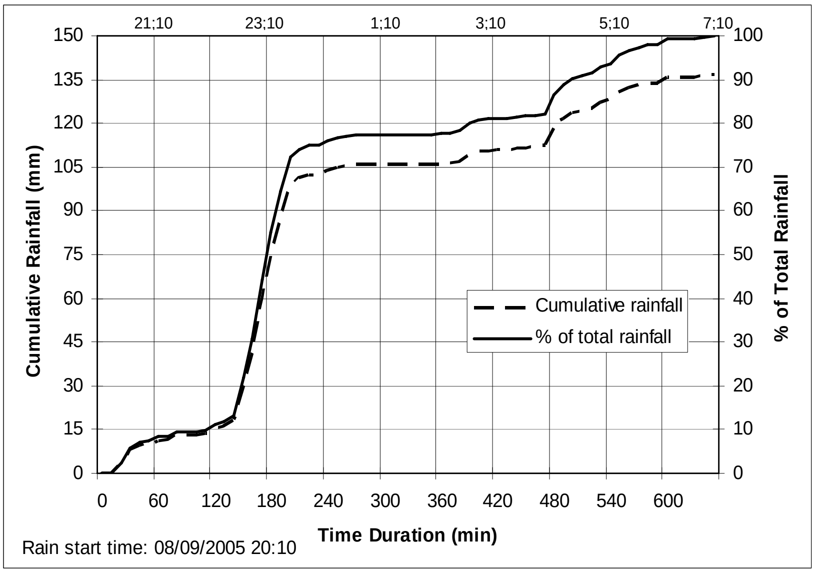

Figure 2.10 Rainfall Distribution Pattern at Tangrah

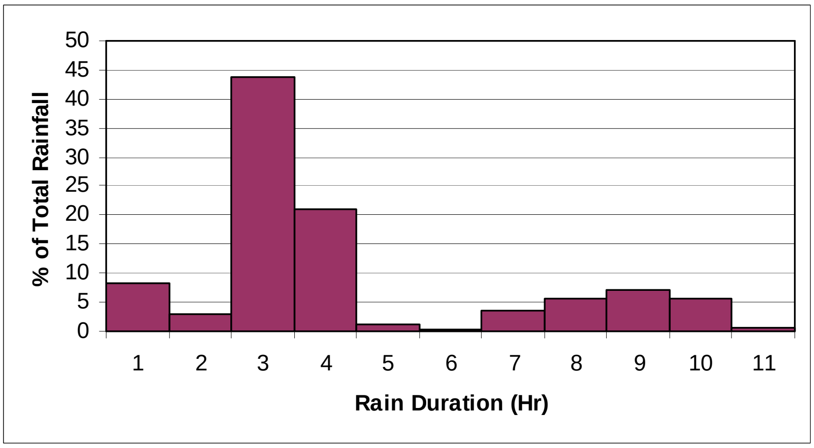

Figure 2.11 Hourly Rainfall Distribution at Tangrah

<u>Flow Estimation at Dasht Bridge</u>

Online hourly water levels data at Dasht Bridge were available for the 2005 flood event (Figure 2.12). The peak water level at Dasht Bridge was 5.20 m during the flood. Online water levels hydrograph shows peak flow was at 2:00 AM of 10 August. The flood hydrograph is quite sharply risen and fallen; it indicates flash-flood has occurred. Further, river flows were estimated using Broad Crested Weir formula based on the bridge dimensions and online hourly water levels data (Figure 2.13). The peak discharge estimated is 725 m^3/s; and formula used for discharge estimation is as written below.

$$Q = 1.7BH^{3/2} \quad (1)$$

where,

Q = Flow (m^3/s)
B = Crest width (m)
H = Flow depth over the crest (m)

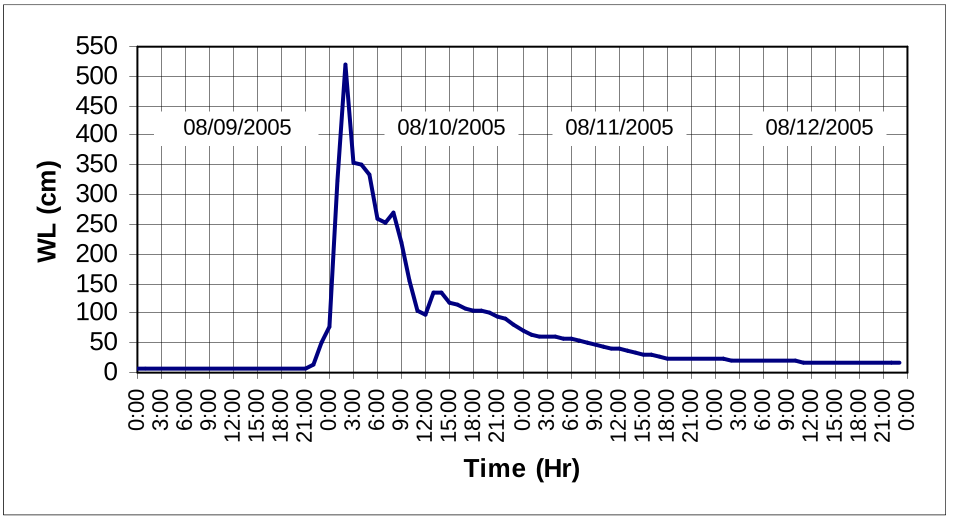

Figure 2.12 Water Levels at Dasht Bridge in the 2005 Flood

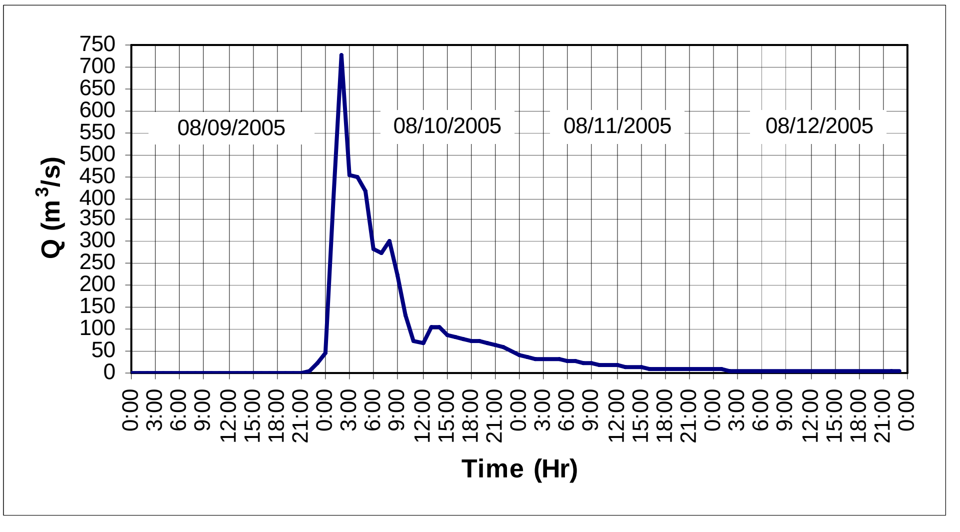

Figure 2.13 River Flows at Dasht Bridge in the 2005 Flood

2.3.2 Basin (Aerial) Rainfall Estimation

Representative rainfall stations selection, calculating weighting factors for those stations and determining basis of estimation are pre-requisites for basin rainfall estimations. After this, basin rainfalls can be calculated.

Selection of Representative Rainfall Stations

Stations were selected based on spatial coverage and availability of daily rainfall time series. With the criteria, from inside basin, Tangrah, Chesmeh Khan, Robat Gharebil, Dasht Kalpoush, Dasht Shad, Soodaghleen and Nardin stations were selected. From outside the basin, Pishkamar, Galikesh and Tilabad stations were selected with looking spatial coverage and nearness from the basin. Altogether 10 representative rainfall stations were selected to get good spatial coverage.

Weighting Factors for Stations

Among the selected 10 representative stations, for Soodaghleen and Nardin stations, 2001-05 years rainfall records are available. Similarly, for Dasht Shad and Dasht Kalpoush stations, 1997-2005 years daily rainfall records are available. For other 6 stations, 1974-2005 years daily rainfall records are available. Because of this, three combinations of the selected representative stations were made for Thiessen polygons development.

Combination (1): Six representative stations with long time series of daily rainfall available for 1974-96 years are used in Thiessen polygons development (Figure 2.14(1)).

Combination (2): Eight representative stations with time series of daily rainfall available for 1997-2000 years are used in Thiessen polygons development (Figure 2.14(2)).

Combination (3): All 10 representative stations with daily rainfall records available for 2001-05 years are used to develop Thiessen polygons (Figure 2.14(3)).

In this way three sets of weighting factors for stations have been computed for the entire basin and sub-basin rainfall calculations (Tables 2.1 and 2.2).

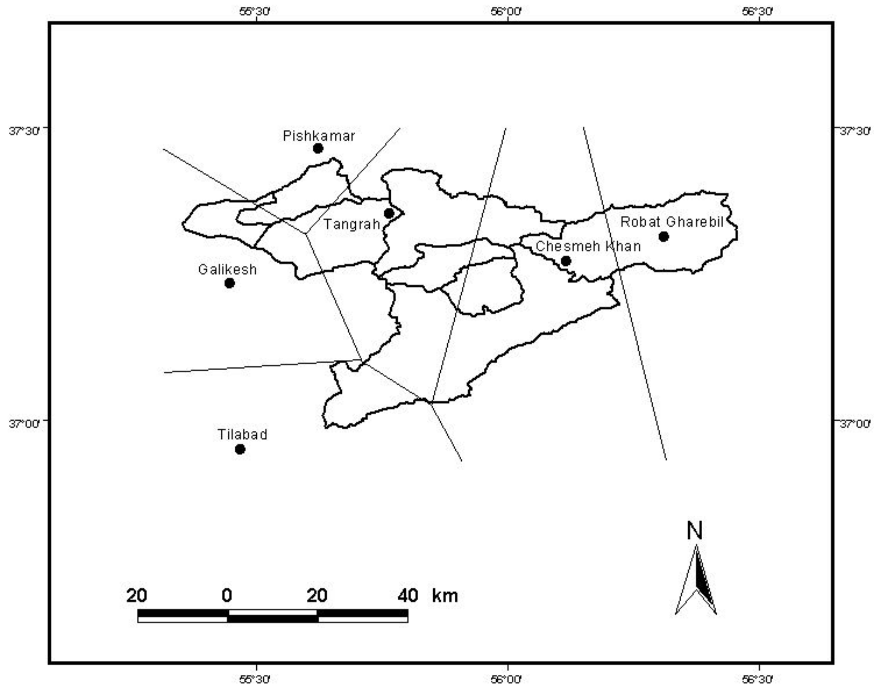

Figure 2.14(1) Thiessen Polygon used for 1974-96 Years

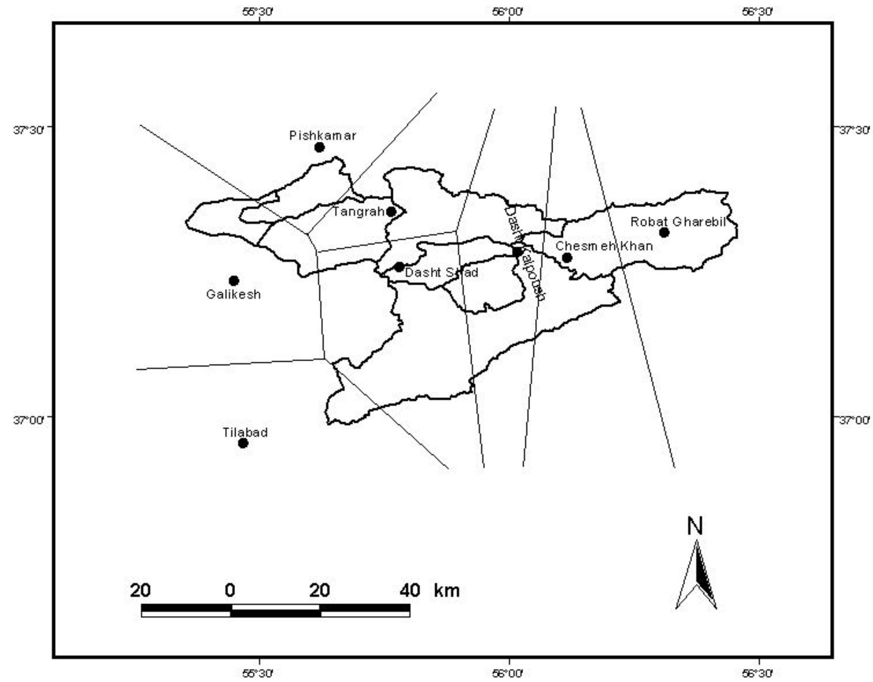

Figure 2.14(2) Thiessen Polygon used for 1997-2000 Years

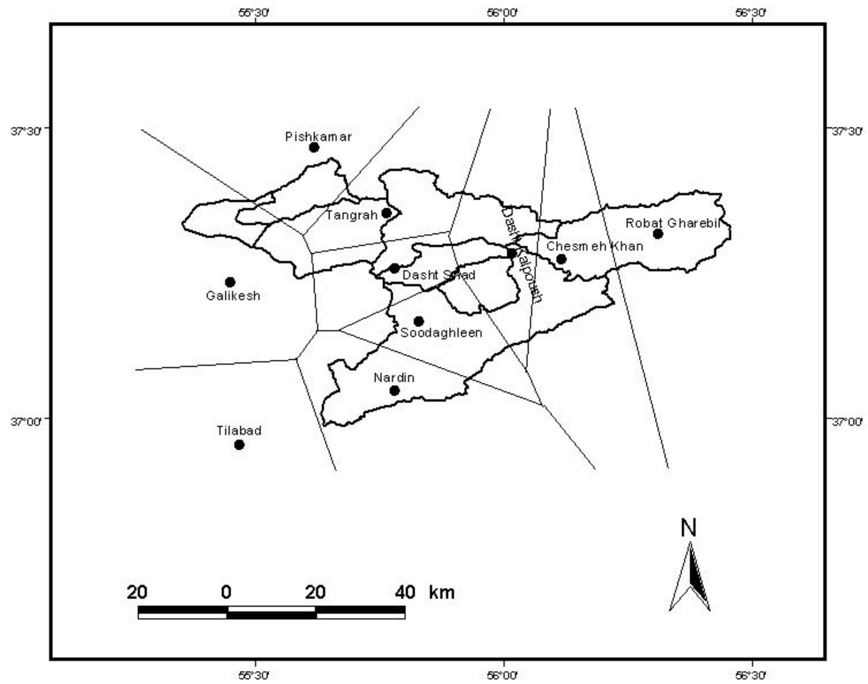

Figure 2.14(3) Thiessen Polygon used for 2001-05 Years

<u>Basis of Estimation</u>

Annual maximum 2-day rainfall data at stations in the basin were used for generating series of estimated basin and sub-basin rainfall. The distribution of annual maximum 2-day basin rainfalls is quite good, and probability distribution function could be good-fit.

Estimation of Basin and Sub-basin Rainfalls

For estimation of 2-day basin and sub-basin rainfalls, weighting factors for the selected stations with respect to basin as a whole and sub-basins individually are determined (Tables 1.1 and 1.2). Series of 2-day basin and sub-basin rainfalls were estimated for days of annual maximum 2-day rainfalls at 5 stations inside basin. If two or more stations have annual maximum 2-day rainfalls on the same days then only one series was considered. In this way series of estimated 2-day basin and sub-basin rainfalls were generated. The relation used for estimation of aerial rainfalls (2-day basin and sub-basin rainfalls) is as presented below.

$$P = \sum_{i=1}^{N} W_i R_i \quad (2)$$

Where,

P	=	Basin or sub-basin rainfall (mm/2day)
W	=	Thiessen weight factor for i^{th} station (0 – 1.0)
R	=	Rainfall at i^{th} station (mm/2day)
N	=	Number of rainfall stations considered
i	=	Index for station

Using the cited relation, the annual maximum 2-day aerial rainfall series for the basin and sub-basins was computed (Table 2.3).

Rainfalls Distribution Pattern Analysis

The distribution patterns of 2-day basin rainfalls over sub-basins were analyzed. For this, relative coefficients ($R_{sub\text{-}basin}/R_{basin}$) were calculated for all generated series of 2-day sub-basin rainfall with respect to 2-day basin rainfall. Frequency analysis of the relative coefficients of each sub-basin has performed and frequency histograms of relative coefficients were developed for all sub-basins (Figure 2.15). After developing the frequency histogram of relative coefficients, top-most 5 heavy rainfall years have been selected from generated 2-day basin rainfall series. Hence, 1988, 1992, 2001, 2002 and 2005 heavy rainfall years were selected to use rainfall distribution patterns of these flood years as probable types of rainfall which may cause disastrous floods in future in the basin. The spatial distribution of 2-day aerial rainfall over sub-basins during those 5 types of floods was analyzed (Figure 2.16) and distribution factors for 2-day basin rain into 2-day sub-basin rains were determined (Table 2.4). Results show that sub-basins 4, 5 and 6 got much rainfall than other sub-basins during the past floods, therefore, much attention should be paid on these sub-basins for debris flow and flood control activities.

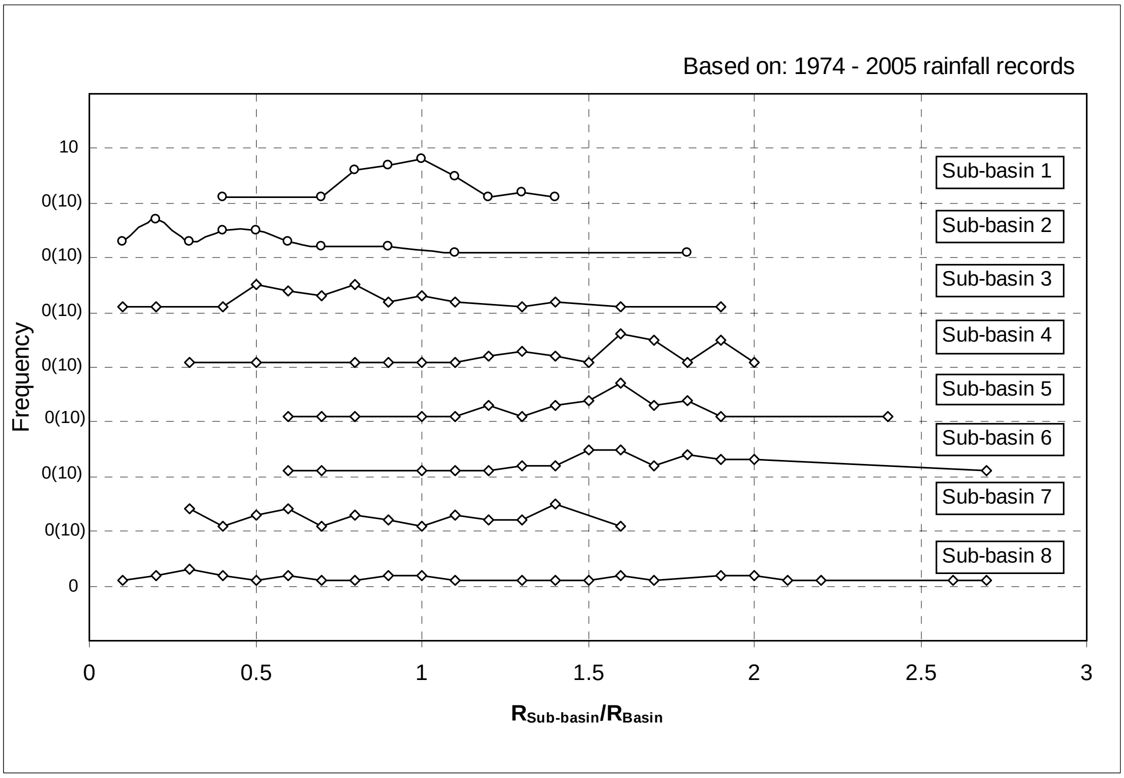

Figure 2.15 Rainfall Distribution Pattern over Sub-Basins

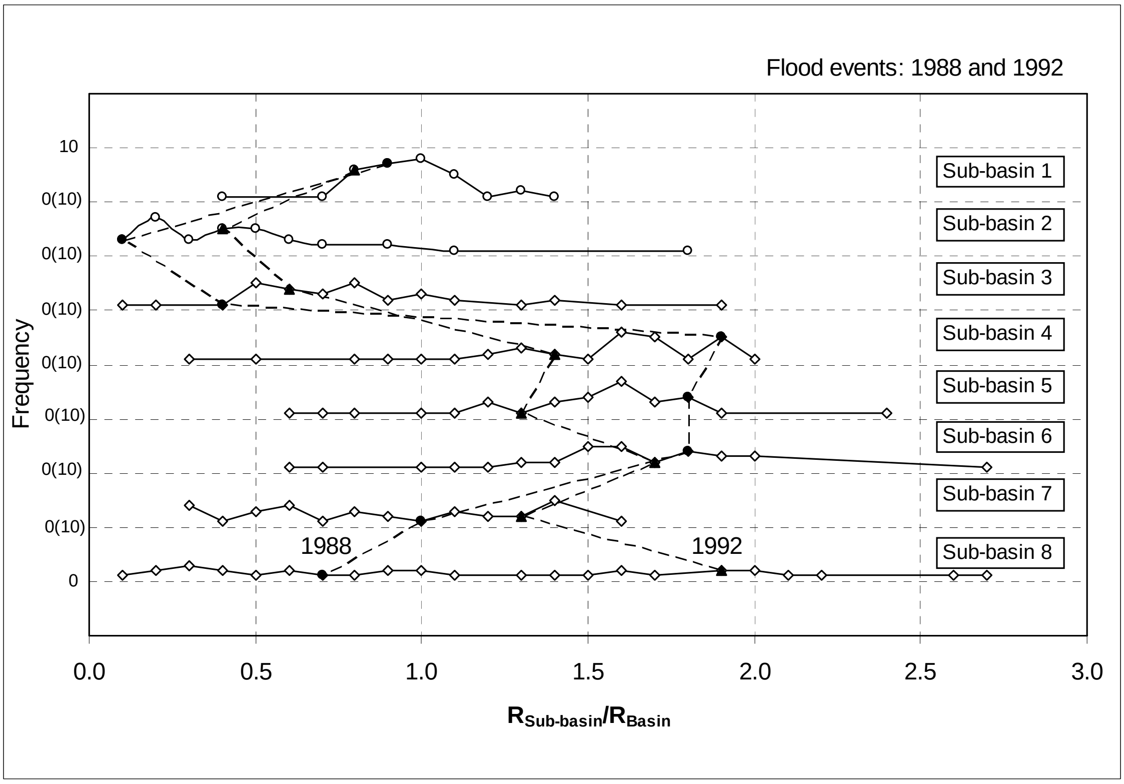

Figure 2.16(1) Rainfall Distribution over Sub-Basins in the Past Floods

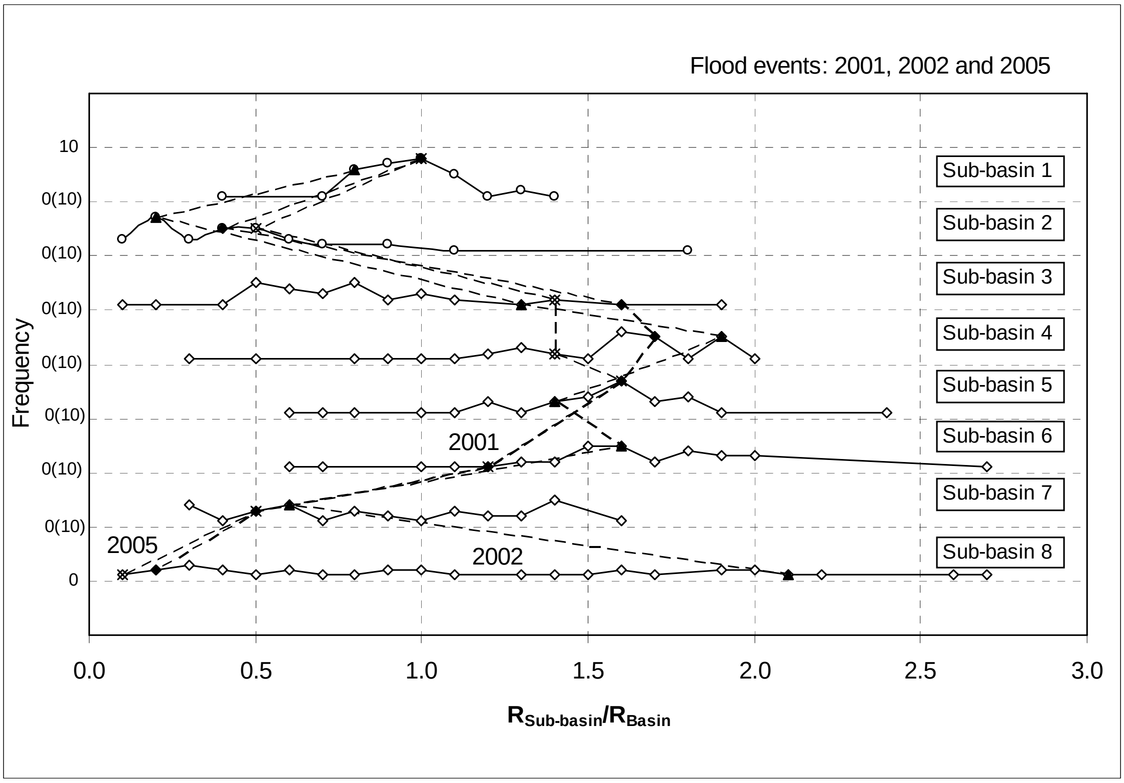

Figure 2.16(2) Rainfall Distribution over Sub-Basins in the Past Floods

Table 2.1 Thiessen Weight of Stations for Basin Rainfall Computation

Item	Robat-Gharebil	Chesmeh-Khan	Tangrah	Pishkamar	Galikesh	Tilabad	Dasht-Shad	Dasht-Kalpoush	Soodaghleen	Nardin
Long time series data (1975-96)	0.128	0.331	0.347	0.058	0.079	0.058	0.000	0.000	0.000	0.000
Short time series data - 1(1997-00)	0.130	0.126	0.134	0.059	0.075	0.024	0.255	0.197	0.000	0.000
Short time series data - 2 (2001-02)	0.129	0.125	0.133	0.058	0.075	0.000	0.088	0.154	0.134	0.104

Table 2.2 Thiessen Weight of Stations for Sub-Basin Rainfall Computation

Item	Robat-Gharebil	Chesmeh-Khan	Tangrah	Pishkamar	Galikesh	Tilabad	Dasht-Shad	Dasht-Kalpoush	Soodaghleen	Nardin
A. Long time series data (1975-96)										
Sub-basin 1	0.000	0.513	0.313	0.000	0.000	0.175	0.000	0.000	0.000	0.000
Sub-basin 2	0.674	0.326	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sub-basin 3	0.000	0.846	0.154	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sub-basin 4	0.000	0.231	0.769	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sub-basin 5	0.000	0.270	0.730	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sub-basin 6	0.000	0.000	0.655	0.069	0.276	0.000	0.000	0.000	0.000	0.000
Sub-basin 7	0.000	0.000	0.071	0.786	0.143	0.000	0.000	0.000	0.000	0.000
Sub-basin 8	0.000	0.000	0.000	0.100	0.900	0.000	0.000	0.000	0.000	0.000
B. Short time series data - 1 (1997-00)										
Sub-basin 1	0.000	0.211	0.000	0.000	0.000	0.104	0.502	0.183	0.000	0.000
Sub-basin 2	0.668	0.301	0.000	0.000	0.000	0.000	0.000	0.031	0.000	0.000
Sub-basin 3	0.000	0.000	0.000	0.000	0.000	0.000	0.111	0.889	0.000	0.000
Sub-basin 4	0.000	0.000	0.000	0.000	0.000	0.000	0.619	0.381	0.000	0.000
Sub-basin 5	0.000	0.027	0.459	0.000	0.000	0.000	0.163	0.351	0.000	0.000
Sub-basin 6	0.000	0.000	0.500	0.071	0.250	0.000	0.179	0.000	0.000	0.000
Sub-basin 7	0.000	0.000	0.071	0.786	0.143	0.000	0.000	0.000	0.000	0.000
Sub-basin 8	0.000	0.000	0.000	0.100	0.900	0.000	0.000	0.000	0.000	0.000
C. Short time series data - 2 (2001-02)										
Sub-basin 1	0.000	0.208	0.000	0.000	0.000	0.000	0.019	0.078	0.372	0.323
Sub-basin 2	0.668	0.301	0.000	0.000	0.000	0.000	0.000	0.031	0.000	0.000
Sub-basin 3	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.706	0.293	0.000
Sub-basin 4	0.000	0.000	0.000	0.000	0.000	0.000	0.591	0.381	0.028	0.000
Sub-basin 5	0.000	0.027	0.459	0.000	0.000	0.000	0.163	0.351	0.000	0.000
Sub-basin 6	0.000	0.000	0.500	0.071	0.250	0.000	0.179	0.000	0.000	0.000
Sub-basin 7	0.000	0.000	0.071	0.786	0.143	0.000	0.000	0.000	0.000	0.000
Sub-basin 8	0.000	0.000	0.000	0.100	0.900	0.000	0.000	0.000	0.000	0.000

Table 2.3 Annual Maximum 2-Day Basin Rainfall

Year	Date	Basin	Sub - basins							
			1	2	3	4	5	6	7	8
1974	27-28 Nov	36	34	11	31	54	53	50	49	21
1975	29-30 Nov	30	27	15	20	36	35	46	33	57
1976	24-25 Apr	20	18	2	9	38	36	35	24	6
1977	21-22 Apr	26	23	12	20	42	41	41	8	27
1978	2-3 May	33	33	12	33	53	51	49	9	32
1979	13-14 Sep	23	23	4	18	40	39	36	18	13
1980	29-30 Dec	15	15	3	13	27	27	22	8	1
1981	6-7 Oct	20	19	3	15	37	36	31	7	5
1982	24-25 Jun	20	20	5	19	33	32	28	9	9
1983	12-13 Dec	28	33	17	38	21	22	29	29	59
1984	6-7 Oct	34	37	19	36	52	51	41	10	10
1985	11-12 Oct	26	20	5	12	43	41	51	25	48
1986	3-4 Aug	37	31	15	24	58	55	59	51	35
1987	20-21 Mar	41	33	8	20	65	62	75	57	63
1988	1-2 Apr	54	46	4	24	100	95	98	56	40
1989	5-6 Jan	30	40	27	56	30	32	15	8	4
1990	15-16 Mar	30	28	19	23	37	36	42	22	46
1991	4-5 May	38	42	34	41	35	35	37	34	48
1992	13-14 May	77	62	28	45	105	101	131	102	146
1993	15-16 Feb	18	13	7	6	29	28	36	13	35
1994	5-6 Jan	30	23	7	14	46	44	53	45	42
1995	22-23 Jun	34	30	17	25	45	44	50	43	45
1996	25-26 Jun	31	27	5	18	57	55	56	15	27
1997	6-7 Nov	16	11	17	1	8	18	31	9	41
1998	18-19 Mar	13	16	23	2	11	7	9	11	5
1999	12-13 Jul	20	24	10	10	25	14	27	13	53
2000	7-8 Feb	17	17	0	10	22	23	31	21	29
2001	10-11 Aug	97	94	41	147	165	152	115	53	22
2002	12-13 Aug	45	36	8	56	88	64	73	25	96
2003	24-25 May	44	32	22	41	51	75	75	51	27
2004	19-20 Sep	21	8	4	13	5	50	55	27	18
2005	9-10 Aug	75	72	40	102	107	118	93	37	10

Table 2.4 Conversion Factors for 2-Day Basin Rainfall into Sub-Basin Rainfall

Flood Type	Basin	Sub-basin 1	Sub-basin 2	Sub-basin 3	Sub-basin 4	Sub-basin 5	Sub-basin 6	Sub-basin 7	Sub-basin 8
1988	1.00	0.85	0.07	0.45	1.86	1.77	1.83	1.05	0.74
1992	1.00	0.80	0.36	0.58	1.36	1.31	1.71	1.32	1.90
2001	1.00	0.96	0.42	1.51	1.70	1.57	1.18	0.54	0.23
2002	1.00	0.78	0.18	1.24	1.93	1.40	1.61	0.56	2.11
2005	1.00	0.97	0.54	1.36	1.44	1.58	1.24	0.49	0.13

2.3.3 Computation of Probable Basin and Sub-Basin Rainfall

The series of annual maximum 2-day basin rainfall (1974-2005) was analyzed using different types of probability distribution function (Figure 2.17). As mentioned earlier, the probability distribution functions are fitting well with the estimated annual maximum 2-day basin rainfall series. However, Log Pearson 3 (Log P3) probability distribution function has the best fit with the rainfall series. The probable 2-day basin rain with different return periods are derived from the Log P3 distribution function (Table 2.5). The probable 2-day basin rains with 25, 50 and 100 years return periods are 76.1, 94.4 and 115.4 mm, respectively. Using these probable 2-day basin rains of 25, 50 and 100 years return periods, probable 2-day sub-basins rains have been computed using distribution or multiplier factors (Table 2.6). These probable 2-day sub-basins rains with 25, 50 and 100 years return periods were used in MIKE SHE hydrological model to estimate flows in river system in the basin.

As a result of the probability computation, recurrences of the recent three floods could be evaluated using 2-day basin rainfall as tabulated in Table 2.3. These are:

- 2001 Flood (97 mm): 55-year
- 2002 Flood (45 mm): 5-year
- 2005 Flood (75 mm): 25-year

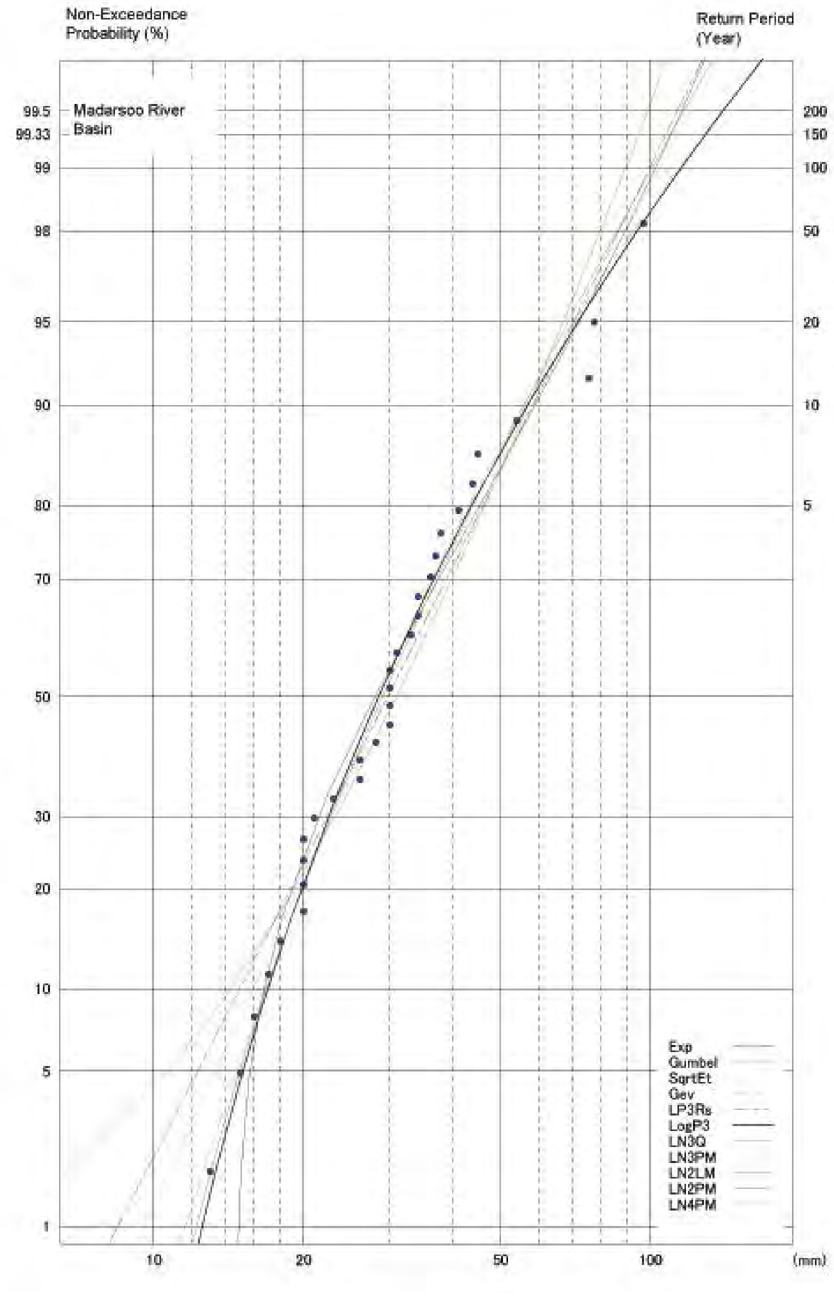

Figure 2.17 Probability Distribution Functions and 2-Day Basin Rainfall

Table 2.5 Probable 2-Day Basin Rainfall

Item	Return Periods									
	2 - Years	5 - Years	10 - Years	20 - Years	25 - Years	30 - Years	50 - Years	80 - Years	100 - Years	200 - Years
Probable 2-day basin rainfalls (mm/2day)	28.3	43.6	56.5	71.2	76.1	80.9	94.4	108.3	115.4	139.8

Table 2.6 Probable 2-Day Basin and Sub-Basin Rainfall

Return Period	Flood Type	Probable Aerial Rainfalls (mm/2day)								
		Basin	Sub-basin 1	Sub-basin 2	Sub-basin 3	Sub-basin 4	Sub-basin 5	Sub-basin 6	Sub-basin 7	Sub-basin 8
25 Years	1988	76.1	65	6	34	141	134	139	80	56
	1992		61	28	44	104	100	130	101	145
	2001		73	32	115	129	119	90	41	17
	2002		60	14	94	147	106	122	42	161
	2005		74	41	104	109	120	95	37	10
50 Years	1988	94.4	81	7	42	175	167	172	99	69
	1992		76	34	55	128	124	161	125	180
	2001		91	39	143	160	148	112	51	22
	2002		74	17	117	183	132	152	53	200
	2005		92	51	129	136	149	117	46	12
100 Years	1988	115.4	99	9	51	214	204	211	121	85
	1992		93	42	67	157	151	197	152	220
	2001		111	48	174	196	181	136	63	26
	2002		90	21	143	223	161	186	64	244
	2005		112	62	157	166	182	144	57	15

2.3.4 Time Distribution of Rainfall

Time distribution of rainfall is one of the most important factors as well as spatial distribution of rainfall, to generate flows precisely in river system. Therefore, the study team requested Meteorological Organization (MO), Tehran to provide hourly rainfall data of Gonbade Kawoos during the past floods. This station is the only synoptic station that lies near from the Madarsoo River basin. But 6 hourly rainfalls data were available of the station for the past 2001-02 floods that could not be used as time distributed rainfall data. Similarly, rainfall intensity curve was also not available for Gonbade Kawoos. Thus, as an alternative measure, rainfall intensity curve of Gorgan, which is the next nearest synoptic station from the basin, was used to develop hourly distribution pattern of rainfall. The 20- and 100-year return period rainfall intensity curves of Gorgan (Figure 2.18) were used to derive hourly distribution pattern of rainfall. The rainfall intensity relations of Gorgan station are as follows:

<u>For 20-Year Return Period</u>

$$i = \frac{338.43}{(t + 5.47)^{0.6}} \tag{3}$$

<u>For 100-Year Return Period</u>

$$i = \frac{339.95}{(t + 2.24)^{0.57}} \tag{4}$$

where,

i = Rainfall intensity (mm/hr)
t = Time duration (min)

On the other hand, the rainfall records of Gonbade Kawoos show that in one-day there were: less than 6 hours rainfall on 1996 flood day, a bit greater than 6 hours rainfall on 2001 flood day; and less than 6 hours rainfall on 2002 flood day. Further, on line rainfall data of Tangrah for the 2005 Flood were available. The online data show total rain duration was 11 hours at Tangrah during the 2005 Flood. But in-between 11 hours rain duration 3 hours have nominal rainfalls. Considering these facts, 2-day sub-basins rainfalls were distributed in 9 hours. Thus, based on the rainfall intensity curves, symmetric or centralized hourly rainfalls distribution patterns up to 9 hours were developed for 20- and 100-year return periods (Figure 2.19). While analyzing the rainfall intensity at Tangrah during the 2005 Flood, it also shows that rain was distributed in more or less symmetric manner. Moreover, percentages of rain occurred on the first and second days during the past 5 major flood events were analyzed

(Tables 2.7 and 2.8). Based on these percentages, rain was distributed between the first and second days to develop time distribution of rain. In this way, 9 hours time distribution patterns of rainfalls were developed to distribute 2-day sub-basin rains to be used in MIKE SHE for river flows estimations with 25-, 50- and 100-year return periods.

For time distribution of rainfall during the 2005 Flood, online rainfall data of Tangrah with 10 minutes intervals were used. Using the online rainfall data of 10 minutes intervals at Tangrah, river flows are estimated for the 2005 Flood.

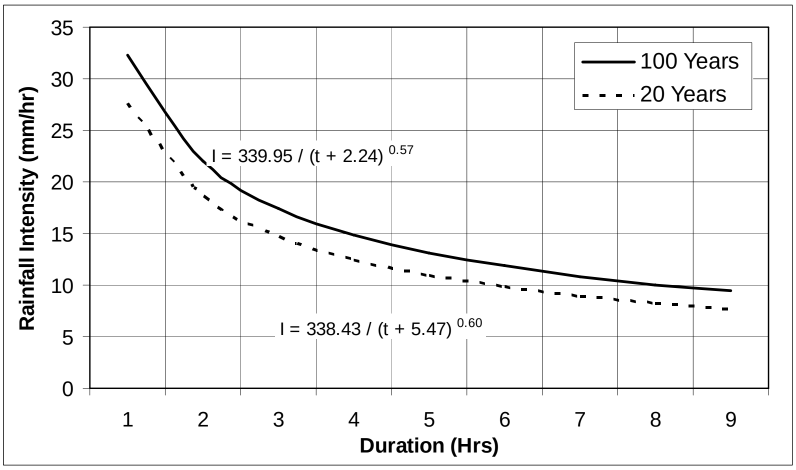

Figure 2.18 Rainfall Intensity Curves of Gorgan (20- and 100-Year Return Periods)

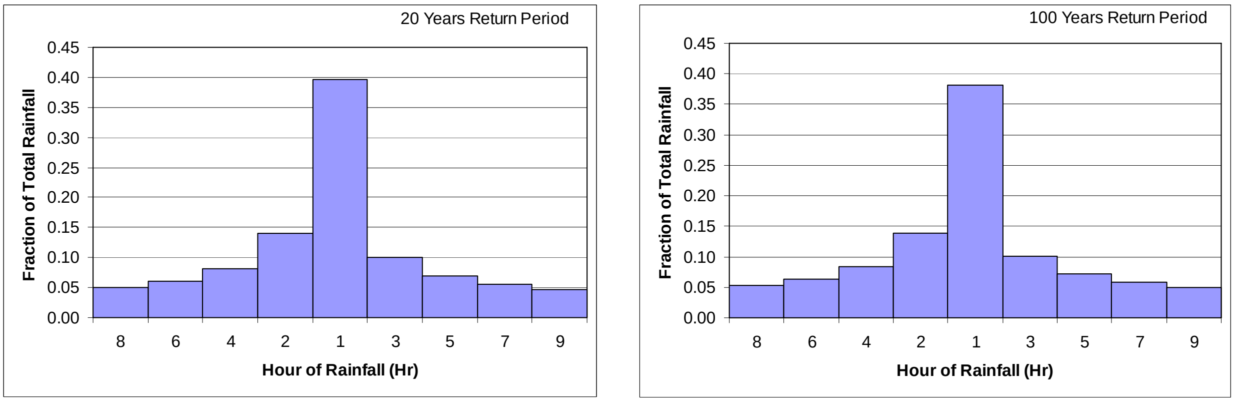

Figure 2.19 Rainfall Distribution Pattern of Gorgan (20- and 100- Year Return Periods)

Table 2.7 Daily Rainfall at Stations during the Past Floods

Flood Year	Day	Rainfall (mm/d)									
		Tangrah	Chesmeh Khan	Robat Gharebil	Pishkamar	Galikesh	Tilabad	Dasht Shad	Dasht Kalpoush	Soodaghleen	Nardin
1988	1-Apr	72.0	0.0	0.0	41.0	0.0	8.5				
	2-Apr	56.0	5.0	3.5	12.0	38.0	10.0				
1992	13-May	46.0	23.0	16.0	0.0	68.0	32.5				
	14-May	81.0	7.0	11.0	90.0	84.5	4.5				
2001	10-Aug	0.0	0.0	4.5	0.0	4.0	9.5	0.0	50.0	21.2	0.0
	11-Aug	150.0	84.0	11.5	50.3	15.0	8.0	176.0	100.0	117.0	30.0
2002	12-Aug	23.5	0.0	0.0	8.1	32.0	4.5	0.0	0.0	13.6	0.0
	13-Aug	30.0	16.0	2.5	0.0	74.0	11.0	108.0	60.0	33.4	25.0
2005	9-Aug	0.0	0.0	0.0	0.0	0.0	13.0	0.0	0.0	0.0	0.0
	10-Aug	136.9	85.0	17.5	32.8	7.0	14.0	113.0	98.0	110.0	12.0

Table 2.8 Daily Basin and Sub-Basin Rainfall during the Past Floods

Flood Year	Day	Basin and Sub - Basin Rainfalls (mm/d)								
		Basin	Sub-Basin							
			1	2	3	4	5	6	7	8
1988	1-Apr	28	24	0	11	55	53	50	37	4
	2-Apr	26	22	4	13	44	42	48	19	35
1992	13-May	33	32	18	27	41	40	49	13	61
	14-May	44	30	10	18	64	61	83	89	85
2001	10-Aug	11	12	5	42	20	18	1	1	4
	11-Aug	86	82	36	105	145	135	114	52	19
2002	12-Aug	8	5	0	4	0	11	20	13	30
	13-Aug	38	31	8	52	88	53	53	13	67
2005	9-Aug	0	0	0	0	0	0	0	0	0
	10-Aug	75	72	40	102	107	118	93	37	10

Comparison of Time Distribution Patterns of Rainfall

The general 9 hours time distribution pattern of rainfall, developed with the help of rainfall intensity curves of Gorgan for 20- and 100-year return periods, is compared with time distribution pattern of rainfall at Tangrah during the 2005 Flood (Figure 2.20). Non-dimensional comparison of rainfall patterns show in the 2005 Flood quite intense rain has occurred at third hour of rainfall at Tangrah; and about 76% of total rainfall has occurred within first 4 hours of rainfall. Meanwhile the developed 9 hours rainfall distribution patterns for 20- and 100-year return periods show intense rain occurs at fifth hour of rainfall; and about 78% of total rain occurs within 5.5 hours.

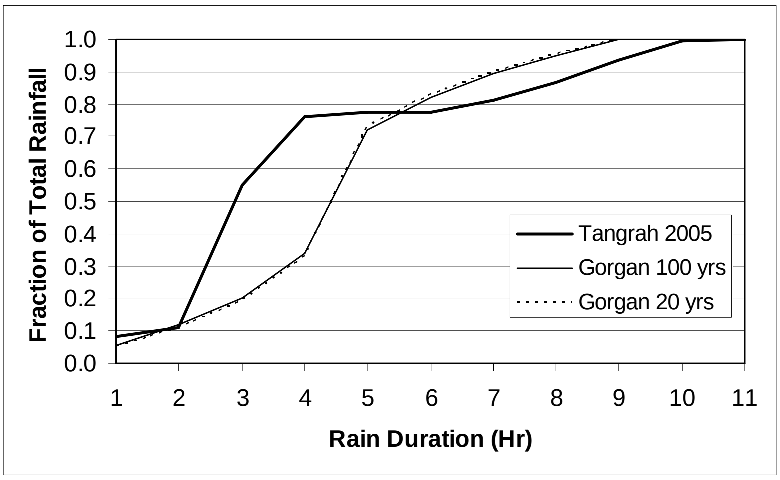

Figure 2.20 Comparison of Rain Distribution Pattern

2.3.5 Analysis of River Discharge

The time series data of river discharge was only available for Tangrah station in the basin. The annual maximum discharges at Tangrah were derived from daily time series discharge data (Table 2.9). The annual maximum discharges of 33 years (1970-2002) at Tangrah were analyzed by various probability distribution functions. However, it is quite difficult to get good-fit functions for the time series data of the annual maximum discharge at Tangrah. It indicates that observed data are not consistent with one year to others and reliability of data is not so good. Generalized Extreme Value (GEV) probability distribution function has only better good-fit with time series than other distribution functions (Figure 2.21). The probable discharges estimated by the GEV at various return periods are presented (Table 2.10). The estimated probable discharges at 25-, 50-, 100-, 200- and 400-year return periods are 222, 398, 731, 1,336 and 2,440 m^3/s, respectively.

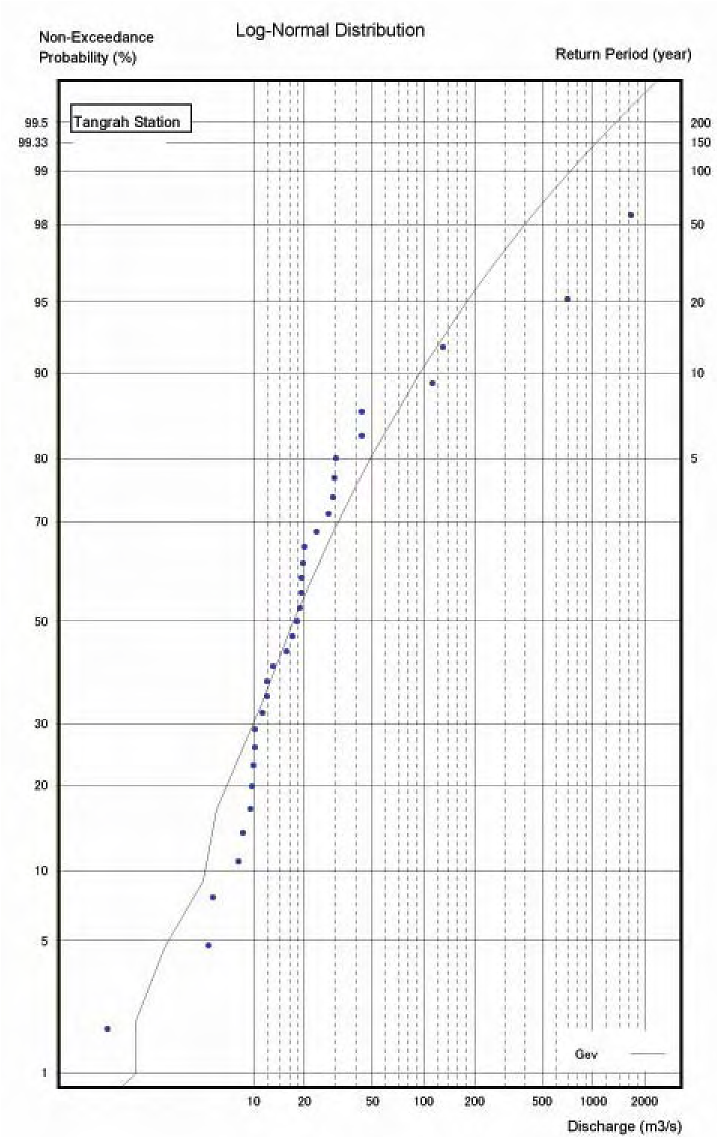

Figure 2.21 Probability Analysis of Annual Maximum Discharge at Tangrah

Table 2.9 Annual Maximum Discharge at Tangrah Station

Date	Max. Q (m^3/s)
1970/3/24	1
1971/4/21	13
1972/4/20	9
1973/4/4	19
1974/11/1	20
1975/3/28	29
1976/4/27	19
1977/3/21	6
1978/4/16	10
1979/5/11	5
1980/10/21	15
1981/9/27	129
1982/4/9	12
1983/4/9	8
1984/5/2	12
1985/3/21	10
1986/4/3	10
1987/4/5	27
1988/4/2	43
1989/4/30	43
1990/5/14	10
1991/5/25	23
1992/5/13	113
1993/3/9	30
1994/3/28	31
1995/4/25	19
1996/4/16	17
1997/5/6	11
1998/3/19	20
1999/3/25	18
2000/3/25	10
2001/8/11	1650
2002/8/13	700

Table 2.10 Probable Discharge at Tangrah Station

Item	Return Period									
	2 - Yrs	5 - Yrs	10 - Yrs	20 - Yrs	25 - Yrs	50 - Yrs	100 - Yrs	150 - Yrs	200 - Yrs	400 - Yrs
Probale Q (m^3/s)	17	48	94	177	222	398	731	1041	1336	2440

<u>Discrepancies and Clarification</u>

When the 2001 flood event is analyzed from the annual maximum discharge series at Tangrah, it shows that the flood event has about 250-year return period. However, if the 2001 flood event is analyzed from the annual maximum basin rainfalls series, it shows that the flood event has about 55-year return period. Therefore, it shows that rainfall and discharge data of the basin are not consistent with each other. The one of the reasons originating the big differences is differences of recorded periods; rainfall data from 1974 to 2005, and discharge data from 1970 to 2002. Thus discharge data exclude the latest 2005 Flood due to lack of observed or estimated peak discharge.

As mentioned before, distribution functions are good–fit with the annual maximum basin rainfalls series. It indicates rainfall data of stations in the basin are consistent and more reliable. Similarly, if we input 2-day sub- basins rainfalls data of the 2001 and 2005 flood events into MIKE SHE model and generate river flows, then we get estimated and model generated flow hydrographs as well as peak flows match well at Golestan Dam, Tangrah and Dasht Bridge. It also verifies that rainfall data are reliable. Therefore, sub-basins rainfalls data are used in the model for estimation of design discharges in river system in the basin to be used in flood control master plan development.