CGIAR Challenge Program on
WATER & FOOD

WATER RESOURCES OF THE KARKHEH RIVER BASIN: HYDROLOGY, RUNOFF, AND WATER BALANCE

Editors: Jahangir Porhemmat, Hamid Siadat and Theib Oweis

Strengthening Livelihood Resilience in Upper Catchments of Dry Areas by INRM (CPWF PN 24)

11

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International Center for Agricultural Research in the Dry Areas

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Contents

Executive summary

The project - 'Strengthening Livelihood Resilience in the Upper Catchments of Dry Areas by Integrated Natural Resources Management' was undertaken in the Karkheh River Basin (KRB) of southwest Iran, from August 2005 to December 2008. The research program was guided by the 'Integrated Natural Resources Management' framework, in which assessment of water resources was one of the most important components. The KRB is a large basin with 47 plains and hydrologic units. This report presents an overall view of its surface water and groundwater status, together with two detailed case studies in Honam and Merek sub-basins.

The overall goal of the project was to strengthen livelihood resilience of the rural poor and to improve environmental integrity in the upper catchments of the basin. The data collected was being fed into new models of catchment management and policy.

The first chapter provides an analysis of annual runoff and annual runoff coefficients to explain spatial variation of surface water in the upper KRB. Runoff analysis is considered for different time scales and places. Runoff was analyzed in different types of basins under varying climates. According to the results, runoff depth has a relatively high correlation with precipitation and slope; however, in single variable analysis, it showed a greater correlation with slope than precipitation.

In the second chapter, a summary of hydrogeology and groundwater quality is presented for the KRB. Alluvial and karstic aquifers and their geological and hydrological properties are described. To prepare a general water balance for the basin, aquifers (alluvial and karstic), groundwater exploitation along with groundwater usage, balance, and quality are considered in the different hydrologic units. In addition, a water balance overview of the KRB is discussed that presents a schematic sketch of groundwater resources and uses in the basin.

Chapter three is devoted to the study of water assessment in Honam and Merek sub-basins of KRB. Two hydrometric data loggers and a rain gauge installed/selected in each watershed are explained. For both catchments, a simple water balance equation is used in which the amount of rainfall is set equal to the sum of outlet discharge, evapotranspiration, and exchanging groundwater.

The application of a single rainfall–runoff event model for evaluation of land use effect on flooding in Honam and Merek is explained in chapter 4. GIS and HEC-HMS models are combined to assess the effects of different scenarios of land-use changes on runoff and hydrograph shape. The results emphasize the effects of land-use changes on hydrologic response of the basin. The simulation by HEC-HMS shows that unsuitable land-use would increase the peak flow and flood volume, whereas proper land use would decrease them.

In chapter five, drought in the upper KRB is analyzed using Standardized Precipitation Index (SPI). The index principles are reviewed and applied to the monthly precipitation data of the nearby stations of Kermanshah and Alashtar for, respectively, Merek and Honam for various time scales, i.e. 1-, 3-, 6-, and 12-month SPIs are used to evaluate hydrological and agricultural droughts. Using rainfall data (1966-2000), it is clear that Honam and Merek catchments experienced, respectively, 14 and 20 droughts of 1–3 months length. During 1966–2000, there was no drought in Honam in October, whereas

Merek experienced drought 11 times in that month. In November, the two catchments suffered very similar droughts, often at the same time. In both catchments, the frequency of drought in April was almost the same. Drought in May was more frequent in Merek than Honam, although in some years both catchments experienced drought in this month.

Chapter 1.

Runoff Analysis of the Upper Karkheh River Basin

Jahangir Porhemmat, Adriana Bruggeman and Bagher Ghermezcheshmeh

Chapter 1: Runoff Analysis of the Upper Karkheh River Basin

Jahangir Porhemmat, Adriana Bruggeman and Bagher Ghermezcheshmeh

1.1. Introduction

The Karkheh River is located in southwest Iran with elongated tributaries to the central part of the country. It originates from high mountains in the north west of Iran and terminates at Hour-Al Azim on the Iran–Iraq border with south. It is completely situated in Iran, with only the outlet at the political borders.

The KRB has a wide range of climates due to the high Zagros Mountains in the upper part, with cold and relatively wet zones, and the Khoozestan lowland plain on the lower part with a hot and arid–semi-arid climate at the outlet. The Karkheh highlands and rugged terrain on the upper part receive considerable precipitation as rain or snow in the mountainous parts, where the river tributaries originate with permanent streams that eventually join to form the Karkheh River. There are different hydrological characteristics and units in the upper part of the basin due to inter-mountainous plains forming many catchments with different hydrological behaviors, which require much data and information for assessment of water resources and water allocation. Although there are many gauging stations in the basin, there are a limited number of such stations at the catchment scale and only a few are gauged. Water scarcity is a dominant problem in KRB dry areas, and so for water resource management and planning, a detailed assessment of water resources and their spatial and temporal distribution is needed, at least, at catchment level. This report provides an analysis of annual runoff and annual runoff coefficients to explain spatial variation of surface water in the upper KRB.

1.2. Materials and methods

1.2.1. General geography and physiographical setting of the KRB

The KRB is one of the second-order basins of the Persian Gulf and one of the six first-order or major basins of Iran located in south west of the country (Jamab, 1999). Figure 1.1 shows the location of the KRB on the Iranian side of the Persian Gulf Basin. All highlands of this basin are in the Zagros Mountain range, spread over the north and northeastern to eastern areas of the

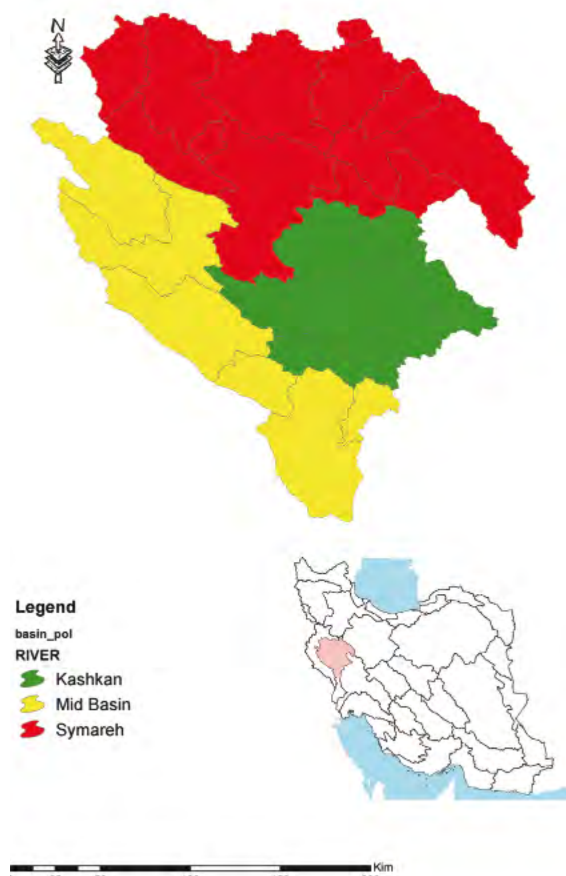

Figure 1.1. Location and the main basin of the KRB in Iran.

Table 1.1. Characteristics of main sub-basins of the KRB.

Sub-Basin	Area (km^2)	Min elevation (m)	Mean elevation (m)	Max elevation (m)	Slope (%)
Saymareh at Holylan	19977	911	1748	3598	17. 6
Kashkan at Pol e Dokhtar	9267	659	1632	3615	22.4
KRB at Paye Pol (Dam)	42191	97	1544	3615	19.3

basin, and elevation is reduced in the western and southern parts of the basin. The highest point elevation of the KRB is 3645 m above mean sea level. The KRB extends over 51 806 km^2, which is 3.2% of Iran, and has a perimeter of 1891 km. KRB is located within 30°49'–34°04'N and 46°06'–49°10'E. The main river tributaries of the upper KRB are the Saymareh and Kashkan Rivers and a mid-basin. The Saymareh River is in the western part and is formed from two sub-basins: the Gamasiab and Gharesoo.

Table 1.1 shows the general characteristics of three main parts (main sub-basins) of the upper KRB. The upper KRB is mountainous areas with different elevations (Figure 1.2). Based on the Digital Elevation Model (DEM) of the KRB (Figure 1.2), the upper KRB ranges in elevation from a few meters to 3645 m above mean sea level. Slopes are varied over different parts of the basin (Figure 1.3). The aspect map of the upper basin (Figure 1.4) was computed using the DEM.

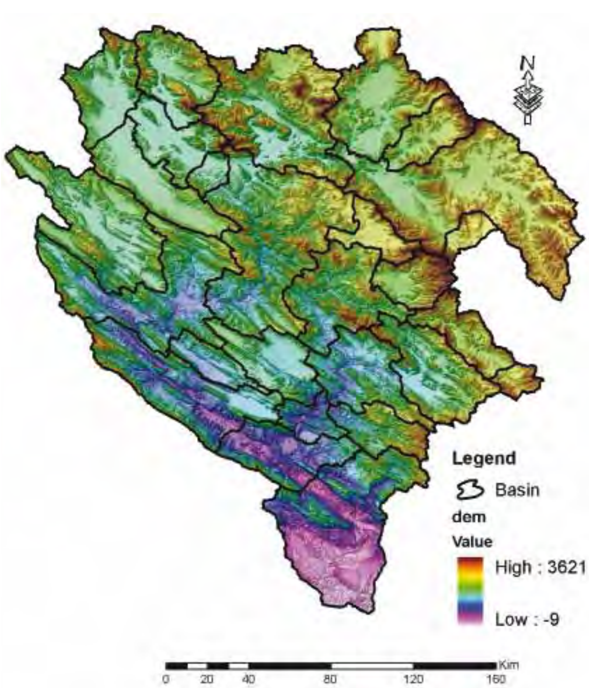

Figure 1.2. DEM of the KRB (Source: SCWMRI).

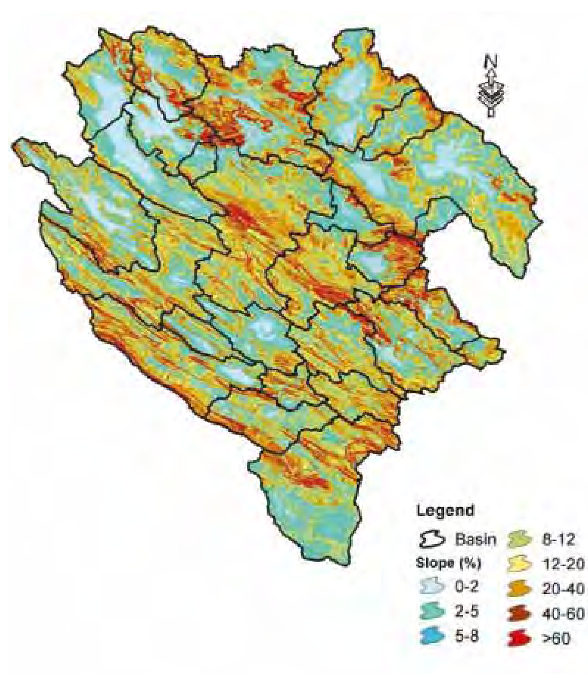

Figure 1.3. Slopes of the upper KRB (source: SCWMRI).

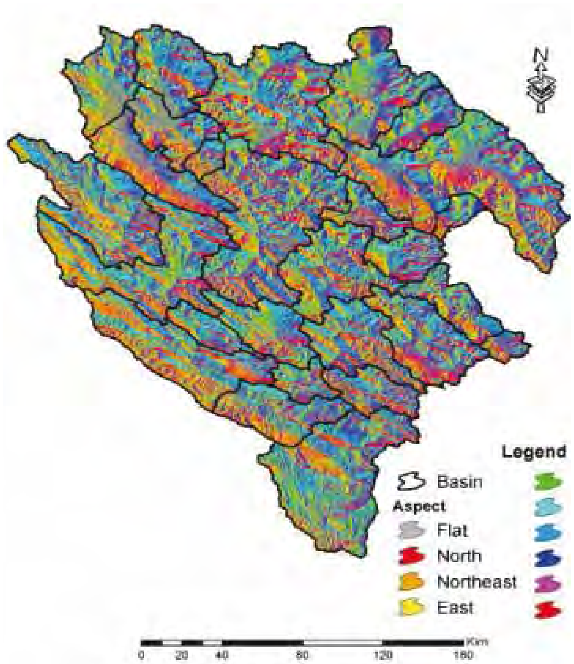

Figure 1.4. Aspect map of the upper KRB (extracted from DEM).

1.2.2. Data collection and processing

The general information needed for surface flow analysis is physiographic, climatic, and discharge from the hydrometric stations.

Physiographic data and information needed for the above analysis can be used from other sections of this report. The DEM of the basin was prepared from digital contour lines of a topography map (1:250 000). Area–elevation classes (hypsometry) were computed for each KRB sub-basin corresponding to hydrometric stations using the DEM of the basin. Table 1.2 shows the general characteristics of the hydrometric stations in the upper KRB. Table 1.3 shows the hypsometry for the selected hydrometric stations in the upper KRB.
Figure 1.5 shows elevation classes corresponding to the upper KRB (as well as Pay-e pol from the lower KRB).

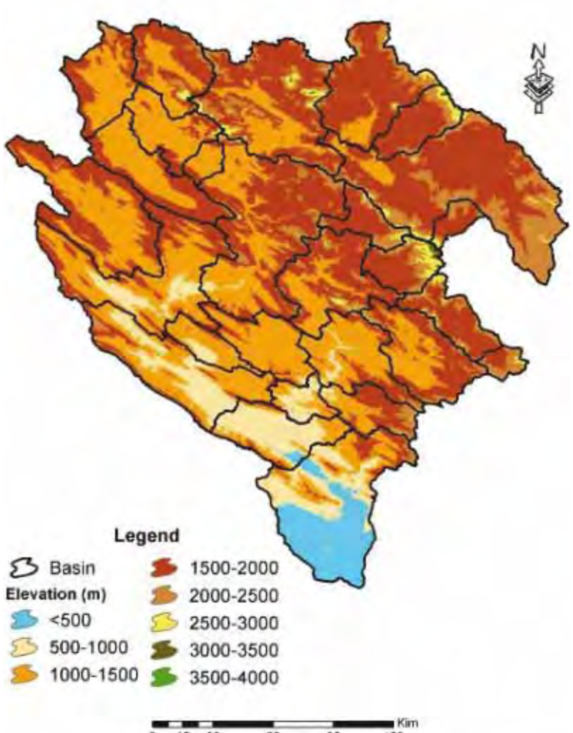

Figure 1.5. Elevation classes (hypsometry) of the upper KRB.

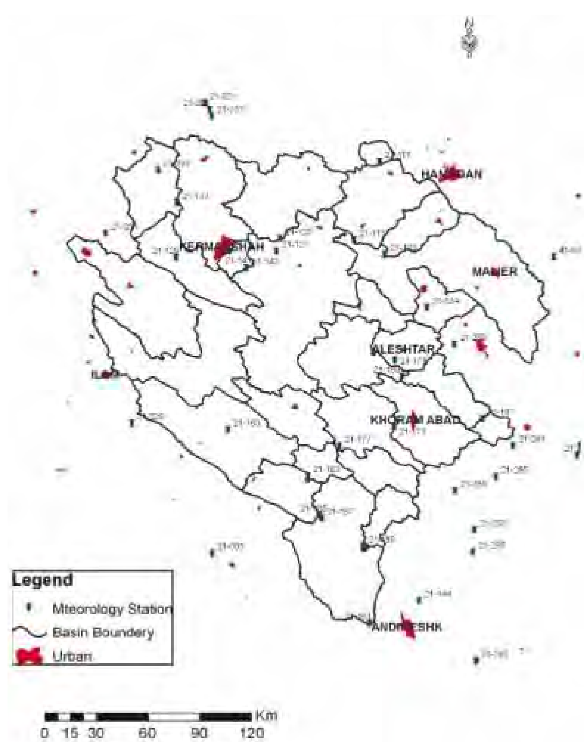

Figure 1.6. Distribution of rain gauges in the upper KRB.

Table 1.2. Selected hydrometric stations for surface water analysis in the upper KRB.

Row	Station	River	Station Code	Area (km²)	Latitude	Longitude
1	Gooshe-Saad	Ab-e Nahavand	21-107	778	48°16′28 ″.1	34°16′14 ″.9
2	Firoozabad	Toviserkan	21-109	869	34°21′00 ″.0	48°07′00 ″.12
3	Aghajan Bolaghi	Shahab	21-111	520	48°03′0 ″.0	34°49′59 ″.88
4	West Aran	Khorram-Rood	21-113	2298	34°25′00 ″.1	47°55′00 ″.12
5	Doab	Gamasiab	21-115	8026	34°22′00 ″.1	47°54′00 ″.00
6	Polchehr	Gamasiab	21-127	10208	34°19′59 ″.9	47°25′59 ″.88
7	Khersabad	Ab Merek	21-131	1434	34°31′00 ″.1	46°43′59 ″.88
8	Doab-e Merek	Gharesoo	21-133	1294	34°33′00 ″.0	46°46′59 ″.88
9	Pol Kohneh	Gharesoo	21-141	5041	34°19′00 ″.1	47°07′59 ″.88
10	Ghoorbaghestan	Gharesoo	21-143	5309	33°43′59 ″.9	47°15′00 ″.00
11	Noorabad(West)	Badavar	21-145	621	34°04′59 ″.9	47°58′00 ″.12
12	Holaylan	Saymareh	21-147	19977	33°42′31 ″.4	47°15′08 ″.20
13	Dartoot	Abchenareh	21-157	2579	33°45′00 ″.0	46°40′00 ″.12
14	Dehnoo	Harrood	21-167	279	33°31′00 ″.1	48°46′59 ″.88
15	Sazbon	Saymareh	21-159	26128	33°34′00 ″.1	46°51′00 ″.00
16	Kakareza	Harrood	21-169	1130	33°43′00 ″.1	48°16′00 ″.12
17	Sarab Saied Ali	Doab	21-171	786	33°48′00 ″.0	48°13′00 ″.12
18	Pol-e Kashkan	Kashkan	21-173	3670	33°30′00 ″.0	47°48′00 ″.00
19	Cham-e Anjir	Khorram Abad	21-175	1630	33°27′00 ″.0	48°13′59 ″.88
20	Afarineh-Kashkan	Kashkan	21-177	6842	33°19′59 ″.9	47°54′00 ″.00
21	Afarineh-Chalool	Chahlool	21-179	808	33°18′00 ″.0	47°52′59 ″.88
22	Baraftab	Madian-Rood	21-181	1132	33°19′00 ″.1	47°49′00 ″.12
23	Pol-e Dokhtar	Kashkan	21-183	9267	33°10′00 ″.1	47°43′00 ″.12
25	Jeloogir	Karkheh	21-185	38493	32°58′00 ″.1	47°48′00 ″.00
26	Polzal	Abzal	21-189	600	32°40′00 ″.1	48°04′59 ″.88
27	Paye Pol	Karkheh	21-191	42191	32°25′00 ″.1	48°09′00 ″.00
28	Nazarabad	Saymareh	21-411	28281	33°11′00 ″.0	47°26′00 ″.00

Runoff coefficient analysis utilized monthly and annual precipitation data. Precipitation is monitored by two organizations in Iran: the Metrological Organization of Iran (MOI) and the Water Office of the Ministry of Energy (MOE). As the data of the latter are distributed corresponding to hydrometric stations and at basin scale, the rain gauge data of the water office was used in this study. Table 1.4 shows the geographic coordinates and Figure 1.6 shows the locations of the rain gauge stations in the KRB.

Climate is an important factor in controlling water resources. The climate map used in this study (Figure 1.7) was a version prepared by Soil Conservation and Watershed Management Research Institute (SCWMRI). The KRB has a range of different climates based on SCWMRI

Table 1.3. Area (km^2)–elevation (m) classes (hypsometry) for selected hydrometric stations in the upper KRB.

Station code	Elevation class								
	Basin type	**0_500**	**500_1000**	**1000_1500**	**1500_2000**	**2000_2500**	**2500_3000**	**3000_3500**	**3500_4000**
21_107	Basin	0	0	0	475	238	34	13	0
21_109	Basin	0	0	4	599	179	63	21	0
21-111	Basin	0	0	0	129	85	5	0	0
21_113	Mid-basin	0	0	199	1261	271	40	3	0
21_115	Mid-basin	0	0	193	2339	1442	81	1	0
21_127	Basin	0	0	305	1195	561	112	9	0
21_131	Basin	0	0	771	631	30	1	0	0
21_133	Basin	0	0	748	448	86	4	0	0
21_141	Mid-basin	0	0	1155	884	219	46	5	0
21_143	Mid-basin	0	0	203	57	8	0	0	0
21_145	Basin	0	0	0	379	195	42	4	0
21_147	Mid-basin	0	24	1732	2396	543	30	4	0
21_157	Basin	0.0	4.5	12763.1	12 639.7	401.6	0.0	0.0	0.0
21-159	Mid-basin	0.0	4128.5	15129.1	9037.0	601.0	5.0	0.0	0.0
21_167	Basin	0	0	0	102	152	20	0	0
21_169	Mid-basin	0	0	0	531	272	58	5	0
21_171	Basin	0	0	0	413	203	117	50	2
21_173	Mid-basin	0	0	448	988	236	23	0	0
21_175	Basin	0	0	627	764	217	20	0	0
21_177	Mid-basin	0	94	989	359	81	18	0	0
21_179	Basin	0	35	274	358	129	13	0	0
21_181	Basin	0	16	908	208	0	0	0	0
21_183	Mid-basin	0	253	210	22	0	0	0	0
21_185	Mid-basin	31	657	154	97	6	0	0	0
21-189	Mid-basin	9	122	206	181	63	1	0	0
21-191	Mid-basin	1529	882	567	112	2	0	0	0
21_411	Mid-basin	0	816	1535	372	96	4	0	0

Table 1.4. Geographical coordinates of rain gauge stations in the upper KRB.

Row	Station code	Name	Latitude	Longitude	Elevation (m)
1	21-002	Khaneh (Peeranshahr)	36.7333	45.1333	1450
2	21-021	Sheelan (Lore Aval)	35.0833	46.9167	1330
3	21-051	Totshami Ggahvareh)	34.3667	46.3500	1553
4	21-095	Pole Jadeh Dehloran	32.7333	47.1500	220
5	21-109	Firoozabad (Gharb)	34.3500	48.1167	1450
6	21-111	Aghaganbolaghi	34.8333	48.0500	1710
7	21-113	Aran (Gharb)	34.4167	47.9167	1440
8	21-125	Bisotoon (Hydarabad)	34.4000	47.4500	1280
9	21-127	Pole chehr	34.3333	47.4333	1275
10	21-129	Mahidasht	34.2667	46.8000	1360
11	21-133	Doabe merek	34.5500	46.7833	1300
12	21-141	Pole kohneh	34.3167	47.1333	1260
13	21-143	Ghrbaghestan	34.2333	47.2500	1230
14	21-144	Sade dez	32.5500	48.4500	525
15	21-163	Tange siab	33.3833	47.2000	880
16	21-167	Dehno	33.5167	48.7833	1770
17	21-169	Kakareza	33.7167	48.2667	1530
18	21-171	Alashtar- Sarabe Sydali	33.8000	48.2167	1520
19	21-175	Cham anjeer	33.4500	48.2333	1140
20	21-177	Afarineh (Kashkan)	33.3333	47.9000	820
21	21-183	Poldokhtar (Kashkan)	33.1667	47.7167	650
22	21-185	Jeligeer	32.9667	47.8000	350
23	21-187	Cham gaz	32.9500	47.8167	380
24	21-189	Pole zal	32.8167	48.0833	300
25	21-191	Paye pol	32.4167	48.1500	90
26	21-243	Gotvand	32.2500	48.8167	100
27	21-259	Vanaee (Galeh Rood)	33.9000	48.5833	2000
28	21-271	Cham zaman	33.4000	49.4000	1830
29	21-275	Daretakht	33.3500	49.3833	1940
30	21-281	Cham cheet (Absabzeh)	33.3833	48.9833	1290
31	21-285	Sepeed dasht (Sezar)	33.2167	48.8833	970
32	21-289	Keshvar	33.1333	48.6333	770
33	21-293	Tangepanj (Bakhtiyari)	32.9333	48.7667	550
34	21-295	Talehzang	32.8167	48.7667	440
35	21-337	Tunele Ramesht	35.0167	46.9667	1390
36	21-393	Ravansar (Nahre Asli)	34.7167	46.6500	1320
37	21-526	Arakoocemalekshahee	33.3833	46.6000	1300
38	21-534	Varinehe Nahavand	34.0833	48.4000	1800
39	41-033	Josheeran (Khondan)	34.3833	49.1833	1650
40	41-040	Bale Sarugh	34.4167	49.5167	1800

reports: a wide range of arid to wet. Approximately 50% of the KRB area up to the dam site has an arid climate, which includes the lowest part of the upper KRB completely (Table 1.5). Wet and semi-wet climates cover 27% of the KRB area up to the dam. Areas of arid climate in the Saymareh sub-basin represent 18.3% of the KRB area up to the dam site. Thus, this sub-basin is drier than the other two sub-basins, namely the Kashkan and the mid-basin.

Raw data of discharge at hydrometric stations was used from SCWMRI reports on characteristics of basins in Iran. The data were checked and tested by conventional methods in the data processing stage in the SCWMRI reports, e.g. by using run test and double mass curve. Only 27 stations in the upper KRB had sufficient data and 78 stations did not. Figure 1.8 shows the geographical distribution and locations of the hydrometric stations in the upper KRB. Table 1.6 shows the main physiographic parameters of the hydrometric station basins in the KRB using DEM, slope, and aspect digital maps.
Regression analysis was used to fill missing data or for completion of time-series by selection of the stations with data for the whole period. Data of water years (Iranian calendar) of 1349–1350 (corresponding to 1970–1971) to 1378–1379 (corresponding to 1999–2000) was used for the analysis for time-series of discharge and precipitation (SCWMRI, 2006). Table 1.7 shows the regression relationships between hydrometric stations with missing data and the stations with complete data, as suggested by SCWMRI (2006). Time-series were completed using Table 1.7 formula and the observed data in the selected 27 stations. Data processing results were used to compute mean 30-year annual discharge (Table 1.8), which can be considered a consistent time-series for hydrologic components (SCWMRI, 2006).

1.2.3. Precipitation

Spatial distribution of mean annual precipitation for the upper KRB was needed to determine spatial distribution of runoff. This analysis was done based on the point mean annual precipitation obtained from the observed data. The 30-year mean annual precipitation was computed using monthly precipitation records of the Water Office of MOE (Tamab Company) and the results are shown in Table 1.9 for 40 rain gauge stations (SCWMRI, 2006). Figure 1.6 shows the distribution of the rain gauge stations used in spatial analysis of precipitation in KRB (Table 1.9).

Table 1.5. Areas of different types of climate in the three main sub-basins of the upper KRB.

Basin	Area (km^2)				Area (percent of whole KRB at dam)			
	Arid	Semi-arid	Wet and semi-wet	Total	Arid	Semi-arid	Wet and semi-wet	Total
Saymareh at Holylan	7756	4776	7445	19977	38.8	23.9	37.3	100
Kashkan at Pole Dokhtar	4599	2534	2134	9267	49.6	27.3	23.0	100
Mid-basin (lower part of upper KRB)	6779	4589	1579	12947	52.4	35.4	12.2	100
Total (at Pay-e Pol)	19026	11813	11352	42191	45.1	28.0	26.9	100

Table 1.6. Main physiographic parameters of hydrometric station basins in the KRB.

Hydrometric station	Code	Length of basin (km)	Elevation (m)			Slope of basin (%)	
			Min	Max	Mean	Max	Mean
Goosheh-saad	21-107	45.3	1511	2042	1977	124.1	14.5
Firooz Abad	21-109	48.9	1482	3556	1952	129.2	17.3
Aghjanbalghi	21-111	16.1	1607	2924	2002	85.7	16.1
Aran	21-113	61.4	1412	3411	1780	159.6	15.5
Doab	21-115	121.8	1401	3556	1895	159.9	15.1
PoleChehr	21-127	161.7	1275	3556	1891	336.7	17.3
KhersAbad	21-131	77.8	1322	2673	1527	105.5	8.7
DoabeMerek	21-133	46.0	1307	2707	1544	194.1	13.7
PoleKohneh	21-141	81.5	1292	3350	1567	276.2	14.2
GhorBaghestan	21-143	95.0	1278	3350	1562	276.2	14.1
Noor Abad	21-145	34.1	1778	3362	2043	217.0	16.8
Holilan (saimareh)	21-147	181.7	931	3556	1752	336.7	17.5
Dartoot	21-157	83	722	2641	1551	263.5	17.61
Sazbon	21-159	221.9	600	3556	1704	3367	12.4
Dehno	21-167	19.7	1742	2953	2135	138.1	19.6
KakaReza	21-169	71.8	1542	3559	2027	192.8	24.1
Bseid Ali	21-171	26.8	1511	3620	2104	218.8	27.4
Pole Kashkan	21-173	108.2	1001	3620	1887	218.8	25.2
Cham Anjir	21-175	51.6	1110	2808	1650	259.5	20.5
Afarineh	21-177	86.3	798	3620	1718	281.6	23.4
Afarineh	21-179	54.4	805	2935	1647	174.6	23.7
Bar Aftab	21-181	68.1	805	1985	1353	128.5	13.9
Pole Dokhtar	21-183	111.5	659	3620	1632	281.6	22.4
Jeloogir	21-185	242.5	390	3559	1418	336	14.3
Abzal	21-189	41.4	310	2731	1405	253	34.3
Paye Pol	21-191	312	97	3620	1544	336.7	19.27
Nazar Ababd	21-411	206.8	552	3620	1630	218.6	13.1

Figure 1.9 is the result of spatial analysis of annual precipitation in the region and shows the isohyets derived from a combination of geostatistical and regression analyses. Mean annual precipitation over every individual sub-basin was achieved by classifying isohyets (Figure 1.10), and shows that the KRB has a wide range of precipitation with a decreasing trend from north to west in general. However, there are spatial variations in different parts corresponding to mountainous belts such as the northeast and southwest (Figures 1.9 and 1.10). The mean annual precipitation for the three main sub-basins of the KRB varied from 490 to 556 mm (Table 1.10).

1.2.4. Modeling of runoff generation at regional scale

Regional analyses are used in peak discharge analysis by a number of researchers and are used widely for

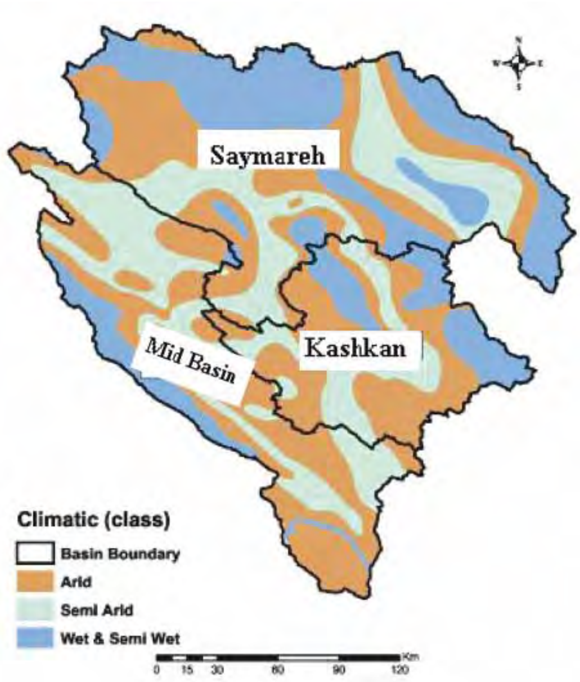

Figure 1.7. Climate map of different sub-basins of KRB (source: SCWMRI).

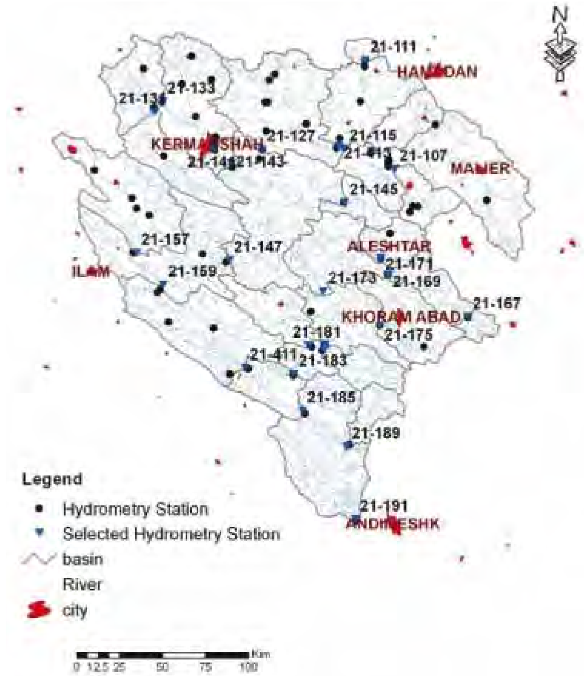

Figure 1.8. Geographical distribution of hydrometric stations in the upper KRB.

Table 1.7. Regression relationships between annual discharges of the stations lacking data with those with complete time-series.

Stations with insufficient data	Reference station	Regression relationship	Regression coefficient	No of data completed
Gooshe Saad	Doab-e Sayed Ali	y = 0.5645x – 0.99	7	0.83
Aghajanbolaghi	Pol-e Kohneh	y = 39.276x – 0.7256	11	0.85
West Aran	Gooshe Saad	y = 1.8109x – 1.4375	11	0.92
Khers Abad	Hamideyeh	y = 0.0115x – 0.2375	13	0.90
Pol-e Kohneh	Ghoorbaghestan	y = 0.9089x + 1.0972	5	0.99
Noorabad (West)	Jelougir (Mazhin)	y = 0.0174x + 0.9057	10	0.91
Dartoot	Polchehr	y = 0.1229x + 1.7929	15	0.88
Harrood (Dehnou)	Taleh Zang	y = 69.281x + 75.264	19	0.97
Kakarezal	Pol Dokhtar (Kashkan)	y = 0.2215x + 0.5514	2	0.90
Doab-e Sayed Ali	Afarineh (Kashkan)	y = 0.1323x + 2.0891	7	0.93
Pol Kashakan	Cham Anjir	y = 3.587x – 7.0367	18	0.95
Baraftab	Pol Dokhtar (Kashkan)	y = 0.0627x^0.8485	12	0.84
Pole Zal	Doab-e Sayed Ali	y = 1.5156x – 2.2827	8	0.82
Paye Pol	Hamideyeh	y = 1.0349x + 18.466	11	0.99
Abdolkhan	Payepol	y = 0.8603x + 15.541	9	0.86
Hamideyeh	Jelougir (Mazhin)	y = 1.1348x – 15.212	1	0.97
Ravansar (Asli)	Sazbon	y = 0.0183x + 0.32	0	0.88
Nazarabad Saymareh	Kakareza	y = 5.3837x + 36.9	7	0.73

Table 1.8. Mean 30-year annual discharge for the selected stations.

Row	Station	River	Station code	Area (km²)	Discharge (m³/s)
1	Gooshe-Saad	Ab-e Nahavand	21-107	778	3.5
2	Firoozabad	Toviserkan	21-109	869	1.9
3	Aghajanbolaghi	Shahab	21-111	520	0.6
4	West Aran	Khorram-Rood	21-113	2298	4.3
5	Doab	Gamasiab	21-115	8026	17.9
6	Polchehr	Gamasiab	21-127	10 208	36
7	Khersabad	Merek	21-131	1434	1.8
8	Doab-e Merek	Gharesoo	21-133	1294	6.7
9	Pol Kohneh	Gharesoo	21-141	5041	22.5
10	Ghoorbaghestan	Gharesoo	21-143	5309	24.1
11	Noorabad(West)	Badavar	21-145	621	3.9
12	Holaylan	Saymareh	21-147	19 977	81.3
13	Dartoot	Abchenareh	21-157	2579	6.2
14	Sazbon	Saymareh	21-159	26 128	94.6
15	Dehnoo	Harrood	21-167	279	2.9
16	Kakareza	Harrood	21-169	1130	12.7
17	Saied Ali	Doab	21-171	786	8.3
18	Pol-e Kashkan	Kashkan	21-173	3670	33.6
19	Cham-e Anjir	Khorram Abad	21-175	1630	11.5
20	Afarineh-Kashkan	Kashkan	21-177	6842	48.2
21	Afarineh-Chalool	Chahlool	21-179	808	4.1
22	Baraftab	Madian-Rood	21-181	1132	1.9
23	Pol-e Dokhtar	Kashkan	21-183	9267	55.9
24	Jeloogir	Karkheh	21-185	38 493	168.8
25	Polzal	Abzal	21-189	600	10.3
26	Paye Pol	Karkheh	21-191	42 191	203.2
27	Nazarabad	Saymareh	21-411	28 281	103.7

flood peak assessments in un-gauged catchments. Different methods of regional analysis have been suggested, with regression models considered the soundest of choices. Regression models use flood peaks as dependent parameters and the available physical and climatic parameters as the variables. Areas, shape factors, elevation components, and slopes are the physical parameters used in regional regression modeling; and precipitation, temperature, and water deficit are the main climatic parameters used.

Peak flow is an important index of floods and surface runoff from flooding. Regional analyses were carried out for peak flow analysis based on the physical and available climatic data. The area, the 30-year annual mean runoff, and precipitation were used as the independent variables in the present study, and the peak discharge was the dependent variable.

Table 1.9. Mean annual precipitation (mm) at rain gauge stations in the upper KRB.

Row	Station code	Station name	Annual precipitation (mm)
1	21-002	Khaneh (Peeranshahr)	542
2	21-021	Sheelan (Lore aval)	443
3	21-051	Totshami (Gahvareh)	693
4	21-095	Pole jadeh Dehloran	254
5	21-109	Firoozabad (Gharb)	357
6	21-111	Aghaganbolaghi	306
7	21-113	Aran (Gharb)	439
8	21-125	Bisotoon (Hydar Abad)	584
9	21-127	Pole Chehr	409
10	21-129	Mahidasht	352
11	21-133	Doabe Merek	489
12	21-141	Pole Kohneh	386
13	21-143	Ghrbaghestan	413
14	21-144	Sade dez	495
15	21-163	Tange siab	409
16	21-167	Dehno	452
17	21-169	Kakareza	464
18	21-171	Alashtar- Sarabe Sydali	518
19	21-175	Cham anjeer	484
20	21-177	Afarineh (Kashkan)	504
21	21-183	Poldokhtar (Kashkan)	421
22	21-185	Jeligeer	475
23	21-187	Cham Gaz	542
24	21-189	Pole Zal	427
25	21-191	Paye Pol	306
26	21-243	Gotvand	410
27	21-259	Vanaee (Galeh rood)	684
28	21-271	Cham Zaman	516
29	21-275	Dare Takht	800
30	21-281	Cham cheet (Absabzeh)	706
31	21-285	Sepeed Dasht (Sezar)	772
32	21-289	Keshvar	984
33	21-293	Tangepanj (Bakhtiyari)	1196
34	21-295	Talehzang	921
35	21-337	Tunele Ramesht	425
36	21-393	Ravansar (Nahre asli)	525
37	21-526	Arakooce Malekshahee	585
38	21-534	Varinehe Nahavand	515
39	41-033	Josheeran (Khondan)	280
40	41-040	Bale Sarugh	251

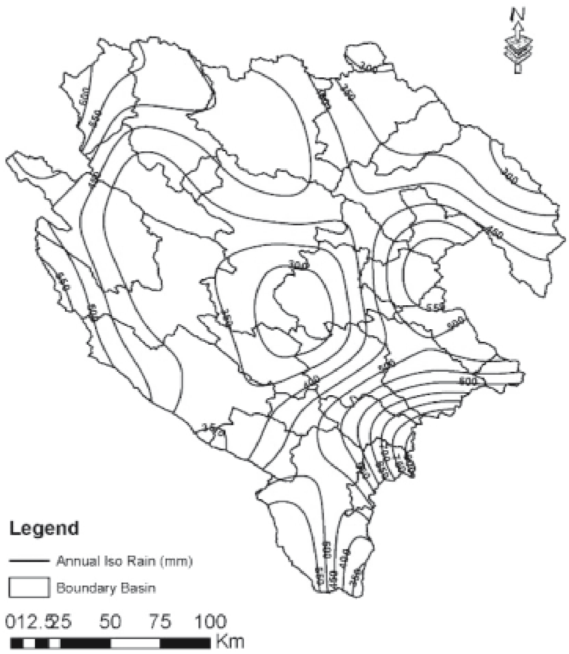

Figure 1.9. Isohyet map of the upper KRB.

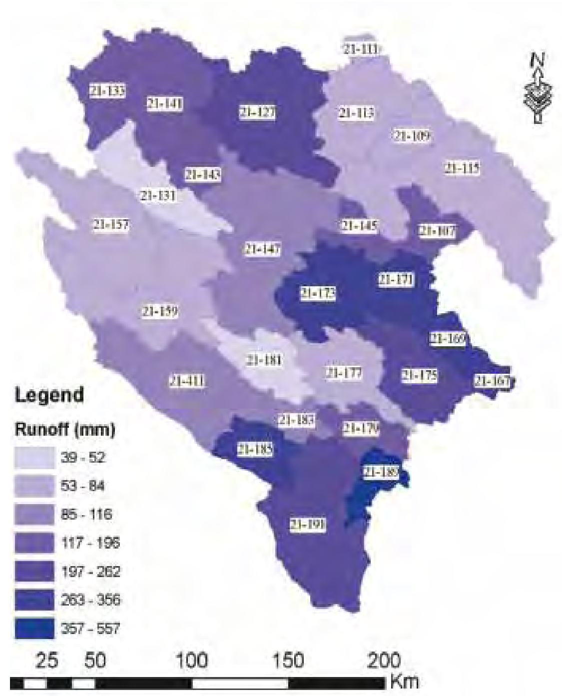

Figure 1.10. Sub-basins spatial distribution of mean annual runoff.

Table 1.10. Annual precipitation (mm) over the main sub-basins of the upper KRB.

Sub-basin	Minimum	Maximum	Mean
Kashkan at Pole Dokhtar	444	785	556
Saymareh at Holylan	359	627	484
Karkheh at Paye- Pole	262	731	453
Karkheh at dam	262	785	490

1.3. Results of runoff regional analysis

1.3.1. Runoff contribution of the sub-basins

Table 1.8 shows the 30-year mean annual flows for different tributaries in the upper KRB up to the dam site (Pay-e pol station is situated just a few kilometers downstream of the dam outlet and is considered the lowest point in the runoff analysis). In addition, Table 1.9 shows the 30-year mean annual precipitation for the different tributaries in the upper KRB.

The spatial mean annual discharge map and the corresponding spatial mean annual precipitation map were derived using mean annual data presented in the previous sections. Figure 1.10 shows the results as digital maps of mean annual runoff and precipitation depth for each sub-basin in the upper KRB, respectively.

Based on Figure 1.10 and Table 1.8 data, runoff discharge increases from the upper to lower parts, except in the upper Gamasiab basin where Sange Soorakh has less discharge relative to Goosheh Saad (situated in the lower part and

Table 1.11. Main parameters of sub-basins used in regional analysis and regression modeling of runoff.

Row	Station	River	Station code	Area (km^2)	Discharge (m^3/s)	Depth of runoff (mm)	Runoff volume (10^6 m^3)	Runoff coefficient (%)	Precipitation (mm)
1	Goosheh Saad	Ab-e Nahavand	21-107	778	3.5	142.4	110.7	36.3	392
2	Firoozabad	Toviserkan	21-109	869	1.9	67.6	58.7	14.8	457
3	Aghajanbolaghi	Shahab	21-111	520	0.6	35.5	18.4	7.3	489
4	West Aran	Khorram-Rood	21-113	2298	4.3	58.6	134.6	12.8	456
5	Doab	Gamasiab	21-115	8026	17.9	70.3	564.5	16.5	427
6	Polchehr	Gamasiab	21-127	10 208	36	111.2	1135.6	26	428
7	Khersabad	Merek	21-131	1434	1.8	39.2	56.2	6.4	613
8	Doab-e Merek	Gharesoo	21-133	1294	6.7	162.5	210.2	31.5	515
9	Pol Kohneh	Gharesoo	21-141	5041	22.5	140.7	709.4	23.8	592
10	Ghoorbaghestan	Gharesoo	21-143	5309	24.1	143.3	760.8	24.3	590
11	Noorabad (West)	Badavar	21-145	621	3.9	195.8	121.5	47.4	413
12	Holaylan	Saymareh	21-147	19 977	81.3	128.4	2564	27.1	474
13	Dartoot	Abchenareh	21-157	2579	6.2	75.6	195	12.3	616
14	Sazbon	Saymareh	21-159	26 128	94.6	114.2	2983	25.7	445
15	Dehnoo	Harrood	21-167	279	2.9	328.4	91.8	47.8	687
16	Kakareza	Harrood	21-169	1130	12.7	354	400	59	600
17	Saied Ali	Doab	21-171	786	8.3	331.7	260.8	69.1	480
18	Pol-e Kashkan	Kashkan	21-173	3670	33.6	288.9	1060.2	52.5	550
19	Cham-e Anjir	Khorram Abad	21-175	1630	11.5	222.9	363.3	33.6	663
20	Afarineh-Kashkan	Kashkan	21-177	6842	48.2	222.1	1519.8	37.3	596
21	Afarineh-Chalool	Chahlool	21-179	808	4.1	161.5	130.5	23.7	683
22	Baraftab	Madian-Rood	21-181	1132	1.9	52.3	59.3	8.9	589
23	Pol-e Dokhtar	Kashkan	21-183	9267	55.9	190.4	1764.1	31.5	604
24	Jeloogir	Karkheh	21-185	38 493	168.8	138.3	5323.6	25	553
25	Polzal	Abzal	21-189	600	10.3	541.5	324.9	81.1	667
26	Paye Pol	Karkheh	21-191	42 191	203.2	151.9	6407.9	27.2	558
27	Nazarabad	Saymareh	21-411	28 281	103.7	115.6	3270.6	21.6	536

drains Sange Soorakh). This anomaly is due to water consumption in the mid part between these two stations. A key value to compare runoff generation level of each catchment is the runoff depth instead of runoff discharge. The runoff depth was computed for each catchment or sub-basin from discharge and area in Table 1.8. Table 1.11 shows the depth of runoff and precipitation with other basin parameters used in regional analysis for each hydrologic unit. Runoff generation varied between 35.5 mm in Shahab catchment at Aghajanbolaghi station in the upper Gamasiab to 541.5 mm in Abzal catchment at Pol-e Zal station in the upper Kashkan River. The maximum runoff in the catchments is 15.3 times more than the minimum, and the minimum is 20% of the arithmetic mean of the 27 sub-basins. These results show a high variation in runoff generation in the upper KRB.

In addition, Table 1.11 shows the contribution of the main sub-basins in runoff generation. Overlaying Figures 1.9 and 1.10 shows the variation of mean annual precipitation and the corresponding basin runoff in different sub-basins from upper to lower parts of the KRB. The two main sub-basins of the upper KRB are Saymareh and Kashkan, which represent 69.3%, Table 1.8) of the upper KRB in both Saymareh at Holylan and Kashkan at Pol-e DokhtarTogether, Gamasiab and Gharesoo are the main upper sub-basins. The runoff depth at Ghoorbaghestan and Pol Chehr are, respectively, 143.3 mm and 111 mm, which shows that runoff generation in Gharehsoo is 1.3 times larger than in Gamasiab.

Khorramabad and the upper Kashkan are the main two sub-sub-basins of Kashkan sub-basin, with areas of 1630 and 6842 km^2 at Chamanjir and Afrineh, respectively, and both have similar runoff generation: 223 mm for Chamanjir and 222 mm for Afrineh. Thus, there is little difference in runoff generation between the main sub-sub-basins of Kashkan sub-basin (Table 1.8).

Kashkan and Saymareh have considerable difference in runoff generation. Kashkan at Pol-e Dokhtar has 16.5% and Symareh at Holylian has 40% of upper KRB runoff.

1.3.2. Modeling of runoff generation at regional scale

Mean annual runoff analysis

Mean annual runoff analysis was done by using physical and climatic parameters. Area, slope, and precipitation are the parameters used in regional analysis of mean sub-basin runoff. Table 1.12 shows the results of regional regression analysis of runoff depth. Correlation coefficients varied from 0.693 to 0.772 for different models. Runoff depth was more highly correlated with two parameters (precipitation and slope) compared to one parameter (slope). Slope, as a single variable, had the highest correlation relative to the other parameters (area and precipitation).

Table 1.12. Results of regional regression analysis of runoff.

Model	R	MAE*
Runoff = (11.809 × S) + (0.517 × P) – 284.23	0.772	60.96
Runoff = (15.455 × S) – 123.54	0.693	74.94
Karkheh at Paye- Pole	262	731
Karkheh at dam	262	785

Note: *MAE = mean absolute error, P = precipitation (mm), S = slope (%), R = regression coefficient, Runoff = mean annual runoff depth (mm)

Table 1.13. Regression models for runoff discharge and hydrological parameters.

Row	Regression relationship	Regression coefficient	No of samples
1	$Q = -14.78 + (0.00423 \times A) + (0.0299 \times P)$	0.99	27
2	$Q = (0.0042 \times A) + 1.69$	0.99	27
3	$Q = 0.0342 \times A^{0.76}$	0.85	27
4	$Q = 26.958Ln(A) - 170.4$	0.79	27
5	$Q = 5.4751e^{9E-05 \times A}$	0.83	27

Note: Q is runoff (stream flow; m^3/s), A is area (km^2), and P is precipitation (mm).

Table 1.13 shows regression models for runoff discharge (instead of runoff depth) and hydrologic parameters. Regression coefficients varied from 0.79 to 0.99 for different models. The highest correlations between different parameters were due to both the linear model with two variables (first row in Table 1.13), and the linear model with single variable (second row in Table 1.13). As precipitation has a key role in runoff generation and the two-variable model had the same regression coefficient as the single variable, the two-variable models for runoff depth and runoff discharge were selected as a regional model for un-gauged catchments in the KRB. The selected equations are as below, based on the two methods:

$$Rd = (11.809 \times S) + (0.517 \times P) - 284.23 \quad [1]$$

$$Q = -14.78 + (0.00423 \times A) + (0.0299 \times P) \quad [2]$$

Where, Rd is mean annual runoff depth (mm), Q is runoff discharge, P is mean annual precipitation (mm), S is slope (%), and A is the area of the basin (km^2). Equation (1) is for the condition in which mid sub-basin runoff depth is needed, and equation (2) is for when discharge of the whole basin is needed.

1.3.3. Regional peak flood analysis

Peak flood is an important index of floods, because it represents the maximum capacity of flood generation by events. Flood peak analysis has been done by SCWMRI in a project entitled 'Characteristics of Watersheds of Iran'.

The results showed that mean daily flood peaks and instantaneous peaks had a high interdependence and the daily peaks had a high correlation with 30-year mean annual discharge. The 30-year mean annual parameters are some available components used in the regional analysis and are consistent parameters. Figures 1.11 to 1.16 show the relationship of daily peaks to the 30-year mean annual discharge for 2, 5, 10, 25, 50, and 100-year return periods, respectively (SCWMRI). Table 1.14 shows different regression models for different return periods of the maximum daily discharge with the 30-year mean annual discharge. The regression coefficients ranged from 0.8 to 0.96 for the different models in the above return periods. For example, the exponential equation for 100-year return periods had the minimum regression coefficient but the linear equation of the two-year return period had the maximum coefficient. The best fitted model for each return period was selected based on the above criteria. For example, the selected model for the two-year return period is as below:

$$Q_m = 10.051 + 7.2853Q \quad [3]$$

Where, Q_m is maximum daily discharge with a return period of two years and Q is the 30-year mean annual discharge, both in m^3/s. The selected model for each return period is shown in Table 1.15 by a star notation.

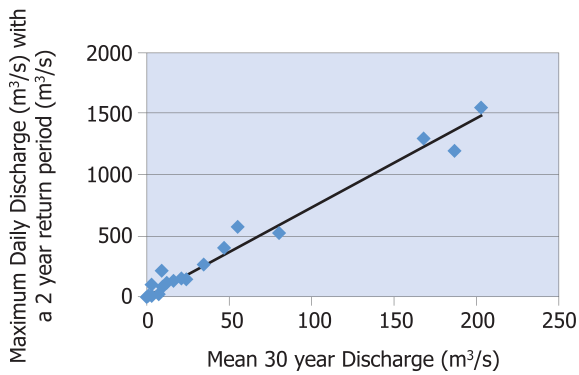

Figure 1.11. Regression relationship of maximum daily discharge with a two-year return period (m^3/s) to 30-year mean annual discharge.

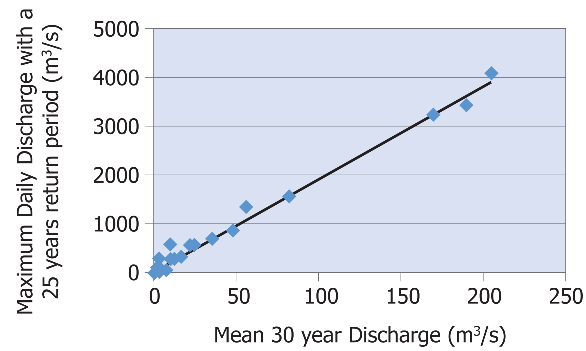

Figure 1.14. Regression relationship of maximum daily discharge with a 25-year return period to 30-year mean annual discharge.

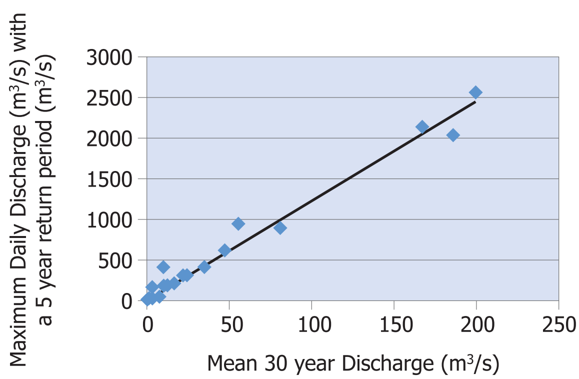

Figure 1.12. Regression relationship of maximum daily discharge with a five-year return period (m^3/s) to 30-year mean annual discharge.

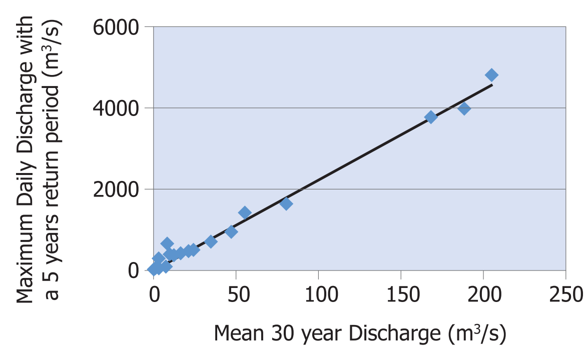

Figure 1.15. Regression relationship of maximum daily discharge with a 50-year return period to 30-year mean annual discharge.

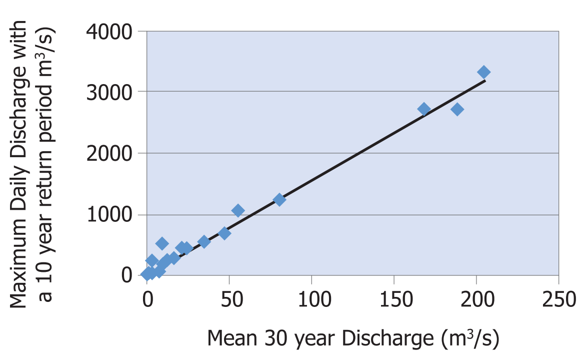

Figure 1.13. Regression relationship of maximum daily discharge with a 10-year return period to 30-year mean annual discharge.

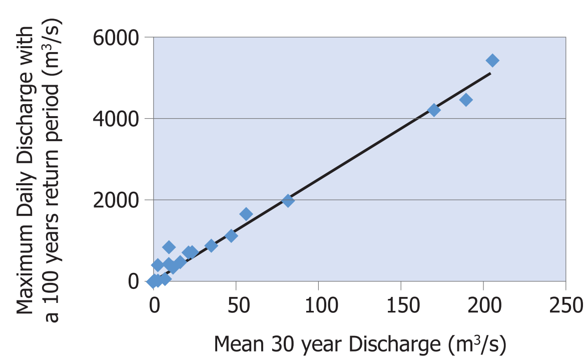

Figure 1.16. Regression relationship of maximum daily discharge with a 100-year return period to 30-year mean annual discharge.

Table 1.14. Regression models for different return periods of maximum daily discharge with 30-year mean annual discharge.

No of samples	Regression coefficient	Regression relationship	Return periods (year)
21	0.96	$Qm = 10.051 + 7.2853Q$*	
21	0.95	$Qm = 8.8833Q^{0.954}$	
21	0.85	$Qm = 62.538e^{0.018Q}$	
21	0.85	$Qm = 303.36Ln(Q) – 528.75$	2
21	0.96	$Qm = 11.543Q + 37.112$*	
21	0.95	$Qm = 15.85Q^{0.9386}$	
21	0.84	$Qm = 109.34e^{0.0175Q}$	
21	0.85	$Qm = 485.3Ln(Q) – 830.64$	5
21	0.95	$Qm = 14.408Q + 62.47$*	
21	0.94	$Qm = 20.923Q^{0.9322}$	
21	0.83	$Qm = 143.36e^{0.0172Q}$	
21	0.85	$Qm = 609.86Ln(Q) – 1033.1$	10
21	0.95	$Qm = 17.175Q + 92.392$*	
21	0.94	$Qm = 26.113Q^{0.9272}$	
21	0.82	$Qm = 178.12e^{0.017Q}$	
21	0.85	$Qm = 731.89Ln(Q) – 1228.4$	20
21	0.95	$Qm = 18.058Q + 103.04$*	
21	0.94	$Qm = 27.826Q^{0.9258}$	
21	0.82	$Qm = 189.57e^{0.017Q}$	
21	0.85	$Qm = 771.16Ln(Q) – 1290.7$	25
21	0.94	$Qm = 20.794Q + 139.37$*	
21	0.937	$Qm = 33.307Q0^{.9218}$	
21	0.81	$Qm = 226.2e^{0.0168Q}$	
21	0.85	$Qm = 893.98Ln(Q) – 1483.6$	50
21	0.94	$Qm = 23.546Q + 180.86$*	
21	0.93	$Qm = 39.067Q^{0.9182}$	
21	0.8	$Qm = 264.62e^{0.0166Q}$	
21	0.85	$Qm = 1019Ln(Q) – 1677.3$	100

Note: 1- Q_m is maximum daily discharge with a return period and Q is the mean 30-year annual discharge, both in m^3/s
2- * selected model for the region

Instantaneous peaks are closely related to maximum daily discharge; therefore, regression analysis was used for extracting equations in SCWMRI (2006). The analysis was based on peak components, obtained by statistical analysis of the observed instantaneous and maximum daily peaks for different return periods. Table 1.15 shows the regression models for different return periods of instantaneous flood peaks with maximum daily discharge. Maximum instantaneous peak flow for some hydrologic units in the KRB was estimated using Table 1.15 equations, and gave the results of estimated maximum daily

Table 1.15. Regression models for different return periods of instantaneous flood peaks with maximum daily discharge.

No of samples	Regression coefficient	Regression relationship	Return periods (years)
21	0.96	$Qp = 7.0101Q + 63.233$*	
21	0.92	$Qp = 13.224Q^{0.8882}$	
21	0.81	$Qp = 82.284e^{0.0165Q}$	
21	0.88	$Qp = 304.71Ln(Q) - 493.98$	2
21	0.94	$Qp = 11.4Q + 115.87$*	
21	0.92	$Qp = 23.014Q^{0.8798}$	
21	0.8	$Qp = 142.11e^{0.0162Q}$	
21	0.87	$Qp = 498.12Ln(Q) – 798.12$	5
21	0.93	$Qp = 14.55Q + 163.72$*	
21	0.92	$Qp = 30.861Q^{0.8737}$	
21	0.79	$Qp = 189.29e^{0.0159Q}$	
21	0.87	$Qp = 639.58Ln(Q) – 1014.4$	10
21	0.92	$Qp = 17.725Q + 219.78$*	
21	0.91	$Qp = 39.385Q^{0.8678}$	
21	0.78	$Qp = 239.99e^{0.0157Q}$	
21	0.86	$Qp = 784.17Ln(Q) – 1230.6$	20
21	0.92	$Qp = 18.762Q + 239.71$*	
21	0.91	$Qp = 42.295Q^{0.866}$	
21	0.78	$Qp = 257.19e^{0.0157Q}$	
21	0.86	$Qp = 831.85Ln(Q) – 1300.9$	25
21	0.91	$Qp = 22.051Q + 307.91$*	
21	0.91	$Qp = 51.901Q^{0.8606}$	
21	0.77	$Qp = 313.6e^{0.0155Q}$	
21	0.85	$Qp = 984.31Ln(Q) – 1522.9$	50
21	0.89	$Qp = 25.462Q + 386.24$*	
21	0.9	$Qp = 62.433Q^{0.8554}$	
21	0.76	$Qp = 374.91e^{0.0153Q}$	
21	0.85	$Qp = 1144.4Ln(Q) – 1751.5$	100

Note: 1- Qp is instantaneous with a return period and Q is the maximum daily discharge, both in m^3/s
2- * selected model for the region

Table 1.16. Estimated maximum daily discharge and instantaneous peaks based on 30-year mean annual discharge for third- and fourth-order upper KRB basins.

	Sub-basin	**Gharehsoo**	**Mid Saymareh**	**Kerend**	**Chardavel**	**Lower-Saymareh-1**	**Lower-Saymareh-2**	**Mid dam**	**Upper Saymareh**	**Kashkan**	**Upper Mid Dam**	**Mid Kashkan**	**Khoramabad**	**Lower Kashkan**	**Gamasiab**
Return period (year)	**Order of basin**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**3**	**3**	**3**	**4**	**4**	**4**	**4**
	Maximum daily	208	175	46	137	59	81	374	924	325	374	137	102	113	359
2	Instantaneous	254	222	98	185	110	131	413	942	366	413	185	151	162	399
	Maximum daily	351	299	95	238	114	149	613	1485	536	613	238	182	200	589
5	Instantaneous	426	375	173	314	192	227	685	1545	608	685	314	259	276	661
	Maximum daily	454	390	134	313	159	203	782	1869	685	782	313	244	265	752
10	Instantaneous	560	494	236	417	261	305	890	1988	792	890	417	347	369	860
	Maximum daily	560	482	178	391	207	259	950	2246	834	950	391	309	334	914
20	Instantaneous	702	622	308	528	338	392	1105	2442	985	1105	528	443	469	1068
	Maximum daily	594	513	193	417	224	279	1004	2368	883	1004	417	330	357	967
25	Instantaneous	750	666	333	566	365	422	1176	2592	1050	1176	566	476	504	1137
	Maximum daily	705	612	243	501	278	342	1177	2747	1037	1177	501	401	432	1134
50	Instantaneous	908	809	418	692	455	522	1409	3073	1260	1409	692	585	618	1363
	Maximum daily	821	716	298	591	338	410	1356	3134	1198	1356	591	477	512	1307
100	Instantaneous	1079	964	513	830	556	634	1657	3579	1486	1657	829	707	745	1604

discharge and instantaneous peaks based on 30-year mean annual discharge for these sub-basins in the upper KRB (Table 1.16).

1.4. Conclusion

Runoff analysis was considered for different time scales and places. Semi-spatial distribution of runoff was analyzed in different sizes and types of basins and in different types of climate. Runoff, as an index of depth of water in sub-basins, is needed for un-gauged basins which may have data of discharge or runoff in some part of the basin, i.e. some mid-basins that are not gauged. Peak flow is an important index of floods and was considered in the regional analysis of the present study. The results are as follows:

1. Runoff depth had a relatively high correlation with precipitation and slope; however, in single variable analysis, it showed a greater correlation with slope than precipitation. Although the first behavior is normal, the second needs more attention in future studies.
2. Runoff discharge in large basins had a high correlation with precipitation and area in multiple regression analysis, but only with area in single variable regression. This is normal behavior, because when area is the input for outflow as a single variable, as the basin gets larger, the contribution of the basin to outlet discharge increases proportionally to increasing area. Such behavior shows that regional analysis results could apply to the same regions, but to avoid omission of the role of major inputs – in this case precipitation – the small to medium sized basins should be considered in regional regression analysis.
3. Peak discharges show different behavior relative to time scale. Daily peak discharge was correlated with mean annual discharge, but instantaneous peak discharge was not. Finally, the instantaneous peak discharge was significantly correlated with daily peak discharge. Such behavior shows an interrelationship between time scales of runoff discharge in which, with increases in time base for outflow discharge, the stability of the relationship between mean discharges over period increased.

1.5. References

Jamab Co. 1999. Comprehensive Water Resources Plan of Iran Reports, Karkheh River Basin, Iran.Ministry of Energy.

Soil Conservation and Watershed Management Research Institute. 2006. Watershed Characteristics of Iran Reports, Iran.

Tamab Co. (Water Resources Basic Studies Office), Data bank of Water resources, Iran.

Chapter 2.

Groundwater in the Karkheh River Basin

Jahangir Porhemmat, Adriana Bruggeman and Pyman Daneshkar Arasteh

Chapter 2: Groundwater in the Karkheh River Basin

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2.1. Introduction

The Karkheh River Basin (KRB) is located within 30°49'–34°04'N and 46°06'–49°10'E in southwestern Iran (Figure 2.1). The basin is a second-order basin belonging to one of the six first-order basins of Iran, namely, the Persian Gulf Basin. The highlands of the KRB are part of the Zagros Mountain range that spreads over the north and northeastern to eastern areas of the basin, with gradual decreases in elevation in the western and southern directions. With its highest elevation at 3645 m above mean sea level, the KRB covers 51 806 km^2, which is 3.2% of Iran's total area, and has a perimeter of 1891 km. The area of the basin upstream of the Karkheh Dam is 42 191 km^2.

The main tributaries of the Karkheh River in the upper KRB are the Saymareh and Kashkan Rivers. The Saymareh River runs in the western part and is formed by the confluence of two smaller streams, the Gamasiab and Gharesoo Streams.

Study of hydrogeology and hydro-geochemistry of a basin groundwater is one of the first and important activities needed in a river basin water management program. In the present report, a brief summary of hydrogeology and groundwater quality is represented for the KRB. Alluvial and karstic aquifers and their geometrical and hydrological properties are described.

2.2. Methodology

According to Jamab (1999), there are 47 recognized 'study area' units within the KRB with hydrogeological study and geophysical measurements. These study areas were named by Jamab (1999) in all the plains, together with the corresponding surface hydrologic units. In effect, any such study area is a watershed or hydrologic unit. Table 2.1 shows those units and their area and codes. The area of the KRB plains is about 22 571 km^2, which covers the above 47 study units (Figure 2.1).

Following the launching of Livelihood Resilience project in the KRB, hydrogeological studies were started.

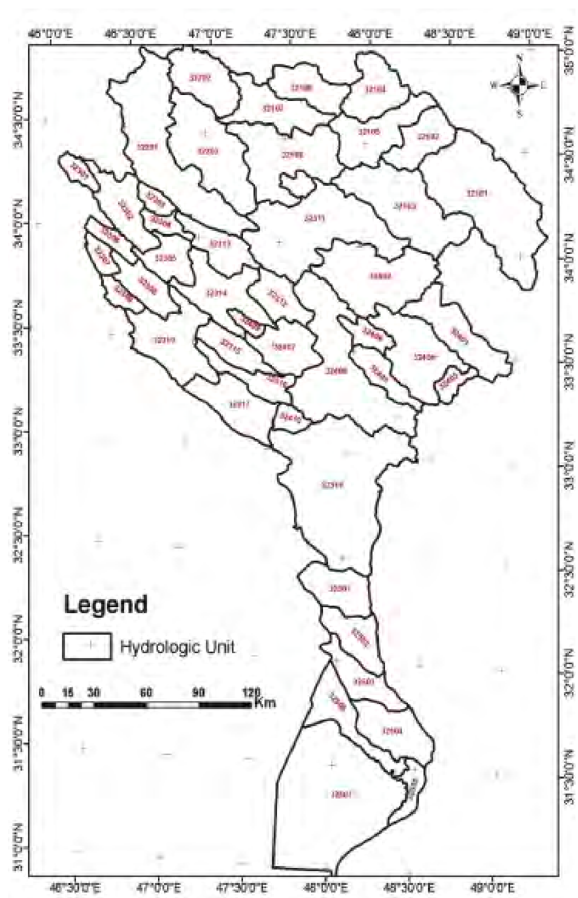

Figure 2.1. Groundwater study area in the KRB, with the study units and their codes.

Table 2.1. Hydrologic units within the KRB (Jamab Co. 1999).

Basin code	**Basin name**	**Area (km^2)**	**Basin code**	**Basin name**	**Area (km^2)**	**Basin code**	**Basin name**	**Area (km^2)**
32101	Malayer	1066	32305	Harsom	279	32403	Gilavand	108
32102	Tooyserkan	310	32306	Goavar	94	32404	Khoram Abad	524
32103	Nahavand	785	32307	Asman Abad	50	32405	Mahmoodvand	111
32104	Asad Abad	482	32308	Chardavol	138	32406	Sarab Doreh	118
32105	Kangavar	535	32309	Shirvan	41	32407	Koohdasht	593
32106	Songhor	357	32310	Badreh	70	32408	Kasmahoor	81
32107	Dinavar	229	32311	Delfan	454	32409	Takht Ab	562
32108	Sahneh-Bistoon	656	32312	Hoomian-Dayali	236	32410	Pol Dokhtar	113
32109	Harsin	71	32313	Talan-Jalalvand	153	32501	Dasht-e-Abbas Evan	499
32201	Mahidasht-Sanjabi	1463	32314	Holeylan	467	32502	Dosalagh	497
32202	Kamyaran-Bilehvar	356	32315	Tarhan	216	32503	Arayez	506
32203	Kermanshah	984	32316	Romishgan-Tang Siab	228	32504	Bagheh-Khosraj-Namarcheh	907
32301	Kerend	89	32317	Dareh Shahr	243	32505	Hamidiah-Dob-e-Hardan	340
32302	Eslam Abad	562	32318	Moolab	946	32506	Ghods	814
32303	Hasan Abad	116	32401	Chogholvandi	423	32507	Azadegan-Hoveyzeh	4073
32304	Ghaleh Shian	115	32402	Alashtar	511	Sum	KRB	22571

Table 2.2. Geometric and hydraulic properties of the KRB unconfined aquifers.

Study area code	Area (km²)	Aquifer thickness (m)		Groundwater depth (m)			Transmissivity (m²/d)		Storativity (%)		
		Max	Mean	Min	Max	Mean	Min	Max	Min	Max	Mean
32101	600	170	-	2	63	-	450	4000	1.9	6.5	3
32102	221	100	20	3	42	12	200	2000	4	6	6
32103	643	300	50	5	30	-	335	885	0.9	1.5	1
32104	300	170	50	3	40	10	400	2658	0.7	3.6	2.2
32105	210	250	-	2	28	-	100	1500	-	-	-
32106	250	42	-	1	8	-	-	-	-	-	-
32107	450	174	-	1	-	-	-	-	-	-	-
32108	600	300	70	1	27	-	500	1500	2	5	-
32109	60	60	20	0	20	-	100	200	3	-	5
32201	1000	250	-	0	18	-	100	1350	0.06	3	-
32202	300	200	-	1	50	-	100	2000	-	-	-
32203	750	240	-	1	32	-	150	1300	0.03	1.8	-
32301	70	60	-	0	-	-	-	-	-	-	-
32302	350	190	-	1	26	-	80	950	4	8	6
32303	80	257	-	-	28	-	100	430	2	10	4
32304	85	62	36	18	45	-	500	650	0.16	5	3
32305	90	-	-	0	15	-	-	-	-	-	-
32306	30	20	10	-	-	-	-	-	-	-	-
32307	40	80	40	1	41	14	-	-	-	-	-
32308	67	15	5	1	10	-	-	-	-	-	-
32309	15	15	5	1	10	-	-	-	-	-	-
32310	20	20	10	1	10	-	-	-	-	-	-
32311	225	300	50	1	30	-	-	-	5	8	-
32312	50	-	-	-	-	-	-	-	-	-	-
32313	60	100	-	1	10	-	-	-	-	-	-
32314	178	200	60	1	39	16	-	-	-	-	-
32315	80	200	-	1	10	-	-	-	-	-	-
32316	140	150	-	1	10	-	-	-	-	-	-
32317	140	80	50	2	30	7	-	-	-	-	-
32318	150	15	-	-	-	-	-	-	-	-	-
32401	105	80	-	1	18	-	150	600	5	7	-
32402	196	150	-	2	10	-	500	1560	1	10	-
32403	50	-	-	0	10	-	-	-	-	-	-
32404	137	150	-	2	22	-	-	-	5	9	-
32405	40	-	-	-	-	-	-	-	-	-	-
32406	40	-	-	-	-	-	-	-	-	-	-

Table 2.2. (Continued).

Study area code	Area (km²)	Aquifer thickness (m)		Groundwater depth (m)			Transmissivity (m²/d)		Storativity (%)		
		Max	Mean	Min	Max	Mean	Min	Max	Min	Max	Mean
32407	215	300	-	1	18	-	-	-	-	-	-
32408	15	200	-	5	20	-	-	-	-	-	-
32409	100	-	-	-	-	-	-	-	-	-	-
32410	100	100	-	-	43	-	-	-	-	-	-
32501	250	280	100	7	42	20	100	2800	0.12	2.6	-
32502	490	175	-	3	16	9	250	1500	-	-	-
32503	100	150	-	1	26	15	-	-	-	-	-
32504	80	100	20	5	29	14	-	-	-	-	-
32505	75	100	-	2	15	5	-	-	-	-	-
32506	70	70	50	0	12	7	3	719	-	-	-
32507	65	80	-	0	10	5	-	-	-	-	-
All	9382	300	-	0	63	-	3	4000	0.03	10	-

For this purpose, many reports and data were gathered and reviewed, of which the Comprehensive Water Plan prepared by Jamab (1999) was the most complete and accordingly much of our information needs were taken from this document.

Study of the hydrogeology of the KRB included groundwater resources, especially aquifers (both alluvial and karstic), springs, and qanats as well as all water uses in different sectors. In order to prepare a general water balance for the basin, aquifers (alluvial and karstic), groundwater exploitation, groundwater usage, groundwater balance, and groundwater quality were considered in the different hydrologic units. Finally, based on the available data, a water balance overview of the KRB was prepared, which presents a schematic sketch of groundwater resources and uses in the basin.

2.3. Groundwater characteristics

2.3.1. Aquifers

There are more than 9382 km² of unconfined aquifers within the 47 study areas, but the area of the confined aquifers is unknown. Area of the aquifers increases southward, but aquifer thickness and transmissivity decreases. Groundwater quality of northern part of the KRB is better than in the southern part. Aquifer thickness varies from 300 to 15 m southwards. The highest aquifer transmissivity is about 2000 m²/d for the study areas 1, 2, 4, 11, and 41. Table 2.2 shows the geometric and hydraulic properties of the 47 unconfined aquifers of the KRB, among which, groundwater elevation isopiece maps and unit hydrographs of water table fluctuations are provided for only 15 aquifers. There are 411 springs with an annual discharge of about 59 Mm³ in these unconfined aquifers.

2.3.2. Hard formations

The area of hard formations in the KRB is about 28 193 km^2, 36% of which is covered by karsts. There are more than 2335 karstic springs in the KRB with a total annual discharge of 1815 Mm^3. Table 2.3 summarizes the characteristics of some of these springs and Table 2.4 shows the properties of the wells dug in the hard formations.

2.3.3. Groundwater exploitation

There are 16 057 groundwater abstraction sources in KRB with an annual water production of about 3.778 Bm^3. Among these resources, 11 901 wells discharge a total amount of 1.581Bm^3. Table 2.5 shows discharges of different types of groundwater sources in KRB. There are 1410 qanats and 2746 springs with annual discharges of 0.17 and 1.874 Bm^3, respectively.

2.3.4. Groundwater usage

The annual demand for groundwater in KRB is about 1.657 Bm^3 with agricultural needs consuming 87.6% of this total. Table 2.6 shows the water demands and requirements in agriculture, industry, and domestic divisions.

2.3.5. Groundwater balance

Groundwater balance components (Table 2.7) were determined according to the hydro-climatological water balance method (Figure 2.2).

2.3.6. Groundwater quality

Groundwater quality is very variable in the KRB. Table 2.8 shows the results of primary analysis of the groundwater samples. Quality classifications of groundwater for agricultural and domestic uses are shown in Tables 2.9 and 2.10, respectively.

2.4. References

Jamab. 1999. Comprehensive Water Resources Plan of Iran, Karkheh River Basin Reports.

Table 2.3. Karstic spring properties in the KRB.

No	Study area code	Cl− (ppm)	EC (μmhos/cm)	Flow rate (L/s)			Annual discharge (Mm^3)
				Min	Max	Mean	
1	32105	11	370	530	1905	852	26.8
2	32105	7	295	121	1108	462	14.5
3	32105	7	322	742	2275	1492	47
4	32105	10	205	52	426	129	4
5	32106	6	267	92	4311	683	21.5
6	32106	16	484	35	340	64	20
7	32108	7	336	42	552	164	5.2
8	32108	8	430	20	1464	231	7.3
9	32108	8	318	15	305	106	3.3
10	32108	7	344	5	11416	1357	42.8
11	32108	7	335	20	15345	2644	79.9
12	32108	7	203	32	4886	796	25.1
13	32108	14	307	39	217	115	3.6
14	32108	25	448	49	1710	168	5.3
15	32109	32	526	362	4545	1120	35.3
16	32201	9	497	133	271	263	8.2
17	32201	7	679	188	917	499	15.7
18	32201	7	345	141	325	235	7.4
19	32201	5	332	480	7623	2586	81.5
20	32201	5	452	131	208	167	5.3
21	32202	5	382	20	850	154	4.8
22	32202	5	450	8	473	102	3.2
23	32202	6	261	58	1425	409	12.9
24	32202	12	567	60	321	133	4.2
25	32203	25	689	673	1450	960	30.3
26	32203	3	280	124	577	274	11.8
27	32203	2	270	82	4238	950	29.9
28	32203	6	375	204	1206	429	13.5
29	32203	3	357	68	829	213	6.7
30	32203	5	365	8	1548	298	9.3
31	32203	5	234	22	7265	1495	47.1
32	32203	7	364	53	2650	592	18.7
33	32203	21	340	134	1254	531	16.7
34	32301	7	427	3	604	151	4.7
35	32301	7	450	3	75	22	7
36	32302	7	489	94	378	198	6.2
37	32302	9	59	108	432	202	6.2
38	32302	11	280	321	925	578	18.2
39	32304	14	700	282	912	525	16.8
40	32304	28	715	15	124	55	1.7

Table 2.3. (Continued).

No	Study area code	Cl– (ppm)	EC (μmhos/cm)	Flow rate (L/s)			Annual discharge (Mm^3)
				Min	Max	Mean	
41	32304	22	600	39	132	66	2.1
42	32304	21	723	92	321	128	4
43	32317	12	419	504	402	444	10.8
44	32317	12	368	906	3100	1606	50.6
45	32317	16	457	18	600	162	151
46	32404	1	576	362	936	600	19
47	32404	1	591	634	1857	1195	27.2
48	32404	1	456	6	614	234	5.2
49	32404	3	785	673	2308	1307	40.6
50	32404	1	399	50	2422	886	27.5
51	32501	1	446	177	540	352	10.1
52	32501	1908	6258	199	570	344	10.8
53	32501	11	413	504	1950	926	29.2

Table 2.4. Properties of wells in the hard formations of the KRB.

No	Study area code	Type of well		Type of consumption	Flow rate (L/s)
		Exploring	Exploiting		
1	32201	*		Drinking	60
2	32203		*	Drinking	25
3	32203	*			
4	32203	*			
5	32308		*	Drinking	50
6	32309		*		13
7	32309	*			
8	32309		*	Drinking	
9	32309		*	Drinking	40
10	32309		*		12
11	32309		*	Drinking	50
12	32309	*			
13	32309		*	Drinking-Industrial	60
14	32309		*		
15	32310		*		
16	32410	*			
17	32410		*		48
18	32410		*		45
19	32410	*			
20	32410		*		50
21	32501		*		

Table 2.5. Groundwater uses in the KRB.

Study Area No	Wells				Qanats				Springs												Total discharge (10^6 m^3)
									Hard formations								Alluvial				
									Highlands				Lowlands								
	No	Discharge (L/s)		Annual discharge (10^6 m^3)	No	Discharge (L/s)		Annual discharge (10^6 m^3)	No	Discharge (L/s)		Annual discharge (10^6 m^3)	No	Discharge (L/s)		Annual discharge (10^6 m^3)	No	Discharge (L/s)		Annual discharge (10^6 m^3)	
		Mean	Max			Mean	Max			Mean	Max			Mean	Max			Mean	Max		
32101	1293	20	120	259	640	8.3	264	167.5	744	2.9	40	68					11	2.2	6	0.7	495.2
32102	999	16.5	60	76.6	254	5.6	80	44.5	396	2	18	37.4	5	3.4	4	0.5	23	2.7	5	2	160.9
32103	574	34.5	83	81.4	141	12.7	110	56.4					88	80	1420	221.2	122	2		9.7	467.8
32104	1349	20	120	194.1	55	12	38	20.9					157	10	324	49.6					464.6
32105	1501	13	76	77.1	27	14.2	71	12.1	37	44	7275	51.3	23	29	1105	23.3	9	2.7	6	0.8	164.6
32106	240	8.6	56	21.5	39	5.2	55	6.4	25	24.7	566	19.5	41	6.1	85	7.9	21	6.8	22	6.6	61.9
32107	349	13.6	90	33.7	25	7.5	72	5.9	15	3.8	12	1.8	40	5.8	30	7.3	1	2		0.1	48.8
32108	932	12.8	54	76.2	35	9.2	65	10.1	35	81	2534	89.4	53	55	1257	91.9	14	6.5	25	2.9	270.5
32109	78	25.3		5									1	900		28.1					32.4
32201	847	18.4	100	96.6	40	4.5	42	5.7	50	8.9	371	14	60	50	7623	94.4	85	4.6	200	12.3	223.1
32202	212	12.2	56	17.1	36	8.8	31	10	4	6.5	25	0.8	59	10	411	18.6	42	5.5	162	7.3	52.8
32203	1411	16.5	65	162.6	71	4.5	230	10	16	1.1	2	0.6	41	142	7365	183.6	39	2.8	65	3.4	360.2
32301	16	21	40	1.4	1	4.8	7	0.1					4	63	435	7.9					9.5
32302	254	20	47	39.5	3	4.7	11	0.4	4	5		0.6	31	53	925	51.8	4	4	19	0.5	92.9
32303	73	11	26	6	5	14.5	31	2.3									1	1.3	2	0.1	8.2
32304	40	31	48	9.6	2	2.7	8	0.3	2	249	682	23.5	3	19	55	1.8	4	0.7	1	0.9	36.1
32305	18	19		2.5													3	2.8		0.3	2.8
32307	70	20	46	2.7					5	93		14.6									17.2
32308	53			9.9	1	29		0.9	42	25	600	33									42.8
32309	5	35	60	1					12	15.7	50	5.9									6.9
32310									5	82.4	400	13									12
32311	85	11	50	7.6	11	16	43	5.5	89	26	40	72.9									86
32313					4	3	5	0.4	2	1.3	2	0.1									0.5

Table 2.5. (Continued).

Study Area No	Wells				Qanats				Springs												Total discharge (10^6 m^3)
									Hard formations								Alluvial				
									Highlands				Lowlands								
	No	Discharge (L/s)		Annual discharge (10^6 m^3)	No	Discharge (L/s)		Annual discharge (10^6 m^3)	No	Discharge (L/s)		Annual discharge (10^6 m^3)	No	Discharge (L/s)		Annual discharge (10^6 m^3)	No	Discharge (L/s)		Annual discharge (10^6 m^3)	
		Mean	Max			Mean	Max			Mean	Max			Mean	Max			Mean	Max		
32314	30	20	40	3	2	10.5	25	0.7	2	2.2	6	0.2									2.9
32315	36	7.3	10	1.7	8	6	8	0.7	12	17.8	74	6.7									9.12
32316	131	15	126	14.1					1	6.5		0.2									14.3
32317	22	28	54	8.3					2	634	2650	40	2	884	3600	55.8					104.1
32318									11	46		16					6	46		9.7	24.7
32401	28	24.2	54	4.2	2	36	60	2.3	115	26	237	94.2					5	26		4.1	104.7
32402	122	19.6	85	10.9	1	25		0.8	58	132	920	241.4									253.1
32403																					
32404	204	17	80	27.9	4	45	87	5.6					23	107	821	77.6					111.1
32407	243	23	60	28.8	1	20	82	0.6	18	1.5	35	0.8									30.2
32408					1	1		0.1					1	1		0.1					0.6
32409																					
32410	64	17	60	7.5																	7.5
32501	230	44	88	116.5																	116.5
32502	173	41	88	76.6																	76.6
Total	11901	18.4	126	1580.7	1410	8.4	264	370.3	1703	15.8	7275	845.9	632	46.5	7623	921.9	411	4.5	200	59.3	3778

Table 2.6. Groundwater demands in the KRB (10^6 m^3).

Study area code	Domestic	Industry	Agriculture	Total
32101	16.9	1.3	280	298.2
32102	4.9	0.1	100	105
32103	6.1	0.1	210	216.2
32104	7.1	0.1	150	157.2
32105	7.5	0.4	76	83.9
32106	4.2	0	24	28.2
32107	1.3	0	38	39.3
32108	5.5	2.4	80	87.9
32109	5.2	0	1	6.2
32201	4.4	0.1	95	99.5
32202	4.4	0	23	27.4
32203	60.6	4.5	103	168.1
32301	1	0	1	2
32302	7.9	2.2	30	40.1
32303	0.3	0	5	5.3
32304	0.5	0	10	10.5
32305	0.5	0	2	2.5
32306	0.1	0	0	0.1
32307	0.8	0	1.5	2.3
32308	0.7	0	9	9.7
32309	0.1	0	0	0.1
32310	0.3	0	0	0.3
32311	3.2	0	10	13.2
32312	0.1	0	0	0.1
32313	0.2	0	0	0.2
32314	0.3	0	3	3.3
32315	0.1	0	2	2.1
32316	0.6	0	13	13.6
32317	2.7	0	5	7.7
32318	0.8	0	4	4.8
32401	0.9	0	5.5	6.4
32402	4	0	7	11
32403	0.3	0	0	0.3
32404	29.9	0.9	0	30.8
32405	0.4	0	0	0.4
32406	0.2	0	0	0.2
32407	6.1	0	22	28.1
32408	0.1	0	0	0.1

Table 2.6. (Continued).

Study area code	Domestic	Industry	Agriculture	Total
32409	0.9	0	0	0.9
32410	2	0	5.5	7.5
32501	0	0	93	93
32502	0	0	43	43
32503	0	0.2	0	0.2
32504	0	0	0	0
32505	0.1	0	0	0.1
32506	0.1	0	0	0.1
32507	0.1	0	0	0.1
Total	193.6	12.1	1451.5	1657.1

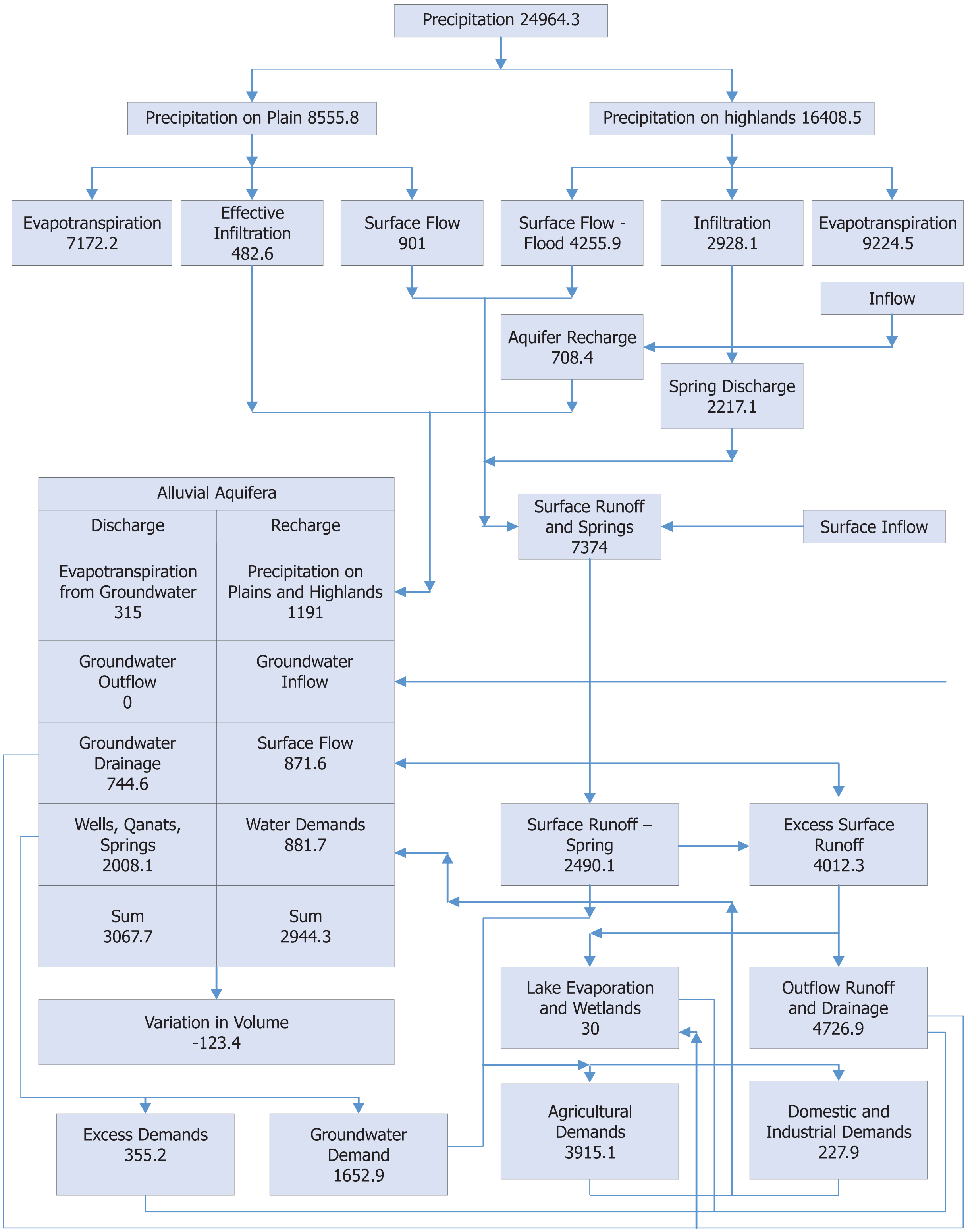

Figure 2.2. Hydro-climatological water balance of the KRB (10^6 m^3).

Table 2.7. Groundwater balance components in the KRB (10^6 m^3).

Study area code	Hard formation reservoirs						Alluvial aquifers														
	Recharge		Discharge				Recharge							Variation in storage							Variation in storage
	Adjacent basins	Infiltration in highlands	Springs	Wells and qanats	Flow to alluvial aquifers	Unknown	Inflow: Adjacent plains	Inflow: Highlands	Precipitation on plains	Surface flow	Irrigation	Waste water	Total	Wells	Qanats	Springs	Drainages	Evaporation	Outflow	Total	
32101		222.2	68	0	150	4.3	0	150	56.3	52.3	89.9	13.1	361.6	259	167.5	0.8	2.4	1	0	431.7	-70.1
32102		77.2	37.9	0	28	1.2	0	38	19	26.4	38.5	1.2	123.1	76.6	44.5	2	7	1	0	131.1	-8
32103		342.8	221.2	0	2	86.5	0	25	56.2	86.2	79.4	4.6	261.4	181.4	56.4	8.7	9.9	5	0	261.4	0
32104	40	75.3	49.6	0	65	0.7	0	65	40.9	25.2	48.9	6.5	186.5	194.1	20.9	0	5	2	0	222	-25.5
32105		104.4	74.6	0	24	5.8	0	24	26.9	20.4	27.4	1.6	100.3	77.1	12.1	0.8	6.8	3	0	101.6	-1.3
32106		53.4	27.4	0	14	12	0	14	14.7	8.6	14.8	1.1	53.2	21.5	6.4	6.6	12.7	6	0	53.2	0
32107		56.7	9.1	0	17	30.6	0	17	7.4	17.4	22.5	0.5	64.8	22.7	5.9	0.1	18.1	7	0	64.8	0
32108		231.7	181.3	0	30	20.4	0	30	19.3	36.2	36.6	1.9	124	76.2	10.1	2.9	29.8	5	0	124	0
32109	9	25.1	28.4	0	4	0.7	0	4	2	4	5.7	1.2	17	5.1	0	0	7.9	4	0	17	0
32201		168.8	108.4	1	50	9.4	0	50	51.3	28.7	22.1	1.1	153.2	95.6	5.7	12.3	11.6	21	7	153.2	0
32202		43.5	19.4	0	9	15.1	0	9	14.2	12.4	22.1	0.7	59.4	17.1	10	7.3	15	10	0	59.4	0
32203	90	128.9	184.2	0.1	24	0.6	7	24	36.6	89.7	25.3	14.4	207	162.5	10	2.4	18.1	12	0	207	0
32301		21.1	8	0	2	10.1	0	3	2.8	2.1	1.9	0.2	10	1.4	0.2	0	7.4	1	0	10	0
32302		73.3	52.8	0	20	0.9	0	20	14.1	11.6	15	2.1	62.8	29.5	0.4	0.5	12.4	10	0	62.8	0
32303		6.4		0	5	1.4	0	5	3	2.9	1.1	0.1	12.1	6	2.3	0	2.8	1	0	12.1	0
32304		28.4	25.3	0	2	0.1	0	3	2.4	4.2	5.3	0.2	15.1	9.6	0.4	0.9	2.2	1	0	15.1	0
32305		15.3		0	4	11.3	0	4	4.7	4.7	2.4	0.2	16	2.5	0	0.3	8.2	5	0	16	0
32306		13.4		0	2	10.4	0	3	2.7	1.4	0.5	0.1	7.7	0	0	0	5.7	2	0	7.7	0
32307		19.6	14.6	0	2	2	0	2	1.3	1.4	0.2	0.2	5.2	2.7	0	0	1.5	1	0	5.2	0
32308		57.1	23	0.5	10	13.6	0	10	4.3	10.3	8.3	0.4	23.3	9.4	0.9	0	8	15	0	23.3	0
32309		25.2	5.9	1	5	12.3	0	5	1.5	0.6	1.2	0	8.2	0	0	0	5.3	3	0	8.3	0
32310		61.9	13	0	4	44.9	0	4	1	21.6	2.9	0.1	29.6	0	0	0	36.6	3	0	29.6	0
32311		169.9	72.9	0	10	87	0	10	9.8	24.2	23	0.7	67.7	7.6	5.6	0	44.5	10	0	67.7	0
32312		16.6		0	8	8.6	0	8	2.8	25.4	1.6	0	27.8	0	0	0	32.8	5	0	27.8	0
32313		11.7	0.1	0	2	9.6	0	2	1.8	1.4	1.4	0.1	6.7	0	0.4	0	4.3	2	0	6.7	0
32314		32.5	0.2	0	7	25.3	0	7	5.4	26.6	5.1	0.1	44.2	2.1	0.7	0	30.4	10	0	44.2	0
32315		17.5	6.7	0	6	4.8	0	6	2.7	2.8	1.6	0.1	13.2	1.7	0.7	0	6.8	4	0	13.2	0
32316		12.6	0.2	0	7	5.4	0	7	3.1	4.8	2.5	0.2	18.6	14.1	0	0	2.5	1	0	18.6	0
32317	25	79.5	95.8	0	6	2.7	0	6	5.1	25.4	10.6	1.6	58.7	8.2	0	0	24.4	16	0	58.7	0
32318		96.3	16	0	5	75.3	0	5	4.3	61.7	2.9	0.2	75.2	0	0	8.7	65.5	1	0	75.2	0
32401		112.5	94.2	0	17	2.3	0	17	8	9	20.1	0.4	54.5	4.2	2.3	4.1	25.9	18	0	54.5	0
32402		266.7	241.4	0	18	7.3	0	18	9.3	8.9	26.4	2.5	65.1	10.9	0.8	0	40.4	13	0	65.1	0
32403		10.4		0	4	6.4	0	4	2.4	1.6	3.2	0.1	11.2	0	0	0	10.3	1	0	11.3	0
32404		98.1	77.6	0	20	0.5	0	20	8.8	18.6	27.2	2.9	78.5	27.9	5.6	0	31	14	0	78.5	0
32405		18.1		0	5	12.1	0	5	1.5	2.7	2.3	0.2	12.7	0	0	0	9.7	2	0	12.7	0
32406		22.5	0.9	0	10	12.5	0	10	1.5	0.9	1.8	0.1	14.3	0	0	0	9.2	5	0	14.3	0
32407		14.6	0.1	0	9	4.7	0	9	6.7	9.2	14	4	42.9	28.8	0.6	0	8.5	5	0	42.9	0

Table 2.7. (Continued).

Study area code	**Hard formation reservoirs**						**Alluvial aquifers**														
	Recharge		Discharge				Recharge							Variation in storage							Variation in storage
	Adjacent basins	Infiltration in highlands	Springs	Wells and qanats	Flow to alluvial aquifers	Unknown	Inflow		Precipitation on plains	Surface flow	Irrigation	Waste water	Total	Wells	Qanats	Springs	Drainages	Evaporation	Outflow	Total	
							Adjacent plains	Highlands													
32408		2.5		0	2	0.4	0	2	1	1.6	0.5	0	5.1	0	0.1	0	4	1	0	5.1	0
32409		39.1		0	2	36.1	0	2	2.5	17.4	2.4	0.4	24.7	0	0	0	23.7	1	0	24.7	0
32410		12.1		0	5	8.1	0	5	1	17.3	6.3	1	30.6	7.5	0	0	21.1	2	0	20.6	0
32501		24.8		0	24	0.8	0	24	5.6	61.7	24.9	0	116.2	116.5	0	0	4.1	4	0	124.6	-8.4
32502		8.8		0	5	2.8	0	5	2.5	61.1	12.8	0	81.4	76.6	0	0	4.8	0	0	81.4	0
32503		4.6		0	4	0.6	0	4	2.2	0	7.9	0.1	14.2	0	0	0	10.2	4	0	14.2	0
32504		3.1		0	2	0.1	0	3	3.6	0	14.3	0.1	21	0	0	0	16	5	0	21	0
32505		0		0	0	0	0	0	0.7	0	21.7	0.5	22.9	0	0	0	11.9	11	0	22.9	0
32506		0.8		0	40	0.4	0	0.4	1.6	0	5.7	0.2	7.9	0	0	0	2.9	5	0	7.9	0
32507		0		0	0	0	0	0	6.1	0	96.4	1.9	104.4	0	0	0	44.4	55	0	104.4	0
Total	168	2928.1	1767.9	2.6	708.4	449.2	7	708.4	482.6	871.6	811.7	70.1	2944.4	1578.2	270.5	59.4	744.6	315	7	2067.7	-123.2

Table 2.8. Groundwater quality parameters in the KRB.

Study area code	Range of variation	Na^+	Mg^{++}	Ca^{++}	SO_4^-	Cl^-	HCO_3^-	pH	EC (µmhos/ cm)	TDS (ppm)
		(meq/L)								
32101	Max	5	5.2	9	8.5	8.7	5.4	8.6	1360	900
	Mean	1.71	2.39	2.6	2.03	1.27	3.89	7.9	673	435
	Min	0.32	1.1	1	1.02	0.4	2.5	7	331	205
32102	Max	1.2	2.5	3	0.91	1.1	5.4	8.2	578	378
	Mean	0.7	1.98	2	0.49	0.65	3.8	8.02	492	314
	Min	0.16	1.1	1.1	0.2	0.3	2.8	7.8	374	240
32103	Max	2.58	4	3.9	6	4.5	4.8	8.3	1357	879
	Mean	0.6	1.96	2.06	0.74	0.76	3.45	7.99	491	318
	Min	0.05	1	0.7	0.05	0.2	2.5	7.2	286	181
32105	Max	6.2	5.62	3.9	2.33	6.2	8.4	7.8	1269	837
	Mean	2.13	2.84	2.94	1.23	1.36	5.19	7.35	815	528
	Min	0.01	1.24	3.03	0.68	0.32	0.05	6.9	464	297
32107	Max	1.3	2.84	6.35	3.1	1.15	6.75	7.7	975	634
	Mean	0.68	1.47	3.25	0.71	0.48	4.5	7.07	574	369
	Min	0.01	0.5	0.04	0.3	0.25	2.65	6.7	327	209
32108	Max	3.3	5.16	6.92	5.62	6.8	10.57	8.4	2163	1449
	Mean	0.82	2.13	2.93	0.86	0.84	4.43	7.01	641	430
	Min	0.08	0.01	0.8	0.1	0.25	0.03	6.6	335	214
32201	Max	12.5	18.43	9.05	7.3	6.8	10.5	8.4	2217	1485
	Mean	1.53	3.46	3.16	1.25	1.09	5.23	7.5	830	547
	Min	0.01	0.02	0.02		0.01	0.03	6.8	164	174
32202	Max	0.88	1.8	3.8	0.51	0.46	4.8	8.45	550	352
	Mean	0.54	1.45	3.11	0.19	0.31	4.46	8.15	487	312
	Min	0.38	1.12	2.6	0.04	0.24	4.1	8	430	275
32203	Max	26.5	27.72	10.2	30.35	21.4	7.7	8.4	4770	3577
	Mean	2.3	3.61	3.12	2.33	2.15	4.38	7.37	886	594
	Min	0.02	0.6	0.04	0.1	0.02	0.04	6.3	297	193
32302	Max	3.8	8.54	5.35	6.4	2.6	9.3	8.4	1425	980
	Mean	1.26	3.93	3.07	1.22	0.69	5.86	7.46	837	548
	Min	0.01	0.02	1.2	0.1	0.01	0.06	6.8	464	297
32304	Max	1.47	3.52	3.14	0.94	0.9	5.45	8.1	701	441
	Mean	0.93	3.23	2.15	0.75	0.66	4.52	7.37	602	383
	Min	0.47	2.8	1.2	0.55	0.4	2.9	6.9	461	295
32314	Max	2.3	5.4	4	3	1.1	7.9	7.7	1091	709
	Mean	1.64	3.51	3.38	1.86	0.8	5.81	7.34	826	536
	Min	0.8	1.5	2.5	0.25	0.5	4.1	7	509	325

Table 2.8. (Continued).

Study area code	Range of variation	Na^+	Mg^{++}	Ca^{++}	SO_4^-	Cl^-	HCO_3^-	pH	EC (μmhos/cm)	TDS (ppm)
		(meq/L)								
32404	Max	3.3	11.7	4.7	0.69	0.8	4.3	7.48	689	455
	Mean	0.93	3.23	3.15	0.66	4.52	0.75	7.37	602	383
	Min	0.09	0.01	2.7	0.03	0.01	0.06	5.5	335	217
32501	Max	40.5	27.4	25.6	65	38.8	4.3	7.9	6334	4242
	Mean	9.53	6.13	8.27	15.21	6.28	2.28	7.27	1936	1408
	Min	0.93	0.4	1.7	1.35	0.5	0.5	6.8	404	258
32502	Max	18.7	11.2	30.1	59.13	11.6	4	8.3	6360	4473
	Mean	10.47	6.81	13.11	24.14	6.24	2.23	7.7	3011	2150
	Min	0.8	2	4.8	4.35	3	1.5	6.9	1480	813

Table 2.9. KRB groundwater quality classes for agriculture according to Wilcox method (%), where C = conductivity (salinity hazard) and S = sodium hazard.

Study Area Code	C1	C2	C3		C4		
	S1	S1	S1	S2	S1	S2	S4
32101		75	25				
32102		100					
32103		94	6				
32105		45	55				
32107		80	20				
32108		83	17				
32201	1	51	46	2			
32202		100					
32203		53	41			6	
32302		35	65				
32304		100					
32314		18	82				
32404		100					
32501		15	45	3	8	25	4
32502			18		36	39	7

Table 2.10. KRB groundwater quality classes for domestic use according to Schuler method (%).

Study area code	Suitable	Allowable	Moderate	Not suitable	Instantaneous allowed
32101	75	25			
32102	100				
32103	94	6			
32105	50	50			
32107	100				
32108	86	8	6		
32201	51	44	5		
32202	100				
32203	56	35	6	3	
32302	45	55			
32304	100				
32314	18	82			
32404	100				
32501	13	40	22	22	3
32502		4	36	57	3

Chapter 3.

Water Resources and Balance of Honam and Merek Catchments

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3.1. Introduction

Water resources are among the most important components in assessing the potential of basins/catchments and their environment in planning for Integrated Natural Resources Management (INRM). To this end, comprehensive assessment of water resources and floods, and water productivity analysis in the Karkheh River Basin (KRB) was considered a priority component in the CPWF project. The large area of KRB was a parameter that limited availability of data and accuracy of achieving results. Honam and Merek, as small basins (catchments), were chosen for collection of detailed data on water resources and water balance to be used in water resources managements. The purpose of this research was to assess the water balance and water resource for these two catchments that had no currently available data. Therefore, it was necessary to collect some data in the research stage to estimate the indices of the relationship between the catchment and basin behaviors.

The ability of water balance models to incorporate monthly or seasonal variations makes them especially attractive for water resource studies and management. The use of conceptual models has increased in recent years and it is likely that computer simulation of catchments will increasingly be used by, and for, water resource managers as an aid to decision making. Different hydrological models have also been developed to account for the changes in physical processes associated with different land use and climate changes, which in most of the early models were lumped and statistical.

A distributed conceptual model, the Darling Range Catchment Model (DRCM), was developed and applied to some catchments in the Darling Range of Western Australia (Mauger, 1986). Sivapalan *et al*. (1996) simplified the conceptual form of DRCM and developed the Large Scale Catchment Model (LASCAM). This model was tested, calibrated, and validated across a range of different catchments, from small experimental to very large (Sivapalan *et al*., 2002). TOPOG (Vertessy *et al*., 1993) and WEC-C (Water and Environmental Consultants-Catchment) are two other fully distributed models that are applicable to hill slopes and experimental scales (Croton and Barry, 2001). Although distributed hydrological models are applied all over the world, it is now well understood that the basic limitations of these models to simulate catchment responses with a small number of parameters is due to their inability to reproduce dynamic variation of saturated areas within the catchment (Beven, 1989; 2001; Binley *et al*., 1989). In fact, the dynamic variation of the saturated area, a function of accumulation and horizontal movement of water in the top soil layers, is mainly responsible for the highly nonlinear nature of catchment response to storm events (Ruprecht and Schofield, 1989; Todini, 1996). Most of the existing conceptual and semi-distributed models require a large number of parameters to represent dynamic variation. Many of these parameters lack physical meaning since they represent averages of the catchment or sub-catchment characteristics.

Recent studies have only been devoted to water balance prediction of steady-state catchments. The monthly water balance model WASMOD was developed for water balance computation for the NOPEX region (Xu *et al*., 1996; Xu, 2002). The model parameters are related to the physical characteristics of the basins (Xu, 1999). The input data for using the model on gauged basins are monthly areal precipitation, potential evapotranspiration, and/or air temperature. To use the model on un-gauged basins, land use and/or soil distribution data are needed. The model outputs are monthly stream flow and other water balance components such as actual evapotranspiration, slow and fast components of stream flow, soil-moisture storage, and accumulation of snowpack.

Another model is the Salas model – a simple watershed model for annual and monthly stream flow simulation (Salas, 2002; Laurel *et al*., 2008). This model assumes a single watershed or lumped basin (not dividing the watershed into sub-watersheds), and the temporal scale is an annual period. The model can also be applied to a season, depending on the particular case. The variables in the hydrologic cycle of the watershed that occur during the time interval t are mean precipitation (P1) over the basin, surface runoff (SR1), infiltration (It), actual evapotranspiration (It), deep percolation (DPt), base flow (BFt), groundwater flow (GFt), groundwater storage at the beginning of the time interval t (GSt-1), and stream flow at the outlet of the watershed (Qt). The model assumes only one storage (reservoir) – the groundwater storage (GS) – this is an important component of the model where water is stored and released depending on the reservoir's inflows and outflows. The conceptual model of the watershed is made up of a number of simple models representing the various processes such as surface runoff, infiltration, evapotranspiration, deep percolation, base flow, groundwater flow, and stream flow. The model(s) essentially routes the precipitation, Pt, through the watershed down to the basin's outlet. The watershed model is quite simple and expresses both the groundwater storage and the streamflow explicitly as a function of precipitation and the model parameters a, b, c, and d – these four parameters must be estimated based on historical precipitation and streamflow data. For this purpose a trial and error procedure can be utilized or more sophisticated methods based on optimization techniques.

The abovementioned models need to have several years of data; however, there is no more than one year of data for Honam and Merek catchments. For these catchments, a simple water balance equation was used. In this equation, the amount of rainfall is set equal to the sum of outlet discharge, evapotranspiration, and exchanging groundwater table.

3.2. Materials and methods

3.2.1. Site selection

In 2006, the report 'Water resources monitoring site selection report for Merek and Honam' was published (Anonymous, 2006). Merek and Honam catchments are two sub-basins of the KRB (Figure 3.1). These two sites were studied and particular locations selected and equipped with data loggers, stages, and rain gauges, in the first year.

General features of Honam

Honam watershed is part of the Alashtar River basin at Sarab-e Seyed-ali hydrometric station located within 49°08'00'–49°17 '35'E and 33°30'15'–33°37'11' N. The area of the basin is 140.16 km^2, and average elevation is 2051 m above mean sea level, with the highest point at 3560 m above mean sea level in the east and the lowest point 1480 m above mean sea level in the western part at the basin outlet.

Figure 3.1. Geographical location of Honam and Merek catchments in the KRB, Iran.

The recorded data at Alashtar Meteorological Station was used to investigate Honam temperature and rainfall variations. The average annual temperature is 10.80°C, with a minimum average temperature of 2.70°C in January and maximum average of 20.80°C in July. The average annual rainfall of the catchment is about 690.5 mm.

Villages in Honam catchment include Presk-Bala, Presk-Paein, Honam, Berdbel, Chahar Takhteh, Jahanabad, Yariabad, Lamdar, Kolah-hil, Hajiabad, Shirabad, Jafarabad, Noorabad, Karamolahi, Farajolahi, Aadelabad, Siahposh, and Espej. Figure 3.2 shows the drainage system and villages in Honam basin.

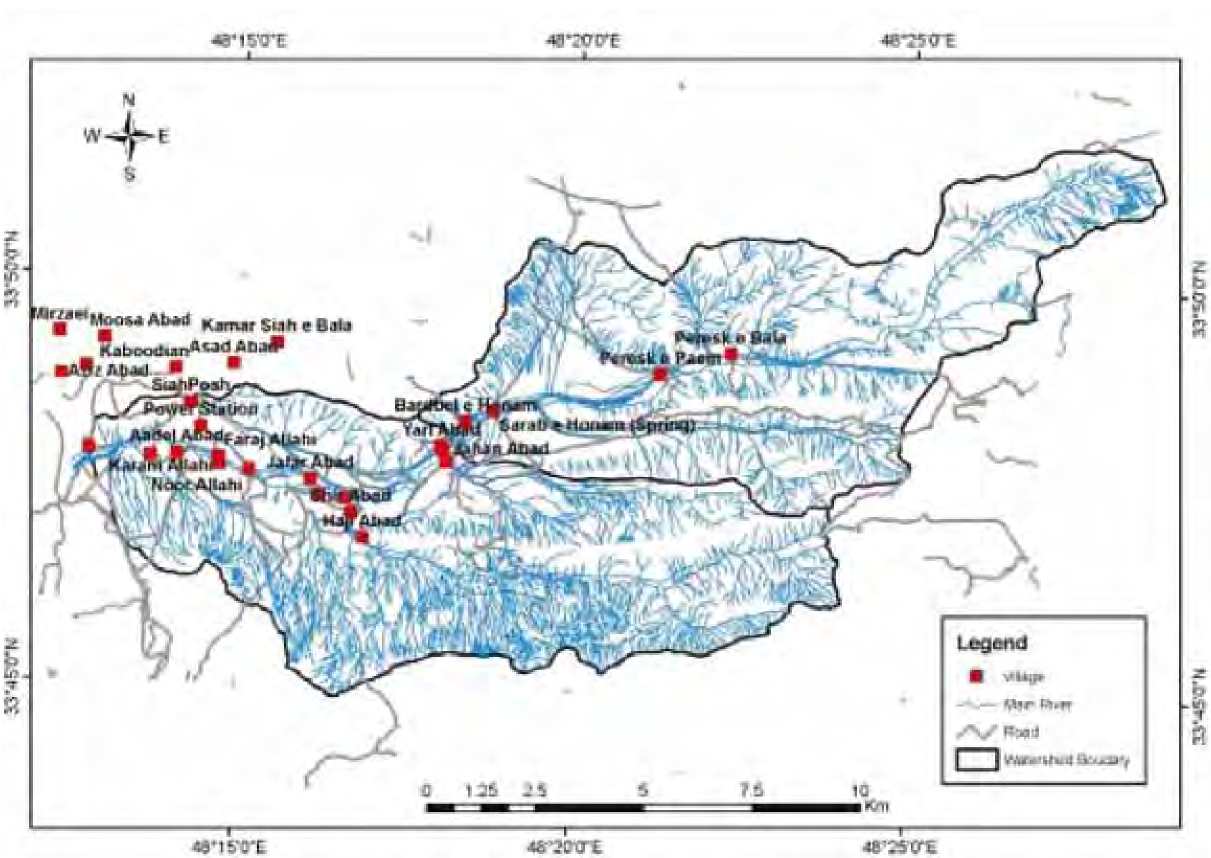

Figure 3.2. Drainage system and villages in the Honam basin.

General features of Merek

Merek is a sub-basin of the KRB. Figure 3.1 shows the geographical location of Merek catchment in Iran and the KRB. Figure 3.3 shows the drainage system in Merek catchment.

Merek basin is a part of the Gharesoo River, and is a sub-basin of the KRB, located within 47º04'52"–47º22'09"E and 34º00'25"–34º14'05"N. The area of the basin is 305 km^2. The highest point is 2774 m above mean sea level in the northeast part of the basin and the lowest point is 1483 m above mean sea level at the outlet in northwest part of the basin. Merek is a part of Mahidasht plain in the southwest of Kermanshah Province of Iran. Based on data of the Mahidasht Meteorological Station in the west border, the climate of Merek is semi-arid according to De-Marton classification.

Table 3.1 shows the temperature components in Mahidasht Station, a climatological station adjacent to Merek basin. Temperature data of 1971–2003 show that the minimum and maximum monthly average temperatures were, respectively, 0.70°C in February and 25.30°C in July.

The average annual rainfall during 1966–2001 was 357 mm. Seasonal variation of precipitation represents a Mediterranean climate with a distinct winter and summer. Precipitation in autumn, winter, and spring is 30, 45, and 25% of the annual total, respectively, with insignificant precipitation in summer.

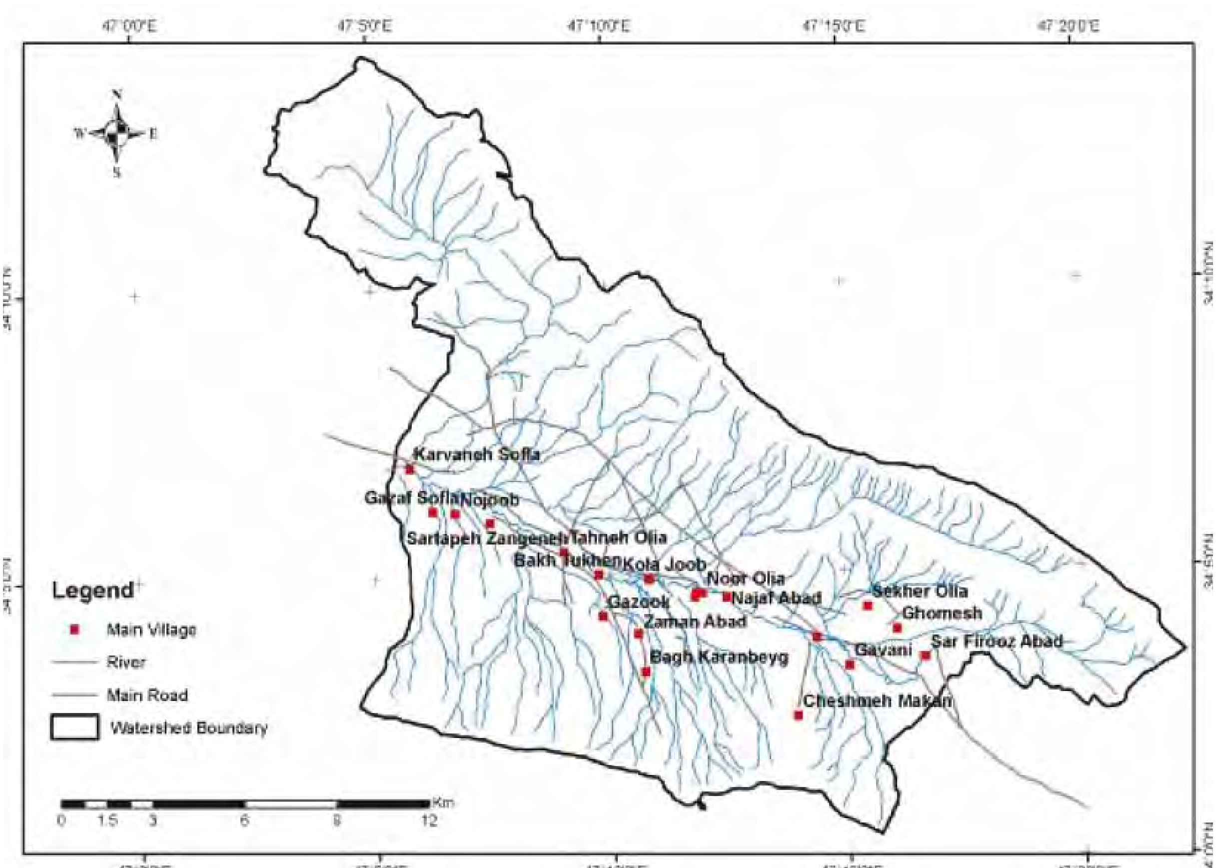

Figure 3.3. Merek drainage network, roads, and villages.

Table 3.1. Temperature components in Mahidasht Station (°C).

Month / Temperature	Absolute minimum	Average of minimum	Mean	Average of maximum	Absolute maximum
Mehr (20 Sept to 20 Oct)	–7	4.7	15.9	27.3	38
Aban (20 Oct to 20 Nov)	–10	1.6	10.9	20	35
Azar (20 Nov to 20 Dec)	–14	–2	5	11.8	28
Dey (20 Dec to 20 Jan)	–25	–5.1	1.7	8.2	17
Bahman (20 Jan to 20 Feb)	–25	–6.2	0.7	8.2	20
Esfand (20 Feb to 20 Mar)	–24	–3	4.3	12.0	26
Farvardin (20 Mar to 20 Apr)	–9	1.4	9.8	17.5	32
Ordibehesht (20 Apr to 20 May)	–4	4.7	13.7	21.5	33.4
Khordad (20 May to 20 June)	0	12.1	21.3	30.4	39
Tir (20 June to 20 July)	0	12.1	24.2	36.3	44
Mordad (20 July to 20 Aug)	3	13.3	25.3	37.3	43
Sharivar (20 Aug to 20 Sept)	1	10.8	22.6	34.3	41
Annual	–25	3.7	12.7	21.8	44

3.2.2. Data collection and measurements

There are different ways to express hydrological parameters, e.g. monthly and annual precipitation depth or flow discharge rate. The precipitation was measured by rain gauge and stream flows were measured by hydrometric instruments. Data of the existing recorder rain gauge in Alashtar synoptic meteorological station and data of the Presk standard rain gauge in Honam catchment were collected and used. In the case of Merek, a weighing recorder rain gauge was installed in the middle of the basin (Najafabad village) in May 2007 and the data were recorded. Hydrometric stations were established for measuring stream flow discharge. Spring and well discharges were monitored by personnel of the Ministry of Energy.

Precipitation

a- Honam catchment

Data of monthly precipitation are necessary to determine water balance in any basin. In the present study, data of the Alashtar Synoptic Station and Presk rain gauge station were used to determine the precipitation pattern in Honam catchment. This requires an adequate number of rain gauges to evaluate spatial variation in precipitation and its role as a major input for assessment of the basin water balance. There were nine standard rain gauges installed by the Meteorological Organization of Iran and local water office of Ministry of Energy within approximately 100 km of Honam basin. Table 3.2 shows the geographical coordinates of those rain gauges located at Chamanjeer, Khorramabad, Kaka Reza, Sarab Seyed Ali, Zaghe Khoramabad, Noorabad, Vanaie, Presk, and Alashtar. Records of these stations were considered for spatial analysis of the basin precipitation. Among these nine stations, Presk had a short history of data and the Khorramabad and Chamangeer stations were not used in spatial analysis due to weak correlations with other stations and being far from them. The relationship between mean annual precipitation and elevation was chosen for spatial analysis.

An annual regional precipitation equation was derived as follows:

$$P = (0.431 \times H) - 150 \quad [1]$$

Where, P is the mean annual precipitation (mm) and H is elevation (m above mean sea level). For the above regression equation, the coefficient of determination (R^2) = 0.97, which was significant at 95% level. Figure 3.4 shows the location of the stations situated inside and outside of the Honam basin within a distance of 15 km.

b- Merek catchment

There were no automatic recording rain gauges in the Merek catchment; however, five standard rain gauges, installed by Iranian Meteorological Organization, were operational. A weighing rain gauge was installed by this project in the middle of the basin (Najafabad village) in May 2007. Table 3.3 and Figure 3.5 show the geographical coordinates and locations of the rain gauges.

Table 3.4 shows the monthly and annual precipitation in the abovementioned stations from April 2007 to March 2008. The Najafabad station data are not shown due to lack of data for the whole period.

Streamflow discharge

a- Honam catchment

Annual and monthly stream flow water level was measured by limnograph and stage in Zirtagh, and by limnograph and critical flume with stage in Presk hydrometric station. During normal days, water level shown by the stage was observed daily at noon. However, during rainy and flood periods, critical flume discharge measurement was made at hourly intervals. Table 3.5 shows the geographic coordinates and location of the hydrometric stations.

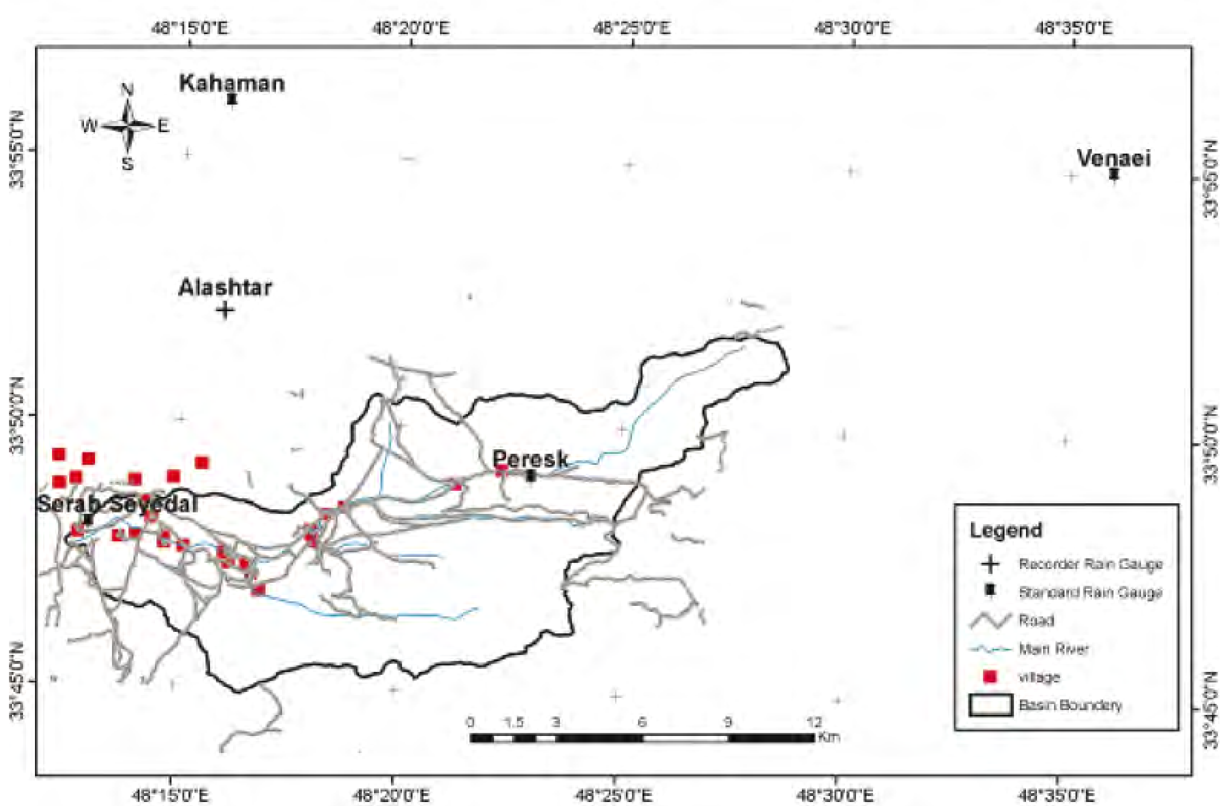

Figure 3.4. Location of Honam basin and standard rain gauge stations.

Table 3.2. Geographical coordinates of meteorological stations inside or near Honam basin.

Station name	Types	Longitude	Latitude	Elevation (m)	Mean annual precipitation (mm)	Observation time interval
Cham anjeer	RG	48°14′00″E	33°27′00″N	1140	482.1	12 h
Khorramabad	RG	48°22′00″E	33°20′00″N	1125	503.9	12 h
Kaka Reza	RG	48°16′00″E	33°43′00″N	1530	508.6	12 h
Sarab Seyed Ali	RG	48°13′00″E	33°47′.00″N	1520	515.7	12 h
Zaghe Khorramabad	RG	48°42′00″E	32°29′00″N	1870	628.4	12 h
Noorabad	RG	48°00′00″N	34°03′00″N	1859	666.6	12 h
Vanaie	RG	48°36′00″E	33°54′59.99″N	2000	722	12 h
Presk	RG	48°22′58″E	33°49′3.31″N	1880	-	12 h
Alashtar	RRG	48°15′58″E	33°52′4.41″N	1567	518	10 min

RG is standard rain gauge and RRG is recorder rain gauge

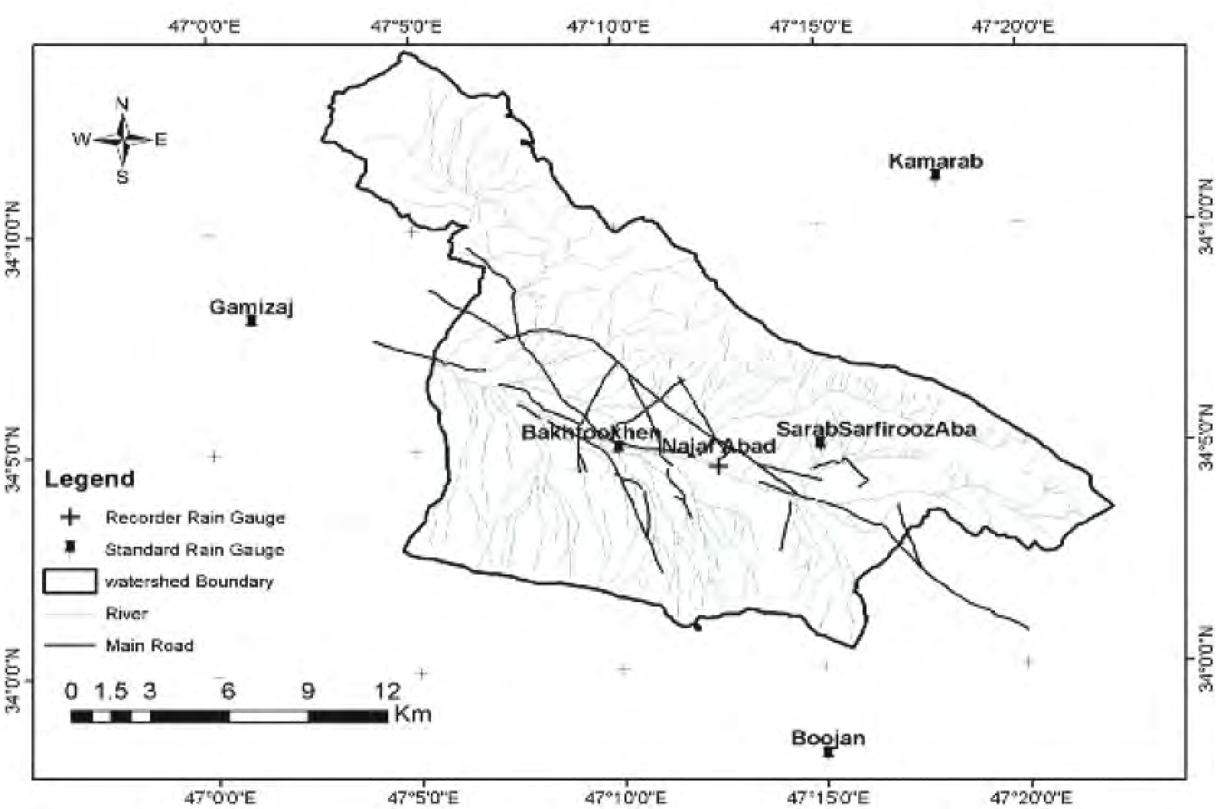

Figure 3.5. Geographical coordinates and locations of rain gauge stations in Merek catchment.

Table 3.3. Type and coordinates of rain gauges in Merek.

Name	Types	Longitude	Latitude	Elevation (m)	Time interval of measurements
Boojan	Standard rain gauge	47°15′00′	33°58′00″	1600	12 h
Kamarab	Standard rain gauge	47°18′00″	34°11′00″	1293	12 h
Gamizaj	Standard rain gauge	47°01′00″	34°08′00″	1480	12 h
SarabSarfiroozAba	Standard rain gauge	47°15′00″	34°05′00″	1510	12 h
Bakhtookhen	Standard rain gauge	47°10′00″	34°05′00″	1540	12 h
Najafabad	Data logger	47°12′27″	34°04′43″	1550	10 min

Table 3.4. Measured monthly precipitation (mm) from April 2007 to March 2008 in Merek catchment.

Date	Boojan	Sarab	Kamar Ab	Bakhtookhen	Gamizaj
April 2007	174.2	177.0	140.9	133.5	68.0
May	55.5	68.5	51.7	55.5	43.5
June	4.0	6.0	0.5	0.0	0.0
July	0.0	0.0	0.0	0.0	0.0
August	0.0	0.0	0.0	0.0	0.0
September	0.0	0.0	0.0	0.0	0.0
October	1.5	0.0	0.0	0.0	0.0
November	4.0	6.5	4.0	0.0	2.6
December	64.5	52.0	47.5	46.5	33.3
January 2008	51.5	33.0	27.0	44.1	25.7
February	55.5	40.5	46.1	51.5	78.1
March	53.5	28.5	42.1	21.0	28.2
Annual	464.2	412	359.8	352.1	279.4

Table 3.5. Type of equipment and coordinates of hydrometric stations.

Name	Equipment	Longitude	Latitude
Zirtagh	Limnograph + Stage	48°18′41.46″E	33°48′23.29″N
Presk	Flume + Water level meter + Stage	48°24′34.67″E	33°49′16.87″N

Zirtagh station

Earlier in our study, a bridge on Khorramabad–Alashtar main road at the outlet of Honam catchment was selected as the site for installing the stage-logger water level meter; however, the installation was destroyed by Alashtar Road Bureau for widening the road. Additionally, this selected site did not include the entire basin area. A new site, downstream near Zirtagh village, was selected with geographic coordinates 48°18'41.46"E and 33°48'23.29"N, at the outlet of the basin and included the whole basin. Figure 3.6 shows a view of the instruments including derricks, telepheric bridge, and stage-logger water level meter. The daily data of the stage were available from 15 February 2006; and for the stage-logger, data with 2-h interval were available from 17 April 2007. The water level recorder use was Global Water Level Meter 9" Model provided by CP project funds. A discharge (Q)–stage (H) curve was prepared for the sites (Figure 3.7) using the measured discharge and corresponding stage at different water levels (Table 3.6).

Presk station

Upstream of Honam catchment, there is a karstic spring called Presk that forms the main part of the base flow of Honam River. A diversion dam at the coordinates 48°24'34.67"E and 33°48'23.29"N was constructed to supply water for Presk village farms and a fish pond. A supercritical flume (Figure 3.8) equipped with a Global Water Level Meter 9" Model data logger was built upstream of the diversion dam – the data were available from 17 April 2007.

Table 3.6. Stage and related discharge of Zirtagh hydrometric station.

H (cm)	**Q (m^3/s)**	**H (cm)**	**Q (m^3/s)**	**H (cm)**	**Q (m^3/s)**
36	1.70	44	2.62	27	1.04
38	2.05	45	2.77	30	1.15
39	2.14	48	3.00	31	1.35
40	2.33	20	0.72	1.38	32
42	2.44	22	0.76	1.52	33
43	2.55	23	0.85	1.55	34

H: Stage reading
Q: Discharge

Figure 3.6. View of Honam hydrometric station with derricks and cable.

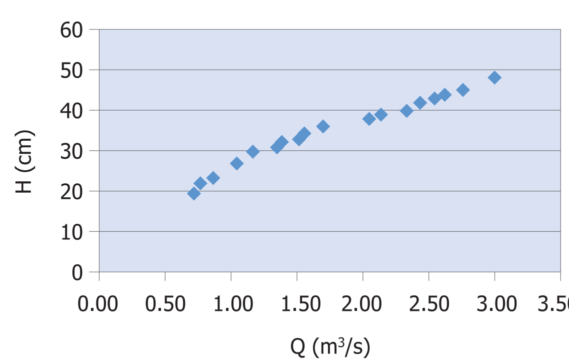

Figure 3.7. The Q–H relation at Zirtagh hydrometric station.

Figure 3.8. View of the supercritical flume installed in Presk spring.

Spring discharge

There are 19 springs in Honam watershed, including the permanent and important Honam and Presk springs. Therefore, hydrometric equipment was installed in these streams. Figure 3.9 and Table 3.7 show the geographical coordinates, mean annual discharge, and annual volume of all springs in Honam watershed.

Honam spring

A spring called Honam is located in the middle of the catchment, at 48°18’43.83”E and 33°48’24.83”N, and has a considerable discharge. The local water office monitors the spring and collects data in monthly periods. Figure 3.10 shows the outlet of the Honam spring with its stage. Discharge of the Honam spring was measured from 17 April 2004. Total discharge and use of Honam spring water amounts to 57.43 × 10^6 and 29.75 × 10^6 m^3/year, respectively.

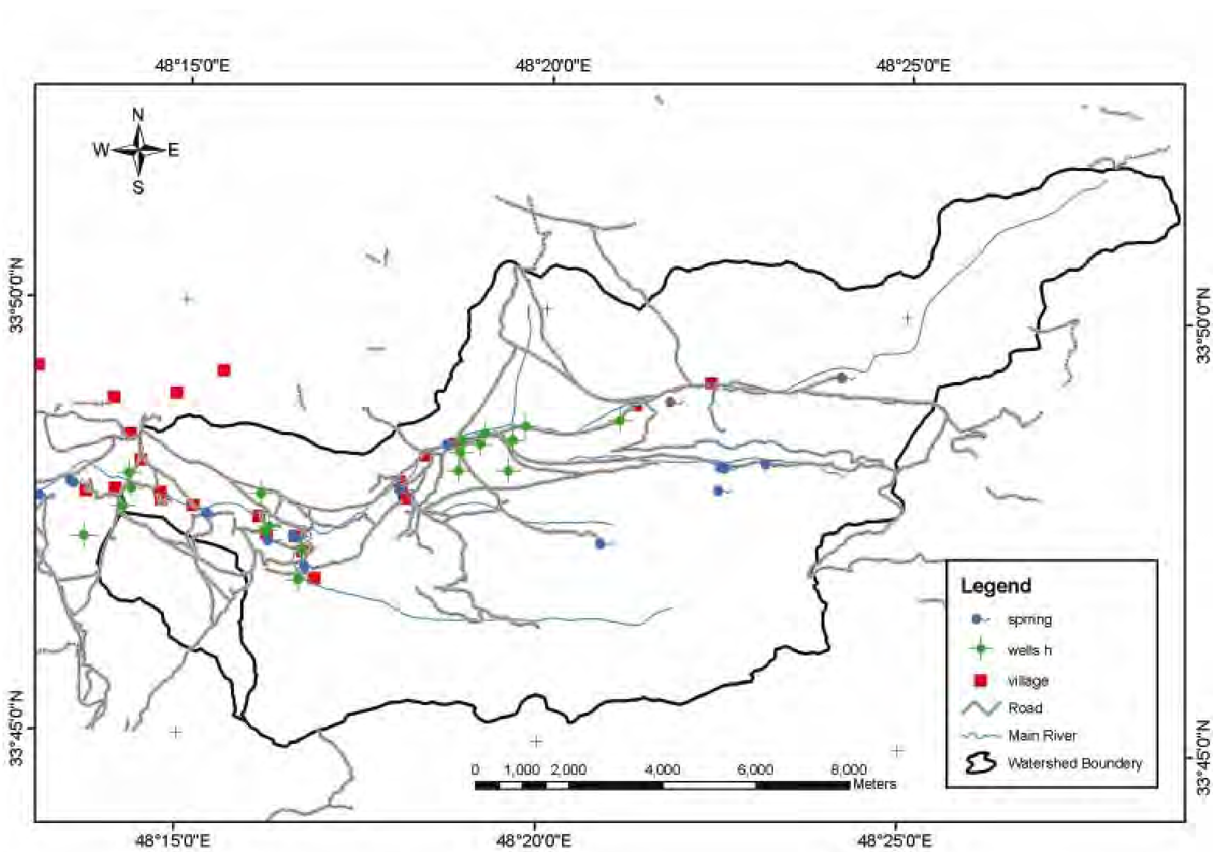

Figure 3.9. Distribution of springs in Honam watershed.

Table 3.7. Geographic coordinates of springs in Honam basin.

Name	Longitude	Latitude	Discharge (L/s)	Volume (10^6 m^3)
Honam	48°18′43.83″E	33°48′24.83″N	444	14.00
Shaikhe	48°18′5.23″E	33°47′52.60″N	15	0.47
Lamdar	48°20′53.28″E	33°47′18.89″N	25	0.79
Darbid	48°21′48.35″E	33°48′57.83″N	15	0.47
Bagajani	48°23′8.81″E	33°48′16.80″N	15	0.47
Shor shor	48°22′31.31″E	33°48′13.57″N	12	0.38
Sarde	48°22′34.98″E	33°48′13.03″N	5	0.16
Mirhossai	48°22′30.56″E	33°47′57.45″N	3	0.09
Presk	48°24′10.27″E	33°49′17.53″N	200	6.31
Zirtagh	48°13′5.83″E	33°47′42.76″N	15	0.47
Aliabad	48°13′31.32″E	33°47′53.20″N	40	1.26
Norolahi	48°15′25.0″E	33°47′30.0″N	20	0.63
Aliabad	48°13′34.11″E	33°47′51.92″N	8	0.25
Norolahi	48°15′25.16″E	33°47′33.22″N	15	0.47
Khosroabad	48°16′16.60″E	33°47′15.05″N	15	0.47
Hossain b	48°16′36.90″E	33°47′18.54″N	6	0.19
Hossain b	48°16′39.09″E	33°47′17.81″N	10	0.32

Figure 3.10. View of Honam spring (left) and the stage used for measuring its discharge (right).

Diversion intakes for the main irrigation channels

There were 28 diversion intakes used for taking irrigation water from Honam River. Figure 3.11 and Table 3.8 show their locations and discharges, respectively. These annual average discharge rates were obtained from the Ministry of Energy (Local Water Office).

Groundwater use in Honam

Honam catchment is mountainous and is a karstic watershed with a small plain area and a shallow alluvial layer. Thus, this watershed has low capacity for retaining groundwater. In addition, there is little demand for groundwater. Nevertheless, there are 18 wells in the Honam Plain (Figure 3.12) and their

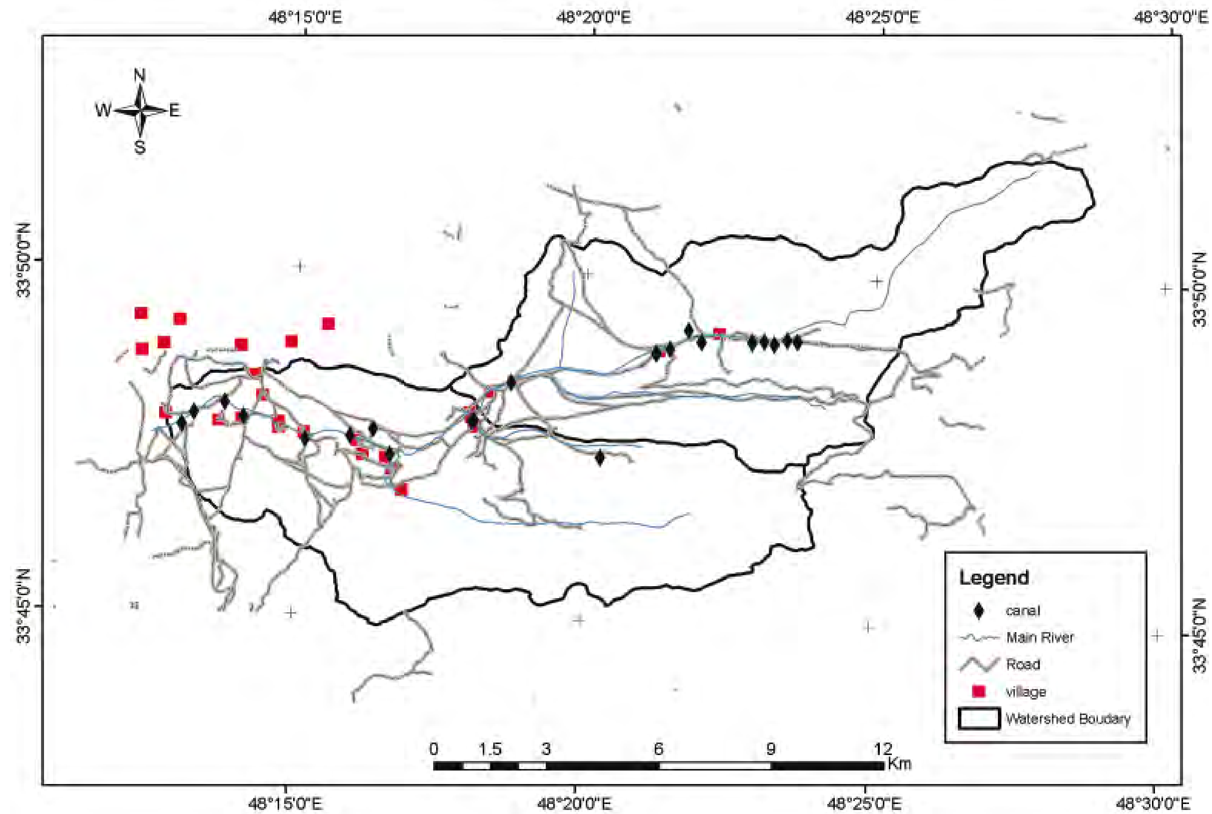

Figure 3.11. Diversion intakes from main irrigation channels in Honam low Lands.

characteristics are presented in Table 3.9. The water table depth is reduced from 49 to 2 m from upstream to downstream, and shows no drawdown due to overdraft of water by wells.

B- Stream flow in Merek catchment

There are many methods to determine different parameters of monthly and annual flow measuring and estimating. There were neither discharge data available nor any hydrometric stations present in the study area at beginning of the CP project. The necessary equipment were provided and installed by the project during the first year of the study.

The CP project provided two water level meters (model Global Water 3") in Charvarish and Halashi station; however, the instrument in Halshi did not work properly and so the Soil Conservation and Watershed Management Research Institute added a limnograph Model WBEDIEN 32 at the Halashi station in addition to the previous CP Global Water Level level Meter . Figure 3.13 and Table 3.10 show the geographic coordinates and locations of the site. A uniform and rectangular shape cross-section of Merek River below the flume allowed for measuring discharge correctly without constructing a telepheric bridge.

Annual and monthly stream flow water level was measured by limnograph and stage in two hydrometric stations. Halashi Bridge on Merek River was selected as the outlet of the whole catchment. A stage was installed and was read daily by an operator on normal days. During rainy and flood periods, the readings

Table 3.8. Diversion intakes from the main irrigation channels in Honam.

Stream name	Longitude	Latitude	Discharge (L/s)	Annual volume of discharge (10^6 m^3)	Duration of use (d)	Use volume (10^6 m^3)
Cham Panjshanbe	48°13′2.44″	33°47′42.82″	20	0.63	210	0.13
Dom cham	48°13′15.21″	33°47′53.23″	15	0.47	210	0.19
Khalil khani	48°13′46.91″	33°48′2.29″	50	1.58	210	0.25
Asiab	48°14′6.43″	33°47′50.10″	147	4.64	210	0.25
Asiabjagodarzi	48°15′10.52″	33°47′32.06″	65	2.05	210	0.95
Sia sia	48°15′58.22″	33°47′35.81″	83	2.62	210	1.10
Kotal sia	48°16′21.57″	33°47′42.11″	148	4.67	210	0.18
Chal bageri	48°16′39.32″	33°47′20.50″	187	5.90	210	1.75
Kard miri	48°16′39.32″	33°47′20.50″N	166	5.23	210	1.15
Badam shirin	48°18′3.54″	33°47′50.55″	63	1.99	210	0.90
Baba hossain	48°18′6.46″	33°47′51.72″	73	2.30	210	1.65
Sha joo	48°18′43.83″	33°48′24.83″	208	6.56	210	1.85
Daim joo baraftab	48°18′43.83″	33°48′24.83″	30	0.95	210	1.55
Daim joo nesar	48°18′43.83″	33°48′24.83″	66	2.08	210	0.76
Lamdar	48°20′17.92″	33°47′21.99″	16	0.50	210	0.12
Lamdar	48°20′17.92″	33°47′21.99″	15	0.47	210	0.20
Khak lak	48°21′13.42″	33°48′53.32″	40	1.26	90	0.15
Bikes	48°21′13.59″	33°48′52.77″	60	1.89	90	0.25
Alinaghi	48°21′27.66″	33°48′56.77″	50	1.58	90	0.28
Ghab soza	48°21′46.35″	33°49′13.66″	150	4.73	180	2.10
Chapi joo	48°21′59.92″	33°49′3.63″	60	1.89	75	0.55
Dom ghelma	48°22′52.64″	33°49′5.11″	7	0.22	180	0.14
Asiab	48°22′52.83″	33°49′3.94″	13	0.41	180	0.23
Asiab ghadim	48°23′5.14″	33°49′5.63″	10	0.32	180	0.22
Golha	48°23′15.87″	33°49′3.33″	6	0.19	180	0.07
Nesar	48°23′15.87″	33°49′3.33″	25	0.79	180	0.45
Bar aftab bagh	48°23′29.10″	33°49′6.92″	8	0.25	180	0.17
Den larra	48°23′39.81″	33°49′6.11″	40	1.26	75	0.28
Annual Total				**57.43**		**29.75**

were taken hourly. Figure 3.14 shows the bridge and the stage from the upstream view. The data were available in Halashi station from 21 January 2007. There was a flume across the Merek River, less than 100 m upstream of Halashi Bridge. This was the point selected for a water level recorder (model Global Water Level Meter 9” Model) from the CP project, but it malfunctioned and was replaced by a limnograph Model WBEDIEN 32. The data of the stage were available from 21 January 2007, but data from the logger were available from 21 February 2007.

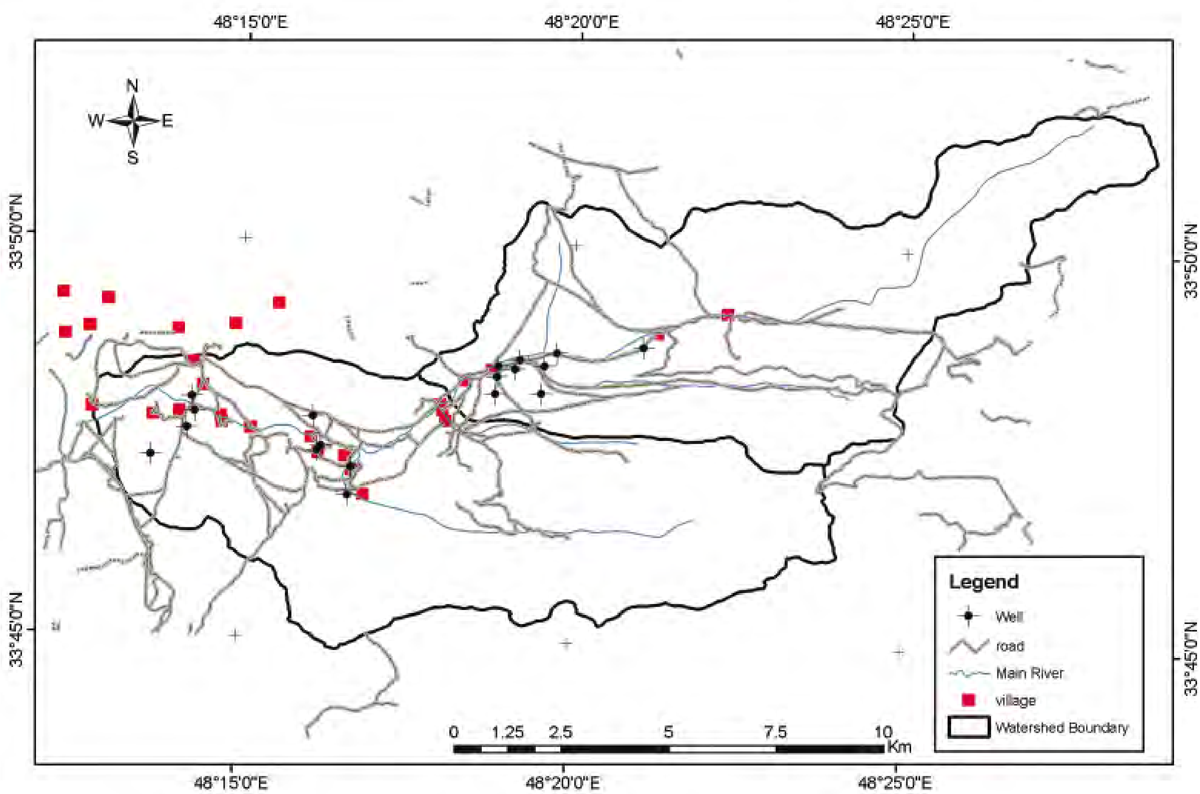

Figure 3.12. Location of wells in Honam watershed.

Figure 3.15 shows the cross-section of the river with limnograph (data logger) with a stage and the flume above it.

There was a bridge at Charvarish on the main road of Merek, adjacent to Lower Tahneh village, which divided forestry sub-catchment of the southern region of Merek. In Charvarish Bridge, a water level meter (logger) was installed to measure the contribution of the forest area to total surface runoff (Figure 3.16). The data were recorded after 21 March 2007. A rating curve was drawn based on discharge–stage measurements for 24 times at different water levels. Table 3.10 shows the stage and the corresponding discharge and Figure 3.17 shows the rating curve derived for Halashi station. Data of daily and instantaneous discharge were derived using the rating curve and water level over 12 months, to provide one year of data for water balance analysis. Table 3.11 shows the monthly discharge at Halashi station; however, stream flow was not recorded at Charvarish station due to a severe drought during the study (April 2007 to May 2008).

Springs

There is no spring in the Merek catchment. Seepage from the river and drainage are the main type of groundwater outlet.

Qanats

There are four qanats in Merek, situated in different parts of the plain. Qanats are monitored by the Ministry of Energy (MoE) in Iran, who carry out regular monthly monitoring of discharge and quality of the qanat in Merek. In this

Table 3.9. Geographical coordinates, annual discharge, and other specifications of the wells in Honam watershed.

Name of owner	Depth (m)	Level (m)	Use (L/S)	Yield (h/year)	Volume (M^3/year)	Type of use	Longitude	Latitude
Mherdad norifar	25	5	2	2000	14 400	Agriculture	48° 18' 52.89" E	33° 48' 27.40" N
Bhaman rhamati	60	12	10	2000	72 000	Agriculture	48° 19' 12.09" E	33° 48' 32.68" N
Darvish rhamati	60	12	30	4000	432 000	Agriculture	48° 19' 34.77" E	33° 48' 28.44" N
Gholam rhamati	65	12	2	2000	14 400	Poultry	48° 19' 7.96" E	33° 48' 25.52" N
Kiomars rhamati	70	20	2	2000	14 400	Poultry	48° 19' 31.88" E	33° 48' 7.67" N
Ebrahim rhamati	20	3	2	2000	14 400	Poultry	48° 18' 50.35" E	33° 48' 6.70" N
Mohamad reza rhamati	60	12	11	2000	79 200	Agriculture	48° 19' 45.27" E	33° 48' 38.40" N
Abfar	70	8	5	3000	54 000	Drinking water water	48° 18' 51.70" E	33° 48' 19.48" N
Abdola saremi	150	35	30	3000	324 000	Agriculture	48° 21' 3.56" E	33° 48' 44.05" N
Mirza hossain khosravi	25	17	1	3500	12 600	Agriculture	48° 16' 6.40" E	33° 47' 47.26" N
Mohamad sadegh ahmady	10	3	20	2778	200 016	Agriculture	48° 16' 13.84" E	33° 47' 24.74" N
Farid farajolahi	6	2	5	2778	50 004	Fish production	48° 14' 16.23" E	33° 47' 59.60" N
Sed esa farajolahi	17	14	1	4000	14 400	Poultry	48° 14' 12.11" E	33° 47' 36.53" N
Abdolhossain karamolah	8	4	2	2000	14 400	Poultry	48° 13' 39.98" E	33° 47' 15.43" N
Yhaya karamolahi	6	2	1	3000	10 800	Drinking water	48° 14' 18.63" E	33° 47' 48.91" N
Ali khosravi	80	12	12	2778	120 009.6	Agriculture	48° 16' 10.28" E	33° 47' 21.77" N
Honarestan	223	49	25	3000	270 000	Agriculture	48° 16' 38.94" E	33° 46' 48.42" N
Yazdan Ahmady	20	14	8	3000	86 400	Agriculture	48° 16' 41.14" E	33° 47' 9.73" N
Total			**169**	**48 834**	**1 797 430**			

study, field data was derived from the four abovementioned qanats (Figure 3.18). The mean annual flow was calculated using the mean monthly discharge data from the MoE. Table 3.12 presents the mean annual discharge from October 2006 to September 2007.

Qanat discharge was computed using Table 3.12 data. Annual discharge of the four qanats was 2.2×10^6 m^3 for October 2006 to September 2007. The monthly volumes of qanat discharge are shown in Table 3.13. Qanat water resources were used for agriculture and drinking, of which about 0.25×10^6 m^3 per year was allocated for village residents. Figure 3.19 shows the monthly variation of qanats in Merek plain. Peak discharge of Sarfiroozabad qanat was in May and minimum discharge in September–October (Figure 3.19). Sarfiroozabad

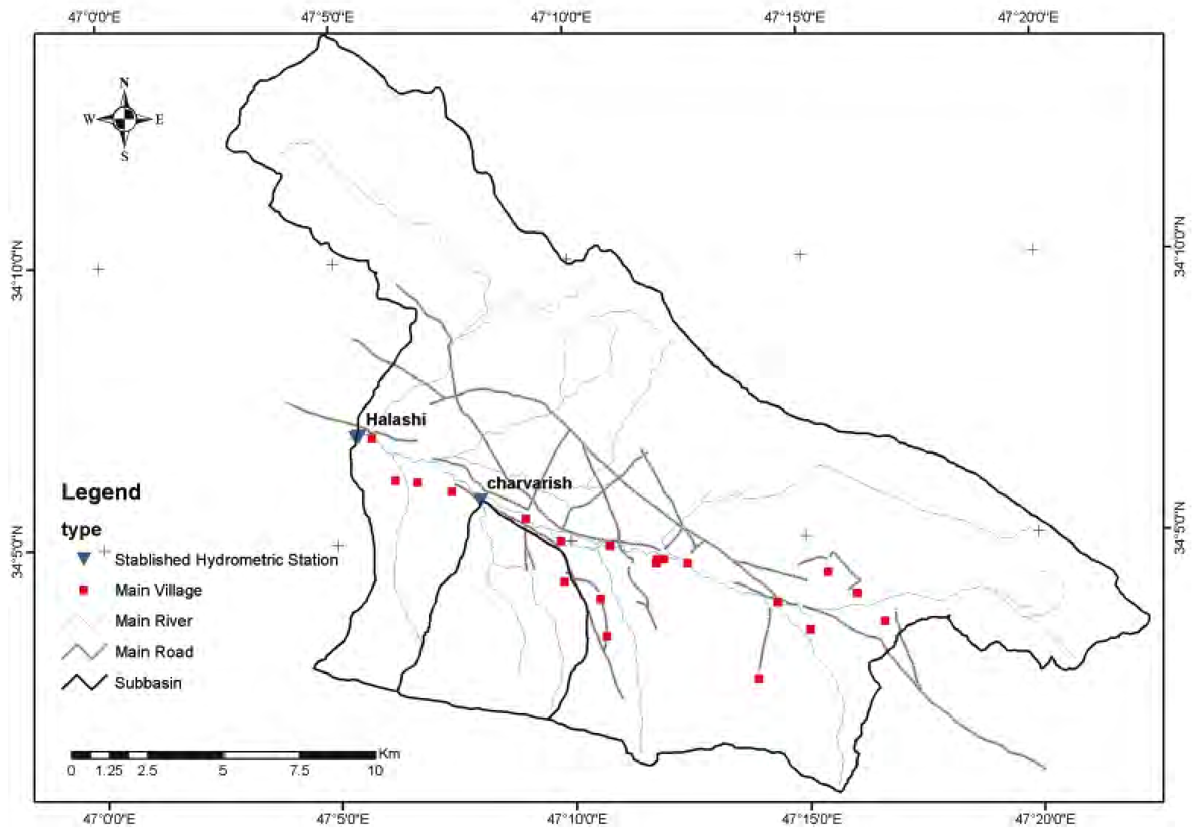

Figure 3.13. Geographical coordinates and locations of hydrometric stations.

Table 3.10. Type and coordinates of hydrometric stations.

Location name	Equipment	Longitude	Latitude	Elevation (m)
Halashi	Limnograph + Stage	47°05′47″	34°06′47″	1483
Charvarish	Water level meter + Stage	47°48′10″	34°05′41″	1500

Figure 3.14. Halashi Bridge with stage on the upstream right bank.

Figure 3.15. The data logger and a stage attached to the flume wall at Halashi station.

Figure 3.16. Downstream view of Charvarish Bridge with installed logger.

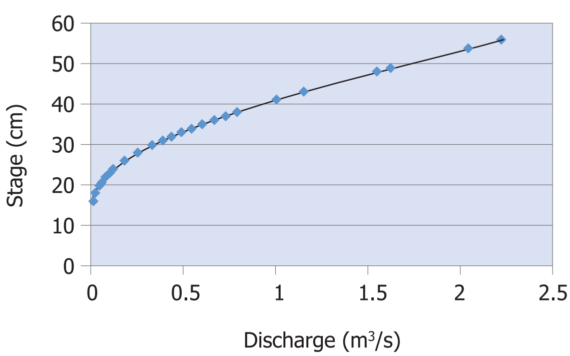

Figure 3.17. Stage–discharge curve for Halashi hydrometric station.

was more sensitive in response to recharge than the other three qanats; the hydrograph increased more rapidly during March–May and then decreased to July, after that hydrograph shape variation gradually decreased up to October (Figure 3.19).

Wells

There are 303 wells in Merek watershed located in the mid parts of the catchment, from upper part of the plain to downstream. The wells in this area are scattered in the low lands and mostly on the banks of the river (Figure 3.20). Discharge of wells is monitored by the Ministry of Energy. Appendix I contains coordinates of the wells in Merek. Annual discharge of wells was estimated by data obtained from Water Office of

Table 3.11. Stage and corresponding discharge at Halashi station.

Date	**Stage (cm)**	**Discharge (m^3/s)**
25 June 2007	16	0.01
30 May 2007	18	0.023
20 May 2007	20	0.044
19 Apr 2007	21	0.059
24 May 2007	22	0.077
18 May 2007	23	0.098
5 March 2008	24	0.122
15 May 2007	26	0.181
26 March 2007	28	0.253
30 March 2007	30	0.337
7 Dec 2007	31	0.385
22 Apr 2007	32	0.435
13 Apr 2007	33	0.488
27 Apr 2007	34	0.544
8 Dec 2007	35	0.602
18 Apr 2007	36	0.663
17 Apr 2007	37	0.726
28 Mar 2007	38	0.792
16 Apr 2007	41	1.001
28 Apr 2007	43	1.149
27 Mar 2007	48	1.542
15 Apr 2007	49	1.624
12 Apr 2007	54	2.044
11 Apr 2007	56	2.215

Kermanshah. Annual discharge of wells was 6.8×10^6 m^3, of which 99% was used for agriculture and the other 1% for drinking and industry (use of drinking water from wells by villages was 0.033×10^6 m^3).

Groundwater level data in Merek

In Merek, there are eight piezometer wells installed and monitored by MoE (Table 3.14). Water level of piezometer wells are measured monthly by local Water Office of Kermanshah Province. Unit hydrograph of the aquifer is an index

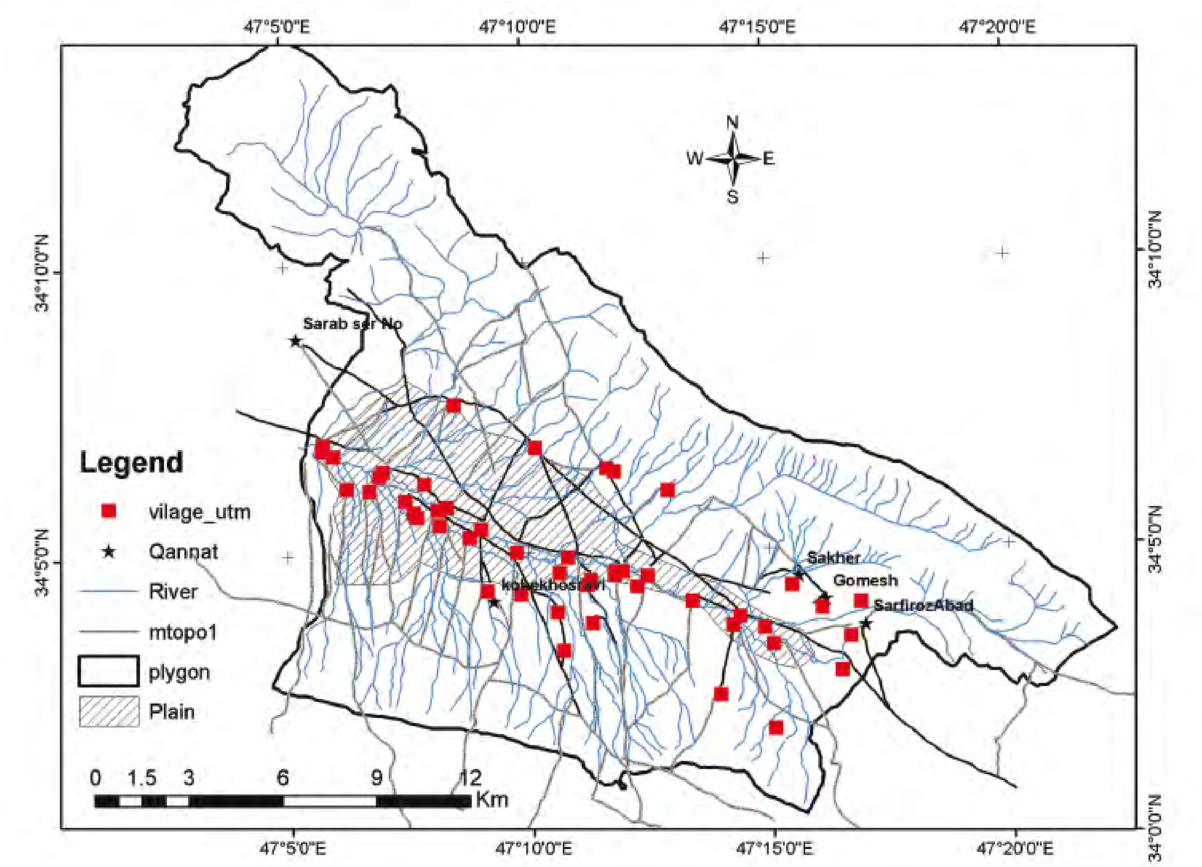

Figure 3.18. Geographical distribution of Merek qanats.

Table 3.12. Mean annual discharge of qanats (m^3/s) from October 2006 to September 2007 (Kermanshah Water Office 2008).

Iranian calendar dates (month)		Sekher	Sarfiroozabad	Khosravi	Ghomesh
Mehr	(20 Sept to 20 Oct)	11	32	4	5
Aban	(20 Oct to 20 Nov)	13	42	5	7
Azar	(20 Nov to 20 Dec)	14	38	5	8
Dey	(20 Dec to 20 Jan)	14	44	6	8
Bahman	(20 Jan to 20 Feb)	15	46	6	8
Esfand	(20 Feb to 20 Mar)	15	44	7	8
Farvardin	(20 Mar to 20 Apr)	12	60	5	9
Ordibehesht	(20 Apr to 20 May)	14	76	7	10
Khordad	(20 May to 20 June)	12	62	6	9
Tir	(20 June to 20 July)	10	40	5	7
Mordad	(20 July to 20 Aug)	10	36	5	6
Shahrivar	(20 Aug to 20 Sept)	10	28	4	5
Annual		12.5	45.7	5.4	7.5

Table 3.13. Monthly discharges (m³) of Merek qanats in 2006–2007.

Month	Sakhr	Sar Firoozabad	Kooreh Khosravi	Ghomesh
October 2006	28 512	82 944	10 368	12 960
November	33 696	108 864	12 960	18 144
December	36 288	98 496	12 960	20 736
January 2007	36 288	114 048	15 552	20 736
February	38 880	119 232	15 552	20 736
March	37 584	110 246.4	17 539.2	20 044.8
April	32 140.8	160 704	13 392	24 105.6
May	37 497.6	203 558.4	18 748.8	26 784
June	32 140.8	166 060.8	16 070.4	24 105.6
July	26 784	107 136	13 392	18 748.8
August	26 784	96 422.4	13 392	16 070.4
September	26 784	74 995.2	10 713.6	13 392
Annual	**393 379.2**	**1 442 707**	**170 640**	**236 563.2**

for the evaluation of the water level variation. The unit hydrograph of the Merek plain (Figure 3.21) was derived using observed data of water level in the piezometers during 1997–2008.

There was a decreasing trend of the water table level from the southeast to the northwest of the plain (Figure 3.22). Although some parts of the unit hydrograph were omitted due to uncertainty in the data, its overview shows seasonal variation due to dry and wet seasons or years. Neglecting some oscillation due to error in raw data, it could be concluded that the water table of the aquifers has not undergone considerable drawdown. Seasonal variation of groundwater levels shows that the maximum water table level was in April while the minimum was in October.

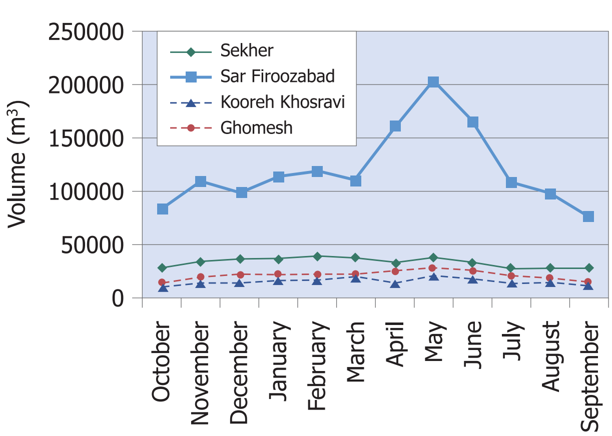

Figure 3.19. Monthly discharge of qanats in Merek during October 2006 to September 2007.

__Discharge from the Merek River__

Discharge from the Merek River was taken at three points: Gavani diversion dam, Gazaf diversion dam (Figure 3.23), and water taken directly from the river by pumping. Both Gavani and Gazaf diversion dams were constructed by the MoE local office, but are operated by the farmers who use the water for irrigation. These diversions convey the water by concrete-lined channels from the diversion dam to the farm land. They are used in the irrigation season (from April or May to October or November). Although the diversion dams were constructed by the government, they are monitored by the farmers – the local Water Office has no clear responsibility in operating and maintenance of the dams or the related channels.

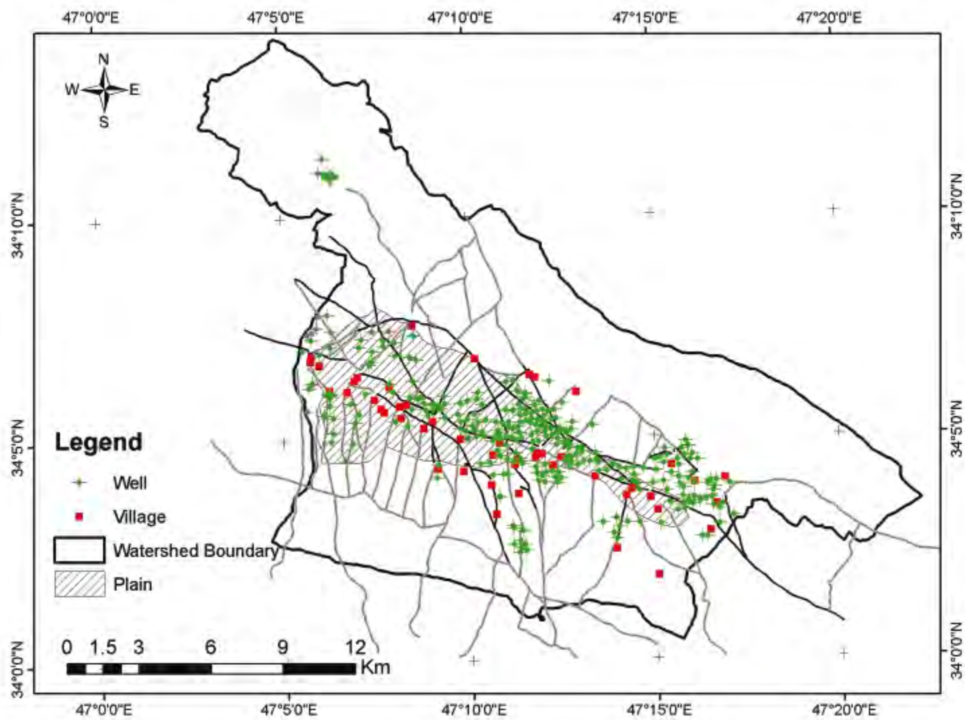

Figure 3.20. Distribution of wells in Merek plain.

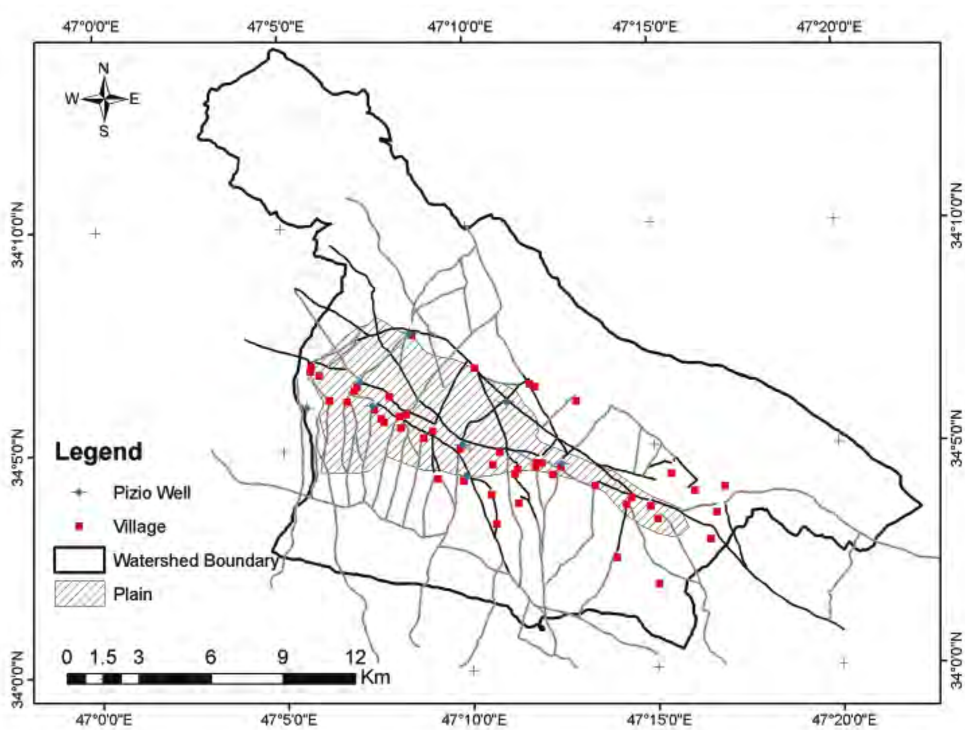

Figure 3.21. Distribution of piezometer wells in Merek plain.

Table 3.14. Geographic coordinates of the piezometer wells in Merek.

Location Name	Longitude	Latitude
Najafabad	47°12′30.78″E	34°04′37.85″N
Seid Sekher	47°08′27.64″E	34°07′36.10″N
Golm Kabood	47°11′02.64″E	34°06′02.10″N
Bakh Tikhoon	47°09′49.57″E	34°05′05.81″N
Dilanchi	47°07′05.57″E	34°06′32.35″N
Kachak	47°09′57.13″E	34°04′22.57″N
Sar Tapeh	47°07′25.41″E	34°06′00.20″N
Gazaf Olia	47°05′39.41″E	34°05′59.09″N

3.2.3. Salas model for water balance analysis

Volume and mass equilibrium were used in hydrological water balance computations and the Salas model was used for analyzing water balance parameters. For our purposes, we used a simple water balance model that operates at the annual time-scale and requires only the precipitation data as input (Saito *et al*., 2008). This model assumes that the watershed is homogeneous and is composed of three storages: surface, subsurface (unsaturated zone), and groundwater (saturated zone). Each storage has input and output variables that are either known (e.g. measured or reconstructed precipitation) or calculated by parametric relationships, and the storages are linked to each other by inputs and outputs (e.g. infiltration and deep percolation). The basic processes considered in the model are surface runoff, infiltration, evapotranspiration, deep percolation, base flow, and stream flow. Model parameters include 'a' as the fraction of precipitation that becomes surface runoff; 'b' is a fraction of infiltrated water that evaporates; 'c' is the fraction of groundwater storage that becomes base flow; and 'd' is the fraction of groundwater storage that becomes groundwater flow. These parameters do not change with time. In addition, the model requires an initial boundary condition of starting groundwater storage.

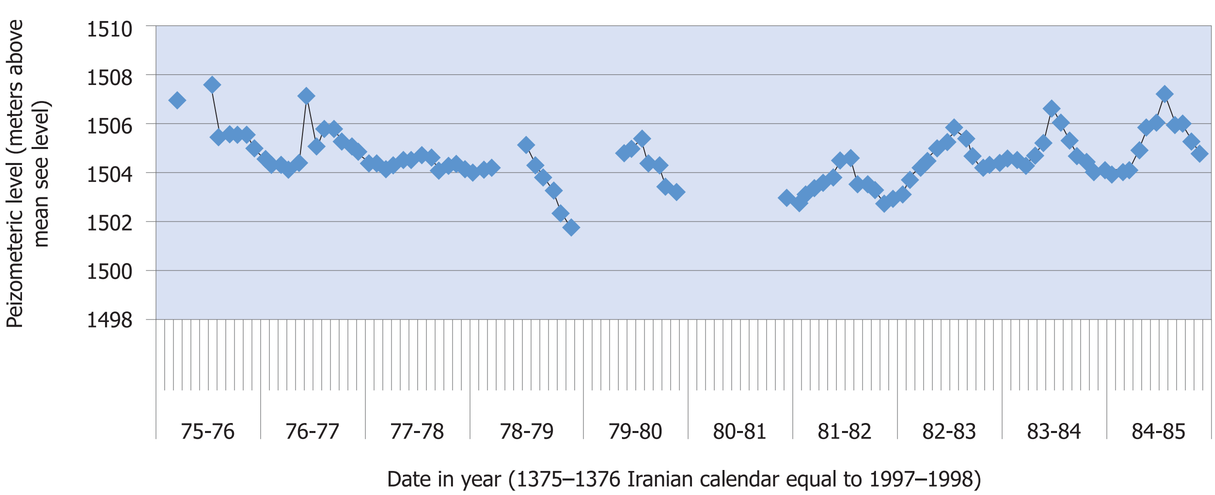

Figure 3.22. Unit hydrograph of Merek plain

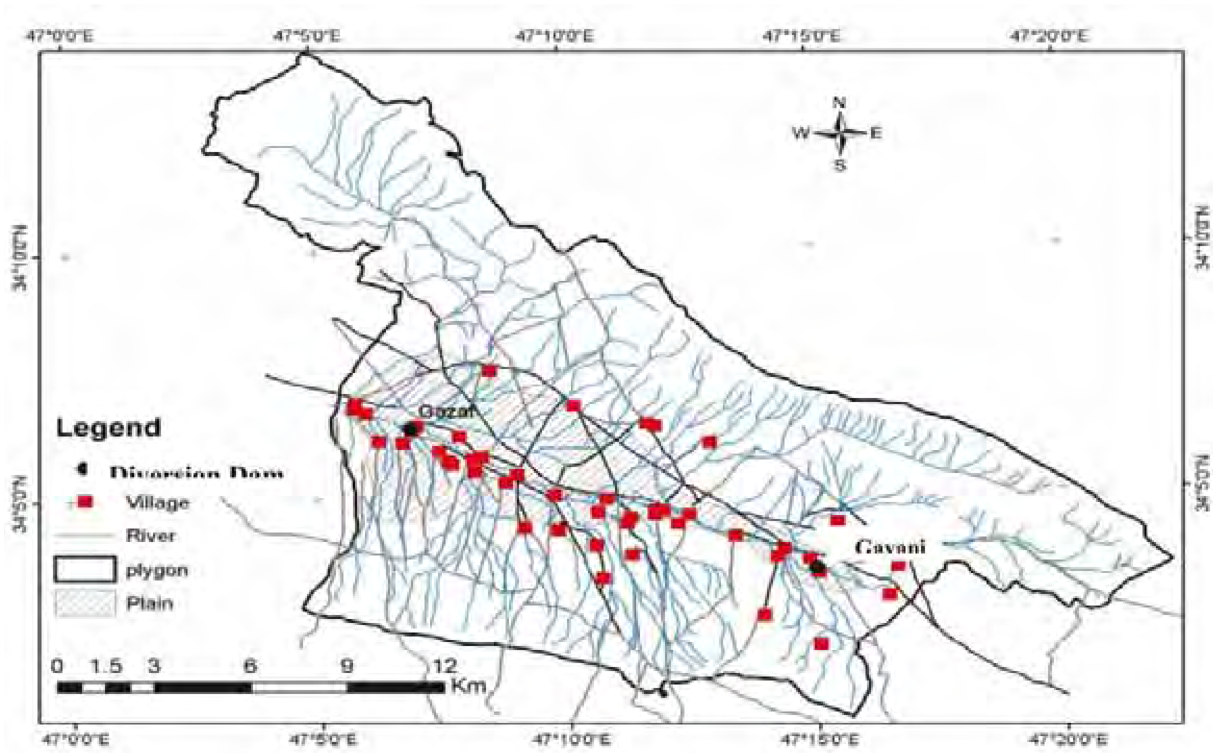

Figure 3.23. Location of diversion dams in Merek.

3.3. Analysis of water balance components in Honam and Merek catchments

3.3.1. Water balance components in Honam catchment

Data collections were carried out for one year (21 March 2007 to 20 March 2008) to estimate annual water resources and water balance components. The results are reported below.

Precipitation

The monthly and annual precipitation in Presk rain gauge station (Table 3.15) was monitored by the Meteorological Organization of Iran from 21 March 2007 to 20 March 2008, corresponding to the first and the last day of the Iranian year 1386. The precipitation of Presk station was 826.1 mm, at an altitude of 1880 m above mean sea level. A regional mean annual precipitation equation (mentioned in the previous section) was applied for simulation of spatial distribution of this precipitation over the whole basin area. The average altitude of Honam and Presk watersheds are, respectively, 2055 and 2709 m above mean sea level and their precipitation was estimated at 735.7 and 1017.6 mm, respectively, by applying regional weighted precipitation for 21 March 2007 to 20 March 2008.

The measured monthly precipitation of Presk station (Table 3.15) was used for dividing the estimated annual basin precipitation into 'calculated' monthly precipitation (Table 3.16 and Figure 3.24). There was no precipitation for five months from June to the end of October.

Table 3.15. Monthly precipitation of Presk station.

Month		Precipitation (mm)
Iranian calendar	**Christian calendar**	
Farvardin	(21 March to 20 April) April	288.0
Ordibehesht	(21 April to 20 May) May	99.7
Khordad	(21 May to 20 June) June	0.0
Tir	(21 June to 20 July) July	0.0
Mordad	(21 July to 20 Aug) August	0.0
Shahrivar	(21 Aug to 20 Sep) September	0.0
Mehr	(21 Sep to 20 Oct) October	0.0
Aban	(21 Oct to 20 Nov) November	44.5
Azar	(21 Nov to 20 Dec) December	207.6
Dey	(21 Dec to 20 Jan) January	62.0
Bahman	(21 Jan to 20 Feb) February	44.4
Esfand	(21 Feb to 20 March) March	79.9
Total		**826.1**

Table 3.16. Calculated average monthly precipitation values of Presk and Honam.

Periods (corresponding to Iranian months)	Honam watershed ppt (mm)	Presk sub-watershed ppt (mm)
(21 March to 20 April) April	256.5	354.7
(21 April to 20 May) May	88.8	122.8
(21 May to 20 June) June	0.0	0.0
(21 June to 20 July) July	0.0	0.0
(21 July to 20 Aug) August	0.0	0.0
(21 Aug to 20 Sep) September	0.0	0.0
(21 Sep to 20 Oct) October	0.0	0.0
(21 Oct to 20 Nov) November	39.6	54.8
(21 Nov to 20 Dec) December	184.9	255.7
(21 Dec to 20 Jan) January	55.2	76.4
(21 Jan to 20 Feb) February	39.5	54.7
(21 Feb to 20 March) March	71.2	98.4
Mean annual	**735.7**	**1017.6**

Stream discharge

Zirtagh hydrometric station

The volume of outlet discharged water was 57.4×10^6 m^3 in this station from 21 March 2007 to 20 March 2008; Table 3.17 and Figure 3.25 show the average monthly discharge. The maximum discharge was in April and May and the minimum discharge in October and November. Table 3.18 shows seasonal volume and percentage of outlet discharge.

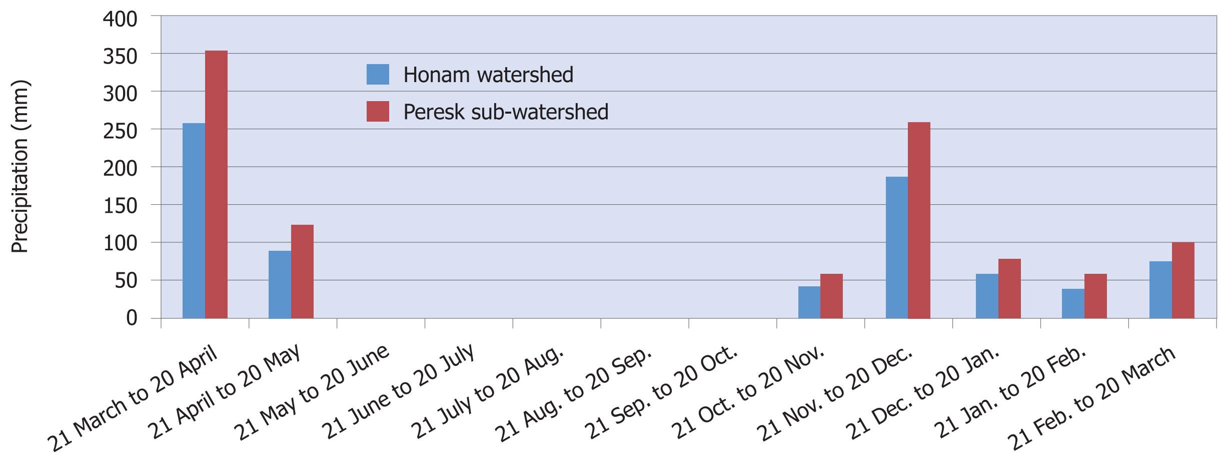

Figure 3.24. Histogram of monthly precipitation for whole basins from 21 March 2007 to 20 March 2008.

Table 3.17. Outlet discharge in Honam watershed from 21 March 2007 to 20 March 2008.

One-month periods	Discharge (m^3/s)
(21 March to 20 April) April	3.09
(21 April to 20 May) May	2.71
(21 May to 20 June) June	1.38
(21 June to 20 July) July	1.35
(21 July to 20 Aug) August	1.62
(21 Aug to 20 Sep) September	1.52
(21 Sep to 20 Oct) October	1.12
(21 Oct to 20 Nov) November	1.15
(21 Nov to 20 Dec) December	2.33
(21 Dec to 20 Jan) January	1.62
(21 Jan to 20 Feb) February	1.62
(21 Feb to 20 March) March	2.33

Table 3.18. Volume and percentage of seasonal water use in Honam basin.

Season	Volume (106 m^3)	%
Spring	19.20	33.44
Summer	12.02	20.93
Fall	11.95	20.81
Winter	14.25	24.82
Total	**57.43**	**100**

Presk hydrometric station

Annual water yield of Presk springs (from 21 March 2007 to 20 March 2008) was 26.02×10^6 m^3 (Table 3.19). Figure 3.26 shows monthly variation in discharge of Presk spring and its runoff discharge at Presk hydrometric station.

Table 3.19. Discharge in Presk hydrometric station from 21 March 2007 to 20 March 2008 corresponding to Iranian year of 1386.

One-month period	Discharge (m^3/s)
(21 March to 20 April) April 2007	2.786
(21 April to 20 May) May	1.749
(21 May to 20 June) June	0.387
(21 June to 20 July) July	0.153
(21 July to 20 Aug) August	0.087
(21 Aug to 20 Sep) September	0.060
(21 Sep to 20 Oct) October	0.049
(21 Oct to 20 Nov) November	0.435
(21 Nov to 20 Dec) December	1.211
(21 Dec 2007 to 20 Jan) January 2008	0.735
(21 Jan to 20 Feb) February	0.784
(21 Feb to 20 March) March	1.471

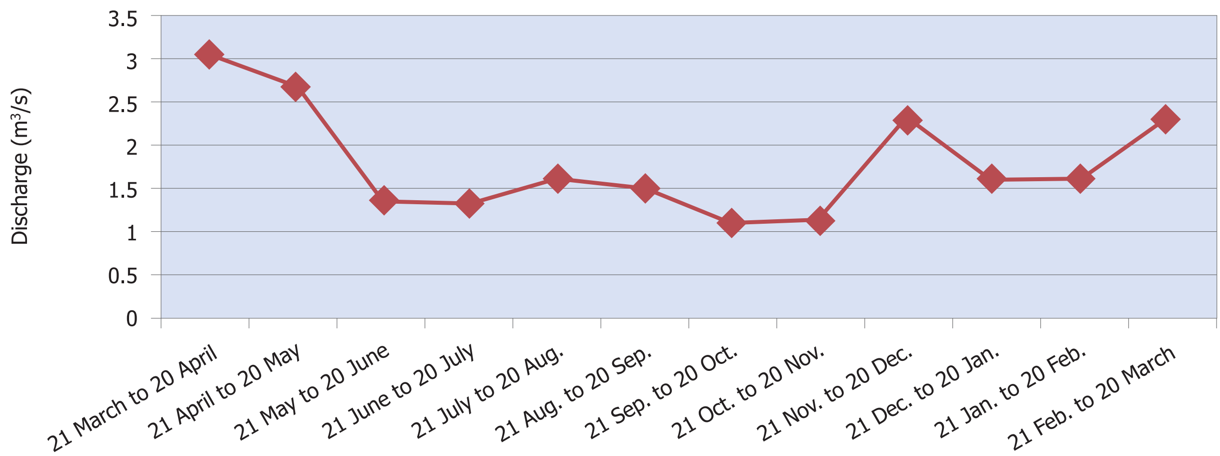

Figure 3.25. Discharge curve of Honam hydrometric station (21 March 2007 to 20 March 2008).

Honam spring and other springs in the basin

The monthly maximum, minimum, and mean discharge values of the Honam River for 1998–2005 are shown in Figure 3.27. Average annual flow was 444 L/s and the minimum and maximum monthly discharges in October were 333 and 672 L/s, respectively. Average mean annual discharge volume was 14.0×10^6 m^3. Irrigation efficiency in these lands is low and water loss is high. Despite adequate water in the middle parts of the basin, much agricultural land is under rainfed farming due to steep slopes, topographical limitations, and lack of pumping facilities to convey water from the bottom of the river to marginal uplands.

The annual volume of the spring discharge over the whole Honam watershed was about 28.02×10^6 m^3. When the Presk spring runoff water measured at Presk station was added to the above figures then the total volume was 54.02×10^6 m^3.

Channel discharge for irrigation

The total mean annual use of water for irrigation was 17.0×10^6 m^3 in the whole Honam plain (Table 3.8).

Withdrawal from wells

The total mean annual use of water from wells was 1.817×10^6 m^3 in Honam plain (Table 3.9).

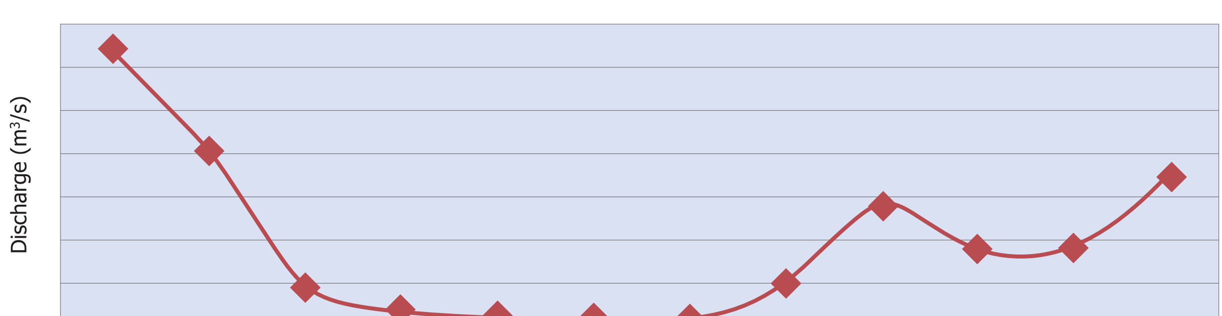

Figure 3.26. Monthly discharge at Presk hydrometric station (2007–2008).

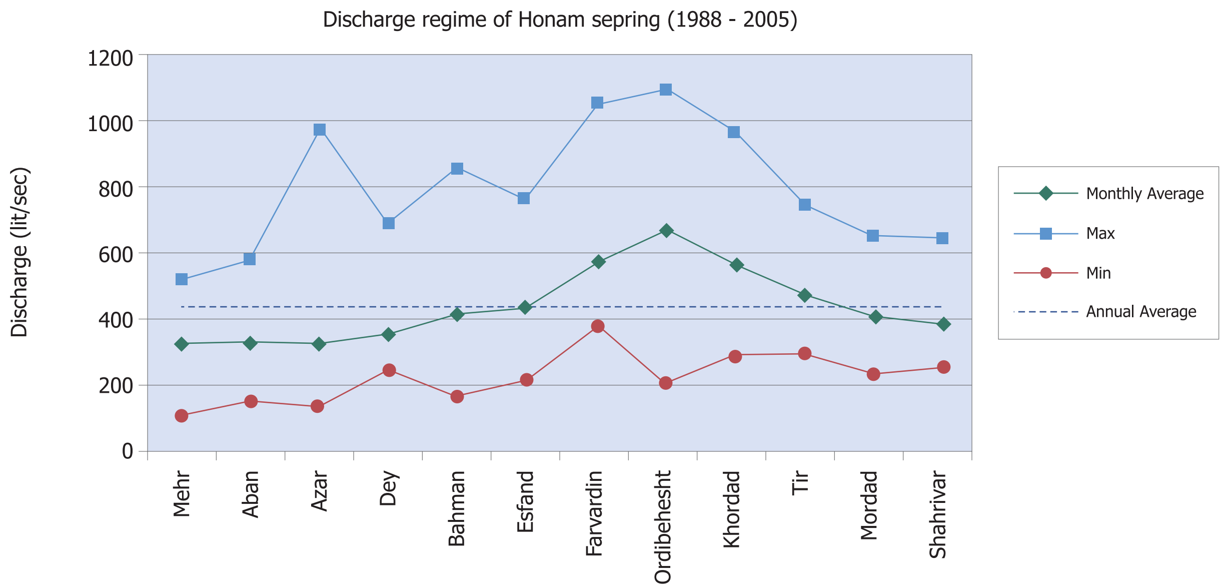

Figure 3.27. Monthly discharge variation of Honam spring for 1988–2005.

Brief Honam watershed water balance

The investigation on water balance in Honam watershed for 2007–2008 is summarized below.

a- Surface water balance at Presk station upstream

- The area of Presk sub-catchment is 67.71 km^2, and precipitation was 1017.6 mm over the whole area, which means that total volume was equal to 68.9×10^6 m^3.
- Discharge at Presk hydrometric station was 26×10^6 m^3

These values show that excess inflow as precipitation over the whole watershed was 42.88×10^6 m^3, which is more than the discharge of surface outflow. This means that sum of the evapotranspiration and probable underground outflow was 42.88×10^6 m^3. There are no data on underground water flow due to karstic outcrops at the Presk hydrometric station outlet. Additionally, the annual runoff coefficient of Presk was 0.38×10^6.

b- Water resources over the whole Honam watershed

The water balance of Honam watershed (Table 3.20) had the following figures for different components:

- Area was 140.49 km^2
- Precipitation was 735.7 mm over the whole 140.49 km^2 area, with total volume equal to 103.34×10^6 m^3
- Springs
- Outlet of Presk hydrometric station (springs + runoff) was 26.0×10^6 m^3
- Total discharge volume of springs was 56.8×10^6 m^3, of this agriculture and drinking uses 29.75×10^6 m^3 over the whole basin
- Total discharge of wells was 1.8×10^6 m^3
- Diversion intake was 17.8×10^6 m^3
- Outlet from hydrometric station was 57.4×10^6 m^3

Water balance components showed that the annual runoff coefficient of Honam basin was equal to 0.56. Usage of surface and subsurface water in Honam basin was 49.45×10^6 m^3, i.e. 47.8% of total precipitation. This is a high ratio, but the basin inflow was less than the total basin outflow by 3.35 × 10^6 m^3, i.e. > 3.2%. This shows that Honam watershed was recharged by adjacent basins through underground flow.

Outflow components from Honam basin and its precipitation were 57.4 × 10^6 and 103.34 × 10^6 m^3, respectively, giving a surface runoff coefficient of 0.56. This amount is 1.5 times more than the runoff coefficient at Presk in the upper part of Honam, which had a lower evapotranspiration and higher precipitation. The conclusion is that the upper part of the basin discharged high amounts of underground flow to the lower part at Presk station.

3.3.2. Analysis of water balance components in Merek basin

Water balance components are precipitation over the water balance area, surface and subsurface discharge (outflow), surface and subsurface recharge (inflow), and discharge by wells and qanats in the study area.

Precipitation

Table 3.3 shows the monthly and annual precipitation in the five stations of the Meteorological Organization of Iran from April 2007 to March 2008. A rain gauge at Najafabad station was installed as complementary for recording precipitation in short intervals, but it did not have enough data for the full period and was omitted from the list of data. Correlation analysis between precipitation and elevation was used to draw several standard curves (Figure 3.28), showing relatively linear behavior of the precipitation–elevation relationship; however, the weak correlation shows that it was unlikely that precipitation was related to elevation. Sarfiroozabad data was selected as representative of mid-basin precipitation for the whole basin because the site is in the middle of the basin at an elevation near the mean basin elevation. Sarfiroozabad rain gauge mean precipitation was 412 mm from April 2007 to March 2008. Figure 3.29 shows the histogram of monthly precipitation over the Merek basin from April 2007 to March 2008. Total volume of precipitation was 125.66 × 10^6 m^3 in the water balance period (one full year from April 2007 to the end of March 2008).

Table 3.20. Water balance components (10^6 m^3) at basin scale for Honam watershed.

Source	Inflow	Outflow
Precipitation	103.4	*
Surface outflow	0	57.4
Usage by wells	*	1.8
Usage from springs	*	29.75
Usage of surface flow	*	17.8
Underground flow	*	*
Sum	**103.4**	**106.75**

*Inflow – Outflow = –3.35

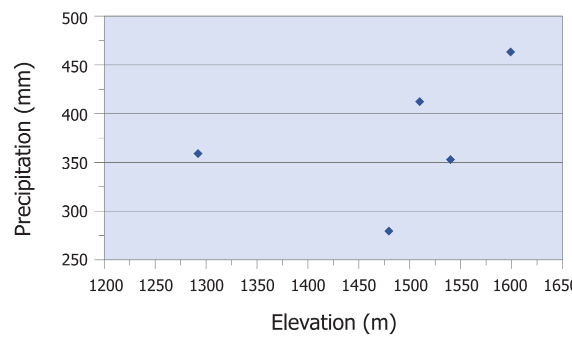

Figure 3.28. Precipitation–elevation relationship.

Outlet discharge of the Merek basin

Discharge at the outlet of Merek plain was calculated based on Table 3.21. The total volume of discharge water from Merek River at Halashi station was 5.4 × 10^6 m^3 from April 2007 to 20 March 2008. Table 3.21 and Figure 3.28 show average monthly discharge. The maximum discharge was in April and May and the minimum in July and August.

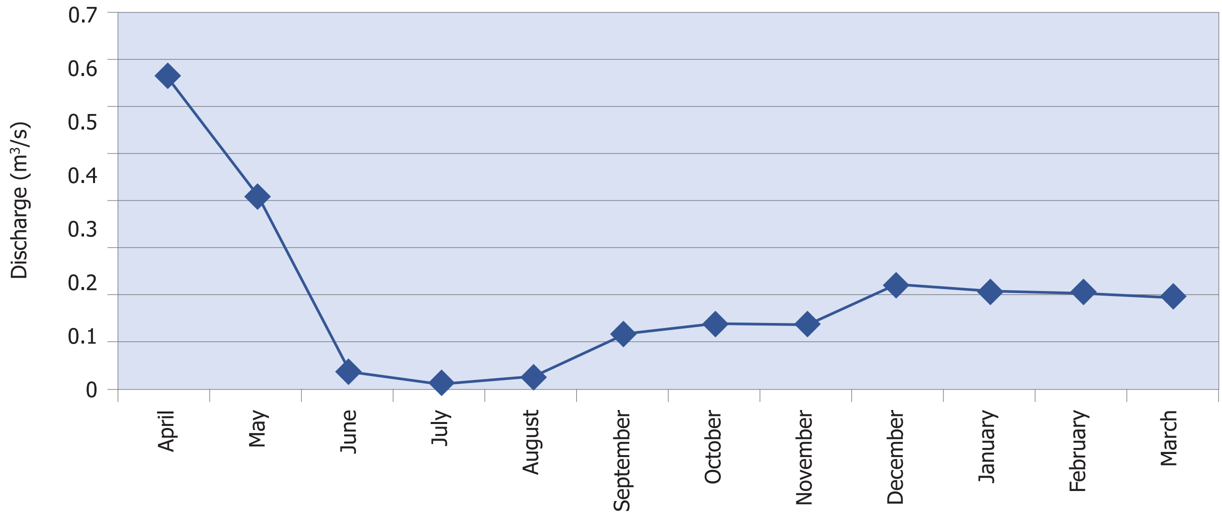

Figure 3.28. Monthly discharge at Merek outlet during water balance periods.

Table 3.21. Surface outlet discharge from Merek plain.

Month	Outlet discharge (m^3/s)
April	0.58
May	0.36
June	0.03
July	0.01
August	0.02
September	0.10
October	0.12
November	0.12
December	0.19
January	0.18
February	0.18
March	0.17

Discharge by wells

Discharge by wells is an important component of water balance that can be accurately recorded. The annual discharge by wells was 6.8×10^6 m^3, of which 99% was used for agriculture and the other 1% for drinking and industry (drinking water from wells used by villages was 0.033×10^6 m^3).

Discharge by qanats

Qanat discharge was computed using Table 3.13 data. Annual discharge of the four qanats was 2.2×10^6 m^3 for October 2006 to September 2007. The monthly volumes of qanat discharge are shown in Table 3.12. Qanat water resources were consumed for agriculture and drinking, of which 1.95×10^6 m^3 was used for agriculture and 0.25×10^6 m^3 for drinking.

Discharge from Merek River

Water from Merek River was taken at three points: Gavani diversion dam, Gazaf diversion dam, and directly from the river by pumping. Discharge by these structures was 0.59×10^6 and 0.35×10^6 m^3 per year, respectively, and abstraction by pumping was 0.005×10^6 m^3 per year.

Subsurface inflow and outflow

There were insufficient data to analyze subsurface inflow and outflow. There are limestone outcrops in the eastern part of the upstream of Merek that may discharge some groundwater through karstic channels. However, we have no information on the subsurface behavior of this karstic area.

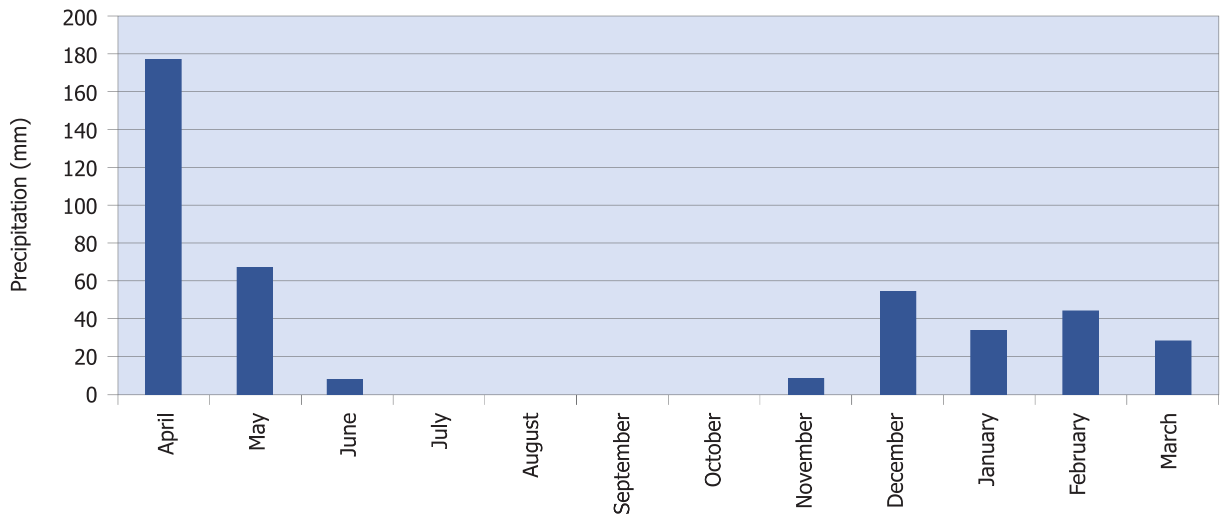

Figure 3.29. Histogram of monthly precipitation over the Merek basin.

The Merek plain is formed from alluvium, which constitutes the structure of Merek aquifer/aquifers and recharges the wells, qanats, and seepage of the Merek River banks. Merek basin at Halashi is a part of the Merek plain and continues downstream of the Merek River to join the west part of the Mahidasht plain. It seems that there are no appreciable subsurface inflows from adjacent basins to Merek basin aquifers, but it is clear that the upper parts of Merek plain at Halashi have an elongated recharge boundary with the downstream adjacent aquifers that directly connect them. Unfortunately, there were insufficient data to analyze this recharge boundary.

3.4. Results of water resources and water balance estimation

The different components of water resources and the water balance of Merek were studied from April 2007 to March 2008 (Table 3.22). Annual total volume of precipitation and outlet discharge in the whole catchment were 125.66 × 10^6 and 5.4 × 10^6 m^3, respectively. The sum of discharges by diversion intakes from the main irrigation channels was 0.945 × 10^6 m^3 per year. Water use from wells and qanats was 6.8 × 10^6 and 2.2 × 10^6 m^3, respectively.

Based on the water balance components, the surface runoff coefficient was 0.04; while for the whole Mahidasht watershed (including Merek and other areas up tot Doab station), with approximately 2.5 times larger area, the coefficient was 0.09. The difference indicates that groundwater is more important than surface water in Merek catchment.

As the above results show, there was considerable difference between the sum of outflow and inflow of the water budget components in Merek at Halashi outlet. Part of the difference between inflow and outflow was due to actual evapotranspiration that could not be measured or estimated in this study; however, subsurface outflow from upper parts of Merek plain to lower parts behind Halashi section also played a role.

Table 3.22. Water balance components in a basin scale in Merek watershed.

Type of water resource		Volume (10^6 m^3)	Type of consumption
Qanats	Sakhr	0.39	Agricultural use 2.21
	Sarfiroozabad	1.44	
	Khosravi	0.17	
	Ghomesh	0.23	
Total		2.24	Domestic use 0.03
Wells	6.76		Agricultural use 6.72 Domestic use 0.03 Industrial use 0.01
Canals			Agricultural use 0.945
Merek watershed outlet		5.435	

3.5. Conclusion and suggestions

The CP project team tried to install some equipment to monitor some important factors such as surface outflow and precipitation. Water balance and resource assessment were the major needs for planning natural resource use and management. Water balance or water resource components were not available for most of the basins over any time interval. Some major components were monitored by this project and some were estimated based on available data in the short period of the project. The results of research are:

1. The total outflow of the catchment showed that water was not a limiting factor for the development of this region and the supply of water was more than the demand – although there are some problems in the distribution of the available water resources over the different parts of the catchment.
2. Use of surface and subsurface water on Honam basin was 49.45 × 10^6 m^3, i.e. 47.8% of total precipitation.
3. The basin inflow was less than the total basin outflow by 3.35 × 10^6 m^3, i.e. > 3.2%. The sum of the evapotranspiration, probable underground flow, and excess outflow (3.35 × 10^6 m^3) was the amount of water recharged by underground flow from adjacent basins.
4. The downstream outcrops of Honam did not provide enough evidence for underground outflow, therefore the underground inflow in Honam watershed was the sum of evapotranspiration plus excess outflow (3.35 × 10^6 m^3). However, the data for actual basin evapotranspiration were not available to determine the amount of those two components.
5. The surface runoff coefficient over the whole Honam was 0.56, which was 1.5 times more than the runoff coefficient at Presk in the upper part of Honam, which had a lower evapotranspiration and higher precipitation. The conclusion is that the upper part discharged a high amount of underground flow to the lower part at Presk station.
6. For future study, it is necessary to distinguish and separate the amount of underground inflow and evapotranspiration in the water balance equations, in addition to underground outflow. It is necessary to continue research for the estimation of basin evapotranspiration and recognizing geological formation

and structures in downstream sections – in which, probable underground outflow can be indirectly determined by geological setting, and evapotranspiration by a detailed water balance plus vegetation cover routing.

7. Data collection on the hydrodynamic parameters of alluvial and karstic aquifers of Honam is needed for completion of water balance analysis and determination of all water resource components.
8. Water use, precipitation, and surface water outflow and inflow were the components of water balance that were estimated reliably.
9. The results show that total water usage was 9.98×10^6 m^3 and the surface water outflow 5.435×10^6 m^3. The main use of water in Merek was for agriculture, especially for irrigation that constituted 99% of the total water use. The remaining 1% was used for drinking and other domestic purposes.
10. Water balance analysis shows that the runoff coefficient (0.043) was very low in Merek, which shows the importance of natural aquifer recharge and groundwater in this area.
11. One of the problems for studying water resources in this area is lack of data. Therefore, a priority for water monitoring is to continue collecting surface outflow data at Halashi Hydrometric Station. In addition, completion of the piezometric well network for observation and exploration is necessary for water management planning.

3.6. References

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Chapter 4.

Application of a Single Rainfall–Runoff Event Model for Evaluation of Land Use in Flooding of Upland Areas of the Karkheh River Basin (Case Study: Honam and Merek Catchments)

Jahangir Porhemmat, Adriana Bruggeman, Majid Heydarizadeh, Mohammad Ghafouri, Bagher Ghermezcheshmeh, Iraj Vaiskarami and Homayoun Hesadi

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4.1. Introduction

For many centuries, humans have changed land use and intervened in natural resources for different purposes such as development of urban and rural residential areas or expansion of agricultural activities for food production. In some cases, these activities have resulted in deterioration and degradation of the natural resources. Such changes have affected the hydrologic regime of drainage basins dramatically and therefore land-use changes are nowadays considered a global challenge more critical than climatic change (Sala *et al*., 2000).

Generally, the runoff volume and hydrograph shape of flood events have been related to physical variables including soil, vegetation cover, topography, and hydrologic characteristics of the watershed. One of the manageable parameters in this regard is land use that is continuously changing. There is a relative equilibrium between physical and climatic parameters in nature, thus the formation and amount of the runoff are functions of rainfall. However, the variation of land use could result in changes in vegetation cover, infiltration rate, and roughness of the basin, all of which could affect the amount of runoff and flood hydrograph shape. Hence, variation of hydrologic regime in the long- and medium-term is a function of land use (Miller *et al*., 2002). The effects of such changes in hydrologic response of the basin are reflected as changes in run off depth, minimum and maximum discharge, flood volume, soil moisture, and evapotranspiration amount (Sikka *et al*., 2003).

Research has shown that development of urban areas would increase the peak value and runoff, while an increase in forest area would decrease these amounts (Hundecha and Bardossy, 2004).

Investigation of land-use change effect on flood event frequency indicates an increase in these phenomena (Crooks and Davies, 2001). Recently, news and reports of flood events in Iran indicate that most parts of the country are in danger of destructive and periodic floods that affect residential areas financially and socially. These phenomena have had an increasing trend during recent decades, therefore flood and flood risk is a socio-economic concern for the country, and mitigation strategies are being considered by scientists and government authorities.

The present research involves some of the factors affecting flood events and flooding area and the studies were carried out to determine hydrological behavior of the basin in response to land-use changes using the HEC-HMS model and also to develop a suitable approach for using rainfall–runoff models in other basins.

4.2. Literature review

Croke and Jakeman. (2001) and Fohrer, *et al*. (2002), in their studies on the effect of land-use changes by HEC-HMS, showed different results on the effect of decreasing forest area and expansion of agricultural and residential area on runoff amount. Sharifi *et al*. (2002) believes that the main cause of the catastrophic flood of Golestan dam basin was land-use change, especially deterioration of forests and rangeland. Sikka (2003) cites that land use and vegetation cover management hydrologically affect the runoff, minimum and maximum discharge, soil moisture, and evapotranspiration. Similarly, Singh (1996) concluded that the runoff of a basin depended on many factors such as dynamics of rainfall, infiltration, and antecedent soil moisture. Hawkins (1997) reported that unexpected variation of curve number (CN) could change the antecedent moisture and the following runoff depth. In order to develop and improve the HEC-1 hydrologic model and GIS, Suwanwerak (1994) investigated the effect of land-use changes on past and future flood events. He also studied land-use changes of upland areas on flood pattern downstream and reported that reduction of upland forest area could increase the level of flood water downstream.

Hundecha and Bardossy (2004) used a descriptive rainfall–runoff model, to investigate the effect of land use on runoff rate and concluded that city area development could increase the peak values of flood events and, conversely, by increasing the forest area, the peak value decreased. Effect of land-use changes on flood event frequency was investigated by Croke and Jakeman (2001) in a 30-year period and they concluded that the frequency was increased by land-use change. In a study of land-use change and flooding potential in a 45-year period, Khalighi (2004) used HEC-HMS and showed that by increasing area of rainfed farms from 4528 to 20231 ha, the time of concentration decreased by 14%.

By combining GIS and HEC-HMS, Farazjou *et al*. (2007) investigated the effect of vegetation cover changes on volume and peak discharge of floods in the upland of Golestan dam basin. They predicted the hydrologic response of the basin in different land-use scenarios, and their results showed that the vegetation cover effects were limited in capacity to control catastrophic flooding with high frequency. Moreover, they showed that in a pessimistic scenario of land-use change with deteriorating trends in forest and rangeland and expansion of farming area the values of flood peak with a return period of 5–100 years would be increased by 24–35%.

Using outlet hydrograph analysis by assuming lumped basin, Khosroushahi and Saghafian (2005) investigated some factors affecting flooding, such as land use, vegetation cover, and climatic factors in the sub-basins. They concluded that hydrologic responses of sub-basins in relation to outlet discharge were nonlinear processes. They showed that the CN was the most important factor in flood mitigation strategies.

By using HEC-HMS and GIS for flood simulation in reservoir routing, Farajzadeh (2004) concluded that the HEC-HMS models were suitable for simulation of flood events. Also, in simulation of rainfall–runoff using the HEC-1 model, Morid *et al*. (1998) concluded that this model could give reasonable results; however, hydrographs with a normal bell shape should be used in its calibration. Jahantigh (2000) demonstrated that HEC-HMS was a suitable model for Sivand River in Kor basin of Fars Province and concluded that hydrologic-based models had greater capability to predict runoff compared to hydraulic-based models. Shaghaghi (2002) used the HEC-HMS model for simulation of peak discharge in tributaries of Mohammadabad Basin in Golestan Province, and estimated runoff using rainfall data and found reasonable agreement between the results and the observed values.

4.3. Materials and methods

4.3.1. Procedure

In this study, in order to investigate effects of land-use changes, the following actions were carried out:

- Collecting and estimating physiographic data and the required parameters
- Collection of rainfall and flood events data in Honam basin, and computed or estimated the required parameters
- Preparation of land use map
- Preparation of hydrologic soil groups data in the basin
- Overlaying land use map and hydrologic soil group data for estimation of basin CN, using weighted mean methods
- Input of information into the HEC-HMS software in order to simulate rainfall–runoff in the basin
- Setup of primary rainfall–runoff model
- Calibration of the parameters
- Validation of the calibrated parameters
- Using CN in the optimistic and pessimistic scenarios
- Comparison of model output of simulated hydrograph, analysis of the results, and conclusion
- Suggesting improved land-use management for the future

4.3.2. Study area

Geographic location

Honam is a catchment as a part of Sarab-Sayed Ali sub-basin in the upper northeast part of the KRB in southwest Iran (Figure 4.1a). It is located within 49°08'–49°17'E and 33°30'15"–33°37'11"N. This catchment has an area of 140 km^2 and an elevation range of 1480–3560 m above mean sea level.

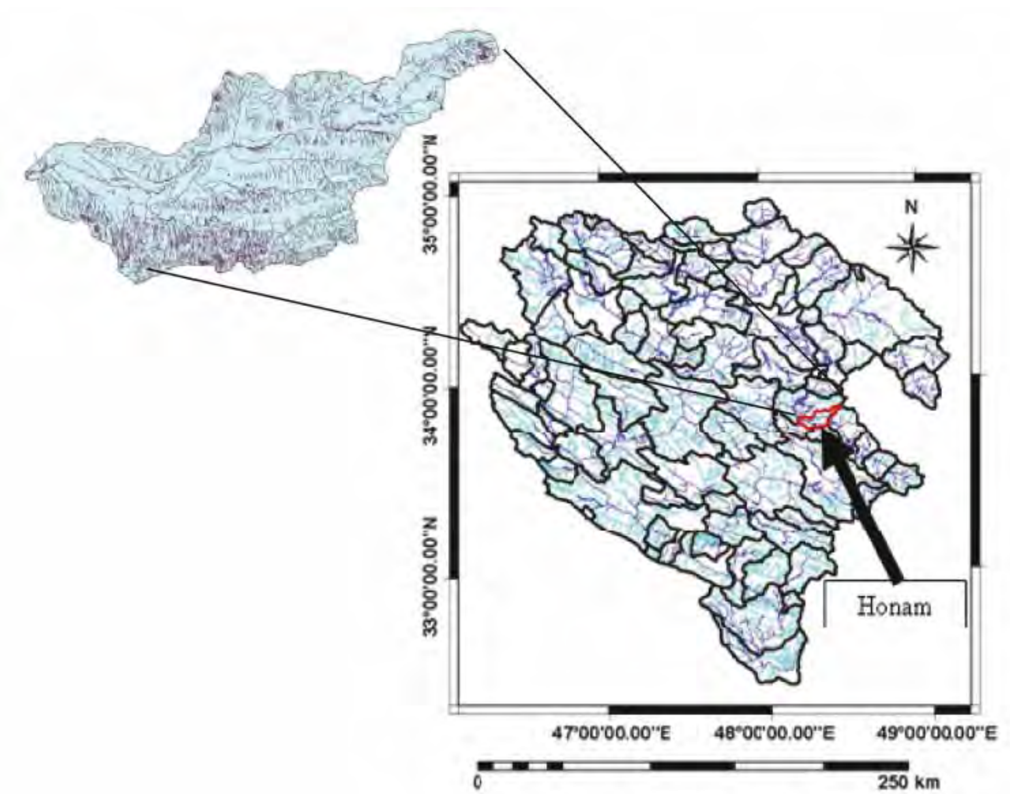

Figure 4.1a Honam basin and drainage network in the upper KRB.

Figure 4.1b. Merek catchment and drainage network in upper Karkheh.

Merek catchment is a part of Polchehr sub-basin in the upper northwest of the KRB in southwest Iran (Figure 4.1b). It is located within 47°04'30"–47°22'30"E and 34°01'–34°09'30"N. This catchment has an area of 309.1 km^2 and an elevation range of 1440–2760 m above mean sea level.

Land use

The land use map was produced in Arc GIS using Landsat TM images of 2002 (Mirghasemi, 2008). Figure 4.2 shows the different land uses and percent of variation of each unit in the Honam basin. Figure 4.3 is a view of land use in Honam (April 2005). The mountainous areas are rangelands and lower parts are cultivated areas.

Figure 4.4 shows the different land uses and percent of variation of each unit in Merek in Halashi basin. The mountainous areas are rangelands and the lower parts are cultivated.

Soil texture

The soil texture of the Honam catchment is mainly clay to silt in the plains area with medium permeability due to the presence of high amounts of fine gravel. A large percentage of the hills and hillside

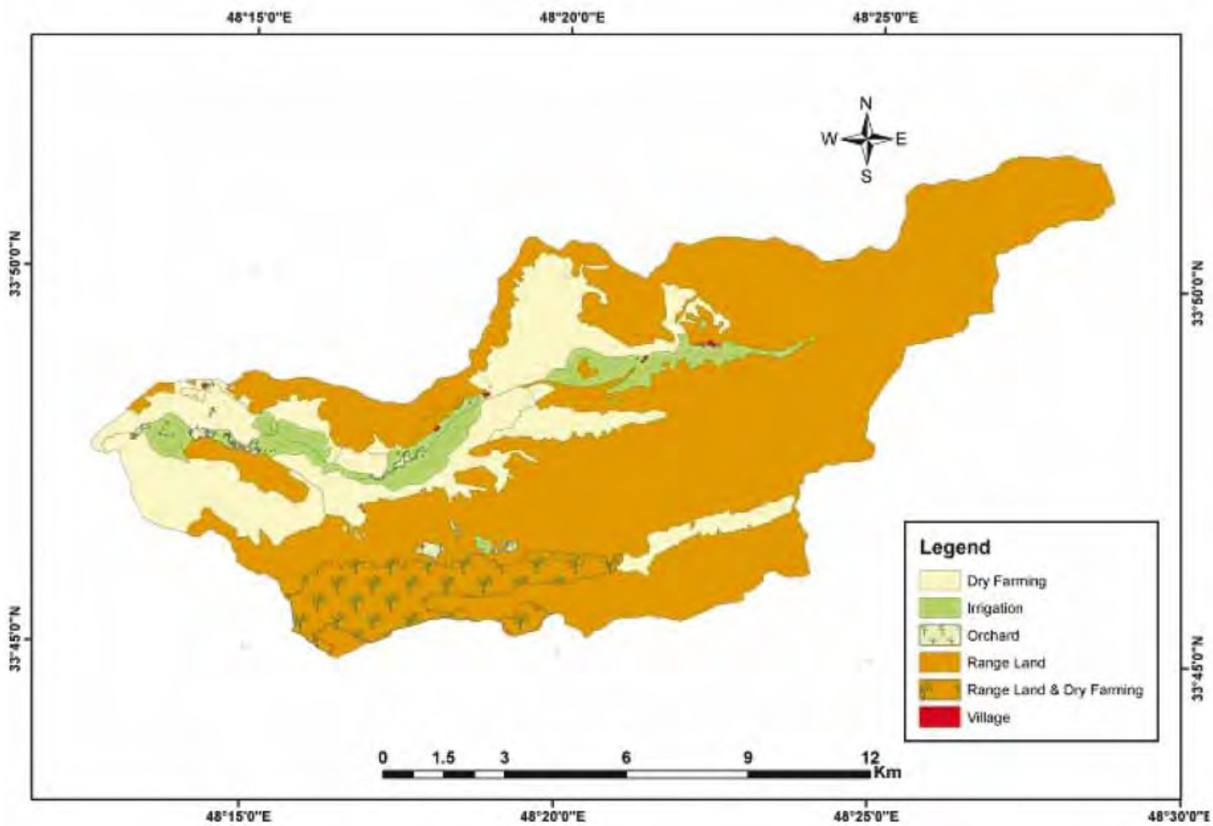

Figure 4.2. Land use map of Honam catchment in 2002.

Figure 4.3. A view of land use in Honam (April 2005).

areas are covered by (mostly fine) rocks. Hydrologic soil groups map was produced according to soil texture (Milani, 2009) and infiltration rates in different parts of the basin. Figure 4.5 shows the soil texture and Figure 4.6 shows the corresponding infiltration index or hydrologic soil groups, where No. 3 and 4 correspond to hydrologic soil groups C and D, respectively.

The soil texture of the Merek catchment is mainly clay–silt in the plains area and has medium permeability due to high amounts of fine gravel. In the hill and hillside areas, the percentage of rock and fine rock is high. A soil hydrologic group map (Figure 4.8) was produced from soil texture (Figure 4.7) according to Milani (2009).

The area of hydrologic soil groups and corresponding CNs in Merek catchment (Table 4.1) were prepared by crossing Figure 4.4 and Figure 4.8. The weighted average of CN was 76.53, with a

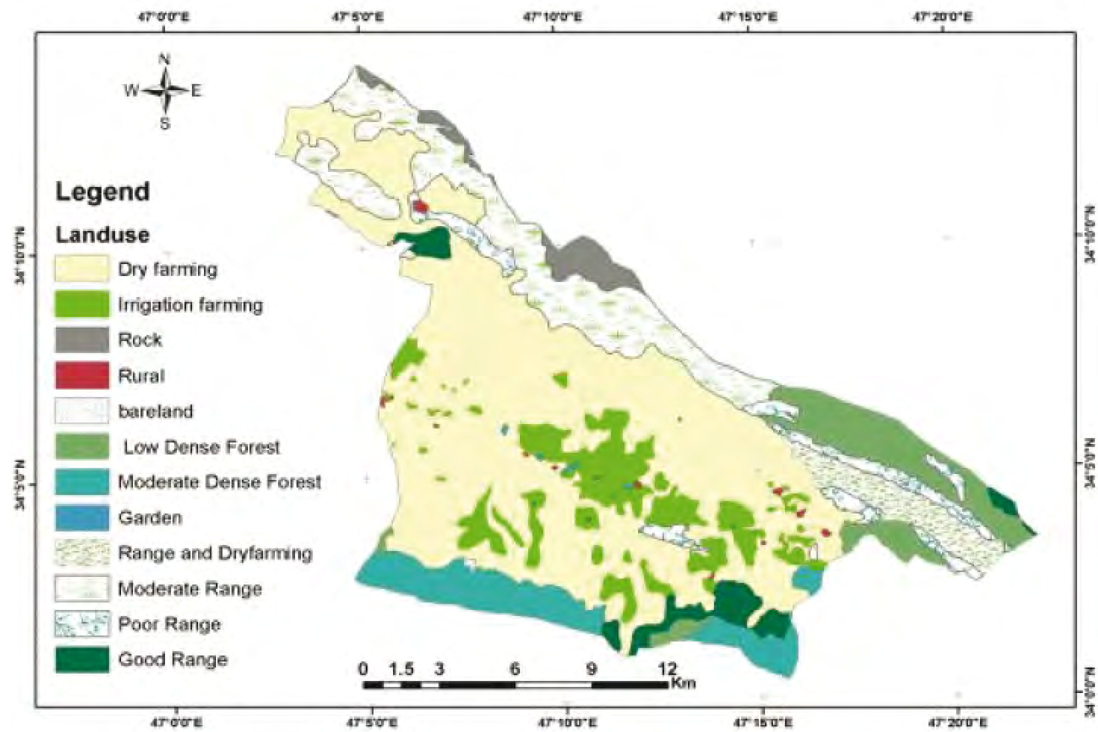

Figure 4.4. Land use map of Merek catchment in 2002.

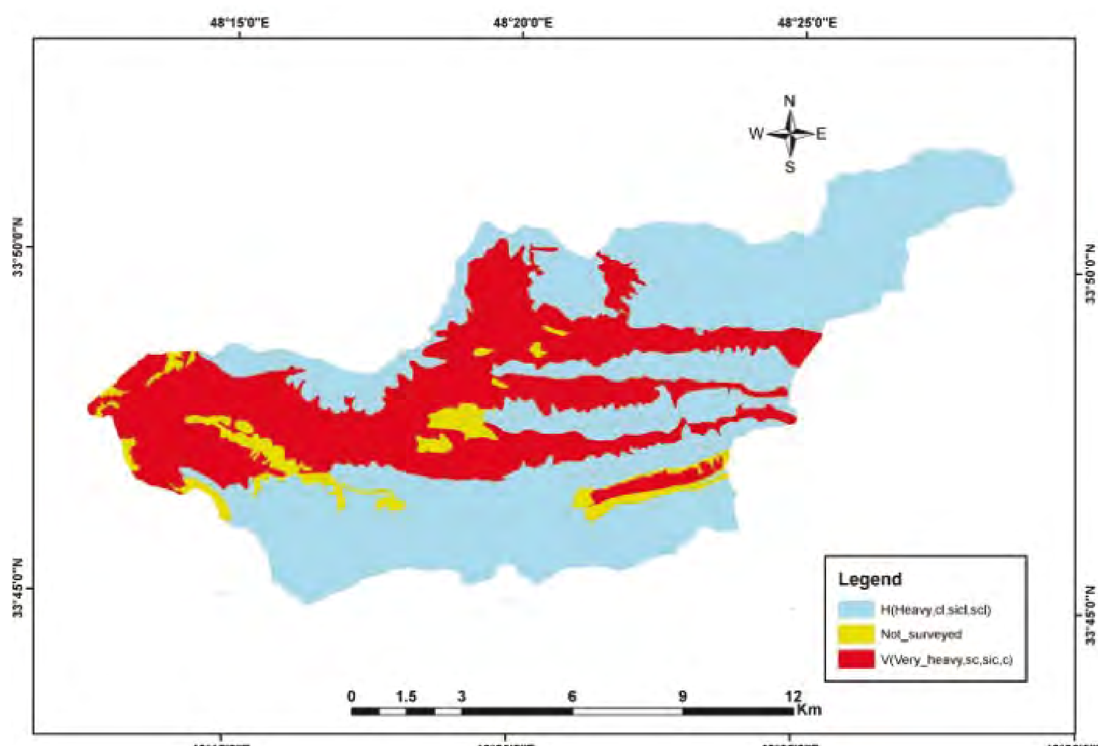

Figure 4.5. Soil texture map of Honam catchment.

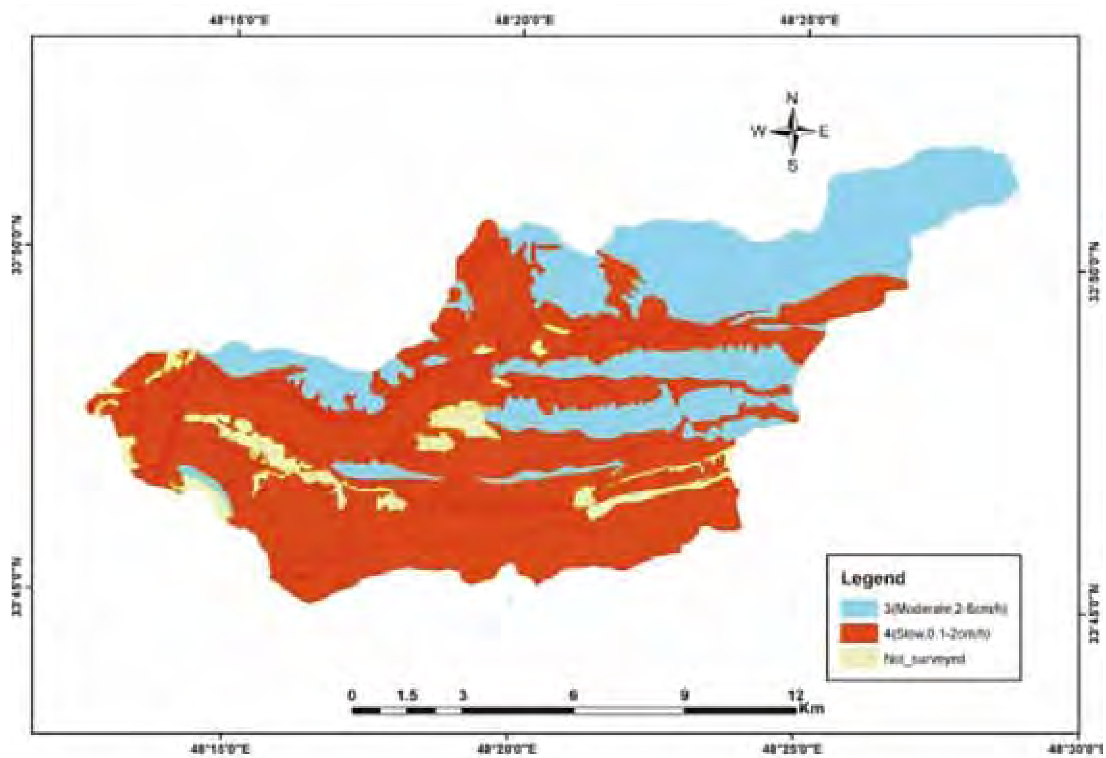

Figure 4.6. Infiltration rate map of Honam catchment.

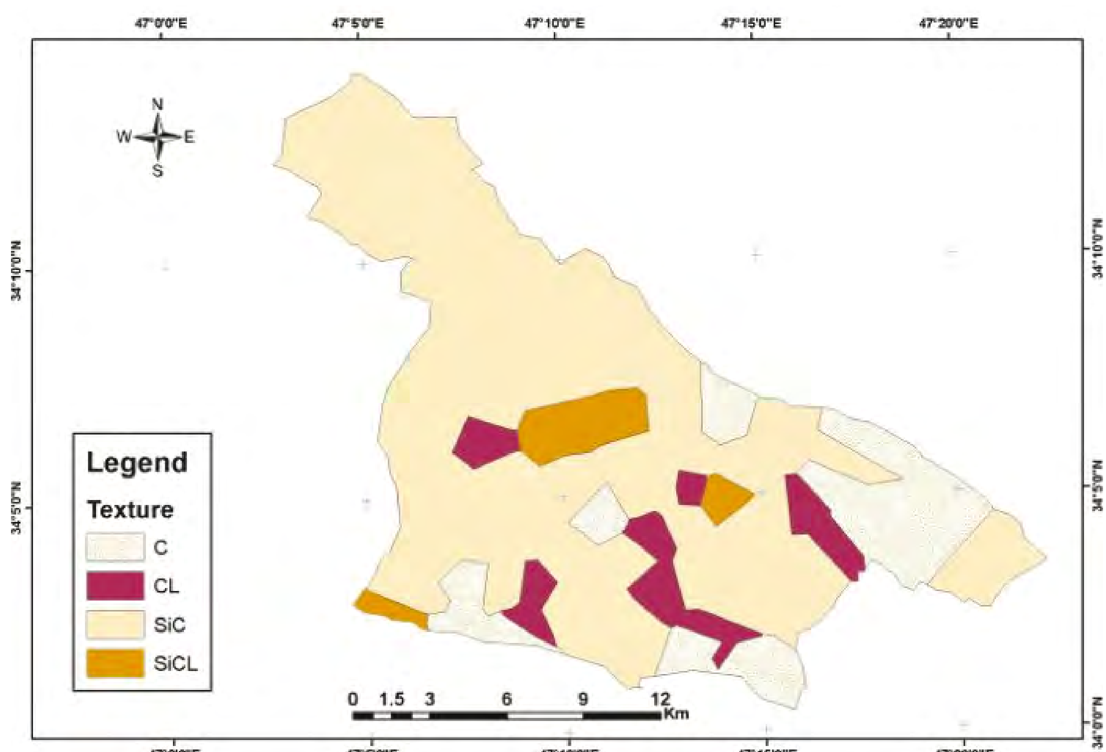

Figure 4.7. Soil texture map of Merek catchment.

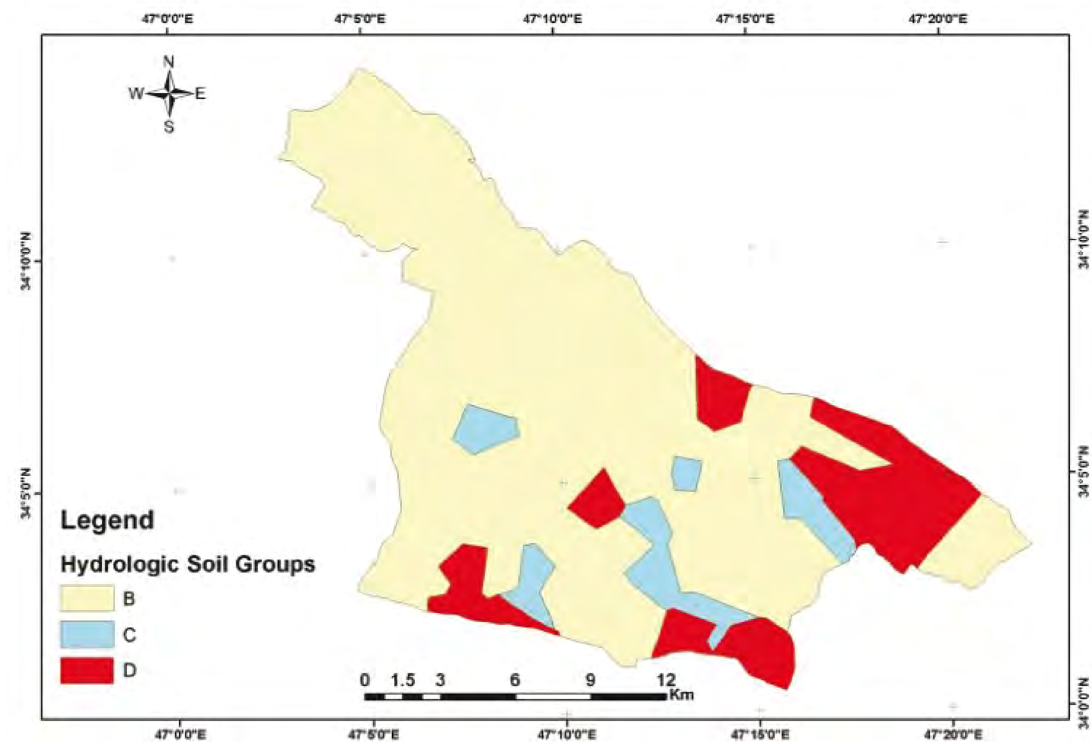

Figure 4.8. Hydrologic group map of Merak basin.

minimum of 55 for an area of 8.844 km^2 of moderately forested parts, and maximum CN of 100 for the 6.814 km^2 covered by rock outcrops (Table 4.1).

4.4. Approach of HEC-HMS model

The HEC series software was prepared by the Hydrologic Engineering Center of the US Army in different hydrologic, hydraulic, and water engineering sections and has been internationally recognized. The first series of this software is HEC-1, which is specific to hydrology, and was developed in 1968 and is capable of simulating response of the watershed in a rainfall event as a flood or surface runoff.

In the 1990s, a Windows operating system of the new and graphical version of the software was developed as HEC-HMS, by the above Center. This program is essentially modern software with a Windows interface and some features that make it more user friendly for simulation of rainfall–runoff in basins, water supply studies, flood hydrology, predicting basin response to urban developments, surface water drainage, reservoir spillway designing, flood mitigation, and management of flood plain areas.

4.4.1. Modeling processes and estimation

Simulation of hydrologic processes by HEC-HMS includes three main components: basin model, meteorological model, and control specifications. Watershed model includes estimation of watershed losses, transformation of rainfall to runoff, amount of base flow and simulation channels and reservoirs routing in basin model. One basic component of the basin model is basin

Table 4.1. Area of hydrologic soil groups and corresponding CN in Merek basin.

Land use	Hydrologic soil groups	CN	Area (km^2)
Bare land	D	86	0.16
	B	76	139.60
Dry farming	C	84	14.29
	D	88	4.34
	B	66	8.75
Low dense forest	C	77	0.75
	D	83	12.58
	B	55	8.85
Moderate dense forest	C	70	1.83
	D	77	9.51
	B	60	0.30
Orchards and arboriculture	C	73	0.08
	B	69	21.90
Irrigated farming	C	78	2.90
	D	83	2.55
	B	67	3.40
Rangeland and dry farming	C	81	0.29
	D	88	7.51
	B	79	35.60
Moderate rangeland	D	89	2.80
	B	69	7.40
Poor rangeland	C	86	0.59
	D	84	5.60
	B	61	5.40
Good rangeland	C	74	1.31
	D	80	2.88
Rock	B	100	6.85
	B	92	0.94
Urban	C	95	0.07
	D	95	0.06
Weighted average of CN = 76.5		**Sum of area = 309 km^2**	

area, which in Honam basin was set to 140.16 km^2. Selection of methods for calculation of the losses and estimation of its required parameters is an important step in the basin model. There are different methods for calculation of losses based on the user's choices, including the following:

- Flow deficiency and constant-rate losses model
- SCS model (simple and girded)
- Green and Ampt model
- Soil moisture accounting model
- Initial and constant rate model

The SCS simple model was selected for the present research, due to the available information and data layers. Simplicity of the model and the minimum data requirement are the reasons that SCS has been applied worldwide and in many projects over the last 50 years.

Calculation of losses in this method needs the determination of CN, initial losses, and percentage of impervious area.
The famous CN model introduced by SCS considers excess rainfall as a function of cumulative rainfall, vegetation cover, land use, and antecedent soil moisture. By analyzing some small experimental watersheds, the SCS developed an empirical equation between initial abstraction (Ia) and specific retention (S), as $Ia = 0.2S$, and suggested that this amount could be changed to as much as 0.05S by local calibration.

Maximum interception could be correlated to catchments characteristics and CNs. The CN values in a basin are a function of land use, soil type, and antecedent soil moisture. Generally, the CN value varies from 100 for impervious surfaces to 30 for highly permeable soil. By applying these factors, the estimated CN was 79.1, as a weighted average for the study area. Thus, S was 67.1 mm and the initial loss ($Ia = 0.2S$) was 13.4 mm.

To investigate the land-use change effects in management and programming processes in the study area, two conditions of optimistic and pessimistic scenarios were considered, based on the latest conditions of land use. The pessimistic scenario implies the deterioration of vegetation cover and land disturbance and with increasing trends, while in the optimistic scenario the land use is assumed under suitable management condition. The condition for such a scenario is that S = 67.12 mm and Ia = 13.43 mm.

Based on the residential areas, rock outcrops, and hard surface roads, the impervious area was estimated as 2% and was inputted into the model.

For runoff estimation and the required parameters, there are different methods to calculate runoff from sub-basins, but users can only select one of the following:

- Modified Clark method
- Snyder method
- Kinematics wave method
- SCS method
- User-specified S Graph method
- User-specified unit hydrograph method

The SCS method was used in the present research, due to available information and data, in which lag time is the main input parameter for the model.

The following equation was used to calculate lag time (t_{lag}) in SCS methods:

$$T_{lag} = ((l^{0.8} * (s+1)^{0.7}) / (1900 * y^{5})) \quad [1]$$

Where, t_{lag} is the lag time of the basin (h), *l* is main channel length (feet), *y* is mean slope (%), and *s* is the index of water retention in the basin (inches).

Table 4.2. Constant monthly discharge in Honam catchment.

Month	Feb	March	December
Constant discharge (m^3/s)	1.7	4.42	2

Table 4.3. Constant monthly discharge in Merek catchment.

Month	March	April	May
Constant discharge (m^3/s)	0.5	0.48	0.43

Using this equation and the CN of the study area, the lag time was estimated at 14.22 h. The value of s was calculated by the following equation;

$$s = (100/CN) - 10 \quad [2]$$

l was estimated using topography and drainage system, and *y* was calculated using the slope map.

4.4.2. Base flow calculation

In each sub-basin, base flow can be calculated using the following methods:

- Recession method
- Constant monthly method
- Linear reservoir method
- Bounded recession method

In the present research, according to the available data and information, the constant monthly method was used to calculate the base flow, hence, it was necessary to obtain the constant monthly discharge. Using the data of 2008 as a baseline, constant monthly discharges for 2008 were calculated for Honam and Merek catchments (Tables 4.2 and 4.3, respectively).

4.4.3. Meteorological model

The meteorological model includes rainfall and evapotranspiration components. In order to analyze rainfall data, the following methods can be used:

- User specified hyetograph
- SCS hypothetical storm
- Frequency storm
- Girded precipitation
- Gauge weighting inverse distance
- User specified weighting

In this research, according to the available data, the user specified hyetograph method was used and the hyetograph of rainfall events was input for the model. In this research two storm events were used for model calibration and validation. It is to be noted that there was only one rain gauge recorder in the Honam catchment and that was used for the study of temporal pattern of the rainfall. The mean rainfall value over the basin was calculated by using daily precipitation of this station by the weighting mean method.

4.4.4. Control specifications

Control specifications are the other components for hydrologic simulation by HEC-HMS. The date and time of start of a project was introduced in this step. The final task in the model setup involves establishing the model's time limits.

4.4.5. Data analysis for rainfall–runoff relationship and optimizing the model's parameters

Calibration and data analysis for rainfall–runoff relationships are another step in the HEC-HMS model. In the modeling processes, the result of the first run of the model can be calibrated and optimized in three conditions:

1. Automatic method, in which the model itself optimizes the parameters
2. Manual method
3. Both manually and automatically

HEC runs automatically for optimizing parameters, but the user can manually manage it by putting the first estimation as input data for the model. The model automatically carries out optimization by minimizing the difference between the observed and the estimated hydrograph to attain reasonable results. The objective function was Percent Error Peak, and the optimization method was Univariate Gradient, which were put in the model structure.

4.5. Processing Honam catchment data

4.5.1. Data collection and model setup

The Aleshtar hydrometric station is located at the outlet of the basin. Data of flood discharge and the corresponding storm event were extracted from records of this station. A hydrograph of each storm event was extracted by considering the date of the storm and was then used in the HEC-HMS model.

Figure 4.9 and 4.10 show the hydrographs of 7 December 2007 and 26 February 2008 at the outlet of Honam (at Aleshtar station), respectively.

4.5.2. Model setup, calibration, and validation

In order to use HEC-HMS and prepare a rainfall–runoff model to study the effects of land-use change on runoff, the required information and data layers were prepared, and then setup as input for the model. The parameter calibration was carried out with one event and the model accuracy was validated with another event in the next step.

4.5.3. Rainfall–runoff simulation by the model

To calibrate the model, the parameters were estimated based on available data, which were used as the first trial for the input of the model. These parameters included CN as 79.1, initial loss of 13.43 mm, and the lag time of 853.2 min and were used as input of the model to simulate the flood hydrograph, e.g. the simulated and observed hydrographs based on the storm of 25 February 2008 (Figure 4.11). Comparison of the

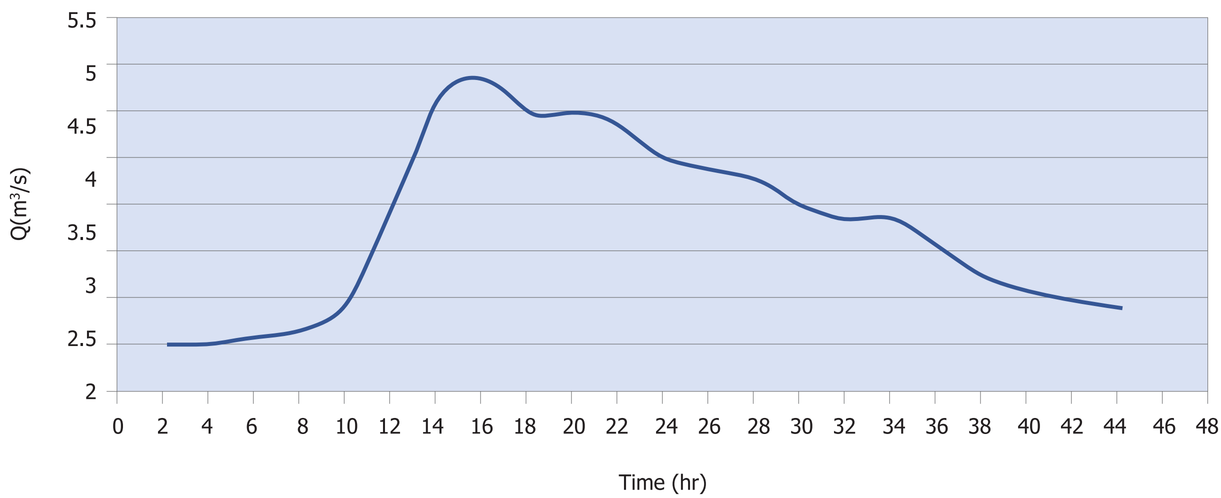

Figure 4.9. Hydrograph of storm event on 7 December 2007.

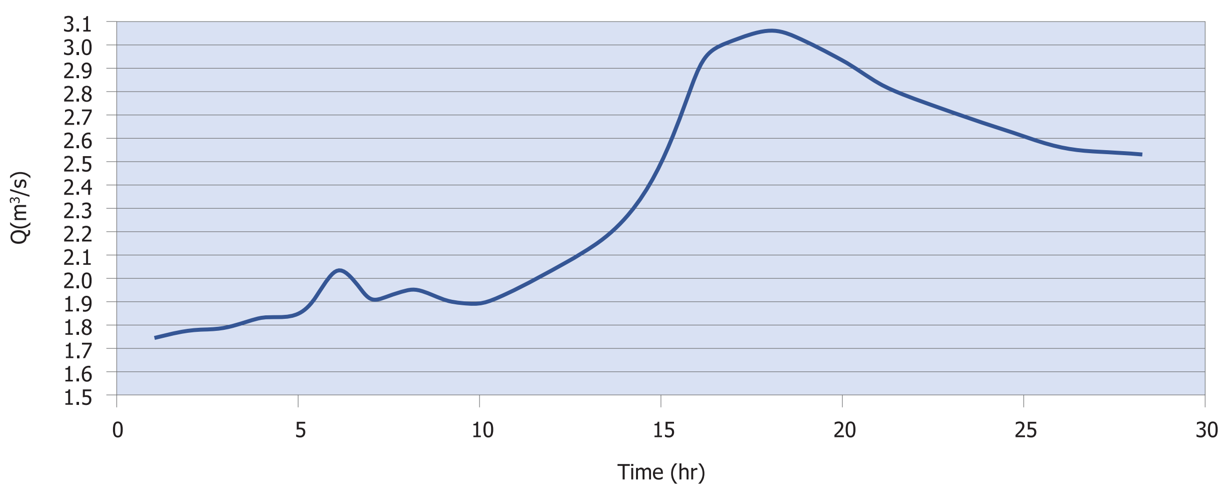

Figure 4.10. Hydrograph of storm event on 26 February 2008.

two hydrographs indicates considerable difference in peak values and other dimensions; therefore, another trial to calibrate the required parameters is necessary.

Model calibration and parameter optimization were continued in the next step, which used the first step parameters as the initial input and continued automatically to optimize the parameters. Calibration is a process in which the initial parameters are corrected by comparison with the results of the model. It is possible to calibrate the model automatically and manually.

Calibration of the model was carried out, based on objective function of percent of error in peak discharge since the purpose of this study was to investigate peak discharge variations.

Since the estimated and the observed peak discharge and storm volume differed, attempts were made to change

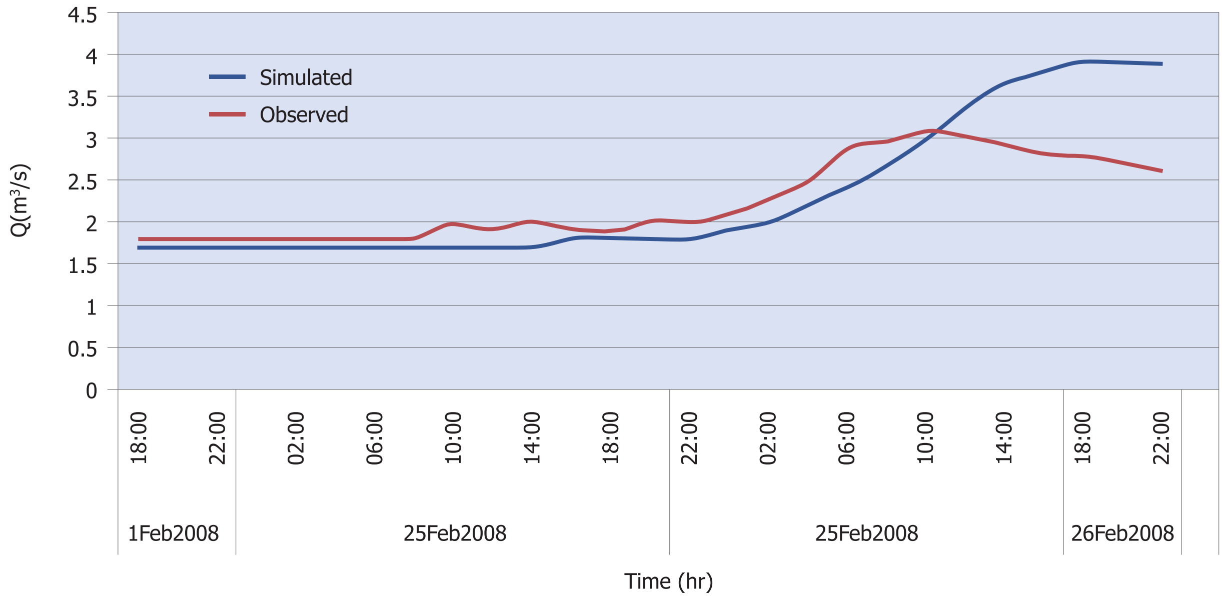

Figure 4.11. Observed and simulated hydrograph of the storm on 25 February 2008.

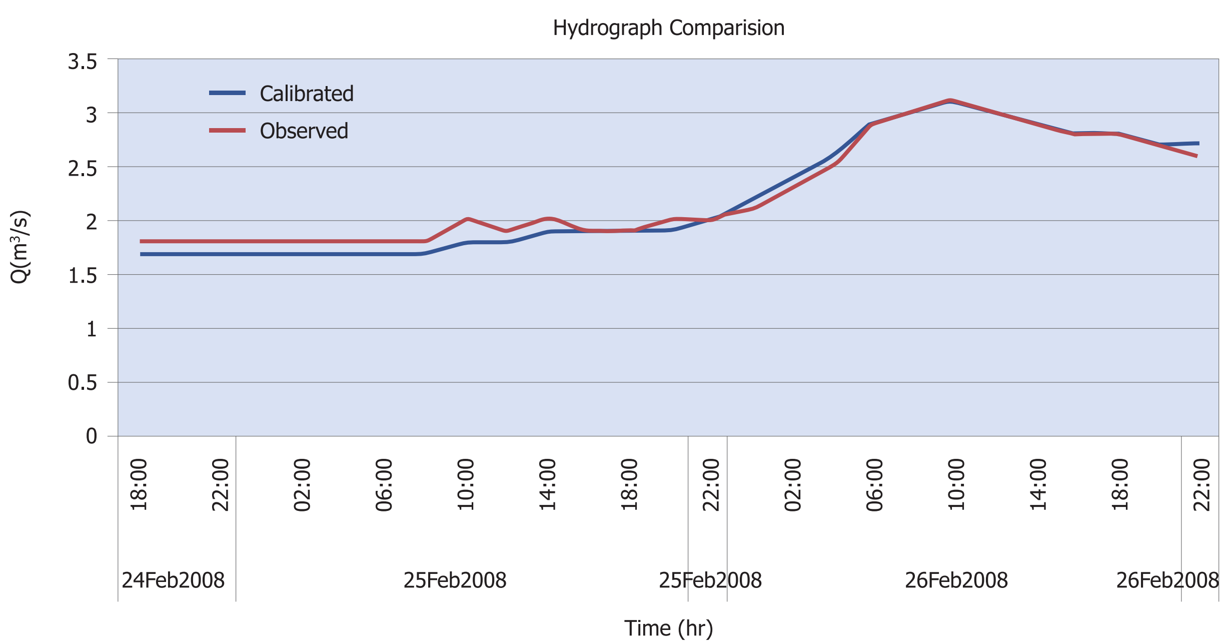

Figure 4.12. Calibrated and observed hydrographs of the storm of 25 February 2008.

the parameter so that those values were close to the real values. The lag time and initial loss also changed. The initial loss value changed from 13.43 to 17.43 mm (i.e. coefficient 0.2S increased to 0.26S) and the lag time decreased from 853 to 410.7 min. Finally, the calibrated parameters obtained were as follows: lag time equal to 410.7 min, initial loss 17.43 mm or 0.26S, and CN equal to 79.1.

Table 4.4. Parameters including CN, initial loss, lag time, peak discharge, and flood volume in calibration steps based on the storm of 25 February 2008.

Date	Initial loss (mm)	Lag time (min)	Peak discharge (m^3/s)	Storm volume (Mm^3)	Hydrograph description
25Feb 2008	13.43	853.2	3.1	2.91	Observed
			3.9	3.28	Estimated
	17.43	410.7	3.1	3.1	Calibrated

Figure 4.12 shows the simulated and the observed hydrographs based on the storm of 25 February 2008, in the calibration step. The result of calibration is summarized in Table 4.4, which shows the values of CN, initial loss, lag time, peak discharge, and flood volume.

4.5.4. Model validation

Validation is the process for evaluation of calibrated parameters, therefore the accuracy of the corrected parameters was evaluated in this step. To this end, the corrected parameters of the model were applied to the new rainfall event

Table 4.5. The observed and optimized hydrograph parameters in model validation.

Date	Peak discharge (m^3/s)			Flood volume (Mm^3)	Total rainfall (mm)	Total rainfall loss (mm)	Total direct runoff (Mm^3)
	Observed	Estimated	Observed	Estimated			
6/12/2007	4.8	4.8	3.86	5.1	27.65	25.77	1.81

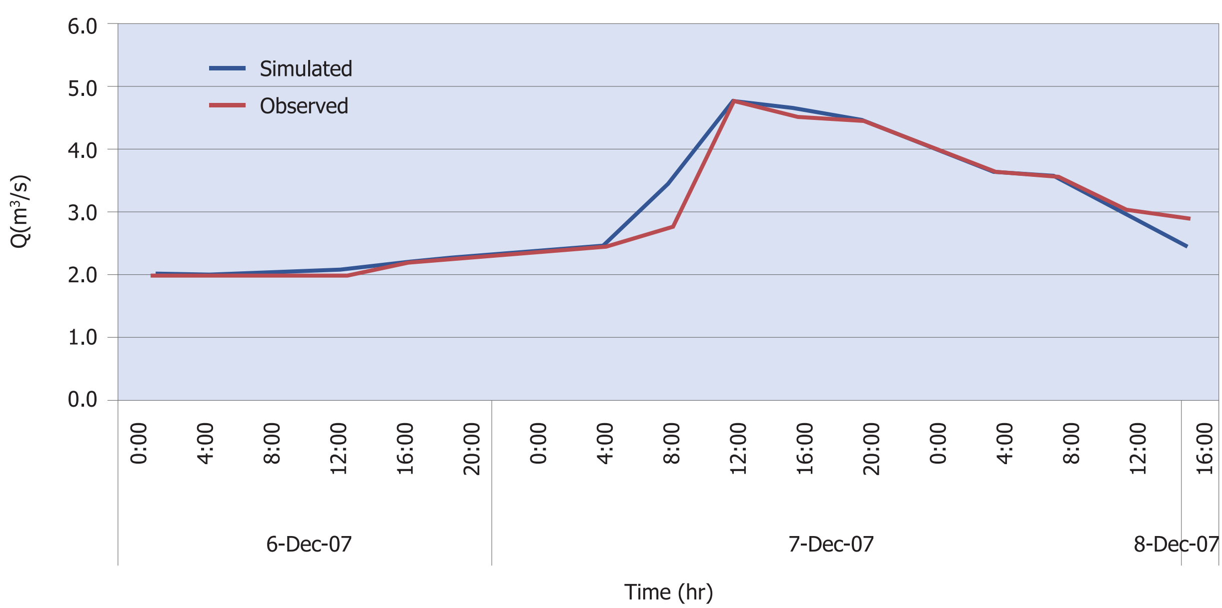

Figure 4.13. The observed and simulated hydrographs in validation steps for the storm of 6 December 2007.

to determine whether the observed and simulated hydrographs were similar. The storm of 6 December 2007 was selected for validation. The observed and estimated hydrograph parameters in validation step are presented in Table 4.5, which shows that the error percent for peak discharge and hydrograph volume were in acceptable range; thus, the model could be validated. Figure 4.13 depicts the observed and simulated hydrographs in validation steps for the abovementioned storm.

4.6. Scenarios of hydrologic response to land-use change

The main goal of this study is simulation of the effects of land-use changes on runoff magnitude in the watershed. Therefore, for different land-use conditions, the pertinent hydrographs were simulated.

Scenarios of land-use change are of two types: optimistic and pessimistic. Hence, these two scenarios were assumed for Honam basin land-use in the future. In the optimistic condition, due to improved vegetation cover and suitability of land use, the CN decreased and reached a value of 68. In the pessimistic condition, however, trends of the last three decades continued and CN increased to 85.

The optimistic condition implies proper management practices, while the pessimistic condition assumes increasing trend of disturbance over the catchments.

Table 4.6. Peak value, flood volume, total rainfall loss, and direct runoff in pessimistic condition.

Peak discharge (m^3/s)	**Flood volume (Mm^3)**	**Total rainfall (Mm^3)**	**Total loss (Mm^3)**	**Total direct runoff (Mm^3)**
11.3	7.83	27.65	22.98	4.54

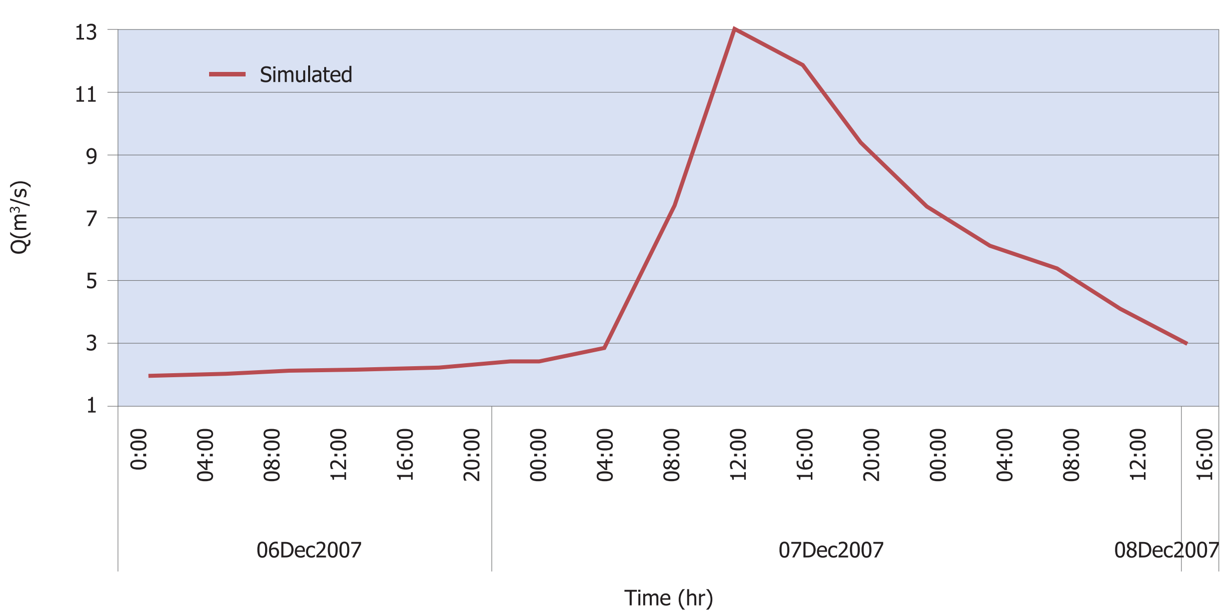

Figure 4.14. Simulated hydrograph for pessimistic scenario.

Table 4.7. Peak discharge, flood volume, total rainfall loss, and direct runoff in simulated hydrograph in optimistic condition.

Peak charge (m^3/s)	Flood volume (Mm^3)	Total rainfall (Mm^3)	Total loss (Mm^3)	Total direct runoff (Mm^3)
3	3.83	27.65	27.1	0.55

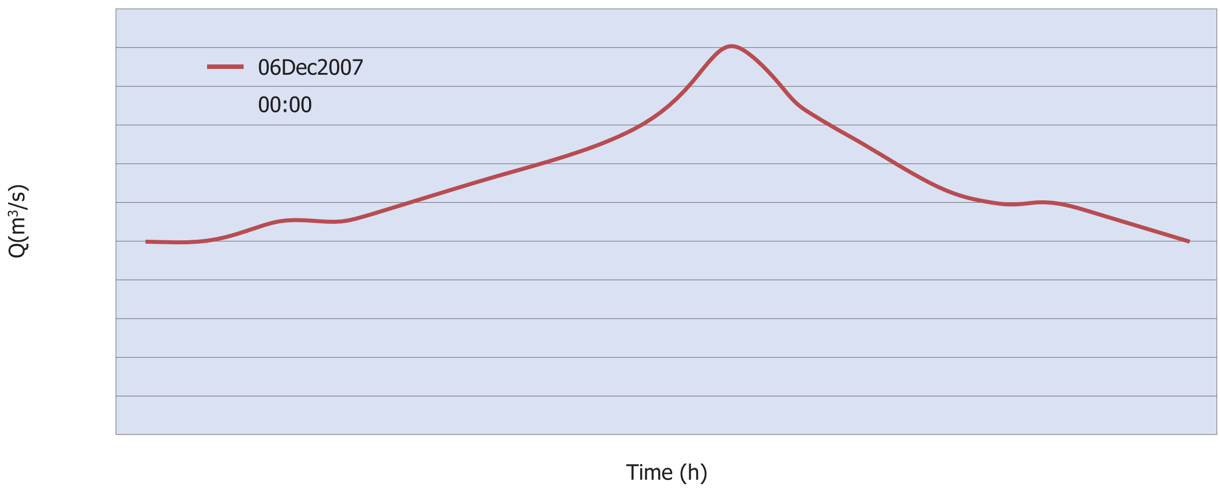

Figure 4.15. Simulated hydrograph for optimistic scenario.

With the other conditions kept constant and assuming a constant lag time of 410.7 min for both scenarios, Figure 4.14 and 4.15 show the simulated hydrographs of the optimistic and pessimistic conditions, respectively; and Tables 4.6 and 4.7 show the corresponding peak value, flood volume, base flow, total rainfall and total direct runoff.

4.7. Processing Merek catchment data

4.7.1. Data collection and model setup

Flood data

Obviously, data of the temporal and spatial pattern of precipitation are essential for rainfall–runoff analysis; however, when the study began there was no rain gauge recorder in the Merek catchment. Therefore, a weighing recorder rain gauge was installed in the middle of the catchment (Najafabad village) on May 2007. In addition, four standard rain gauges were available for rainfall spatial analysis, two of which were situated in the study area and the others in adjacent basins (Figure 4.16 and Table 4.8).

Discharge of floods

At the beginning of this research project, there were no hydrometric stations and no discharge data for the study area. Therefore, the necessary equipment were provided by the project and installed during the first year of the study. Two water level recorders (model Global Water Level Meters (3 inch) were installed in Charvarish and Halashi sections. However, the one in Halashi did not work properly and, therefore, the Soil Conservation and Watershed Management

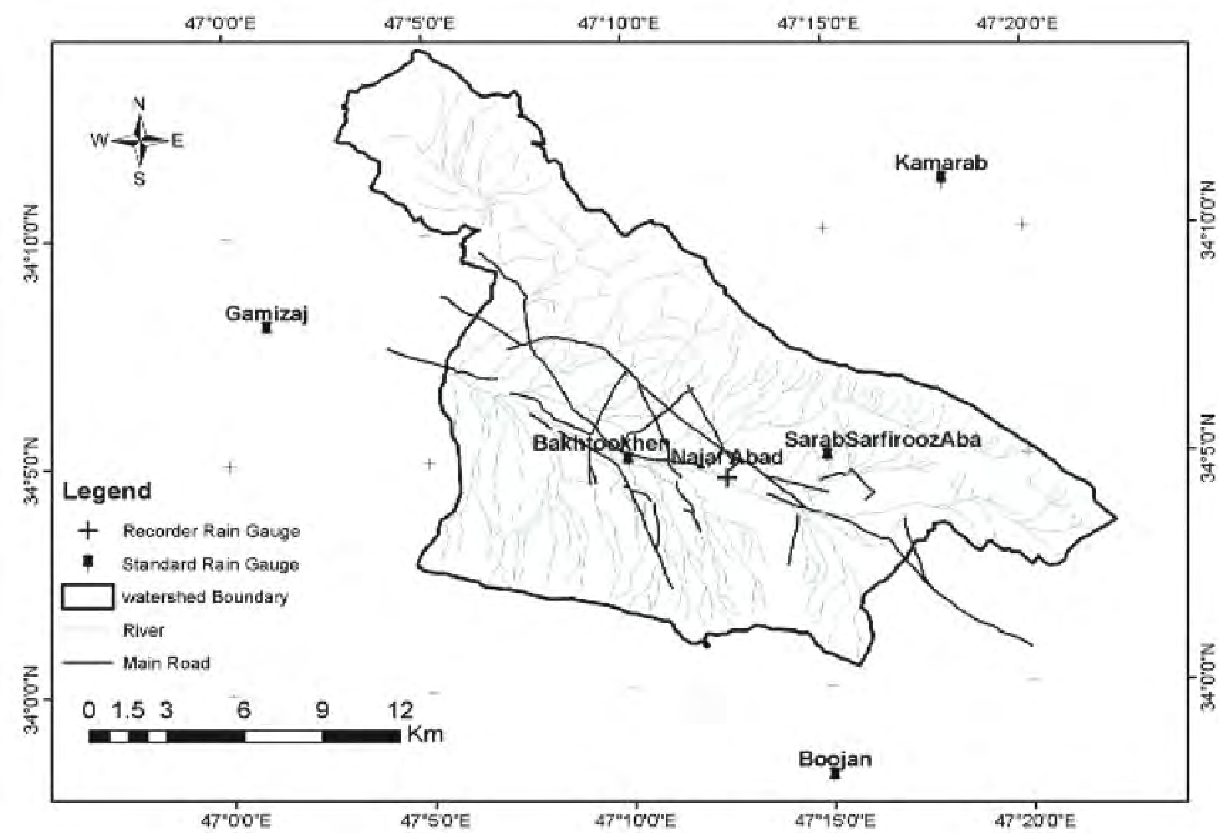

Figure 4.16. Geographical coordinates and locations of the rain gauge stations.

Table 4.8. Type and coordinates of the rain gauges used in this study.

Name of location	Types	Longitude	Latitude	Elevation (m)	Time interval of measurements
Boojan	Standard rain gauge	47°15′00″	33°58′00″	1600	12 h
Kamarab	Standard rain gauge	47°18′00″	34°11′00″	1293	12 h
Gamizaj	Standard rain gauge	47°01′00″	34°08′00″	1480	12 h
Sarab Sarfirooz Abad	Standard rain gauge	47°15′00″	34°05′00″	1510	12 h
Bakhtookhen	Standard rain gauge	47°10′00″	34°05′00″	1540	12 h
Najafabad	Data logger	47°12′27″	34°04′43″	1550	10 min

Research Institute installed a limnograph Model WBEDIEN 32 at the same station, in addition to the previous Global Water Level Meters. Figure 4.17 and Table 4.9 show the geographic coordinates and locations of these hydrometric stations. A uniform and rectangular shaped cross-section of the Merek River below the flume allowed for correct measurement of discharge without constructing a telepheric bridge. Figure 4.18 shows a view of Halashi hydrometric station.

The Halashi hydrometric station is located in the outlet of the catchment. Data of flood discharge and the corresponding

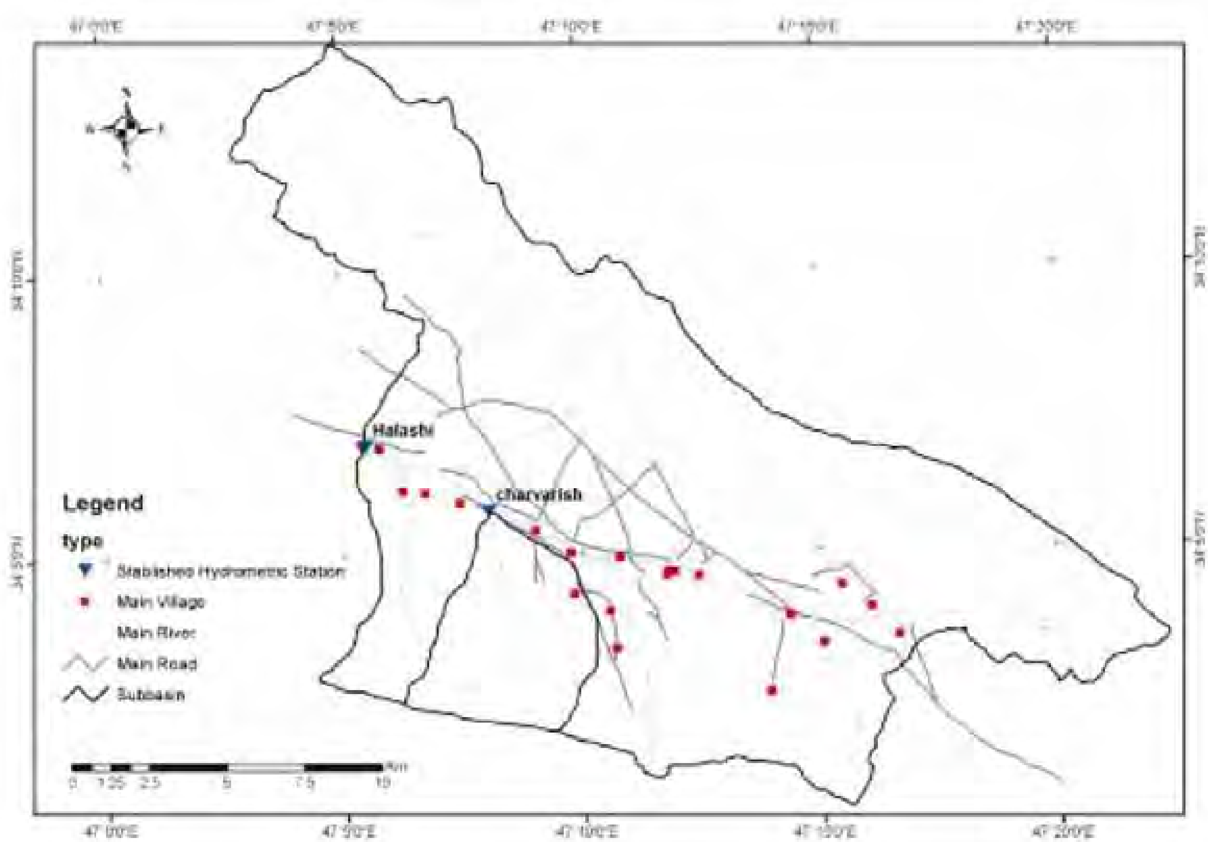

Figure 4.17. Geographical coordinates and locations of hydrometric stations.

Table 4.9. Type and coordinates of hydrometric stations.

Location	Equipment	Longitude	Latitude	Elevation (m)
Halash	Limnograph + Stage	47°05′47″	34°06′47″	1483
Charvarish	Water level meter + Stage	47°48′10″	34°05′41″	1500

Figure 4.18. The data logger and a stage attached to the flume wall in Halashi station.

storm event were extracted from records of this station. A hydrograph of each storm event was extracted by considering the date of the storm and was then used in HEC-HMS model. Figure 4.19 and Figure 4.20 show the hydrographs of 11 April and 25 March 2007, in the outlet of Merek (at Halashi station), respectively.

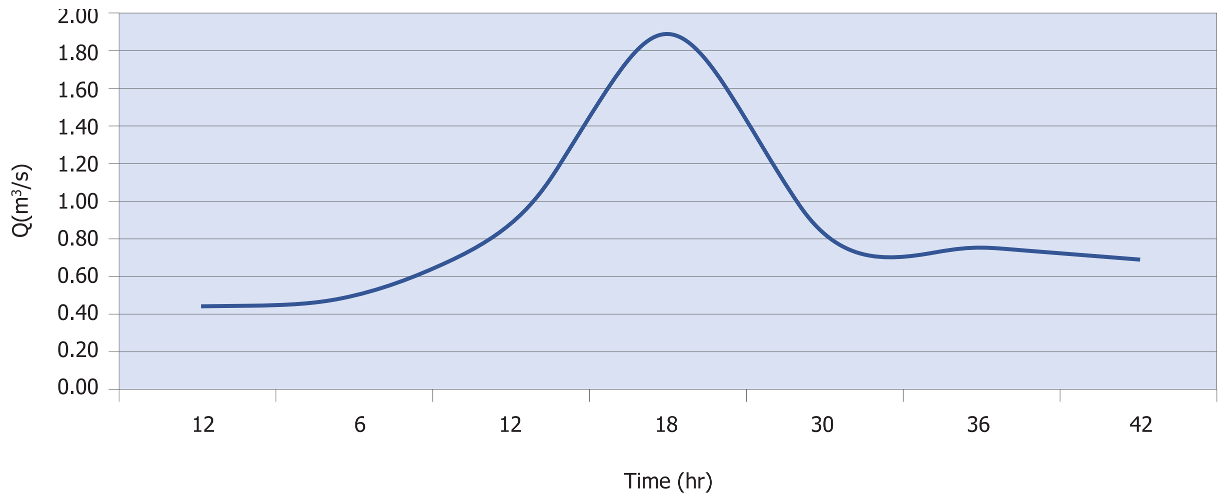

Figure 4.19. Hydrograph of the storm event on 25/03/2007.

4.8. Model setup, calibration, and validation

In order to use HEC-HMS and prepare a rainfall–runoff model for investigation of land-use change effects on runoff, the required information and data layers were prepared and setup as input of the model. The parameter calibration was carried out with one event and afterwards the model accuracy was validated with another event.

4.8.1. Rainfall–runoff simulation by model

To calibrate the model, the parameters were estimated based on the available data, which were used as the first trial for the input of the model. The parameters included CN = 76.5, the antecedent soil moisture, with the moisture condition based on the previous 5 d of rainfall set in group II (moist group based on SCS), initial loss of 14.3 mm, and lag time of 283 min. These parameters were used as

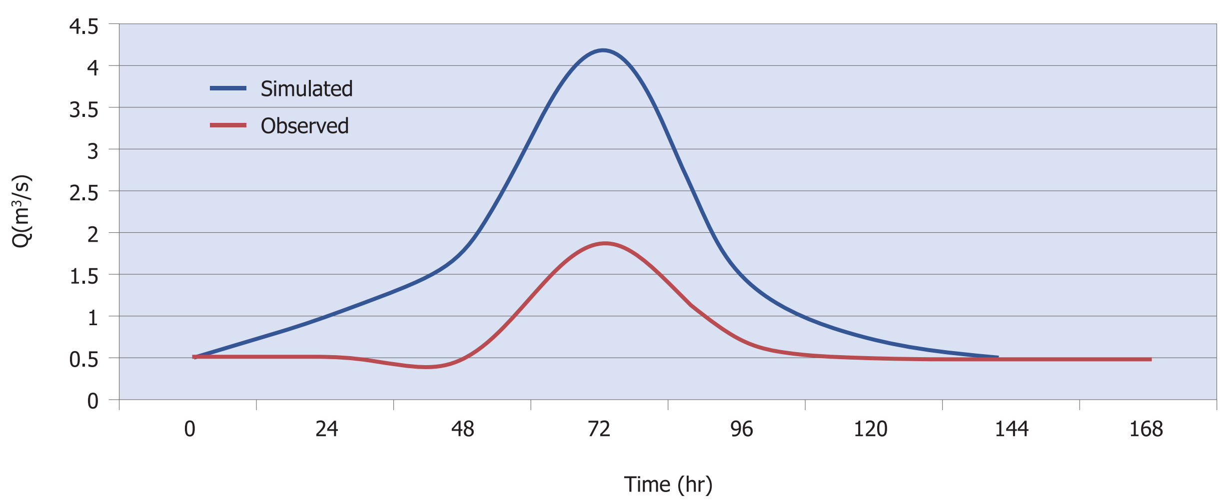

Figure 4.20. Observed and simulated hydrograph of the storm of 25 March 2007. 2007.

inputs of the model and a hydrograph of the flood was simulated.
Figure 4.20 shows the simulated and the observed hydrograph based on the storm of 25 March 2007. Comparison of the observed and simulated hydrograph indicates considerable difference in the peak values and other dimensions and make another trial necessary to calibrate the required parameters.

Model calibration and parameter optimization was continued in the next step, which used the first step parameters as initial input and automatically optimized the parameters. Calibration is a process in which the initial parameters are corrected by comparison with the results of model. It is possible to calibrate the model automatically and manually.

Calibration of the model was carried out based on the objective function of percent of error in peak discharge, since the purpose of this study was investigation of the peak discharge variations.

Since the estimated and observed peak discharge and storm volume differed, attempts were made to change the parameter so that those values were close to the real values. The lag time and initial lose also changed. The initial loss value changed from 14.33 to 38.8 mm (i.e. coefficient 0.2S increased to 0.54S) and the lag time decreased from 280 to 606 min. Finally the calibrated parameters obtained were as follows: lag time equal to 606 min, initial loss 38.8 mm (or 0.5S), and CN equal to 78.6. Figure 4.21 shows the corresponding

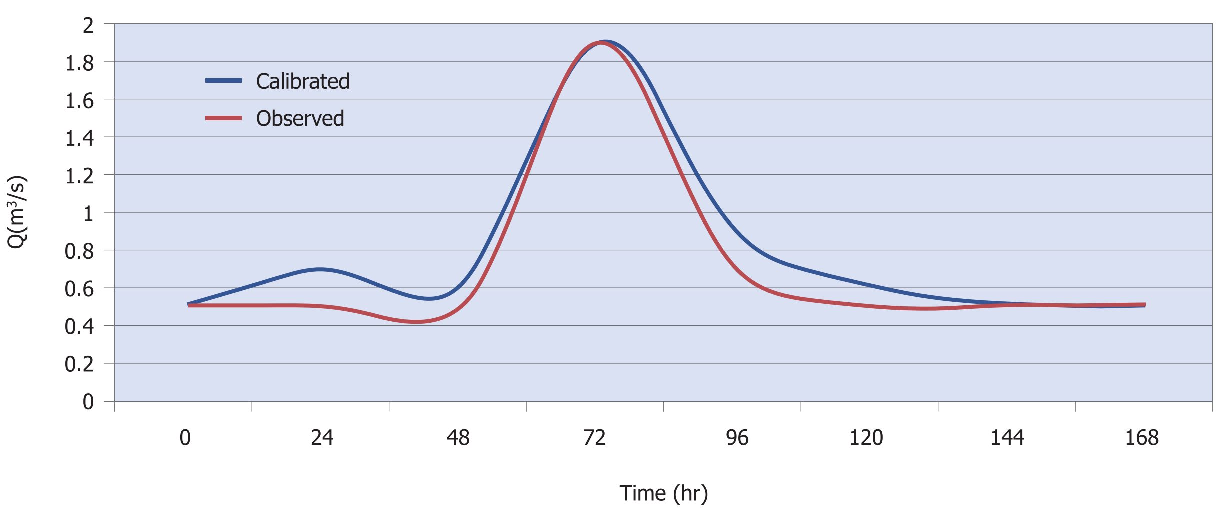

Figure 4.21. Calibrated and observed hydrographs of storm of 25 March 2007.

Table 4.10. Parameters including CN, initial loss, lag time, peak discharge, and flood volume in calibration steps based on the storm of 25 March 2007.

Date	**Initial loss (mm)**	**Lag time (min)**	**Peak discharge (m^3/s)**	**Storm volume (Mm^3)**	**Hydrograph description**
25/03/2007	14.33	280	1.94	0.445	Observed
			4.2	0.886	estimated
	38.8	606	1.9	0.488	calibrated

Table 4.11. The observed and optimized hydrograph parameters in model validation, based on the storm of 11 April 2007.

Peak discharge (m^3/s)	Error (%)	Flood volume (Mm^3)			Error (%)	Total rainfall mm	Total rainfall loss (mm)	Total direct runoff (Mm^3)
Observed	**Estimated**		**Observed**	**Estimated**				
2.2	2.2	0.5	0.721	0.734	5.67	68.5	58.21	0.375

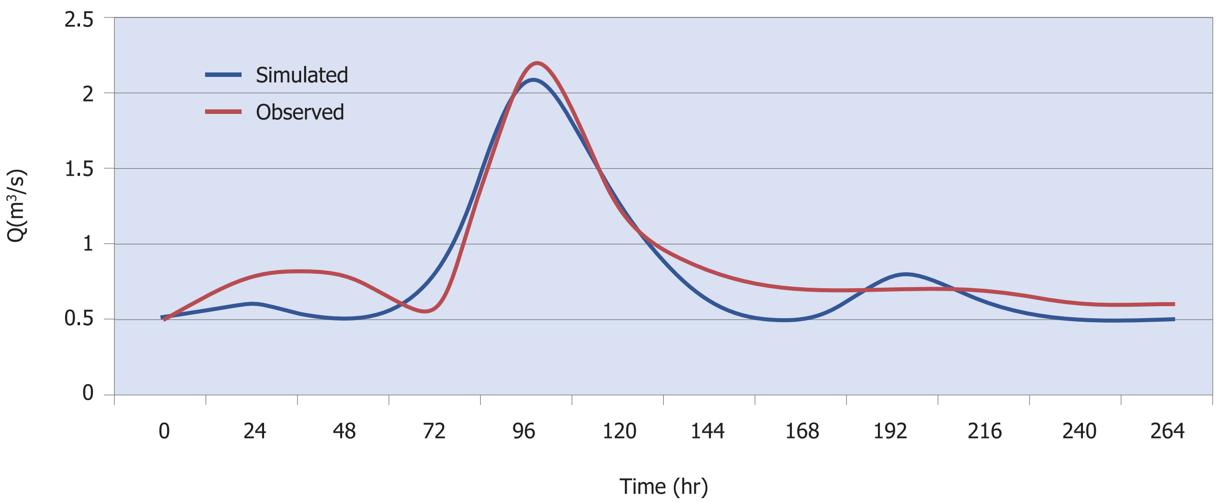

Figure 4.22. The observed and simulated hydrographs in validation steps for the storm of April 10-11, 2007.

calibrated and observed hydrographs for this event. The results of calibration are summarized in Table 4.10, which shows the values of CN, initial loss, lag time, peak discharge, and flood volume.

4.8.2. Model validation

Validation is the process for evaluation of the calibrated parameters; therefore accuracy of the corrected parameters was evaluated in this step. To this end, the corrected parameters of the model were applied to the new event to determine whether the observed and the simulated hydrographs were similar. The storm of 11 April 2007 was selected for validation. The observed and estimated hydrograph parameters in validation step are given in Table 4.11, which shows that the error percent for peak discharge and the hydrograph volume are in acceptable range. Thus, the model could be validated. Figure 4.22 shows the observed and the simulated hydrographs in validation steps for the storm of 11 April 2007. Since the error percent for peak discharge and hydrograph volume are in acceptable range (0.5% and 5.76% respectively) the model could be considered as validated.

4.9. Scenarios of hydrologic response to land-use change

The main goal of this part of the study was to simulate the effects of land-use changes on runoff magnitude in the Merek watershed. For this purpose, the pertinent hydrographs were simulated for different land use conditions.

Two scenarios of land-use change were considered for the study: optimistic and pessimistic. In the optimistic condition, the CN decreased to 60 due to improving vegetation cover and suitable land; while in the pessimistic condition, CN value reached 86, as a consequence of continuing management trend of the last three decades.

The optimistic condition implies proper management practices and the pessimistic condition considers increasing land-use disturbance over the catchment. The other conditions are assumed constant in the storm dated 11 April 2007 with rainfall amount of 59.7 mm.

In the optimistic scenario, the lag time value was kept constant (606 min), but the effects of land-use changes decreased CN to 68 and accordingly increased the initial losses to 0.54S.

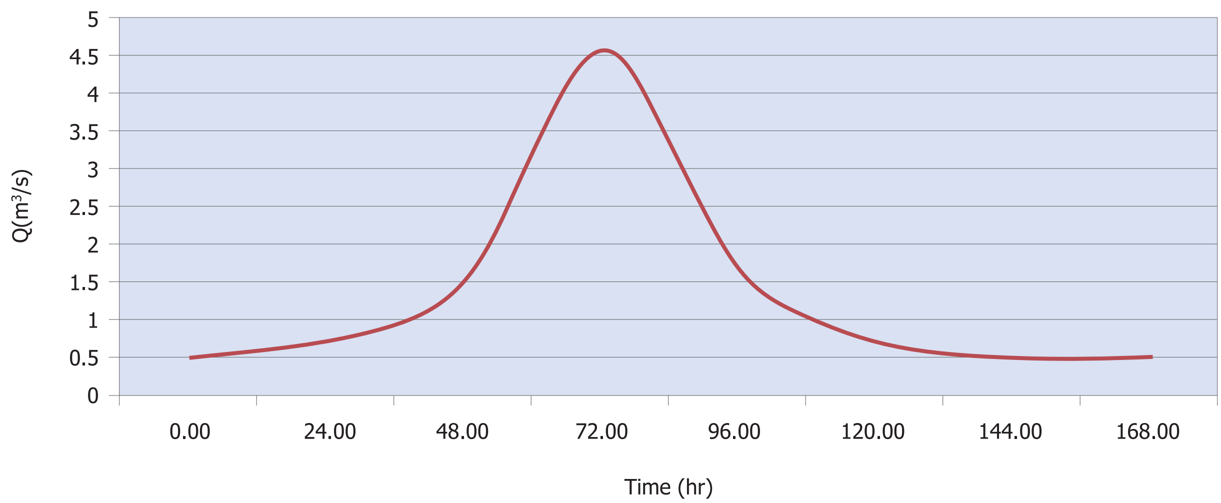

Figure 4.23. Simulated hydrograph for the pessimistic scenario.

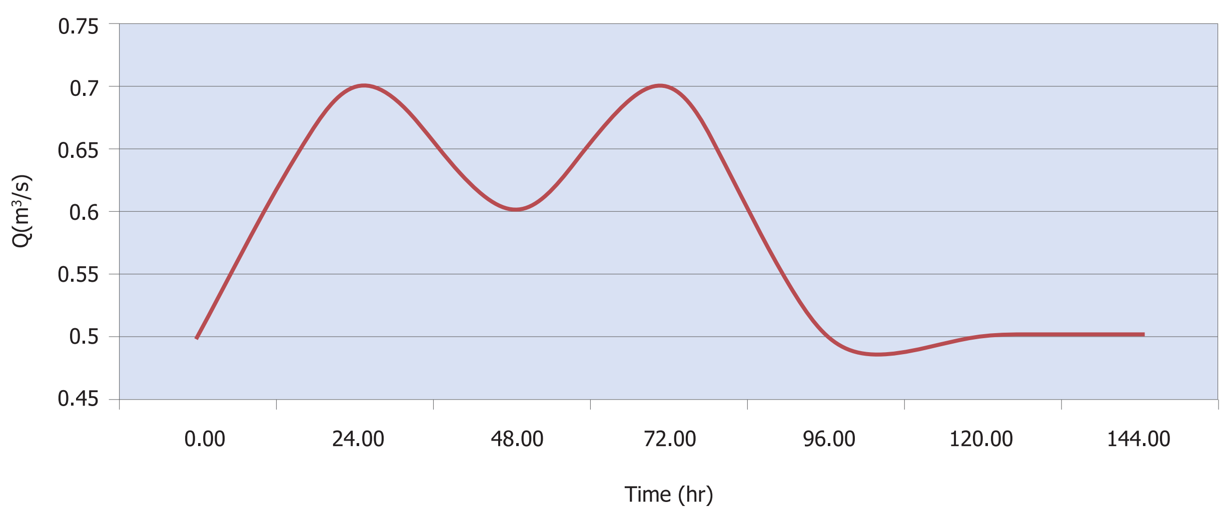

Figure 4.24. Simulated hydrograph for the optimistic scenario.

Table 4.12. Peak value, flood volume, total rainfall loss, and direct runoff in the pessimistic scenario.

Peak charge (m^3/s)	Flood volume (Mm^3)	Total rainfall (Mm^3)	Total loss (Mm^3)	Total direct runoff (Mm^3)
4.6	0.886	59.7	40.97	0.583

Table 4.13. Peak discharge, flood volume, total rainfall loss, and direct runoff in simulated hydrograph in the optimistic scenario.

Peak charge (m^3/s)	Flood volume (Mm^3)	Total rainfall (Mm^3)	Total loss (Mm^3)	Total direct runoff (Mm^3)
0.7	0.347	59.7	58.33	0.045

In the pessimistic assumption, the lag time value was kept constant (606 min) as for the optimistic scenario; however, the effects of land-use changes increased CN to 86 and accordingly decreased the initial losses to 0.2S.

Figure 4.23 and Figure 4.24 depict the simulated hydrographs of the optimistic and pessimistic scenarios; and Tables 4.12 and 4.13 show the corresponding peak values, flood volumes, base flows, total rainfalls, and total direct runoff.

4.10. Discussion and conclusion

4.10.1. Model calibration

In Honam

In the first step of calibration, there was considerable difference between the observed and simulated hydrographs. In that step, the hydrograph of the storm of 26 February 2008 had a peak value and flood magnitude of 3.1 m^3/s and 2.91 Mm^3, respectively; whereas, in the simulated hydrograph, the corresponding values were 3.9 m^3/s and 3.28 Mm^2 with errors of 12.7% in the peak value and 25.8% in runoff volume. However, after the second step in calibration, the new values estimated for the peak discharge and storm volume were 3.1 m^3/s and 3.1 Mm^3, respectively, which were close to the observed values. In this study, lag time changed from 853.2 to 410.7 min.

In Merek

Generally speaking, model calibration requires a large amount of data; especially, storm events having considerable runoff should be available in different conditions to present the complexity and variety of the nature of the basin. A severe drought occurred during the monitoring step of the project, and so there were only two storm events data available for the study area. Therefore, one event was allocated for calibration and the other for evaluation and validation of the model parameters. This amount of data is the minimum for modeling of the basin. By using this minimum event data, we had to limit the trial and error iterations for calibration. Therefore, the physical hydrologic parameters such as CN, lag time, and initial abstraction/loss obtained from physiographic study by experimental methods were used as the first trial.
In the primary step of the calibration there was considerable difference between the observed and the simulated hydrographs, e.g. in the hydrograph of 25 March 2007, the peak value and flood magnitude were 1.94 m^3/s and 0.445

× 10^6 m^3, respectively, whereas in the simulated hydrograph the corresponding values were 4.2 m^3/s and 0.886 × 10^6 m^3 with error of 46.19% in peak value and 50.23% in runoff volume. After the second step in calibration by trial and error, the new values of estimation for peak discharge and storm volume were 1.9 and 0.488 × 10^6 m^3, respectively, that were close to the observed values. In this study lag time changed from 280 to 6006 min.

4.10.2. Change of land use

In Honam

The hydrologic response of Honam basin by HEC-HMS shows that land-use change is one of the most important components of hydrologic factors affecting contribution of rainfall to runoff. Optimistic and pessimistic scenarios indicate that unsuitable use of land would increase flood volume and peak discharge, whereas improving land-use condition would decrease peak value and volume of flood under the same condition or in a unique rainfall event.

In Merek

Since land-use change affects the vegetation cover, land management and other factors affecting surface physical properties of soil and ground directly change the infiltration response. Such a change may be a long-term process, and there are usually no historic data on land-use change. The available data on land-use change were usually restricted to one or two time steps, therefore the historic data of land use and corresponding floods did not exist to evaluate the actual response of the basin to such changes. Thus, existing land use was selected as a base and future trends were predicted according to two scenarios. Hydrologic response of Merek basin simulation by HEC-HMS shows that land-use changes as an important component of hydrologic factors affecting contribution of rainfall to runoff. Optimistic and pessimistic scenarios indicate that unsuitable use of land would increase flood volume and peak discharge, whereas improving land-use condition would decrease peak value and volume of flood in the same storm event conditions.

The CN method is one method used to simulate loss or excess rain from a storm. As the method can be applied to basins with minimum recorded data, it has been widely used in hydrologic applications. CN as a hydrologic parameter used in rainfall–runoff simulations is itself a function of land-use changes. In this research, the value of CN was estimated at 79.1 and 76.5 for Honam and Merek, respectively, based on the physical conditions of the two basins under semi-wet conditions. In the optimistic and pessimistic scenarios, CN was estimated at 60 and 86, respectively. Since the CN reflects the land-use effect on runoff and rainfall loss, the more the increase in CN, the more will be the decrease in retention potential and the increase in runoff amount over the basin surface.

4.10.3. Peak discharge and flood volume

In Honam

The simulation results of the calibrated models in Honam basin gave the peak value and flood volume of the 27-mm rainfall event of 6 December 2007 as 4.8 m^3/s and 3.86 Mm^3, respectively. These values decreased to 3 m^3/s and 3.83 Mm^3 in the optimistic scenario, respectively, (Table 4.7) and increased to 11.3 m^3/s and 7.83 Mm^3 in the pessimistic scenario (Table 4.6).

In Merek

The results of the simulated and calibrated models in Merek catchment gave the peak value and flood volume of the rainfall event of 25 March 2007 as 1.9 m^3/s and 0.488 × 10^6 m^3, respectively

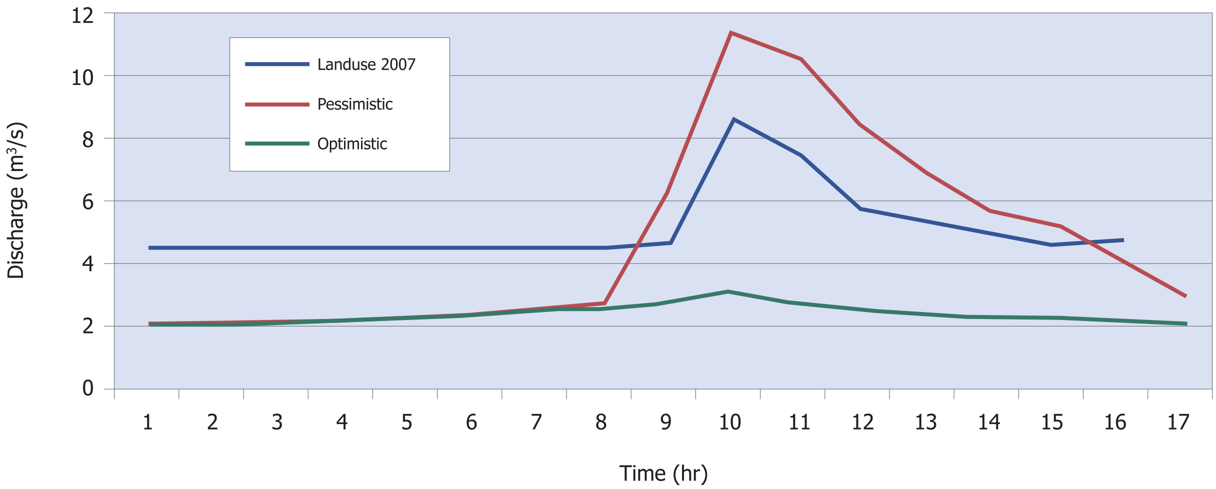

Figure 4.25. Simulated hydrographs of current land use, and optimistic and pessimistic scenarios.

(Yousefipanah, 2007). These values decreased to 0.7 m^3/s and 0.347 × 10^6 m^3 in the optimistic scenario, respectively, and increased to 4.6 m^3/s and 0.886 × 10^6 m^3 in the pessimistic scenario.

4.10.4. Hydrograph shape

In Honam

Figure 4.25 and Table 4.14 show the simulated hydrographs of the basin in the two scenarios for the 6 December 2007 rainfall. Investigation of the simulated hydrograph of HEC-HMS shows that the overall shapes of the pessimistic and the observed 6 December 2007 hydrographs are similar to each other, reflecting the lumping response of the basin (using weighted mean parameters). However, the rising and falling limbs are sharper in the pessimistic than in the optimistic condition. Moreover, the optimistic hydrograph is clearly flatter and differs to the other two.

In Merek

Figure 4.26 shows the simulated hydrographs of the basin in the two scenarios of optimistic and pessimistic conditions for 25 May 2007. Investigation of the simulated hydrograph by HEC-HMS showed that the overall shapes of the pessimistic and the 25 May 2007 observed hydrographs were not similar. The pessimistic condition had a sharp rising and falling limb, but hydrograph of the optimistic condition has a very flat shape. The peak discharge in the pessimistic condition is more than six times larger than the optimistic condition and twice that of the observed one. Some similarity in the hydrographs may be due

Table 4.14. Values of peak discharge, flood volume, total rainfall loss, and direct runoff in observed and in simulated hydrographs in pessimistic and optimistic scenarios.

Condition	Peak discharge (m^3/s)	Flood volume (Mm^3)	Total rainfall (Mm^3)	Total loss (Mm^3)	Total direct runoff (Mm^3)
Observed	4.8	3.86	27.65	25.77	1.81
Pessimistic	13	7.83	27.65	22.29	5.22
Optimistic	3	8.5	27.65	27.1	0.55

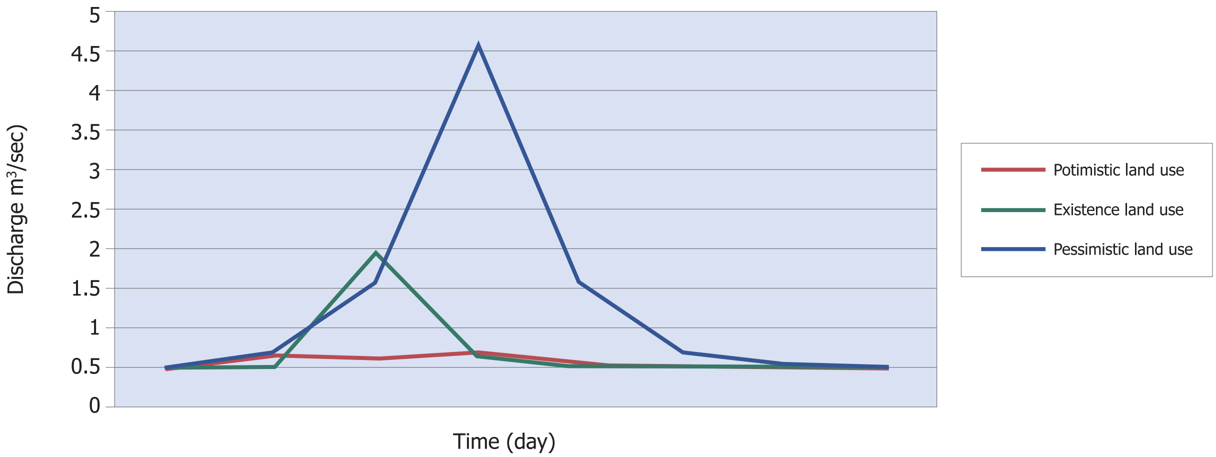

Figure 4.26. Simulated hydrographs of existing land use, and optimistic and pessimistic scenarios.

to a reflection of accounting the whole catchment as one hydrologic unit and, therefore, this is a lumping response of the basin (using weighted mean parameters).

4.11. Conclusion and suggestions

The results of this study on the effects of land-use changes on runoff and hydrograph shapes using HEC-HMS in Honam and Merek basins indicated the following points:

- The result emphasize the effects of land-use changes in hydrologic response of the basin. The simulation by HEC-HMS in the studied periods shows that, by continuing unsuitable land-use trends, the peak values and flood volume would increase, whereas proper land use would decrease them. In addition to peak values and flood volume, the shapes of hydrograph would be affected, i.e. the rising and falling limbs of hydrographs of pessimistic scenarios would be much sharper and steeper relative to the optimistic scenario.
- The main effect of the land-use changes on runoff amount was the change in potential of retention of a basin that is a function of vegetation cover type and density.
- Use of this model in different surface runoff studies would save the expenses of field studies.

Considering the findings of this research, the following are suggested:

- The changing of land use to a condition with intense vegetation cover will considerably decrease the peak runoff and volume of floods over the catchments. Therefore, the first suggestion is to change the present land use in Honam and Merek basins and adopt a management method to improve their vegetation cover.
- According to the availability of the required data for the HEC-HMS model, it could be used to simulate rainfall–runoff processes in hydrologic studies of other basins.
- Such studies could be accelerated by using GIS combined with the HEC-HMS model.
- The Ministry of Jihad-e-Agriculture and Ministry of Energy of Iran can use the results of this study for planning

watershed and water resource management in Honam and Merek basins.

- Finally, it is suggested that measurements of precipitation, surface flow discharge, and the other parameters needed for simulation of rainfall–runoff behavior of the basin be continued. The model can then be run with more data to achieve more reasonable results for application in land use and flood management in these basins.

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Chapter 5.

Drought Analysis in the Upper Karkheh River Basin

Jahangir Porhemmat, Sima Rahimi Bondarabadi and Tayeb Raziei

Chapter 5: Drought Analysis in the Upper Karkheh River Basin

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5.1. Introduction

The Livelihood Resilience (LR) project proposal aimed at strengthening livelihood resilience through improved natural resource management in the Karkheh River Basin (KRB). Thus, knowledge of precipitation events and their temporal and spatial variations was important and necessary because precipitation is the most important component of water balance and its deficiency can lead to drought. In addition, precipitation plays an important role in the general climatic conditions and agricultural development. Amount and temporal distribution of precipitation are two significant factors in agricultural planning since they strongly affect soil moisture and availability of water resources for irrigation. Natural vegetation cover and rainfed crops are also controlled by the amount and temporal distribution of precipitation and its types. Since rainfed crops, livestock, and pastures are the main sources of income in the KRB, seasonal water deficit due to drought spells affects livelihoods of rural communities through impacts on agricultural production and natural vegetation in the rangelands. Therefore, drought analysis was included in the project studies. In this respect, since monthly drought analysis is needed for agricultural planning and the Standardized Precipitation Index (SPI) is an indicator of monthly conditions of this phenomenon, this index was selected for our analysis of drought in the KRB.

5.2. Drought and drought indices

Drought is a normal, recurrent feature of climate that may occur anywhere, although its characteristics and impacts vary significantly from region to region (Wilhite, 1997). It is defined as a natural temporary imbalance of water availability, consisting of a persistent lower-than-average precipitation, of uncertain frequency, duration and severity, of unpredictable or difficult to predict occurrence, resulting in diminished water resources availability and carrying capacity of the ecosystems (Pereira *et al*., 2002). Thus, an objective evaluation of drought conditions in a particular area is the first step for planning water resources in order to prevent and mitigate the negative impacts of future occurrences. For this purpose, several indices have been developed to evaluate water supply deficit in relation to the time duration of precipitation shortage (see Heim, 2002; Keyantash and Dracup, 2002 and references therein). Among them, the most commonly used for drought monitoring are the Palmer Drought Severity Index (PDSI; Palmer, 1965) and the SPI (McKee *et al*., 1993).

The PDSI is based on the supply-and-demand concept of the water balance equation for a two-layer soil model. It depends on several local coefficients that are estimated using local hydrological norms related to temperature and precipitation averaged over some calibration period (at least a 30-year period, according to the World Meteorological Organization recommendation). The basis of the index is the difference between the amount of precipitation required to retain a normal water balance level and the actual precipitation. Nevertheless, if we wish to compare drought conditions of different areas, which often have different hydrological balances, the most important characteristic of any index is the standardization.

The SPI complies with this requirement. It is, in fact, a standardized index that can be computed on different time scales, thus allowing monitoring of most drought types, i.e. meteorological, agricultural, and hydrological. The SPI computation for any location is based on the long-term precipitation record cumulated over the selected time scale. This long-term record is fitted to a probability distribution (usually a Gamma distribution; Guttman, 1999), which is then transformed through an equal-probability transformation into a normal distribution. Positive SPI values indicate greater than median precipitation, and negative values indicate less than median precipitation (Bordi and Sutera, 2001). Thus, because the SPI is normalized, wetter and drier climates can be represented in the same way.

Guttman (1998) compared the Palmer Drought Index (an older version of the PDSI) with the SPI through a spectral analysis in order to evaluate the application accuracy. He recommended the SPI as a more useful drought index because it is standardized and contains a probabilistic interpretation, so it can be used in risk assessment and decision making. Paulo and Pereira (2006) compared the PDSI and the SPI, and concluded that the linear correlation coefficient between the two indices was higher for a 12-month time scale.

Morid *et al*. (2006) examined the performance of seven drought indices requiring only rainfall data for drought detection and monitoring in the Tehran Province of Iran. They concluded that, despite different underlying statistical distributions, the SPI performed in a similar manner with regard to drought identification and drought onset, and that the SPI and Effective Drought Index (EDI) could be recommended for operational drought monitoring in the region. However, the EDI requires daily precipitation, which constitutes a serious limitation for its operational use. Thus, due to its advantages, the SPI appears to be the most powerful drought index.

Many authors (Hayes *et al*., 1999; Szalai *et al*., 2000; Bordi and Sutera, 2001; Lana *et al*., 2001; Lloyd-Hughes and Saunders, 2002; Tsakiris and Vangelis, 2004; Vicente-Serrano *et al*., 2004) have used the SPI to monitor drought in many regions, while others have used the SPI to predict drought class transitions adopting Markov-chain and log linear models (Paulo *et al*., 2005; Paulo and Pereira, 2007; Moreira *et al*., 2008), or to forecast drought with stochastic and neural networks modeling (Mishra and Desai, 2005).

5.3. The state of art of SPI

5.3.1. Selecting a suitable index for drought analysis

Accurate long-term climatic and hydrological data are necessary for studying drought events, and it is not possible to study drought processes without these data. Precipitation is the main factor in creation and controlling drought duration and intensity, but actual evapotranspiration is the most important factor in showing the effects of drought. The difficulties of evapotranspiration estimates have made precipitation the best and most accessible climatic parameter for computing drought indices.

In fact, the indices based on precipitation have had better results when comparing to more complicated hydrological indices (Oladipio 1985). Among the indices based on precipitation, the SPI and Deciles Index have been widely accepted by scientific societies and users. In the present research, the SPI index is used for studying the drought phenomenon in the KRB.

5.3.2. Use of SPI

McKee *et al*. (1993) used SPI when they considered the effect of the precipitation deficit on groundwater, water supply sources, soil moisture, snow pack, and surface water relative to annual average. This index was designed for quantifying precipitation deficits over various time scales. In fact, these time scales declare the required times for the precipitation deficit impact on various water sources supply. The soil moisture condition reacts to short-term abnormality of precipitation, whereas groundwater, surface water, and water supply sources react to long-term abnormalities. Therefore, McKee *et al*. (1993) suggested the SPI for time scales of 3, 6, 12, 24, and 48 months.

Computation of SPI is based on long-term precipitation data and arbitrary time scales. These long-term data follow a probability distribution that can be transformed to a standard normal distribution in such a way that the data average equals zero in the arbitrary time intervals. Positive values of SPI represent higher than median precipitation, while negative values show the precipitation lower than the median. As the SPI index normalizes, drier or more humid weather can be explained through the same method.

McKee *et al*. (1993) used a classification system (Table 5.1) to describe drought severity as calculated by SPI. They also defined a drought criterion for each time interval. Hence, a drought event occurs when the negative SPI values are repeated and reach a severity below –1. Any drought event ceased when SPI approached a positive value. Therefore, every drought event had a duration, beginning, and ending time with a specific severity. Cumulative drought quantities which included a positive total SPI index in different months of a drought period were also considered as the drought amplitude and extension. This index has been used for drought monitoring for the state of Colorado since 1994 – and SPI-based drought maps of this state are prepared continuously for use by drought management planners.

Table 5.1. SPI values and related drought severity (Mckee et al., 1993).

SPI values	Drought classification
≥ 2	Extremely wet
1.5 to 1.99	Severely wet
1 to 1.49	Moderately wet
–0.99 to 0.99	Mildly wet to mild drought
–1.49 to –1	Moderate drought
–1.99 to –1.5	Severe drought
≤ –2	Extreme drought

5.3.3. Advantages of SPI

The SPI was first suggested by McKee *et al*. (1993). Computations of SPI are quite simple and the obtained results are reliable, especially in water resource studies. The SPI is only based on precipitation data and can be calculated in an arbitrary time scale. This ability enables study of water resource conditions in both short-term (best suited to agricultural studies on plant accessible moisture) and long-term time scales (important in the study of surface and groundwater resources). Another advantage of the SPI is that it can simultaneously be applied in the study of wet conditions. There are many research institutes in the USA that have accepted SPI and are using it for drought and wet events monitoring. Turkey, Brazil, Mexico, Costa Rica, Argentina, Chile, Hungary, South Africa, and some European countries like Spain and Italy use the SPI for monitoring drought and wet conditions.

SPI computation needs a long-term monthly data: a minimum of a 30-year period of observation in any location. For computing SPI, first, the Probability Distribution Function (PDF) should be determined by fitting a proper probability function to the total data. Then, the Cumulative Distribution Function (CDF) should be transformed to a normal distribution of zero (0) average and standard deviation of one (1) by using the equivalent probability. Therefore, the estimated SPI is explained as a standard deviation unit.

The SPI is one of the most applicable indices in the study of drought and wet condition. Nowadays, the SPI is used all over the world and many scientific societies have accepted it. One of the most important advantages of this index is its flexibility in studying different types of drought.

Time scales shorter than six months are suitable for the study of agricultural droughts, while in studying impact of the seasonal precipitation changes on surface water resources, 6–10-month time scales are appropriate. A 12-month time scale is used in the study of mid-term changes and 18-months and longer time scales are applied in studies of hydrological and groundwater droughts. We can simply identify and study various drought and wet condition events and their characteristics in any arbitrary time scale using the SPI.

The results of much research have shown that the best PDF for the fitting of monthly precipitation data, especially in arid and semiarid regions, is a Gamma function. McKee and many other researchers consider this distribution the best choice and so recommend it. Guttmann (1999) applied various statistical distributions to the data of different climatic regions of the USA and concluded that the Pierson Type 3 Function was the best fitted distribution and was applicable in most regions. He suggested this as an international model for the SPI. Lana *et al*. (2001) used SPI for the Catalonia region in the Iberian Peninsula and concluded that the Poisson–Gamma distribution was best for calculating this index.

Therefore, SPI estimates is a PDF fitting to a series of precipitation data for computing the probability and frequency of occurrence of any precipitation event based on that data set. Then, the parameters related to this function are estimated for any time scale or months of the year and finally the related CDF will be calculated and transformed into a normal CDF for SPI calculation.

McKee *et al*. (1993) presented SPI classification values (Table 5.1) for analysis of the results and spatial comparison. As the computed SPI values have an almost equal fitting to a normal distribution, it is possible to assume that these values are within one unit of the standard deviation corresponding to 98% probability of occurrence and three units within 99%. According to this classification, an extreme drought (SPI < –2) will occur two or three times in every 100 years. Therefore, one of the other advantages of this method is stating the return periods of SPI values, which are highly valuable in water resource management patterns and studies. As McKee *et al*. (1993) explained, the following reasons make the SPI the best choice in drought analysis (especially spatial analysis): (1) simple computation,

(2) availability of the required precipitation data, (3) applicability for any time scale, and (4) high efficiency in spatial comparison of the results.

Total precipitation for the various time scales of 1, 3, 6, 9, and 12 months can be assessed using the SPI in order to be used in different applications. The concept, calculation methods, and the application of any of these time scales are explained below:

Three-month SPI

A three-month SPI time-series assesses and compares the precipitation amount of a three-month period of a specific year to the average precipitation of the same period in the whole statistical period under study. In other words, February three-month SPI compares the total precipitation of December–February for any year to the average precipitation of the same three months in the time-series. A three-month SPI demonstrates humidity and wet conditions of a region in the short-term and medium-term. Therefore, it is a good criterion to assess seasonal humidity of a region. As a result, the three-month SPI is an appropriate index for agricultural drought assessment. This index is very sensitive and reacts to even trivial precipitation fluctuation.

Six-month SPI

A six-month SPI time-series assesses and compares the precipitation amount of a six-month period of a specific year to the average precipitation of the same period in the whole statistical period under study. For example, six-month SPI of September 2000 in a six-month time scale compares the total amount of precipitation in September and the previous five months (April–September) to the average amount of precipitation in the long-term. This time scale demonstrates the medium-term changes in precipitation and is sensitive to seasonal changes of precipitation and so is a good criterion for investigating total precipitation and water potential of a region in different seasons. Due to the sensitivity of this time scale to precipitation changes that are effective in the discharge of dams and rivers, one can easily forecast and estimate the water level of rivers and discharge and, also, the future water potential of the region.

Nine-month SPI

Like six-month SPI, a nine-month time-series assesses and compares the precipitation amount of a nine-month period in any specific year to the average long-term precipitation of that period. This time scale shows long-term changes in precipitation and is an appropriate criterion in the assessment of seasonal and annual changes of precipitation that are effective in the water supply of dams, surface waters, and rivers.

12-month SPI

A 12-month SPI assesses and compares the precipitation amount of any 12 successive months in any specific year to the average long-term precipitation of that period. This time scale is an intermediate scale between short- and long-term. A 12-month SPI of February compares the total amount of precipitation in February and the previous 11 months to the average amount of the long-term precipitation in this period, which is the sum of precipitation from March 1999 to the end of February 2000. This time-scale analysis shows hydrologic droughts. Such a scale could show the long-period droughts that decrease river flow, or cause drawdown of reservoir water levels or groundwater tables. Investigations in the USA show that the result of this time scale is similar to the Palmer method, and thus SPI and PDSI have a high correlation with each other.

Therefore, SPI analysis can determine severe meteorological and hydrological droughts.

5.4. Methodology

The methodology was based on the method of McKee *et al*. (1993). Accordingly, the probability distribution of rainfall time-series and the best fitted distributions were investigated. Results showed that some of the time-series did not fit the distribution, because of many zero values in the series and high skewness of the data. This condition was observed especially when the time scale for calculating the criterion was less than three months. For example, the sum of summer rainfall in some of the stations was often zero; however, in longer time scales the probability distribution of the data tends to normal. Thus, SPI in longer time scales are more significant.

In this study, 1, 3, 6 and 12-month SPIs were used to evaluate hydrological and agricultural droughts in the study area, although one-month SPI was used whenever possible. To this end, we first established the Gamma distribution as the best distribution for the data. Then, the fitted Gamma distribution was transformed to a normal distribution and SPI values were calculated for 1, 3, 6 and 12-month scales. Drought was determined in the threshold SPI value of –1 in the stations. Characteristics such as mean, maximum, and minimum of drought severity were calculated.

Selection of a suitable statistical time period is very important in studying drought. The longer the length of this period, the more accurate are the results, and the better can long periods of a few years of drought be identified. However, selection of long time periods will eliminate use of stations with short-term data and so reduce the resolution of the study stations. Therefore, it is necessary to fulfill the requirement of a suitable resolution of stations and the length of the statistical period for the study. Consequently, information from stations with long-term records was used to study drought in the KRB.

Monthly precipitation data for 45 stations in the region were obtained from the Iranian Water Resources Institute and the Iranian Meteorological Organization (Appendix II). The randomness of the annual data sets was investigated through tests for homogeneity, absence of artificial trends, and spurious autocorrelation. Following Helsel and Hirsch (1992), a set of non-parametric tests was applied: the Mann–Whitney homogeneity test, the Mann–Kendall trend test, and the Kendall's τ autocorrelation test. These tests were performed for all stations as described by Paulo *et al*. (2003) using software developed by Matias (1998). The test results led to discarding of 17 stations with low quality data or > 5% of missing values. The remaining 28 stations covered 35 hydrological years, from October 1965 to September 2000, and constituted a well-distributed network throughout the study area (Figure 5.1). Missing values for each station were estimated using the Move4 technique (Maintenance of Variance Extension), which developed a linear equation such that a reasonable and unique extended record was generated, while maintaining the variance of the data series unchanged (Vogel and Stedinger, 1985). Tables 5.2, 5.3 and Appendix II show the time-series of rainfall in the KRB.

For evaluation of drought in Merek and Honam watersheds, the two selected catchments in the KRB, the nearby stations of Kermanshah and Alashtar were used. Regional drought characteristics were studied in the entire KRB.

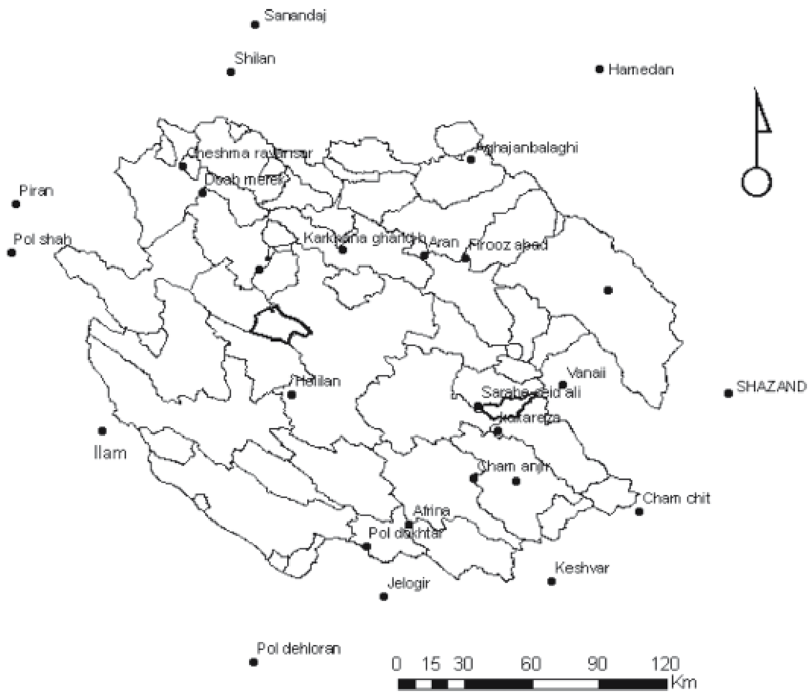

Figure 5.1. Location of meteorological stations in the upper KRB.

The main specifications of drought events are duration, intensity, and magnitude. In drought research, study of these specifications is very important. Frequency or probability of occurrence and maximum intensity are the other specifications of drought. Considering that every long-term drought is not necessarily the most intensive and hazardous drought event, the importance of studying these specifications becomes clear. Therefore, other parameters of droughts such as starting time, mean and maximum intensity, and magnitude should be considered along with drought duration. According to Yevjevich (1967), the amount of negative deviation of the index (SPI in this case) from its mean value or any other selected truncation level measures the severity of drought. The number of consecutive intervals where the index has lower values than the truncated level (e.g. zero value in the SPI index) indicates the drought duration. The sum of deviations between the truncation level and the index values along a deficit run (a drought event) represents the total deficit amount or drought magnitude for that event. Moreover, by dividing the magnitude of the considered drought event to its duration, the drought intensity can be easily obtained.

Intensity and duration are the two main specifications of drought. Degree of hardness or impact value of a drought is described based on these specifications. The greater the intensity (mean deviation of drought index in the drought period) and duration of a drought event, the higher will be its negative effects.

SPI time-series of Kermanshah and Alashtar stations (Appendix III), as two KRB representative stations, were used to analyze the temporal variations of drought. Figures 5.2 to 5.5 show graphs of 1, 3, 6 and 12-month SPIs for Alashtar station: SPI variations of the longer time

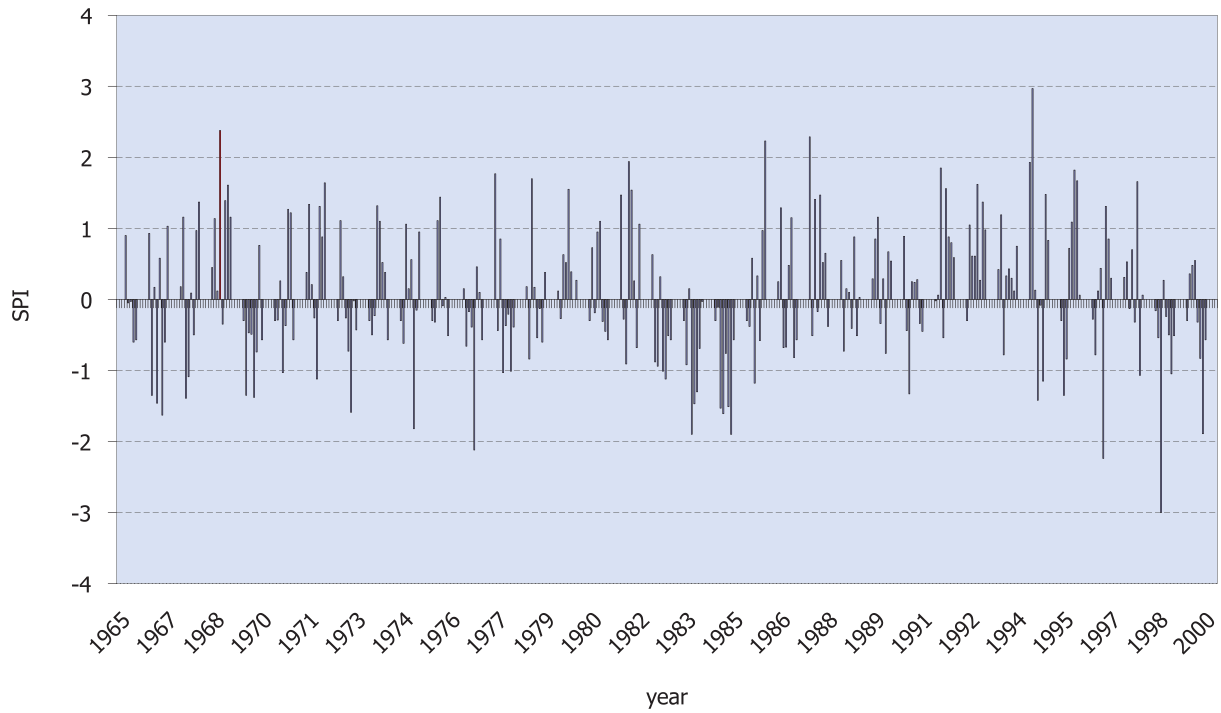

Figure 5.2. One-month SPI time-series for Alashtar station.

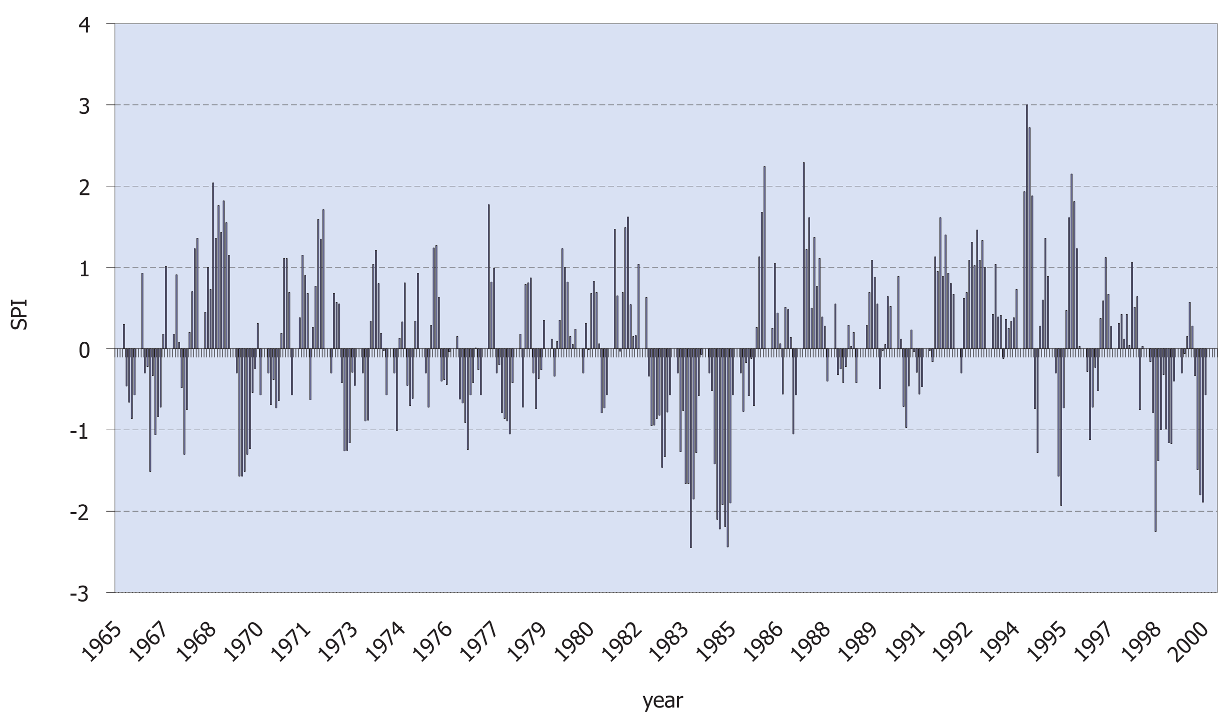

Figure 5.3. Three-month SPI time-series for Alashtar station.

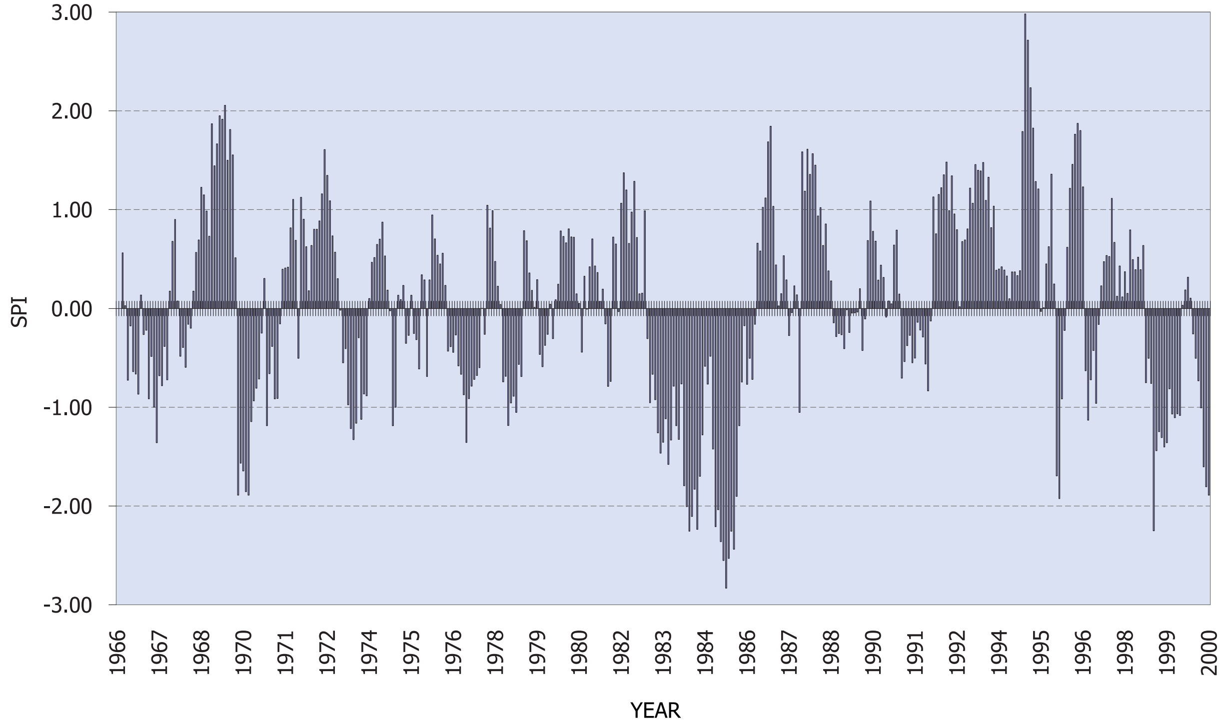

Figure 5.4. Six-month SPI time-series for Alashtar station.

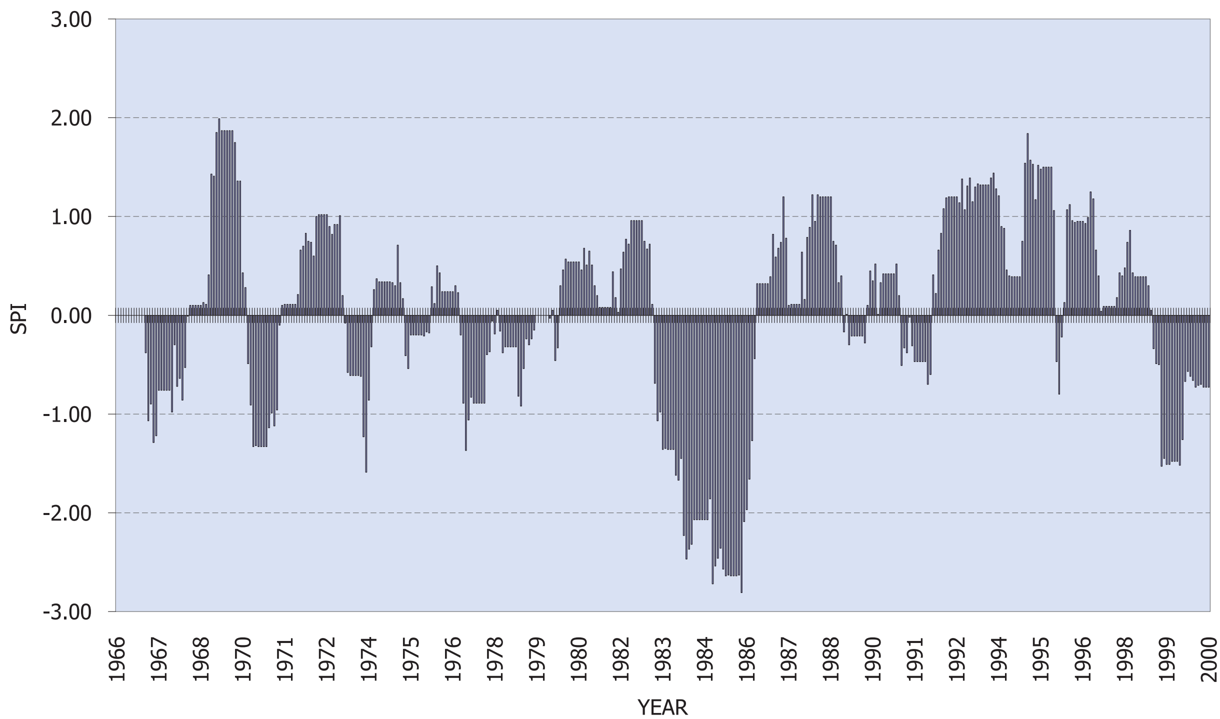

Figure 5.5. 12-month SPI time-series for Alashtar station.

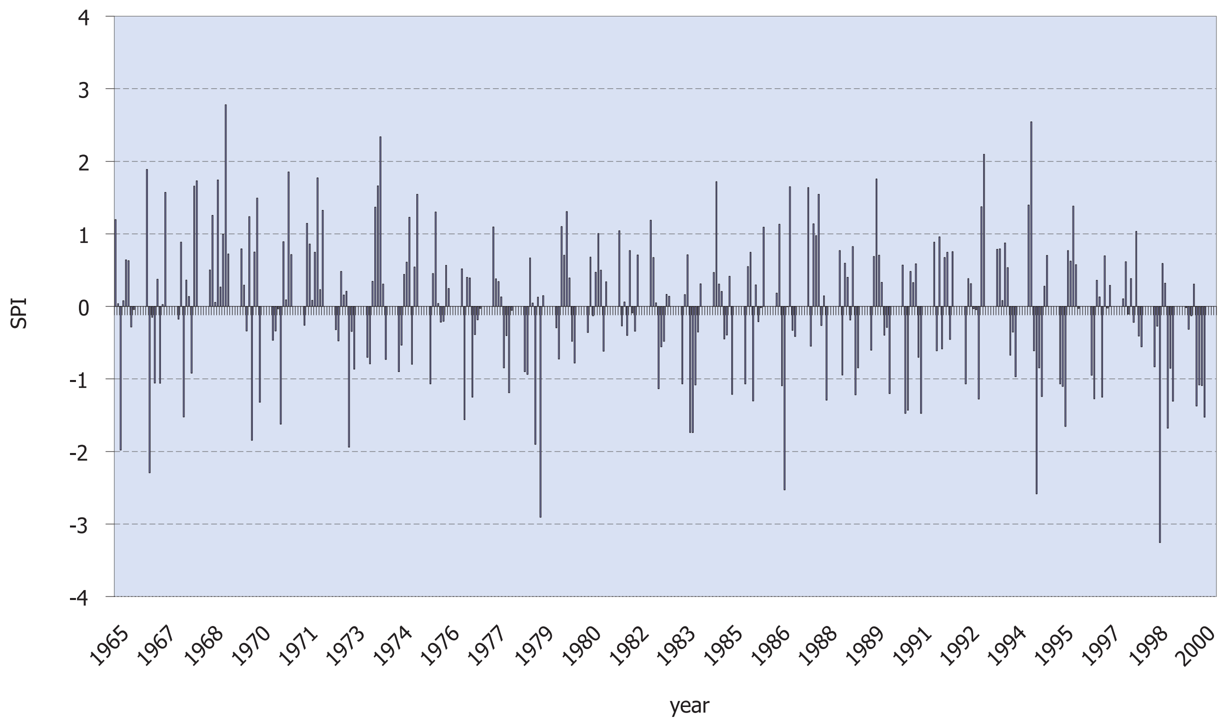

Figure 5.6. One-month SPI time-series for Kermanshah station.

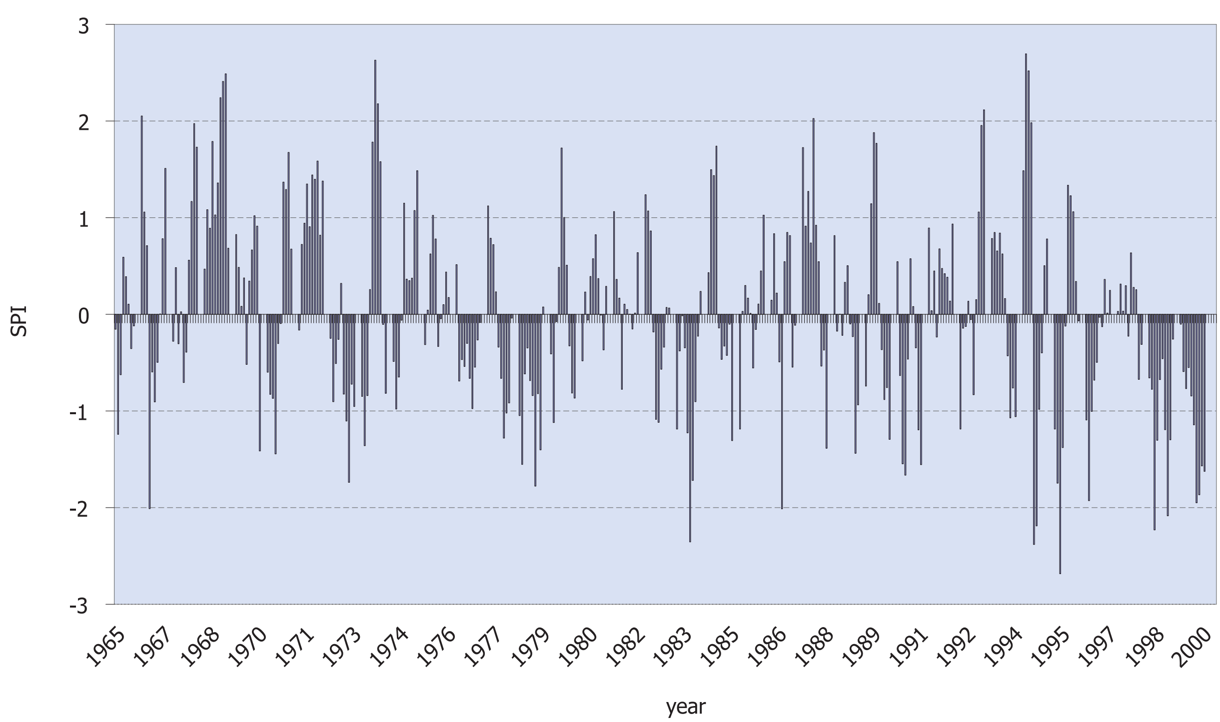

Figure 5.7. Three-month SPI time-series for Kermanshah station.

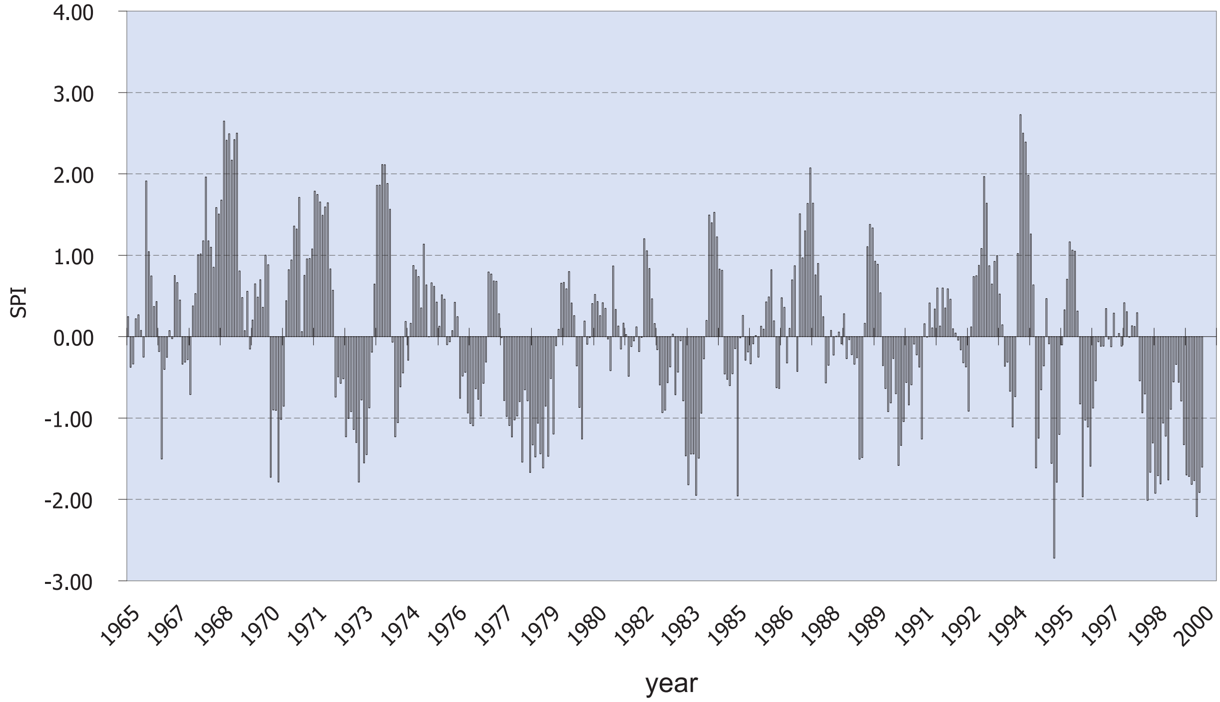

Figure 5.8. Six-month SPI time-series for Kermanshah station.

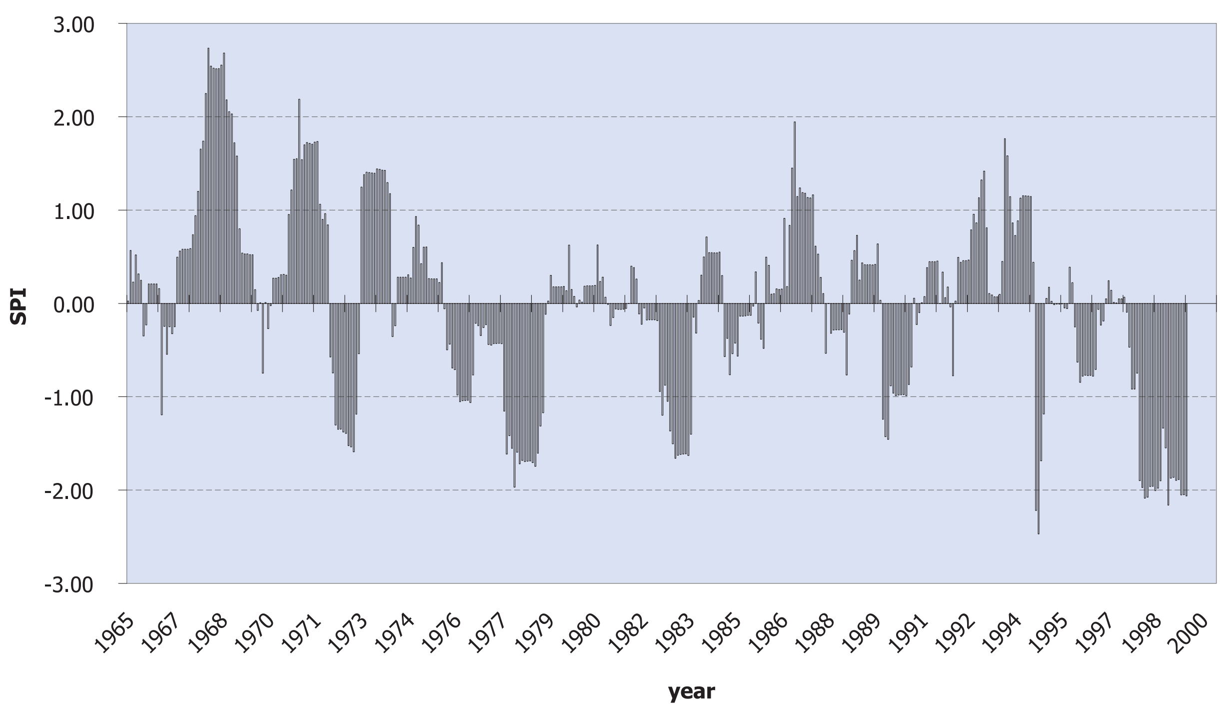

Figure 5.9. 12-month SPI time-series for Kermanshah station.

scales were less than those of one- and three-month values, in comparison with the mean. Therefore, six- and 12-month SPIs are suitable for determination of drought characteristics. Notably, these figures show some of the main drought spells of 1970, 1983–1985, 1999, and 2000. Similarly, Figures 5.6 to 5.9 shows SPI time-series of Kermanshah Station. In Merek catchment, based on three-month SPI, drought events occurred in 1978, 1984, 1991, 1995, 1999, and 2000; while for Alashtar, based on six-month SPI, the drought years were 1974, 1979–1980, 1984, 1991, 1996, 1999, and 2000. Comparison of the drought years showed that 1999 and 2000 were common to both catchments.

5.5. Results in Honam and Merek

To study the specifications of droughts, all drought events in each station were considered. Table 5.2 shows the number of drought events of the two catchments identified using SPI-3. Most of the drought events in the catchments were of 1–3 months type and with a longer duration, the less was the number of drought events. For this time scale in the study period, both catchments experienced 14–20 droughts of 1–3 months duration (Table 5.2). Also, time scales of 4–6-months, up to some extent, showed a considerable number of drought events. However, the number of drought

Table 5.2. Characteristics of droughts in Honam (Alashtar station) and Merek (Kermanshah station) catchments.

Duration (months)	Magnitude	Mean severity	Max severity	Min severity	No. of drought events
Honam (Alashtar station)					
1	–10.18	–0.73	–0.56	–1.51	14
2	–11.8	–0.84	–0.57	–1.3	7
3	–22.44	–0.93	–0.52	–1.93	8
4	–14.76	–1.23	–0.57	–2.25	3
5	–4.01	–0.8	–0.57	–1.24	1
6	–7.72	–1.29	–0.54	–1.57	1
7	……	……	……	……	……
8	–19.22	–1.2	–0.57	–2.45	2
9	–15.28	–1.7	–0.52	–2.44	1
Merek (Kermanshah station)					
1	–18.76	–0.94	–0.52	–2.01	20
2	–11.72	–0.98	–0.51	–1.55	6
3	–34.57	–1.15	–0.55	–2.38	10
4	–25.52	–1.28	–0.60	–2.68	5
5	–16.52	–1.10	–0.66	–2.23	3
6	……	……	……	……	……
7	……	……	……	……	……
8	……	……	……	……	……
9	–10.90	–1.21	–0.55	–1.95	1

events with a six-month time period was quite limited.

Mean severity of drought in Honam was from a minimum of –0.7 with duration of one month to –1.7 with a duration of nine months. The corresponding values in Merek were –0.9 and –1.3, with durations of one and six months, respectively. In general, in both catchments, the magnitude of drought of three months were greater than for other time scales.

5.6. Spatial analysis of climatological drought

SPI maps of September of different years, showing the sum of rainfall of September and the prior 11 months (data not presented), were used to study spatial distribution of drought and high-coverage dry periods in the region. These showed that extensive areas of the KRB experienced mild to severe droughts in 1967, 1970, 1973, 1979, 1980, 1982, 1983, 1984, 1985, 1989, 1991, 1997, 1999, and 2000.

During these years, Merek and Honam catchments also experienced drought periods of different intensities. In 1970, there was no drought in either catchment. In 1973, 1979, and 1982, only Merek experienced drought and in 1985, 1997, and 2000, the intensity of drought in Merek was greater than in Honam. In 1983, 1985, and 1991, the intensity of drought in Honam was high. In 1980, only Honam experienced drought.

Considering the agricultural and rainfall season of the region, spatial distribution maps of one-month SPI were plotted for April, May, October, and November during 1966–2000 (data not presented). The maps for these four months showed that, in general, drought was more frequent in Merek. Table 5.3 shows the years with drought during one or more of the aforementioned four months in the studied catchments.

During 1966–2000, there was no drought in Honam in October, whereas Merek experienced drought 11 times in that month (Table 5.3). In November, the

Table 5.3. Years with drought spells in one or two months in fall or spring (SPI < –1) in the studied catchments.

Merek				**Honam**			
May	Apr.	Nov.	Oct.	May	Apr.	Nov.	Oct.
1970	1978	1966	1973	1973	1978	1966	....
1973	1979	1973	1974	1974	1979	1969	....
1974	1980	1976	1975	1978	1984	1976	....
1980	1989	1978	1978	1984	1985	1978	....
1984	1991	1979	1983	1987	1987	1982	....
1987	1999	1988	1985	1991	1989	1983	....
1988	2000	1990	1989	1999	1991	1988	....
1990		1995	1992	2000	1999	1995	....
1991		1996	1995		2000	1996	....
1994			1996				....
1998			1998				....

two catchments suffered very similar droughts, often at the same time. Also, in both catchments, the frequency of drought in April was almost the same. In different years, drought in May was more frequent in Merek than Honam, although in some years both catchments experienced drought.

To study the frequency of droughts in these four months, the probability of occurrence of SPIs smaller than -1 was determined using the Weibull method and the map of their spatial distribution for the region was extracted.

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Appendices

Appendix I. Geographic coordinates of Merek wells.

Row	Elevation (m)	Long	Lat	Row	Elevation (m)	Long	Lat
1	1629	47°6′6.75″E	34°5′35.16″N	31	1615	47°7′8.74″E	34°7′16.31″N
2	1622	47°6′16.66″E	34°6′0.08″N	32	1625	47°7′25.85″E	34°7′26.56″N
3	1613	47°6′15.64″E	34°6′1.69″N	33	1610	47°8′1.86″E	34°7′11.95″N
4	1618	47°6′14.87″E	34°6′5.01″N	34	1618	47°5′38.61″E	34°5′40.93″N
5	1612	47°6′10.80″E	34°6′2.91″N	35	1656	47°5′42.03″E	34°6′12.00″N
6	1604	47°6′15.22″E	34°6′2.09″N	36	1630	47°8′26.44″E	34°6′51.33″N
7	1627	47°6′17.97″E	34°4′59.59″N	37	1649	47°9′21.54″E	34°5′29.71″N
8	1626	47°6′6.03″E	34°5′34.43″N	38	1673	47°9′9.57″E	34°5′45.66″N
9	1693	47°6′21.52″E	34°5′31.11″N	39	1636	47°8′51.65″E	34°5′40.32″N
10	1623	47°5′48.28″E	34°6′18.48″N	40	1638	47°9′3.50″E	34°5′39.89″N
11	1641	47°6′6.23″E	34°5′34.65″N	41	1637	47°9′3.35″E	34°5′47.84″N
12	1643	47°6′16.08″E	34°5′47.79″N	42	1631	47°9′22.05″E	34°5′29.73″N
13	1623	47°5′47.71″E	34°6′17.55″N	43	1648	47°9′20.51″E	34°5′58.25″N
14	1479	47°6′20.67″E	34°5′10.93″N	44	1637	47°8′54.47″E	34°5′33.04″N
15	1601	47°6′17.68″E	34°6′3.60″N	45	1649	47°9′15.91″E	34°5′41.65″N
16	1628	47°8′3.12″E	34°6′53.59″N	46	1665	47°10′46.46″E	34°4′43.61″N
17	1632	47°7′43.26″E	34°7′15.52″N	47	1635	47°9′0.55″E	34°5′48.12″N
18	1635	47°7′44.15″E	34°7′7.68″N	48	1654	47°9′21.69″E	34°5′47.88″N
19	1621	47°7′20.77″E	34°6′42.41″N	49	1648	47°11′1.10″E	34°5′3.63″N
20	1532	47°7′43.84″E	34°7′7.46″N	50	1652	47°11′1.59″E	34°4′32.63″N
21	1630	47°7′26.17″E	34°7′0.07″N	51	1651	47°10′47.51″E	34°5′10.92″N
22	1621	47°7′25.43″E	34°6′46.06″N	52	1651	47°10′51.19″E	34°4′59.17″N
23	1631	47°7′2.73″E	34°5′36.28″N	53	1649	47°11′25.48″E	34°5′0.54″N
24	1765	47°6′22.90″E	34°10′54.09″N	54	6522	47°11′0.70″E	34°4′51.05″N
25	1755	47°6′21.61″E	34°10′55.76″N	55	1647	47°11′9.47″E	34°5′1.64″N
26	1761	47°6′22.25″E	34°10′54.52″N	56	1655	47°11′42.68″E	34°4′45.24″N
27	1773	47°6′24.80″E	34°10′59.70″N	57	1618	47°10′50.18″E	34°5′7.01″N
28	1763	47°6′22.49″E	34°10′57.99″N	58	1656	47°11′20.37″E	34°5′15.95″N
29	1765	47°6′22.36″E	34°10′54.52″N	59	1646	47°10′49.19″E	34°3′41.08″N
30	1783	47°6′26.54″E	34°10′56.13″N	60	1641	47°10′50.94″E	34°4′37.07″N
61	1653	47°10′55.62″E	34°5′19.77″N	91	1656	47°10′55.24″E	34°4′11.90″N
62	1698	47°11′13.96″E	34°6′18.90″N	92	1647	47°10′38.53″E	34°4′11.09″N
63	1659	47°11′5.25″E	34°5′22.39″N	93	1670	47°10′33.35″E	34°4′28.20″N
64	1626	47°11′12.12″E	34°5′13.63″N	94	1656	47°11′1.36″E	34°4′11.76″N
65	1675	47°11′32.05″E	34°5′55.70″N	95	1656	47°10′48.04″E	34°3′42.01″N
66	1677	47°11′54.84″E	34°5′50.03″N	96	1655	47°11′25.74″E	34°5′39.68″N
67	1675	47°11′59.81″E	34°5′38.52″N	97	1643	47°11′50.32″E	34°5′9.41″N
68	1683	47°11′51.18″E	34°5′36.63″N	98	1676	47°12′8.57″E	34°5′36.32″N
69	1675	47°11′2.27″E	34°6′16.68″N	99	1653	47°11′32.87″E	34°5′23.87″N
70	1675	47°11′19.67″E	34°6′4.33″N	100	1708	47°11′20.48″E	34°2′42.26″N
71	1706	47°11′46.92″E	34°5′45.27″N	101	1793	47°11′28.38″E	34°2′37.21″N
72	1676	47°11′2.27″E	34°6′16.65″N	102	1717	47°11′30.61″E	34°2′28.44″N
73	1673	47°11′32.56″E	34°6′1.76″N	103	1703	47°11′26.23″E	34°2′55.33″N
74	1675	47°11′28.75″E	34°5′53.32″N	104	1663	47°11′41.91″E	34°5′26.50″N
75	1673	47°11′32.00″E	34°5′59.95″N	105	1666	47°11′43.47″E	34°4′54.99″N
76	1671	47°12′11.95″E	34°6′16.37″N	106	1671	47°11′48.87″E	34°5′18.07″N

Appendix I. (Continued).

Row	Elevation (m)	Long	Lat	Row	Elevation (m)	Long	Lat
77	1658	47°11′4.69″E	34°5′16.00″N	107	1712	47°11′10.48″E	34°2′37.37″N
78	1659	47°10′21.34″E	34°5′9.70″N	108	1704	47°11′8.82″E	34°3′2.30″N
79	1648	47°10′9.81″E	34°5′33.24″N	109	1692	47°11′10.76″E	34°2′58.92″N
80	1646	47°9′46.79″E	34°5′48.38″N	110	1692	47°12′31.99″E	34°5′47.19″N
81	1654	47°9′58.54″E	34°5′51.74″N	111	1664	47°11′12.66″E	34°5′37.54″N
82	1650	47°10′16.81″E	34°6′2.88″N	112	1660	47°11′31.84″E	34°5′32.43″N
83	1659	47°10′12.96″E	34°5′3.84″N	113	1671	47°11′21.66″E	34°5′46.24″N
84	1656	47°10′24.87″E	34°5′4.21″N	114	1673	47°11′41.34″E	34°5′33.33″N
85	1643	47°9′47.26″E	34°5′24.16″N	115	1660	47°11′23.23″E	34°5′31.35″N
86	1650	47°9′55.01″E	34°5′11.33″N	116	5155	47°11′22.63″E	34°2′31.99″N
87	1648	47°10′5.83″E	34°5′17.82″N	117	1681	47°12′1.85″E	34°5′29.69″N
88	1653	47°10′18.73″E	34°4′26.90″N	118	1670	47°11′56.77″E	34°5′16.01″N
89	1652	47°10′10.43″E	34°5′11.71″N	119	1679	47°12′21.44″E	34°5′26.93″N
90	1642	47°10′21.74″E	34°5′46.59″N	120	1685	47°12′18.66″E	34°5′38.57″N
121	1721	47°11′19.38″E	34°2′25.46″N	151	1574	47°13′2.85″E	34°4′41.26″N
122	1573	47°12′4.77″E	34°5′16.16″N	152	1554	47°12′41.72″E	34°4′45.99″N
123	1550	47°12′48.01″E	34°5′20.90″N	153	1553	47°12′39.32″E	34°4′51.20″N
124	1570	47°12′22.11″E	34°3′59.83″N	154	1587	47°13′24.17″E	34°4′38.90″N
125	1556	47°12′24.06″E	34°4′13.66″N	155	1580	47°13′15.56″E	34°4′27.53″N
126	1549	47°12′5.83″E	34°5′2.48″N	156	1544	47°11′48.87″E	34°4′13.12″N
127	1555	47°12′12.95″E	34°5′12.48″N	157	1522	47°11′25.92″E	34°4′26.16″N
128	1550	47°12′3.74″E	34°5′9.43″N	158	1535	47°12′2.68″E	34°4′24.01″N
129	1565	47°12′39.93″E	34°4′34.37″N	159	1519	47°11′15.24″E	34°4′40.24″N
130	1563	47°12′45.94″E	34°4′33.13″N	160	1536	47°11′48.06″E	34°4′21.06″N
131	1566	47°12′23.96″E	34°4′59.20″N	161	1547	47°11′58.12″E	34°4′8.83″N
132	1557	47°12′35.29″E	34°4′52.54″N	162	1546	47°12′4.69″E	34°4′14.04″N
133	1555	47°12′21.92″E	34°4′51.15″N	163	1552	47°11′51.79″E	34°4′2.55″N
134	1551	47°12′35.44″E	34°4′28.35″N	164	1583	47°13′29.20″E	34°4′25.63″N
135	1551	47°12′46.10″E	34°5′12.08″N	165	1548	47°12′1.77″E	34°4′0.56″N
136	1490	47°12′42.09″E	34°4′21.38″N	166	1536	47°13′28.75″E	34°4′14.37″N
137	1556	47°12′44.02″E	34°4′28.13″N	167	1530	47°11′22.58″E	34°4′32.71″N
138	1568	47°12′40.81″E	34°4′56.30″N	168	1586	47°13′26.04″E	34°4′30.20″N
139	1575	47°12′53.60″E	34°4′37.93″N	169	1572	47°14′34.52″E	34°3′48.06″N
140	1566	47°13′3.58″E	34°4′46.90″N	170	1583	47°13′41.53″E	34°4′15.38″N
141	1566	47°12′55.99″E	34°4′45.74″N	171	1622	47°14′41.72″E	34°4′16.84″N
142	1554	47°13′20.36″E	34°5′16.81″N	172	1608	47°14′31.17″E	34°3′56.95″N
143	1551	47°12′14.11″E	34°4′14.84″N	173	1592	47°14′26.71″E	34°4′8.22″N
144	1560	47°12′28.33″E	34°4′5.37″N	174	1585	47°14′25.80″E	34°4′18.43″N
145	1536	47°12′39.49″E	34°5′7.04″N	175	1616	47°13′51.93″E	34°2′49.92″N
146	1540	47°12′18.75″E	34°4′7.13″N	176	1614	47°13′57.82″E	34°2′42.61″N
147	1543	47°12′33.58″E	34°5′10.52″N	177	1577	47°13′52.33″E	34°4′22.65″N
148	1544	47°12′27.06″E	34°5′13.43″N	178	1596	47°14′5.65″E	34°4′2.67″N
149	1541	47°12′15.07″E	34°5′4.03″N	179	1593	47°14′3.07″E	34°4′18.65″N
150	1563	47°12′24.15″E	34°5′6.56″N	180	1593	47°14′23.88″E	34°4′0.29″N
181	1397	47°14′14.35″E	34°3′4.60″N	211	1590	47°13′56.80″E	34°3′10.70″N

Appendix I. (Continued).

Row	Elevation (m)	Long	Lat	Row	Elevation (m)	Long	Lat
182	1650	47°15′55.36″E	34°4′46.10″N	212	1600	47°15′13.84″E	34°3′58.73″N
183	1605	47°15′19.03″E	34°3′46.95″N	213	1604	47°15′48.11″E	34°3′21.49″N
184	1660	47°15′43.13″E	34°4′42.53″N	214	1638	47°15′48.13″E	34°4′33.90″N
185	1614	47°15′16.20″E	34°4′43.51″N	215	1649	47°15′54.28″E	34°4′46.57″N
186	1622	47°15′50.71″E	34°4′53.33″N	216	1634	47°17′7.18″E	34°3′12.00″N
187	1616	47°14′56.47″E	34°3′56.61″N	217	1649	47°16′34.42″E	34°3′45.69″N
188	1628	47°16′4.28″E	34°3′56.21″N	218	1651	47°16′36.39″E	34°3′50.68″N
189	1639	47°15′37.15″E	34°4′28.91″N	219	1660	47°16′30.26″E	34°3′59.17″N
190	1641	47°16′9.88″E	34°4′27.59″N	220	1619	47°16′14.96″E	34°2′44.05″N
191	1600	47°15′46.17″E	34°3′49.76″N	221	1630	47°16′34.40″E	34°3′25.99″N
192	1611	47°15′26.62″E	34°4′9.92″N	222	1680	47°16′39.83″E	34°3′59.67″N
193	1641	47°16′1.54″E	34°4′35.34″N	223	1616	47°15′54.32″E	34°3′28.97″N
194	1614	47°15′8.12″E	34°4′31.32″N	224	1670	47°17′1.58″E	34°3′54.86″N
195	1641	47°15′57.96″E	34°4′28.27″N	225	1657	47°16′25.05″E	34°3′55.47″N
196	1629	47°16′1.02″E	34°4′9.93″N	226	1617	47°16′24.18″E	34°2′43.30″N
197	1618	47°15′45.49″E	34°3′38.96″N	227	1607	47°15′36.99″E	34°3′19.65″N
198	1646	47°15′38.87″E	34°4′20.11″N	228	1648	47°16′49.27″E	34°3′27.66″N
199	1615	47°15′39.03″E	34°4′4.34″N	229	1649	47°16′43.70″E	34°3′20.88″N
200	1627	47°15′39.15″E	34°4′4.27″N	230	1694	47°15′45.40″E	34°3′26.63″N
201	1611	47°15′2.86″E	34°4′14.12″N	231	1639	47°16′32.55″E	34°3′36.93″N
202	1603	47°15′40.38″E	34°3′54.93″N	232	1637	47°16′22.14″E	34°3′33.94″N
203	1601	47°15′8.56″E	34°3′1.93″N	233	1618	47°15′54.22″E	34°3′34.23″N
204	1627	47°15′0.24″E	34°4′28.71″N	234	1644	47°16′3.33″E	34°3′38.12″N
205	1612	47°15′19.73″E	34°4′34.03″N	235	1627	47°16′2.05″E	34°3′27.95″N
206	1607	47°15′24.87″E	34°3′30.38″N	236	1629	47°16′44.03″E	34°3′0.85″N
207	1579	47°14′1.32″E	34°2′58.54″N	237	1628	47°16′12.95″E	34°3′31.77″N
208	1613	47°15′55.00″E	34°4′1.90″N	238	1610	47°15′14.43″E	34°4′23.87″N
209	1595	47°14′34.39″E	34°3′4.43″N	239	1623	47°5′47.86″E	34°6′17.45″N
210	1553	47°13′34.97″E	34°3′5.06″N	240	1617	47°6′39.81″E	34°4′32.76″N
271	1617	47°7′58.13″E	34°6′5.83″N	241	1523	47°6′49.34″E	34°5′50.01″N
272	1631	47°8′37.50″E	34°6′47.40″N	242	1637	47°6′57.18″E	34°5′24.95″N
273	1628	47°7′52.75″E	34°6′16.67″N	243	1649	47°6′52.81″E	34°4′56.52″N
274	1620	47°8′38.54″E	34°5′55.68″N	244	1763	47°6′24.89″E	34°10′55.64″N
275	1617	47°8′48.13″E	34°5′49.28″N	245	1762	47°6′22.31″E	34°10′58.64″N
276	1667	47°11′2.16″E	34°6′16.71″N	246	1767	47°6′17.78″E	34°11′0.18″N
277	1650	47°11′16.71″E	34°4′57.74″N	247	1773	47°6′24.80″E	34°10′58.31″N
278	1653	47°11′0.09″E	34°5′38.90″N	248	1775	47°6′22.39″E	34°11′0.20″N
279	1654	47°10′44.08″E	34°5′3.16″N	249	1729	47°6′25.93″E	34°10′56.40″N
280	1653	47°11′22.99″E	34°5′7.07″N	250	1772	47°6′21.95″E	34°10′56.86″N
281	1657	47°11′21.76″E	34°5′7.84″N	251	1775	47°6′25.16″E	34°10′57.00″N
282	1743	47°10′38.19″E	34°4′57.39″N	252	1766	47°6′22.68″E	34°10′57.82″N
283	1656	47°10′44.30″E	34°5′22.73″N	253	1768	47°6′23.38″E	34°10′57.65″N
284	1649	47°10′45.96″E	34°4′43.65″N	254	1774	47°6′25.38″E	34°11′1.02″N
285	1651	47°9′58.18″E	34°5′26.92″N	255	1499	47°5′32.31″E	34°7′2.48″N
286	1661	47°9′57.87″E	34°5′1.15″N	256	4914	47°7′52.89″E	34°7′27.46″N
287	1657	47°7′13.68″E	34°6′3.94″N	257	1637	47°7′36.03″E	34°7′38.49″N

Appendix I. (Continued).

Row	Elevation (m)	Long	Lat	Row	Elevation (m)	Long	Lat
288	1651	47°10′27.89″E	34°5′26.10″N	258	1618	47°6′17.37″E	34°7′6.71″N
289	1653	47°9′42.95″E	34°5′33.84″N	259	1621	47°7′4.80″E	34°7′5.63″N
290	1663	47°10′14.14″E	34°5′54.52″N	260	1620	47°6′19.22″E	34°7′27.77″N
291	1643	47°9′46.27″E	34°5′14.18″N	261	1630	47°8′32.91″E	34°7′20.59″N
292	1652	47°10′15.43″E	34°5′22.62″N	262	1640	47°8′20.95″E	34°5′19.08″N
293	1656	47°11′23.80″E	34°5′21.83″N	263	1621	47°5′47.02″E	34°7′16.83″N
294	1665	47°11′39.84″E	34°5′20.60″N	264	1651	47°9′7.66″E	34°4′8.31″N
295	1069	47°11′52.70″E	34°4′55.70″N	265	1651	47°9′10.09″E	34°4′25.73″N
296	1666	47°11′41.45″E	34°5′4.38″N	266	1609	47°8′29.02″E	34°5′42.02″N
297	1670	47°11′33.83″E	34°5′38.72″N	267	1621	47°8′30.56″E	34°6′19.81″N
298	1673	47°12′0.67″E	34°5′21.79″N	268	1622	47°8′25.93″E	34°5′58.79″N
299	1680	47°11′52.20″E	34°5′24.73″N	269	1629	47°8′44.42″E	34°5′58.53″N
300	1730	47°12′14.13″E	34°5′24.95″N	270	1622	47°8′1.33″E	34°5′25.26″N
301	1575	47°13′5.00″E	34°4′27.92″N	308	1529	47°5′55.88″E	34°7′32.56″N
302	1572	47°12′56.46″E	34°4′23.40″N	309	1517	47°5′48.71″E	34°7′26.48″N
303	1538	47°11′11.86″E	34°4′28.52″N	310	1502	47°5′40.74″E	34°7′23.24″N
304	1596	47°14′14.09″E	34°4′16.54″N	311	1507	47°6′11.35″E	34°11′0.65″N
305	1524	47°6′13.80″E	34°7′49.97″N	312	1513	47°5′57.47″E	34°7′47.78″N
306	1507	47°6′10.73″E	34°11′21.56″N	313	1480	47°6′0.19″E	34°6′56.97″N
307	1507	47°6′4.32″E	34°11′2.36″N				

Appendix II. Monthly precipitation data for the upper KRB.

Table 1. January precipitation (mm) in the upper KRB.

Year	Shilan	shaza	Sanandaj	Malayer	Khoramabad	Kermanshah	Ilam	Hamedan	Cheshma ravansar	Keshvar	Cham chit	Vanaii	Jelogir	Pol dokhtar	Afrina	Cham anjir	Sarabe seid ali	kakareza	Holilan	Doab merek	Karkhana ghand bisotoon	Aran	Aghajanbalaghi	Firooz abad	Pol dehloran	Pol shah	Piran
1966	61.7	61.9	49.8	45.0	81.2	62.2	114.0	37.0	91.4	226.9	143.3	170.2	100.0	102.7	117.4	108.5	119.8	111.1	51.8	87.4	101.2	80.6	59.0	63.1	61.0	62.8	101.8
1967	36.0	35.0	79.1	8.5	35.0	32.6	82.0	16.2	37.0	82.5	29.0	49.6	24.0	25.0	23.0	25.0	18.0	34.0	7.0	54.5	90.0	29.0	55.0	18.0	8.0	23.0	67.0
1968	50.0	24.0	35.1	67.5	62.5	71.7	125.0	29.4	74.0	145.0	179.0	121.4	27.0	33.0	62.0	56.0	28.0	78.0	63.0	91.0	107.5	109.0	81.0	63.0	14.5	76.0	15.0
1969	74.0	195.0	108.8	70.5	190.0	131.6	312.0	111.6	150.0	490.5	276.0	583.0	366.0	223.0	288.0	203.0	245.0	296.0	130.0	117.0	183.0	185.0	93.5	133.0	137.0	93.0	190.0
1970	74.0	18.5	121.3	19.5	176.9	107.0	170.0	20.5	189.0	121.0	92.0	140.0	125.0	77.0	71.0	70.0	48.0	120.0	54.0	82.0	95.0	66.0	57.0	56.0	59.0	133.0	120.0
1971	14.0	34.0	18.7	22.0	40.8	22.4	49.2	18.2	126.0	21.0	54.7	27.0	36.5	25.0	38.0	33.0	30.0	21.0	34.0	13.0	49.0	7.0	14.0	39.0	14.0	29.0	36.0
1972	47.0	74.0	42.6	11.5	67.5	62.4	88.7	73.9	69.5	177.5	99.0	151.0	86.5	90.0	82.0	63.0	57.0	72.0	43.5	28.0	55.5	54.0	36.5	18.0	87.0	83.0	101.0
1973	49.0	54.0	44.4	31.0	47.0	64.7	94.5	27.5	36.0	143.8	114.0	115.5	47.5	40.0	55.0	57.0	57.0	88.0	21.1	48.0	69.0	38.0	39.0	18.0	49.0	80.0	46.0
1974	102.5	98.5	107.3	70.0	163.4	113.0	217.5	118.8	122.0	391.3	192.0	325.5	264.0	141.0	158.0	136.0	150.0	200.0	126.0	117.0	89.5	221.0	43.0	114.0	145.0	148.0	125.0
1975	39.0	86.5	38.6	19.0	85.6	80.7	71.0	43.6	64.0	161.5	82.0	281.0	133.0	88.0	102.0	84.0	76.0	94.0	80.0	71.5	67.0	82.0	60.0	59.0	73.0	29.0	38.0
1976	41.0	118.5	41.4	78.0	142.9	61.0	114.5	15.6	102.0	285.5	160.0	150.0	173.0	93.0	119.0	129.0	159.0	118.0	71.0	74.0	97.8	57.0	22.0	61.0	143.0	54.0	96.0
1977	53.0	93.9	136.6	60.9	73.5	72.8	170.0	55.2	72.0	196.2	86.0	109.0	105.0	84.0	82.0	73.0	52.0	98.1	59.0	66.5	103.0	78.0	47.0	76.8	60.4	28.0	103.0
1978	80.0	51.4	115.4	11.5	54.6	63.9	65.0	19.2	94.5	100.6	130.0	188.0	43.0	29.0	53.0	3.0	30.0	65.0	53.7	90.4	57.0	32.0	37.0	65.3	14.0	32.0	12.0
1979	97.0	100.6	128.1	92.7	111.8	61.2	76.0	80.0	106.0	259.9	198.0	51.0	131.5	129.0	106.0	109.0	77.0	162.9	50.7	120.5	99.3	145.0	57.8	61.8	94.0	79.0	183.0
1980	82.0	87.0	0.0	75.0	97.3	84.4	140.0	66.2	95.0	169.5	167.0	162.0	114.0	74.0	92.0	97.0	96.0	48.0	77.0	72.0	113.0	82.0	34.0	0.0	55.0	39.0	104.0
1981	60.0	55.7	70.1	10.5	125.7	75.6	80.0	15.9	76.0	273.0	221.0	172.0	114.0	81.0	125.0	93.0	123.0	139.0	67.0	61.0	123.5	33.0	74.8	84.5	104.8	42.0	147.5
1982	169.5	71.1	123.0	46.5	126.1	48.1	79.0	44.0	93.1	385.2	241.9	287.4	145.0	175.3	199.4	182.3	202.3	187.0	0.0	67.5	80.5	0.0	14.0	44.9	105.2	22.0	104.0
1983	76.0	96.4	85.0	57.6	52.1	31.0	87.0	52.6	48.0	215.0	134.0	76.0	41.3	58.0	62.0	57.0	85.0	84.0	24.0	48.0	62.4	41.0	31.0	50.0	0.0	53.0	189.5
1984	15.0	66.9	35.4	29.0	43.5	20.6	16.7	32.8	13.5	89.5	65.5	30.0	55.0	56.0	64.0	52.0	0.0	7.0	29.0	20.0	27.3	27.0	0.0	23.0	39.5	11.0	12.0
1985	53.0	49.0	79.1	16.0	41.9	66.3	112.0	28.7	32.0	117.0	32.0	32.5	29.8	21.0	38.0	42.0	14.0	11.0	48.0	67.5	109.2	33.0	0.0	7.0	14.0	39.0	117.0
1986	41.0	15.0	31.4	25.3	20.7	27.8	31.7	27.4	35.0	57.5	21.0	50.0	29.7	28.0	31.0	19.0	25.5	18.0	17.0	15.0	23.7	20.0	12.0	6.0	50.0	22.0	39.0
1987	13.0	43.0	20.4	6.8	30.9	11.2	8.1	13.0	21.0	101.0	76.0	42.0	16.0	6.0	17.0	26.0	41.5	29.0	0.0	17.0	26.6	23.0	7.0	14.0	0.0	11.0	9.0
1988	60.5	24.2	60.7	125.0	55.0	95.5	82.3	105.2	104.0	180.0	112.0	171.0	50.0	58.0	49.0	65.0	61.0	20.0	89.6	79.0	78.0	61.0	26.0	47.0	48.0	70.0	130.0
1989	61.0	104.0	43.6	49.4	74.5	73.1	61.3	46.2	67.0	124.0	79.0	316.0	50.8	54.0	27.0	83.0	73.5	135.0	0.0	51.0	55.1	161.0	25.0	49.0	54.4	23.0	59.0
1990	38.5	46.0	37.7	71.3	40.0	84.5	132.6	63.3	89.0	108.5	46.0	93.0	44.0	41.0	52.0	41.0	54.0	67.0	47.0	80.0	85.8	70.0	85.4	39.5	41.0	85.0	125.0
1991	28.0	37.0	37.0	25.5	66.5	76.0	94.8	27.6	70.0	126.5	48.0	30.0	108.0	114.0	83.0	63.0	81.0	0.0	67.4	71.5	70.8	65.0	16.0	38.0	76.0	59.0	88.5
1992	62.0	61.0	42.5	16.6	57.4	43.3	85.1	39.3	82.5	145.5	81.0	85.0	62.2	48.0	51.0	48.5	46.0	65.0	28.0	80.5	62.5	62.0	19.5	26.0	11.0	82.0	127.0
1993	46.0	60.0	36.7	39.6	133.3	58.7	122.7	29.7	78.5	185.0	143.0	93.0	0.0	94.0	112.0	100.0	101.5	44.0	47.8	41.5	111.8	59.0	7.0	55.0	87.0	61.0	86.0
1994	77.0	76.0	83.0	35.7	113.7	91.2	145.2	33.9	90.5	212.0	109.0	54.0	183.0	99.0	144.0	109.0	85.5	102.0	0.0	107.0	135.4	45.0	57.0	24.5	42.0	128.0	166.0
1995	22.0	18.0	17.9	4.1	7.3	10.7	18.0	2.6	34.0	41.5	44.0	55.0	4.0	4.0	8.0	13.0	19.0	18.0	3.0	15.5	52.5	18.0	16.0	6.0	12.0	23.0	36.0
1996	63.0	101.0	60.7	42.5	94.4	87.0	149.7	50.3	135.9	251.0	96.0	128.0	227.0	135.0	177.0	98.0	108.0	137.0	55.0	84.5	180.9	105.0	86.5	70.0	139.0	118.0	99.0
1997	53.0	2.0	60.9	13.4	45.6	63.9	134.3	11.8	42.7	121.5	82.0	79.0	79.0	55.0	82.0	42.0	91.5	60.0	37.0	52.0	82.3	17.0	28.5	13.0	54.0	50.0	87.5
1998	115.5	86.6	103.5	30.7	98.7	72.4	178.4	59.7	142.2	260.5	181.7	101.0	143.0	90.0	146.5	101.0	107.0	167.0	63.0	106.0	136.7	103.0	57.0	71.0	122.5	95.0	205.0
1999	63.0	52.2	49.1	42.0	81.3	80.1	172.0	26.8	123.6	223.5	183.0	70.0	85.0	46.0	109.0	97.0	82.5	90.0	112.5	78.0	136.1	72.0	97.5	43.0	93.0	118.0	106.0
2000	94.0	117.6	68.7	31.3	69.4	69.8	143.7	43.8	105.1	185.2	117.4	139.4	81.3	83.6	95.9	89.1	98.1	91.2	60.4	100.9	116.0	92.8	68.0	72.9	49.4	73.1	117.5

Table 2. February precipitation (mm) in the upper KRB.

Year	Shilan	shaza	Sanandaj	Malayer	Khoramabad	Kermanshah	Ilam	Hamedan	Cheshma ravansar	Keshvar	Cham chit	Vanaii	Jelogir	Pol dokhtar	Afrina	Cham anjir	Sarabe seid ali	kakareza	Holilan	Doab merek	Karkhana ghand bisotoon	Aran	Aghajanbalaghi	Firooz abad	Pol dehloran	Pol shah	Piran
1966	109.9	56.5	78.0	46.0	53.4	82.1	189.0	36.0	127.1	128.8	82.3	97.6	55.9	57.8	66.6	62.8	68.7	64.1	74.4	122.9	140.0	112.6	82.5	88.8	33.7	89.6	142.8
1967	30.0	91.0	91.8	61.0	111.4	71.3	209.5	47.3	85.0	149.5	88.0	249.0	97.0	67.0	132.0	118.0	99.0	150.0	65.0	106.0	208.0	76.0	100.0	91.2	93.0	75.1	75.0
1968	23.0	68.0	40.2	70.0	58.0	62.4	87.0	85.0	33.0	137.0	71.0	109.6	85.0	56.0	67.0	61.0	75.0	65.0	40.0	53.5	88.5	98.0	55.0	41.0	20.0	77.0	49.0
1969	41.0	46.0	98.3	17.0	52.0	67.2	51.1	26.9	86.0	108.0	72.0	311.0	63.0	18.0	35.0	37.0	57.0	88.0	40.0	57.0	84.5	61.0	80.5	38.0	11.0	29.5	50.0
1970	41.0	7.0	3.6	16.0	58.2	8.0	17.5	6.2	10.0	53.0	58.0	97.5	34.0	38.0	5.0	37.0	27.0	17.0	24.0	3.0	8.0	8.0	4.5	11.0	26.0	0.0	0.0
1971	96.0	14.4	89.1	32.5	64.4	93.2	115.0	57.2	124.0	136.0	106.5	104.0	45.0	41.0	53.0	54.0	56.0	90.0	52.0	90.0	53.0	47.0	31.0	35.0	48.0	117.0	128.0
1972	57.0	45.0	44.0	17.0	48.0	86.6	87.0	51.2	66.0	96.0	57.0	143.0	42.0	36.0	46.0	48.0	33.0	111.0	31.5	79.5	87.0	70.0	47.5	43.0	26.0	46.0	49.0
1973	74.0	41.0	51.2	31.0	37.3	65.0	74.0	29.6	35.5	86.3	92.0	139.0	62.0	24.0	37.0	33.0	44.0	46.0	15.2	49.5	91.0	42.0	17.0	27.0	25.0	18.0	14.0
1974	83.5	41.0	82.5	45.0	110.3	132.8	188.5	115.8	181.0	230.8	165.0	153.5	199.0	108.0	108.0	84.0	129.0	150.0	102.0	137.5	97.0	132.0	38.0	99.0	83.0	126.0	119.0
1975	87.0	31.0	73.3	23.0	107.2	109.4	146.5	40.3	81.0	165.8	102.0	113.5	134.0	75.0	88.0	90.0	98.0	115.0	75.0	96.0	135.0	99.0	63.0	62.0	50.0	155.0	116.0
1976	44.5	132.5	63.3	77.0	91.7	50.5	85.0	14.1	89.0	175.5	146.0	107.5	92.0	68.5	83.0	90.0	67.0	73.0	38.0	85.0	117.0	38.0	44.0	47.0	53.0	29.0	86.0
1977	29.0	9.0	36.0	0.0	37.0	23.3	22.5	5.3	50.0	69.5	22.0	34.0	31.5	30.0	36.0	38.0	14.0	36.4	50.0	16.0	47.0	40.0	15.0	12.9	12.0	8.0	57.0
1978	93.0	55.7	106.0	17.5	86.0	32.8	99.0	21.1	38.7	187.7	101.0	153.0	220.0	72.0	91.0	82.0	56.0	38.0	18.5	35.0	34.0	25.0	56.0	25.1	78.0	17.0	112.0
1979	29.0	12.1	51.0	23.0	62.7	0.0	66.0	25.6	30.0	88.6	41.0	98.0	36.0	59.0	61.0	62.0	50.0	79.8	0.0	61.5	0.0	52.0	0.0	0.0	20.0	16.0	48.0
1980	31.0	151.0	101.0	95.4	169.9	113.4	151.0	82.1	73.0	328.5	239.0	226.5	220.0	161.0	159.0	157.0	160.0	80.0	109.8	116.0	158.0	134.0	37.0	0.0	84.5	46.0	117.0
1981	77.0	118.9	106.0	78.1	130.7	98.4	123.0	68.6	147.0	193.0	205.0	167.5	86.0	97.0	114.0	172.0	129.0	120.0	92.8	107.0	133.9	45.0	101.8	123.0	109.8	37.0	118.0
1982	99.8	99.2	126.2	58.3	102.8	87.6	279.0	53.2	71.5	303.0	190.7	226.6	78.7	137.6	156.9	144.0	159.5	147.6	0.0	97.5	85.5	30.0	48.0	95.9	82.3	43.0	160.0
1983	41.5	9.3	52.4	27.2	85.4	40.4	88.0	28.9	48.5	161.5	139.0	61.0	93.5	47.0	75.0	85.0	36.0	41.0	35.0	52.0	60.8	45.0	16.0	46.0	0.0	28.0	47.0
1984	31.0	24.7	38.4	32.0	12.8	11.9	0.0	22.3	21.0	18.5	44.0	15.0	4.0	4.0	3.0	8.0	25.0	5.0	32.0	15.5	59.1	78.0	11.0	24.0	3.0	7.0	28.0
1985	85.0	42.4	87.0	51.0	95.0	43.5	64.5	66.4	40.0	197.0	91.0	64.0	53.5	67.0	62.0	71.0	43.0	70.0	25.5	51.5	64.8	67.0	32.0	65.0	17.5	79.0	150.0
1986	115.0	56.0	89.1	32.6	104.2	68.2	116.0	33.1	122.5	243.5	119.0	150.0	104.5	154.0	125.0	106.0	86.0	124.0	72.5	86.0	119.4	47.0	35.0	31.0	98.0	88.0	144.0
1987	88.0	100.5	43.9	12.7	63.6	57.4	101.6	17.6	88.0	116.0	126.0	75.0	61.5	39.0	34.0	66.0	93.5	38.0	0.0	47.5	72.3	68.0	8.0	40.0	0.0	73.0	71.0
1988	128.0	65.5	86.2	80.8	98.1	126.2	128.4	70.7	138.0	228.5	161.0	307.0	52.0	99.0	175.0	113.0	154.5	38.0	124.4	105.0	98.0	75.0	49.0	64.0	60.5	92.0	129.0
1989	49.0	54.0	62.1	38.9	74.8	51.4	83.3	38.0	84.0	120.5	79.0	112.0	62.0	72.0	83.0	77.0	54.5	7.0	0.0	50.5	49.5	71.0	9.0	33.0	54.7	50.0	56.0
1990	86.0	49.0	49.3	87.7	43.4	69.6	129.3	76.1	86.5	190.5	100.0	81.0	18.0	63.0	65.0	47.0	84.0	109.0	40.5	63.0	20.0	50.0	67.7	39.0	22.0	137.0	112.0
1991	87.5	73.0	76.8	63.2	50.9	69.5	148.5	57.0	112.5	155.5	65.0	13.0	13.0	24.0	63.0	49.0	81.5	124.0	60.1	91.0	88.4	69.0	28.0	60.5	31.0	56.0	135.0
1992	72.5	113.0	88.1	53.9	157.8	83.5	160.2	56.6	95.0	269.5	241.0	122.0	221.6	91.0	135.0	121.0	161.0	90.0	45.5	71.5	95.1	86.0	26.0	49.5	43.0	61.0	87.0
1993	26.0	131.0	30.0	96.1	218.9	56.0	59.6	47.5	21.0	302.5	170.0	153.5	0.0	159.0	212.0	129.0	165.5	118.0	44.8	50.0	135.9	73.0	22.0	54.0	104.0	40.0	54.0
1994	33.0	76.0	51.9	45.3	61.6	77.6	104.2	46.4	38.1	75.0	70.0	57.0	43.0	95.0	111.0	71.0	91.0	79.0	0.0	57.5	116.3	100.0	48.5	64.5	41.0	57.0	48.0
1995	45.0	56.0	54.5	33.2	86.7	32.8	95.4	36.6	61.5	198.0	55.0	33.5	114.0	80.0	95.5	77.0	67.5	85.0	34.0	48.0	79.9	43.0	59.0	40.0	94.0	65.0	76.0
1996	81.0	118.0	63.8	54.9	140.4	81.4	113.7	70.7	125.9	213.0	81.0	106.0	180.0	115.0	152.0	154.0	128.5	124.0	90.3	68.0	149.9	102.0	107.0	80.0	152.0	53.0	69.0
1997	39.0	11.8	27.3	5.1	6.2	23.3	18.1	17.6	28.8	17.0	21.0	50.5	16.0	2.0	3.0	6.0	12.5	5.0	4.0	16.0	39.6	23.5	31.0	14.5	2.0	26.0	39.5
1998	56.0	67.0	44.2	26.2	74.7	50.4	65.5	33.0	69.0	124.5	129.1	76.0	35.0	39.0	48.0	54.0	58.0	74.0	31.0	62.5	72.5	45.0	27.0	30.0	31.5	42.0	96.0
1999	43.0	91.8	58.5	21.1	75.1	69.1	84.0	26.7	103.8	131.5	148.0	83.0	107.5	53.0	95.0	77.0	61.0	178.0	47.0	64.5	114.6	64.0	83.0	0.0	86.0	104.0	97.0
2000	10.1	31.3	19.6	10.6	47.5	20.6	49.2	12.2	16.8	108.0	69.4	82.2	46.5	48.2	55.9	53.1	57.9	54.1	4.6	13.2	20.2	13.5	9.7	9.4	27.8	6.8	16.3

Table 3. March precipitation (mm) in the upper KRB.

Year	Shilan	shaza	Sanandaj	Malayer	Khoramabad	Kermanshah	Ilam	Hamedan	Cheshma ravansar	Keshvar	Cham chit	Vanaii	Jelogir	Pol dokhtar	Afrina	Cham anjir	Sarabe seid ali	kakareza	Holilan	Doab merek	Karkhana ghand bisotoon	Aran	Aghajanbalaghi	Firooz abad	Pol dehloran	Pol shah	Piran
1966	120.6	58.0	84.3	59.0	67.5	116.1	210.0	65.0	188.1	178.5	113.3	134.4	78.3	80.6	92.4	86.0	94.6	87.9	112.9	183.5	206.1	167.4	122.8	132.7	47.5	135.4	212.7
1967	6.0	38.0	25.8	7.5	44.6	41.7	54.4	17.0	24.0	77.0	69.0	74.7	32.0	25.0	36.0	30.0	32.0	57.0	0.0	49.0	57.0	31.0	21.5	21.0	0.0	35.2	35.0
1968	75.0	81.0	71.6	36.1	57.0	46.0	40.0	43.0	16.0	67.0	47.0	107.0	14.0	23.0	20.0	21.0	71.0	33.0	13.0	56.5	51.0	68.0	83.0	63.0	6.0	12.0	0.0
1969	93.0	158.6	156.2	141.5	147.0	139.0	132.7	67.4	130.0	314.0	209.0	586.0	53.0	66.0	92.0	143.0	195.0	210.0	75.0	103.0	156.0	112.0	138.5	107.0	22.0	159.0	137.0
1970	93.0	0.0	127.0	38.0	72.4	123.4	100.4	46.4	144.0	109.0	75.0	206.0	106.5	42.0	51.0	54.0	61.0	94.0	40.0	117.0	93.0	57.0	85.5	40.0	41.0	112.0	127.0
1971	48.0	46.0	57.9	142.5	161.4	86.7	70.5	61.5	48.0	260.0	319.3	298.0	143.0	98.0	142.0	185.0	184.0	194.0	39.0	28.0	109.0	82.0	97.0	114.0	52.0	44.0	57.0
1972	142.0	36.0	142.7	68.5	96.8	197.9	253.7	94.4	222.0	310.0	209.0	267.5	217.5	160.0	159.0	117.0	188.0	186.0	180.5	204.0	273.0	214.0	198.5	137.0	124.0	175.5	215.0
1973	6.0	53.0	20.1	51.5	30.2	21.0	38.0	16.9	19.0	52.5	68.0	121.0	37.0	17.0	37.0	35.0	33.0	49.0	21.0	14.5	21.0	6.0	20.5	16.0	8.0	18.0	38.0
1974	235.0	17.5	119.1	26.5	151.2	249.0	352.5	36.6	375.8	188.4	100.0	248.5	139.0	158.0	156.0	135.0	128.0	121.0	142.0	186.0	273.0	95.0	173.0	90.0	80.0	212.0	168.0
1975	77.5	56.0	76.6	42.0	34.3	50.0	25.0	53.4	13.0	80.8	48.0	65.0	24.0	11.0	17.0	45.0	27.4	29.0	11.0	92.5	49.0	48.0	57.0	35.0	2.0	22.0	82.5
1976	64.0	109.5	83.4	82.8	115.4	72.9	181.0	38.4	123.0	188.3	117.0	196.5	84.0	75.5	105.0	97.0	98.0	62.0	75.5	124.0	117.0	77.0	26.0	95.0	44.0	44.0	149.0
1977	22.0	49.0	94.6	32.3	71.1	65.2	75.7	32.9	74.0	93.5	83.0	120.0	58.0	88.0	111.0	75.0	124.0	94.0	75.5	49.0	110.0	89.0	37.0	66.9	45.0	8.0	92.0
1978	49.0	96.4	108.0	49.5	79.4	64.6	107.5	42.1	95.7	171.6	140.0	209.0	133.0	44.0	71.0	84.0	85.0	126.0	54.5	91.7	60.0	50.0	81.0	66.2	22.0	17.0	124.0
1979	72.0	109.1	91.8	81.2	108.5	88.5	99.0	71.0	97.0	122.3	115.0	117.5	64.0	62.0	61.0	71.0	89.0	157.3	81.6	123.5	152.4	39.0	90.1	97.0	15.0	9.0	84.0
1980	75.0	63.0	132.4	95.8	73.3	102.4	108.0	82.4	93.0	180.5	161.0	127.5	86.0	58.0	72.0	59.0	119.0	16.0	97.4	96.5	181.0	116.0	173.0	0.0	16.4	43.0	161.0
1981	39.5	110.5	118.8	40.1	100.2	108.4	123.0	39.0	122.0	172.5	177.0	176.0	72.5	85.0	74.0	87.0	80.0	43.0	104.2	117.5	128.0	96.0	113.7	88.0	79.7	51.0	170.0
1982	77.3	93.6	95.3	64.6	76.6	78.1	0.0	58.1	79.0	210.6	133.2	158.2	66.3	95.3	109.0	100.9	111.4	103.3	0.0	96.5	79.0	112.0	39.0	83.6	56.5	36.0	93.0
1983	64.0	139.7	53.0	53.9	86.9	61.5	123.0	49.7	54.0	124.5	108.0	77.0	67.5	107.0	97.0	84.0	47.0	69.0	91.0	56.0	71.1	89.0	18.0	70.0	0.0	34.0	70.0
1984	102.0	54.2	138.4	41.5	101.1	41.0	59.3	61.3	101.0	146.0	134.0	125.5	58.2	82.0	80.0	99.0	41.0	35.0	34.0	78.0	121.5	43.0	50.0	19.0	22.5	49.0	195.0
1985	55.0	97.0	59.0	36.0	56.5	65.0	109.3	33.5	36.0	99.5	48.0	40.5	36.3	37.0	40.0	58.0	35.0	42.0	45.0	88.0	106.7	52.0	27.0	30.0	0.0	20.0	78.0
1986	38.0	140.0	51.6	97.9	90.8	72.6	125.2	84.1	56.0	131.0	57.0	152.0	83.0	97.0	70.0	102.0	67.5	63.0	51.5	50.5	61.0	77.0	10.0	44.0	51.0	37.0	28.0
1987	173.0	194.8	120.0	144.8	131.3	187.7	283.0	120.7	234.0	461.0	391.0	217.0	190.0	124.0	143.0	129.0	174.0	229.0	20.0	197.5	256.2	155.0	41.0	117.0	0.0	119.0	273.0
1988	83.5	137.0	103.0	30.4	98.2	70.4	101.4	31.4	176.0	269.0	189.0	350.0	175.0	138.0	148.0	97.0	127.5	140.0	61.1	95.2	193.8	71.0	27.0	58.0	74.5	96.0	117.0
1989	138.0	73.7	131.7	91.0	126.8	128.1	163.6	78.7	209.0	292.0	115.0	276.0	82.0	89.0	148.0	136.0	153.5	90.0	0.0	117.5	163.5	106.0	56.0	81.0	105.9	134.0	233.0
1990	55.0	68.0	60.8	31.3	53.3	64.8	54.7	32.1	68.5	80.5	81.0	79.0	62.0	27.0	63.0	49.0	60.0	76.0	24.0	62.5	90.1	39.0	62.0	38.5	14.0	44.0	102.0
1991	80.0	127.0	67.9	78.7	90.8	113.5	128.2	69.1	115.5	254.0	126.0	97.0	122.0	35.0	109.0	67.0	112.5	126.0	110.0	117.5	131.8	78.0	63.0	87.5	28.0	92.0	150.5
1992	89.0	92.0	57.7	60.8	157.6	123.1	209.6	97.4	126.5	237.5	184.0	121.0	221.3	99.0	130.0	151.0	153.0	53.0	110.0	147.0	113.5	136.0	39.0	98.5	84.0	92.0	151.0
1993	71.0	131.5	67.1	53.4	73.2	35.6	75.5	51.0	80.0	206.0	126.0	162.5	0.0	56.0	89.0	71.0	112.0	54.0	21.6	63.0	90.4	69.0	54.0	35.5	23.0	29.0	35.0
1994	115.0	152.0	88.8	73.0	99.6	54.3	66.7	45.9	96.5	215.0	126.0	54.5	63.0	39.0	63.0	42.0	113.5	101.0	0.0	115.5	66.2	32.0	48.5	44.0	18.0	69.0	42.5
1995	55.0	57.0	55.9	30.2	17.1	36.5	64.8	47.5	47.0	41.5	27.0	9.0	32.0	40.0	32.5	25.0	46.0	37.0	25.5	75.5	43.6	39.0	41.0	23.5	15.0	63.0	138.0
1996	102.0	224.0	71.0	120.5	171.8	166.8	188.7	79.9	279.1	276.0	218.0	199.0	209.0	197.0	176.5	142.0	234.5	235.0	134.0	122.0	169.3	154.0	104.5	114.0	126.0	113.0	167.0
1997	56.0	121.4	55.9	105.1	194.4	120.1	162.8	81.3	74.3	401.0	293.0	241.5	233.0	147.0	202.5	213.0	187.5	98.0	118.0	89.0	149.5	128.5	88.0	91.0	65.0	111.0	126.5
1998	138.0	188.2	143.7	113.8	169.5	141.8	214.9	92.2	158.9	421.0	337.1	226.0	121.0	195.0	201.0	179.0	219.5	226.0	136.5	142.0	188.3	148.0	182.0	160.5	116.0	113.0	194.0
1999	17.0	45.0	23.0	36.7	63.6	26.1	23.4	34.5	26.7	120.0	91.0	196.0	40.0	42.0	48.5	74.0	71.0	101.0	18.0	32.3	31.0	48.0	36.0	0.0	40.0	7.0	20.0
2000	120.4	73.6	84.2	52.9	47.1	41.0	46.0	47.8	53.4	106.6	68.5	81.2	45.9	47.6	55.1	52.4	57.2	53.4	27.8	49.6	60.0	46.4	33.8	35.7	27.5	34.3	58.2

Table 4. April precipitation (mm) in the upper KRB.

Year	Shilan	shaza	Sanandaj	Malayer	Khoramabad	Kermanshah	Ilam	Hamedan	Cheshma ravansar	Keshvar	Cham chit	Vanaii	Jelogir	Pol dokhtar	Afrina	Cham anjir	Sarabe seid ali	kakareza	Holilan	Doab merek	Karkhana ghand bisotoon	Aran	Aghajanbalaghi	Firooz abad	Pol dehloran	Pol shah	Piran
1966	66.6	35.0	52.7	14.5	33.3	43.1	69.0	15.6	57.2	57.9	38.2	45.2	24.0	25.3	29.9	29.7	31.8	30.1	30.1	53.3	64.0	49.8	36.3	38.4	13.9	37.1	62.6
1967	46.0	33.0	37.8	27.0	51.7	54.6	40.5	32.2	34.0	23.5	39.0	93.2	0.0	4.0	22.0	27.0	32.0	28.0	0.0	72.5	70.0	40.0	57.0	33.0	3.0	52.6	0.0
1968	111.0	74.0	126.4	72.0	145.0	149.0	30.5	80.6	102.0	121.0	86.0	336.8	146.0	154.0	92.0	122.0	115.0	68.0	55.0	200.0	243.0	137.0	113.5	100.0	110.0	132.0	80.0
1969	130.0	72.5	182.7	62.0	150.0	251.2	222.7	77.0	172.0	201.0	159.0	367.0	75.0	102.0	152.0	142.0	169.0	209.0	110.0	231.0	140.0	148.0	147.0	108.0	81.0	168.5	139.0
1970	143.0	79.9	84.7	88.0	60.4	136.6	107.9	51.5	80.0	67.0	39.0	138.5	39.5	33.0	45.0	48.0	100.0	71.0	13.0	83.0	44.0	83.0	90.0	128.0	7.0	24.0	16.0
1971	97.0	133.0	94.7	100.5	113.8	164.5	171.5	109.7	69.0	202.5	214.9	347.0	169.8	135.0	140.0	113.0	134.0	204.0	126.0	170.5	114.0	114.0	154.0	108.0	67.0	129.0	117.0
1972	34.0	71.0	40.5	49.0	117.1	63.3	101.0	37.0	82.6	105.5	89.0	75.5	96.0	89.0	108.0	89.0	108.0	67.0	47.5	54.5	108.0	51.0	53.0	33.0	69.0	65.0	124.0
1973	48.0	37.0	35.5	50.0	34.2	41.0	36.0	27.3	65.9	35.8	52.0	216.0	17.5	14.0	30.0	29.0	55.0	41.0	26.0	42.0	82.0	58.0	61.0	64.0	18.0	27.0	34.0
1974	47.0	34.6	37.2	21.0	64.6	66.7	80.5	20.8	69.7	128.2	106.0	121.5	40.5	41.0	58.0	47.0	76.0	77.0	6.5	29.5	58.0	28.0	128.0	32.0	23.0	46.0	45.0
1975	38.0	67.0	64.7	35.0	106.9	78.0	99.0	37.4	75.0	91.8	89.0	94.5	70.0	67.5	88.0	93.0	49.0	99.0	48.0	74.5	68.0	46.0	53.0	44.0	34.0	20.0	119.0
1976	84.0	127.0	104.2	51.5	119.8	79.3	61.0	68.4	101.0	58.5	117.0	231.5	82.5	44.0	62.0	96.0	35.0	48.0	69.0	107.5	67.0	114.0	49.0	91.0	67.0	13.0	50.0
1977	53.5	47.0	66.8	45.4	51.0	46.5	62.0	43.1	54.0	46.4	68.0	116.0	31.0	35.0	25.0	39.0	61.0	60.0	21.0	42.5	45.0	39.0	76.0	42.8	27.0	27.0	85.0
1978	11.0	0.0	24.0	3.0	1.9	19.2	2.0	10.2	14.3	10.5	0.0	0.0	0.0	3.0	41.0	0.0	20.0	0.0	3.1	10.7	29.0	16.0	0.0	7.6	17.0	0.0	6.0
1979	0.0	26.1	25.8	36.8	12.8	2.2	3.0	36.4	18.0	4.3	0.0	0.0	0.0	0.0	0.0	3.0	32.0	0.0	0.0	7.0	0.0	0.0	0.0	0.0	17.0	0.0	2.0
1980	48.0	60.0	67.2	44.0	37.0	36.7	13.0	42.0	36.0	50.5	69.0	107.0	21.5	12.0	24.0	31.0	56.0	0.0	22.9	62.0	60.0	36.0	27.0	0.0	26.0	16.0	50.0
1981	41.0	130.1	52.0	63.2	36.5	32.7	43.0	57.0	15.0	87.0	71.0	77.0	12.0	6.0	21.0	29.0	37.0	25.0	18.4	26.0	52.0	52.0	24.0	65.0	17.0	0.0	6.0
1982	31.4	2.2	75.4	12.2	31.9	41.1	91.0	17.2	0.0	53.0	35.1	41.5	21.8	23.0	27.4	27.4	29.2	27.7	0.0	102.0	54.5	27.0	34.0	35.8	12.5	30.0	118.0
1983	41.5	168.1	51.6	33.0	86.4	60.4	59.0	33.4	46.5	129.0	95.0	67.0	20.0	41.0	61.0	47.0	35.0	55.0	24.0	58.5	47.8	20.0	41.0	48.0	0.0	0.0	60.0
1984	55.0	29.0	94.5	23.0	0.0	40.7	58.6	46.1	42.0	51.0	42.0	49.5	10.0	6.0	29.0	21.0	29.0	27.0	28.5	41.0	109.2	55.0	44.0	16.0	35.0	16.0	54.0
1985	80.0	63.0	78.4	35.5	31.8	71.7	123.3	37.4	40.3	51.2	76.0	95.0	40.0	29.0	24.0	25.0	0.0	68.0	45.0	82.0	119.7	45.0	22.0	37.0	35.0	33.0	49.0
1986	68.0	127.0	94.9	70.5	98.6	52.8	83.9	62.7	90.0	117.5	56.0	87.0	66.0	81.0	90.0	121.0	114.5	97.0	0.0	93.0	91.4	81.0	28.5	92.0	17.0	90.0	57.0
1987	58.0	35.0	45.2	8.5	21.8	41.5	21.4	14.3	61.0	29.0	25.0	41.0	9.0	11.0	19.0	23.0	25.0	14.0	0.0	32.0	37.4	21.0	7.0	36.0	17.0	0.0	22.0
1988	66.5	79.0	79.9	82.9	72.4	59.5	53.3	72.4	87.0	106.0	122.0	251.0	36.0	71.0	66.0	76.0	92.5	86.0	48.7	56.0	110.6	121.0	81.0	78.0	0.0	48.0	54.0
1989	5.0	26.0	2.7	0.0	41.5	18.7	40.3	6.6	22.0	30.0	100.0	36.0	19.7	39.0	14.0	40.0	35.0	10.0	0.0	0.0	15.5	10.0	3.0	15.0	21.9	9.0	14.0
1990	66.5	41.4	50.9	34.0	71.5	42.9	59.0	34.2	40.0	200.5	66.0	87.0	15.0	69.0	60.0	68.0	94.0	69.0	30.0	36.0	43.8	42.0	36.1	55.0	35.0	43.0	34.0
1991	64.5	15.0	51.9	18.5	27.5	30.4	33.9	22.1	50.0	58.5	73.0	70.0	17.0	16.0	20.0	68.0	41.5	23.0	15.7	36.5	49.0	31.0	13.0	35.5	0.0	30.0	43.0
1992	37.0	150.5	44.2	107.6	74.6	37.5	20.5	37.7	34.5	155.0	190.0	107.0	89.5	53.0	89.0	99.0	102.5	36.0	48.5	40.5	54.8	94.0	47.0	88.5	0.0	24.0	24.0
1993	66.0	114.7	59.2	61.6	122.2	128.2	154.4	40.8	98.0	260.5	46.0	72.5	0.0	140.0	137.5	95.0	147.0	125.0	126.6	74.5	119.7	86.0	43.0	86.0	92.0	80.0	92.0
1994	65.0	51.0	78.1	24.4	34.6	40.7	62.1	46.1	70.5	32.5	46.0	61.0	20.5	42.0	42.5	20.0	62.0	64.0	0.0	68.0	55.9	66.0	35.0	47.0	23.0	82.0	98.0
1995	118.0	87.0	129.3	60.0	120.2	65.3	97.7	66.6	95.5	173.5	85.0	119.0	108.0	86.0	110.0	136.0	156.5	156.0	82.0	94.0	74.5	106.0	144.0	51.0	63.0	64.0	123.0
1996	123.0	123.4	128.3	61.7	129.2	79.7	126.9	57.2	122.8	218.5	107.0	147.0	148.0	77.0	99.0	164.5	174.5	130.0	67.0	70.9	170.5	83.0	139.0	50.0	28.0	30.0	20.0
1997	109.0	73.0	110.2	55.2	50.7	52.6	149.1	76.8	73.3	126.0	132.5	102.5	41.0	65.0	74.0	82.0	106.0	123.0	76.5	59.0	56.4	65.0	79.0	61.5	13.0	63.0	98.5
1998	53.5	61.4	61.8	39.7	23.6	38.9	43.3	42.8	53.7	31.5	16.9	46.5	6.0	10.0	26.0	27.0	18.5	14.0	17.0	48.0	92.8	53.0	65.5	24.5	17.0	22.0	51.0
1999	29.0	27.2	26.1	16.3	14.1	26.5	19.7	45.0	27.4	26.5	20.5	27.5	7.0	23.0	16.5	13.0	19.0	10.0	9.0	2.9	31.7	17.0	36.0	0.0	8.0	19.0	20.5
2000	51.3	19.2	43.7	15.5	16.6	21.2	19.6	11.8	17.9	0.0	1.5	1.6	0.0	0.0	0.0	2.2	1.1	1.9	5.3	14.3	21.4	14.5	10.4	10.2	0.0	7.6	17.5

Table 5. May precipitation (mm) in the upper KRB.

Year	Shilan	shaza	Sanandaj	Malayer	Khoramabad	Kermanshah	Ilam	Hamedan	Cheshma ravansar	Keshvar	Cham chit	Vanaii	Jelogir	Pol dokhtar	Afrina	Cham anjir	Sarabe seid ali	kakareza	Holilan	Doab merek	Karkhana ghand bisotoon	Aran	Aghajanbalaghi	Firooz abad	Pol dehloran	Pol shah	Piran
1966	33.7	20.5	33.4	30.5	14.6	22.2	17.0	36.4	19.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.5	16.1	23.4	16.1	11.6	11.4	0.0	9.0	19.6
1967	34.0	36.0	80.5	40.5	120.4	77.2	94.5	51.5	91.0	56.5	55.0	272.5	42.0	62.0	67.0	99.0	58.0	73.0	68.0	97.5	50.5	41.0	64.0	61.5	68.0	83.0	91.0
1968	72.0	71.0	91.2	64.5	81.2	85.2	77.0	126.4	61.0	62.0	52.0	170.2	76.0	71.0	82.0	73.0	77.0	74.0	120.0	69.0	114.0	128.0	100.0	118.0	9.0	68.0	146.0
1969	40.0	44.0	48.5	42.5	71.0	42.9	63.0	58.8	56.0	76.5	48.0	122.0	35.0	50.0	46.0	101.0	65.0	47.0	23.0	36.0	48.0	65.0	45.0	40.0	36.0	25.0	36.0
1970	0.0	0.0	16.1	18.5	12.0	4.9	0.0	22.4	8.0	3.5	14.0	11.0	4.0	1.0	8.0	9.0	0.0	0.0	0.0	36.0	28.0	16.0	24.0	12.0	8.0	0.0	0.0
1971	18.0	29.5	39.6	24.0	14.0	42.6	11.7	18.7	34.0	11.5	0.0	35.0	7.5	17.0	7.0	29.0	0.0	9.0	11.0	32.0	36.0	22.0	35.0	15.0	1.0	0.0	0.0
1972	66.0	101.5	111.2	37.0	106.0	65.9	32.1	108.5	148.3	33.5	50.0	167.5	29.5	50.0	50.0	73.0	94.0	52.0	38.3	52.5	69.0	71.0	116.5	48.0	26.0	51.0	88.0
1973	9.0	8.0	15.7	3.5	6.2	9.0	0.0	24.1	11.0	2.9	5.0	6.0	0.0	0.0	0.0	3.0	4.0	0.0	0.0	0.0	25.0	10.0	20.0	9.0	0.0	6.0	12.0
1974	10.0	26.0	7.0	2.0	8.5	10.6	6.0	1.4	9.0	6.5	4.0	21.5	0.0	4.0	4.0	18.0	0.0	0.0	0.0	10.0	8.0	8.0	12.0	1.0	0.0	0.0	19.0
1975	72.5	79.0	70.6	113.0	41.1	76.0	53.0	69.1	53.5	53.2	56.0	67.0	28.0	23.0	28.0	50.0	54.0	71.0	31.0	60.0	70.0	75.0	104.0	57.0	16.0	26.0	22.0
1976	32.5	37.0	53.0	10.0	22.9	29.0	24.0	45.5	69.0	64.2	49.0	71.0	3.0	8.0	22.0	24.0	16.0	6.0	39.5	62.0	47.0	21.0	33.0	23.0	3.0	13.0	52.5
1977	29.0	61.0	54.3	45.1	61.8	22.5	32.0	42.9	40.0	41.2	54.0	177.0	8.0	17.0	14.0	39.0	0.0	78.3	26.0	25.5	37.0	12.0	21.0	11.8	6.0	2.0	8.0
1978	37.0	0.0	40.7	6.5	8.3	21.9	14.0	24.8	19.1	14.5	0.0	0.0	0.0	3.0	2.0	0.0	5.0	7.0	6.1	15.6	5.0	12.0	6.0	11.1	0.0	6.0	12.0
1979	0.0	65.5	46.0	44.1	23.8	26.5	17.0	42.1	27.0	33.2	0.0	15.0	3.0	10.0	31.0	20.0	29.0	14.0	11.3	30.0	31.7	33.0	16.7	17.0	9.0	0.0	0.0
1980	0.0	23.0	0.0	0.0	22.9	10.0	11.0	7.4	22.0	22.0	25.0	42.0	0.0	7.0	12.0	19.0	25.0	0.0	0.0	33.0	16.0	24.0	18.0	0.0	3.5	1.0	20.0
1981	25.0	19.1	42.5	23.9	20.6	31.4	33.0	26.3	53.0	19.0	32.0	15.0	4.5	3.0	9.0	16.0	0.0	13.0	16.9	41.0	39.5	37.0	22.5	4.5	1.4	12.0	48.0
1982	76.0	66.9	76.0	54.0	48.3	42.4	44.0	49.8	1.0	110.8	71.1	84.3	25.0	49.5	57.3	54.4	59.4	55.5	0.0	52.5	50.5	81.0	57.0	37.5	28.6	8.0	39.0
1983	33.0	7.9	73.0	31.8	35.4	26.3	39.0	32.5	39.0	32.0	19.0	45.0	1.0	4.0	4.0	33.0	0.0	21.0	15.5	29.0	48.7	13.0	69.0	23.0	0.0	7.0	33.0
1984	45.0	120.3	65.5	31.5	15.4	30.6	37.6	45.4	24.5	21.5	11.0	36.0	0.0	6.0	8.0	22.0	15.0	0.0	20.0	23.0	12.1	27.0	30.0	34.0	31.0	0.0	7.0
1985	6.0	35.0	6.4	19.0	10.2	5.7	0.0	28.1	11.3	19.5	5.0	17.0	3.0	1.0	8.0	7.0	0.0	0.0	15.0	3.5	0.0	4.0	9.0	6.0	0.0	0.0	14.0
1986	102.0	19.6	91.6	94.0	96.4	56.3	91.2	81.0	76.0	151.0	110.0	110.0	69.0	55.0	74.0	90.0	138.0	92.0	0.0	72.0	115.0	91.0	39.8	63.0	7.0	11.0	93.0
1987	25.0	22.0	9.0	9.9	9.9	15.2	27.4	15.4	5.0	1.5	7.0	10.0	0.0	0.0	2.0	11.0	0.0	8.0	0.0	11.0	30.4	21.0	0.0	20.0	0.0	0.0	0.0
1988	0.0	7.0	0.0	0.0	1.0	5.1	2.4	0.5	6.0	2.5	0.0	10.0	16.0	0.0	0.0	0.0	5.5	18.0	0.0	4.0	8.9	0.0	15.0	6.0	0.0	0.0	0.0
1989	5.5	22.0	11.3	2.5	23.2	9.2	17.7	9.6	17.0	25.5	37.0	56.0	10.5	25.0	10.0	26.0	17.0	12.0	0.0	0.0	24.5	30.0	0.0	21.0	3.9	0.0	0.0
1990	3.5	32.0	5.2	14.1	20.2	5.8	0.2	18.7	6.0	16.0	20.0	28.5	0.0	4.0	17.0	20.0	35.5	38.0	9.0	5.0	17.4	9.0	0.0	24.5	0.0	4.0	10.0
1991	3.0	4.5	1.8	0.0	1.0	3.9	0.2	0.8	1.5	0.0	0.0	0.0	0.0	0.0	0.0	20.0	3.5	0.0	0.0	2.5	4.7	5.0	0.0	3.0	0.0	0.0	0.0
1992	46.0	89.0	46.9	56.0	33.7	44.0	56.9	87.7	76.5	72.5	109.0	103.0	24.6	5.0	16.0	19.5	37.5	20.0	16.5	67.5	24.7	50.0	22.0	32.5	0.0	29.0	42.0
1993	42.0	59.0	71.2	28.5	50.3	105.0	75.2	37.1	79.0	43.5	15.0	32.5	0.0	13.0	20.0	63.9	55.5	27.0	100.3	86.5	56.4	67.0	48.0	45.0	22.0	17.0	41.0
1994	17.0	38.0	27.1	28.0	24.0	7.9	4.9	22.8	4.5	30.5	15.0	62.0	0.0	9.0	12.0	27.0	44.5	38.0	0.0	5.0	33.1	25.0	46.0	0.0	0.0	15.0	0.0
1995	129.0	160.0	126.8	46.9	63.2	42.3	31.2	66.7	65.5	51.5	30.0	87.0	36.0	45.0	40.5	58.0	48.0	0.0	23.5	47.5	98.3	88.0	64.0	69.0	7.0	18.0	43.0
1996	0.0	31.9	14.4	19.5	14.0	22.5	11.5	38.1	20.2	10.5	2.0	16.0	0.0	12.0	8.0	11.0	18.0	0.0	11.5	19.0	15.9	15.0	17.0	3.0	7.0	0.0	0.0
1997	11.5	39.4	20.5	17.2	21.1	30.1	12.2	15.6	9.2	18.0	22.0	43.0	0.0	2.0	14.5	15.0	26.0	10.0	5.5	11.0	25.6	18.0	29.0	7.0	0.0	7.0	0.0
1998	13.0	34.4	14.7	31.5	16.1	13.0	20.2	50.3	34.9	19.0	0.4	17.0	0.0	16.0	16.5	16.0	18.0	21.0	4.0	15.5	26.9	22.0	58.0	10.5	0.0	5.0	15.0
1999	5.0	0.0	3.4	0.2	0.4	5.0	0.8	9.0	0.0	0.0	0.0	0.0	3.0	0.0	5.0	0.0	2.0	0.0	5.0	7.5	0.0	5.7	7.0	0.0	0.0	0.0	0.0
2000	0.0	1.2	3.9	1.2	0.1	3.6	2.6	2.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 6. June precipitation (mm) in the upper KRB.

Year	Shilan	shaza	Sanandaj	Malayer	Khoramabad	Kermanshah	Ilam	Hamedan	Cheshma ravansar	Keshvar	Cham chit	Vanaii	Jelogir	Pol dokhtar	Afrina	Cham anjir	Sarabe seid ali	kakareza	Holilan	Doab merek	Karkhana ghand bisotoon	Aran	Aghajanbalaghi	Firooz abad	Pol dehloran	Pol shah	Piran
1966	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1967	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1968	0.0	0.0	8.5	5.0	0.0	3.0	4.0	4.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0
1969	0.0	0.0	4.0	6.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1970	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1971	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1972	0.0	3.0	1.4	0.0	1.2	5.2	5.8	5.3	0.0	0.0	11.0	24.5	0.0	0.0	0.0	0.0	5.0	0.0	5.0	0.0	0.0	0.0	15.0	6.0	0.0	0.0	0.0
1973	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.0	0.0	0.0	0.0
1974	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0	9.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1975	0.0	0.0	0.0	0.0	0.5	0.1	0.0	2.4	4.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.0	0.0	0.0	1.0	0.0	0.0	0.0
1976	0.0	6.0	0.1	0.0	1.0	0.0	0.0	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.0	0.0	10.0	7.0	0.0	0.0	0.0
1977	0.0	0.0	1.0	0.9	0.0	0.4	0.0	8.4	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1978	0.0	0.0	2.9	0.0	0.0	2.0	0.0	4.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0
1979	0.0	0.0	18.0	0.0	0.0	0.1	0.0	7.4	5.0	1.0	0.0	8.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1980	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1981	7.0	0.8	3.3	18.4	2.0	0.6	6.0	22.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1982	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1983	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1984	0.0	0.0	7.0	0.0	0.0	0.0	0.0	36.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1985	0.0	3.0	0.0	5.1	0.0	0.0	0.0	2.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.0	0.0	0.0	0.0	0.0	0.0
1986	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1987	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1988	3.0	0.0	1.9	0.0	0.0	0.0	0.0	1.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1989	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1990	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1991	0.0	2.0	1.0	10.7	0.9	0.1	0.0	16.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.5	0.0	0.0	0.0
1992	7.0	6.0	9.0	8.1	7.3	8.8	0.0	14.6	4.5	3.5	0.0	17.0	0.0	17.0	9.0	3.0	4.5	0.0	1.0	3.5	3.0	4.0	2.0	4.5	0.0	0.0	0.0
1993	2.5	0.0	5.9	0.0	0.0	2.0	1.0	3.6	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1994	0.0	2.0	0.8	0.0	0.2	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1995	26.0	33.0	22.4	16.2	14.4	4.9	0.2	17.2	27.5	0.0	5.0	0.0	0.0	2.0	0.0	11.0	4.0	0.0	0.0	6.0	8.3	10.0	15.0	8.0	0.0	3.0	0.0
1996	0.0	0.6	0.0	0.0	0.0	0.0	0.0	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1997	0.0	2.8	0.0	5.2	0.2	0.7	0.0	6.0	6.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1998	7.0	2.6	3.1	1.0	0.1	0.0	2.0	0.6	4.5	2.0	0.0	0.0	0.0	1.0	1.5	5.0	0.0	0.0	2.0	0.0	0.0	3.0	0.0	0.0	0.0	0.0	0.0
1999	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 7. July precipitation (mm) in the upper KRB.

Year	Shilan	shaza	Sanandaj	Malayer	Khoramabad	Kermanshah	Ilam	Hamedan	Cheshma ravansar	Keshvar	Cham chit	Vanaii	Jelogir	Pol dokhtar	Afrina	Cham anjir	Sarabe seid ali	kakareza	Holilan	Doab merek	Karkhana ghand bisotoon	Aran	Aghajanbalaghi	Firooz abad	Pol dehloran	Pol shah	Piran
1966	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1967	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1968	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1969	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1970	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1971	12.0	13.0	12.0	17.0	0.0	1.0	10.5	4.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.0	4.0	7.0	0.0	0.0	0.0	0.0
1972	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1973	0.0	3.0	0.0	8.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0
1974	0.0	0.0	0.0	0.0	0.4	0.0	0.0	13.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0	0.0	0.0	0.0
1975	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1976	0.0	2.0	0.0	1.0	1.2	0.0	0.0	3.0	0.0	0.0	5.0	17.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.0	0.0	0.0	0.0	0.0	0.0
1977	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1978	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1979	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1980	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1981	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1982	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1983	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1984	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1985	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1986	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1987	0.0	8.0	0.0	13.5	0.9	6.8	2.8	18.2	0.0	2.0	0.0	0.0	7.0	0.0	0.0	0.0	0.0	0.0	0.0	8.5	10.5	3.0	0.0	0.0	0.0	0.0	0.0
1988	0.0	0.0	0.3	0.0	0.0	0.0	0.0	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1989	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1990	0.0	0.0	0.0	5.8	0.0	0.0	0.0	12.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1991	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1992	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1993	0.0	3.0	0.0	2.2	4.0	2.4	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1994	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1995	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.0	0.0	0.0	0.0	0.0	0.0
1996	0.0	0.8	0.1	3.0	0.3	0.8	4.0	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	8.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1997	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.3	1.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1998	0.0	0.0	4.6	2.1	0.4	5.4	0.0	3.5	4.2	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	4.5	5.0	9.0	10.0	2.0	0.0	0.0	0.0
1999	13.0	0.0	7.2	5.9	0.0	14.4	2.8	35.4	5.7	0.0	0.0	0.0	0.0	0.0	3.0	0.0	3.5	0.0	0.0	4.5	8.2	10.0	15.0	0.0	0.0	7.0	0.0
2000	0.0	3.6	0.0	6.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 8. August precipitation (mm) in the upper KRB.

Year	Shilan	shaza	Sanandaj	Malayer	Khoramabad	Kermanshah	Ilam	Hamedan	Cheshma ravansar	Keshvar	Cham chit	Vanaii	Jelogir	Pol dokhtar	Afrina	Cham anjir	Sarabe seid ali	kakareza	Holilan	Doab merek	Karkhana ghand bisotoon	Aran	Aghajanbalaghi	Firooz abad	Pol dehloran	Pol shah	Piran
1966	0.0	0.0	4.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1967	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1968	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1969	0.0	25.0	0.5	0.0	0.0	1.0	0.0	3.0	0.0	0.0	0.0	12.0	0.0	6.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.0	0.0	1.0	0.0	0.0	0.0
1970	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1971	0.0	19.0	6.0	21.0	4.0	4.0	0.5	9.0	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	50.0	7.0	6.0	0.0	0.0	0.0
1972	3.0	10.0	7.0	0.0	0.2	3.2	0.5	15.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0
1973	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1974	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1975	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1976	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1977	0.0	2.0	1.0	0.0	0.0	0.0	0.0	0.0	4.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1978	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1979	0.0	0.0	0.0	0.0	0.0	0.0	7.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1980	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1981	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1982	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1983	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1984	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1985	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1986	0.0	0.0	0.0	0.0	0.0	0.9	0.0	4.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.0	3.9	0.0	0.0	0.0	0.0	0.0	0.0
1987	0.0	0.0	0.2	0.0	0.0	0.2	1.0	0.2	2.0	4.5	0.0	0.0	1.0	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1988	0.0	0.0	0.6	0.0	0.0	0.0	0.0	6.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1989	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1990	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1991	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1992	1.0	4.0	0.7	7.0	0.0	0.0	0.0	7.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.0	0.0	0.0	0.0	0.0
1993	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1994	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1995	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1996	0.0	0.0	0.0	24.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1997	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1998	0.0	2.8	0.0	2.0	0.6	0.0	0.0	30.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.0	5.0	1.0	0.0	0.0	0.0
1999	0.0	0.0	0.0	0.0	4.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 9. September precipitation (mm) in the upper KRB.

Year	Shilan	shaza	Sanandaj	Malayer	Khoramabad	Kermanshah	Ilam	Hamedan	Cheshma ravansar	Keshvar	Cham chit	Vanaii	Jelogir	Pol dokhtar	Afrina	Cham anjir	Sarabe seid ali	kakareza	Holilan	Doab merek	Karkhana ghand bisotoon	Aran	Aghajanbalaghi	Firooz abad	Pol dehloran	Pol shah	Piran
1966	0.0	0.0	0.0	1.0	0.7	7.0	0.0	0.2	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	13.0	0.0	0.0	0.0	0.0	0.0	0.0
1967	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1968	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1969	0.0	0.0	0.2	0.0	0.0	1.0	0.0	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1970	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1971	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1972	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1973	0.0	0.0	0.0	0.0	0.0	0.0	30.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1974	0.0	0.0	9.2	0.0	0.1	4.1	0.0	7.0	2.0	0.0	0.0	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0	0.0	2.0	0.0	0.0	0.0
1975	17.0	0.0	11.0	0.0	0.7	7.0	0.0	1.6	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	26.0	3.5	0.0	12.0	0.0	0.0	0.0	0.0	0.0
1976	0.0	0.0	0.0	4.5	0.0	1.3	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1977	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1978	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1979	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1980	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1981	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1982	0.0	0.0	0.1	0.0	0.0	1.1	2.0	1.4	3.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0
1983	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1984	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0
1985	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1986	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1987	0.0	0.0	0.0	0.0	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1988	0.0	0.0	0.0	0.0	0.0	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.5	0.0	0.0	0.0	0.0	0.0	0.0
1989	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1990	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1991	0.0	3.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.0	0.0	0.0	0.0	0.0	0.0
1992	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1993	0.0	0.0	0.0	1.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1994	3.0	0.0	5.2	0.4	0.2	3.0	1.0	2.4	1.0	5.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1995	3.0	0.0	3.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1996	0.0	10.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1997	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1998	0.0	0.0	0.0	1.4	0.0	2.0	0.0	4.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.5	0.6	0.0	0.0	0.0	0.0	0.0	0.0
1999	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2000	0.0	0.2	3.6	0.0	0.0	0.8	1.1	3.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 10. October precipitation (mm) in the upper KRB.

Year	Shilan	shaza	Sanandaj	Malayer	Khoramabad	Kermanshah	Ilam	Hamedan	Cheshma ravansar	Keshvar	Cham chit	Vanaii	Jelogir	Pol dokhtar	Afrina	Cham anjir	Sarabe seid ali	kakareza	Holilan	Doab merek	Karkhana ghand bisotoon	Aran	Aghajanbalaghi	Firooz abad	Pol dehloran	Pol shah	Piran
1965	55.9	87.1	46.4	46.8	57.0	78.4	64.0	32.3	120.5	141.5	90.2	107.0	61.6	63.6	73.2	68.7	75.4	70.2	70.2	116.3	132.7	106.7	78.1	84.0	37.2	84.6	135.2
1966	52.0	55.5	69.1	55.0	35.4	153.0	87.0	60.5	55.0	87.5	94.0	50.7	63.0	0.0	70.0	67.0	47.0	40.0	30.0	65.0	250.0	98.0	104.0	95.6	21.0	185.0	89.0
1967	0.0	0.0	19.8	12.5	35.3	7.6	59.5	8.0	0.0	8.0	12.0	50.4	0.0	5.0	2.0	15.0	16.0	8.0	13.0	2.0	35.0	20.0	17.0	25.5	0.0	0.0	0.0
1968	0.0	43.5	14.0	17.5	20.0	31.0	17.5	24.1	40.0	35.0	22.0	0.0	2.0	0.0	5.0	13.0	26.0	8.0	18.0	5.0	43.0	27.0	21.0	28.0	0.0	0.0	0.0
1969	0.0	25.5	64.8	29.0	47.4	47.8	23.0	26.7	94.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.0	37.0	46.0	36.0	102.5	34.0	5.0	27.0	49.5
1970	0.0	1.8	12.3	3.5	7.0	3.0	2.5	2.0	0.0	8.5	0.0	6.0	0.0	2.0	3.0	8.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0	0.0	0.0	0.0
1971	6.0	3.5	6.2	18.0	17.0	6.0	5.4	2.3	0.0	5.5	0.0	35.5	0.0	3.0	27.0	12.0	23.0	68.0	0.0	0.0	31.0	11.0	4.0	15.0	0.0	0.0	0.0
1972	12.0	0.0	7.6	0.0	4.0	5.0	0.0	11.6	2.0	3.0	4.0	32.0	0.0	0.0	8.0	4.0	0.0	3.0	0.6	7.0	4.0	0.0	21.5	5.0	0.0	0.0	0.0
1973	0.0	0.0	0.1	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1974	0.0	5.0	0.0	0.0	20.2	0.2	0.0	2.0	0.0	0.0	8.0	10.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0
1975	0.0	0.0	3.3	0.0	0.0	0.0	0.0	10.0	0.0	0.0	0.0	3.0	1.0	0.0	7.0	0.0	0.0	0.0	0.0	0.0	12.0	4.0	0.0	9.0	0.0	0.0	0.0
1976	15.5	56.0	49.4	34.0	30.8	31.8	17.0	29.3	83.0	16.5	15.0	79.0	0.0	15.0	53.0	26.0	15.0	25.9	8.5	53.5	21.0	28.0	11.0	0.0	3.0	7.0	45.0
1977	85.0	116.0	73.0	64.6	94.8	69.9	31.0	58.1	105.3	124.9	135.0	155.5	44.5	67.0	73.0	87.0	96.0	68.0	0.0	101.1	69.0	69.0	61.0	73.0	6.0	61.0	69.0
1978	0.0	0.0	1.0	0.0	4.1	0.2	0.0	0.0	0.0	19.0	10.0	30.0	0.0	0.0	0.0	0.0	16.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1979	18.0	0.0	47.4	0.0	43.1	5.4	51.0	1.2	37.0	35.5	45.0	34.5	38.0	22.0	9.0	36.0	14.0	9.0	0.0	21.0	0.0	3.0	0.0	0.0	15.0	8.0	17.0
1980	8.0	19.0	5.5	0.0	2.0	4.4	0.0	6.1	0.0	2.5	0.0	4.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	3.0	13.0	0.0	0.0	3.0	0.0	0.0	0.0
1981	24.0	13.5	28.6	41.4	57.6	65.6	60.0	40.0	0.0	143.6	91.5	108.6	7.0	64.5	74.3	69.7	76.5	71.2	55.7	60.5	38.0	0.0	56.0	67.5	37.8	16.0	22.0
1982	64.0	141.4	60.5	80.0	46.0	77.6	68.0	70.1	72.5	17.5	74.0	89.0	10.5	16.0	28.0	46.0	33.0	41.0	45.0	51.0	135.5	147.0	64.0	52.0	26.4	16.0	41.0
1983	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.0	0.0	0.0	0.0	0.0	0.0	0.0
1984	79.0	0.0	58.6	15.0	9.6	29.3	34.8	33.1	55.0	16.0	11.0	14.0	0.0	5.0	7.0	9.0	0.0	18.0	26.0	54.5	37.2	36.0	47.0	26.0	0.0	45.0	90.0
1985	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1986	20.0	13.0	24.4	17.7	13.0	17.5	10.2	21.5	20.0	22.0	13.0	0.0	2.0	11.0	13.0	0.0	18.5	0.0	22.0	12.0	11.5	16.0	7.0	21.0	6.0	3.0	17.0
1987	146.0	154.0	172.7	154.7	131.1	123.0	125.6	128.4	145.0	220.0	174.0	217.0	29.5	85.0	113.0	126.0	135.0	74.0	0.0	121.5	133.2	142.0	48.0	101.0	42.0	82.0	117.0
1988	28.0	8.0	42.7	14.5	1.1	46.2	11.6	19.0	1.0	14.5	10.0	48.0	2.0	1.0	9.0	0.0	30.0	28.0	33.7	38.0	20.5	36.0	12.0	33.0	0.0	8.0	0.0
1989	12.0	12.0	22.5	2.8	11.6	1.7	4.5	9.9	10.5	8.0	0.0	36.0	0.0	8.0	26.0	17.0	20.0	0.0	5.0	9.5	9.6	7.0	0.0	4.0	5.0	0.0	0.0
1990	24.0	32.0	10.3	14.4	11.1	34.5	44.8	18.9	29.0	14.5	10.0	13.0	3.0	4.0	4.0	19.0	45.0	9.0	20.4	24.0	30.3	32.0	8.0	21.0	8.0	14.0	28.0
1991	53.0	24.0	40.5	15.8	20.3	54.0	26.1	20.0	43.5	0.0	22.0	18.0	0.0	47.0	17.0	18.0	9.5	0.0	11.5	46.5	42.8	12.0	10.0	13.0	13.0	34.0	23.0
1992	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1993	47.0	13.0	36.0	13.6	15.8	47.3	45.4	12.4	54.0	34.0	19.0	10.0	16.0	16.0	16.0	13.0	24.5	35.0	34.9	50.5	61.7	44.0	18.0	25.0	42.0	36.0	58.0
1994	55.0	59.0	61.6	45.0	70.9	97.1	83.7	24.5	102.0	53.0	57.0	61.0	62.0	43.0	75.5	81.0	107.5	58.0	55.0	62.0	74.8	68.0	38.0	52.5	32.0	60.0	80.0
1995	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.8	0.0	7.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1996	0.0	4.6	26.6	0.0	5.0	0.1	0.0	1.8	4.5	1.0	0.0	0.0	0.0	0.0	0.0	10.0	1.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0
1997	7.0	7.8	14.6	2.9	11.8	14.9	11.9	14.5	17.7	9.5	0.0	0.0	4.0	15.0	11.5	14.0	20.5	6.0	12.5	17.5	19.7	15.0	7.0	16.5	20.0	7.0	19.0
1998	0.0	34.4	0.0	17.9	7.0	0.4	1.2	9.7	0.0	0.0	11.0	22.0	0.0	2.0	2.5	5.0	5.0	0.0	0.0	0.0	0.0	10.0	2.0	10.0	0.0	0.0	0.0
1999	0.0	1.8	13.3	1.3	0.8	11.4	1.4	13.6	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.3	0.0	0.0	0.0	0.0	0.0	0.0

Table 11. November precipitation (mm) in the upper KRB.

Year	Shilan	shaza	Sanandaj	Malayer	Khoramabad	Kermanshah	Ilam	Hamedan	Cheshma ravansar	Keshvar	Cham chit	Vanaii	Jelogir	Pol dokhtar	Afrina	Cham anjir	Sarabe seid ali	kakareza	Holilan	Doab merek	Karkhana ghand bisotoon	Aran	Aghajanbalaghi	Firooz abad	Pol dehloran	Pol shah	Piran
1965	1.2	70.8	14.4	54.0	93.2	45.4	119.0	1.9	61.3	269.2	169.7	201.5	119.1	122.1	139.3	128.2	141.9	131.4	32.8	57.4	68.5	53.5	39.0	41.4	72.8	40.2	67.3
1966	0.0	0.0	0.2	0.0	0.0	1.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1967	87.0	53.5	97.2	71.5	103.9	99.7	278.0	31.1	141.0	229.0	85.0	229.5	99.0	153.0	173.0	114.0	113.0	141.0	106.0	150.0	125.0	60.0	101.0	67.0	108.0	0.0	220.0
1968	89.0	70.5	120.2	79.5	92.2	132.5	185.0	82.7	114.0	107.0	122.0	26.0	72.0	122.0	130.0	87.0	111.0	79.0	90.0	150.0	46.0	104.0	132.0	95.0	25.0	66.0	55.0
1969	59.0	32.0	45.1	22.5	41.1	58.8	37.0	17.0	84.0	2.0	0.0	0.0	2.0	1.0	0.0	0.0	0.0	0.0	14.0	44.0	46.0	23.0	33.0	32.0	28.0	47.0	27.0
1970	15.0	24.1	45.7	4.5	45.1	29.6	37.0	9.0	0.0	56.5	64.1	77.0	41.0	14.0	20.0	35.0	30.0	50.0	36.0	18.0	52.0	16.0	16.0	25.0	10.0	9.0	25.0
1971	66.0	127.0	71.1	82.5	108.6	122.0	211.2	59.5	12.0	244.0	147.0	209.5	83.0	110.0	100.0	80.0	128.0	126.0	81.0	65.0	152.0	125.0	133.0	93.0	68.0	145.0	155.5
1972	38.0	116.0	36.4	79.0	92.8	25.0	100.0	34.5	66.0	278.5	208.0	208.0	69.0	75.0	83.0	72.0	109.0	97.0	57.5	26.5	64.0	87.0	90.0	65.0	24.0	44.0	46.0
1973	7.0	39.0	13.4	14.0	19.2	16.4	20.6	3.7	21.2	50.5	24.0	130.0	10.0	6.0	7.0	15.0	23.0	10.0	5.0	27.5	10.0	5.0	4.0	7.0	0.0	5.0	7.0
1974	35.5	30.0	23.3	0.0	52.0	23.2	28.0	3.0	22.4	28.0	14.0	43.5	8.0	15.0	21.0	40.0	19.0	20.0	0.0	12.0	28.0	0.0	10.0	2.0	20.0	70.0	71.0
1975	42.5	70.5	28.4	14.5	43.5	68.4	63.0	52.7	53.0	55.0	43.0	68.0	45.0	10.0	13.0	34.0	29.0	96.0	35.0	45.5	68.0	51.0	4.0	57.0	57.0	10.0	42.5
1976	91.0	44.0	37.8	5.0	12.7	4.7	0.0	0.4	62.0	13.3	0.0	43.0	0.0	3.0	2.0	7.0	18.0	0.0	5.0	16.5	3.0	7.0	17.0	0.0	1.0	2.0	0.0
1977	61.0	34.0	79.0	53.6	23.0	64.0	43.0	49.5	94.7	87.7	77.0	136.0	23.5	31.0	34.0	39.0	25.0	45.0	0.0	90.6	50.0	54.0	27.0	65.4	39.0	17.0	88.0
1978	0.0	10.7	17.0	3.5	20.0	13.3	11.5	10.0	11.0	8.9	15.0	25.0	1.5	14.0	13.0	19.0	13.0	7.6	0.0	9.0	6.0	0.0	1.0	0.0	14.0	11.0	8.0
1979	18.0	23.3	27.0	0.0	28.0	18.0	10.0	5.0	21.0	64.0	47.0	17.0	30.5	29.0	35.0	28.0	31.0	17.0	1.7	23.0	0.0	24.0	6.0	6.0	3.4	11.0	44.0
1980	82.0	89.0	111.0	40.1	86.7	83.7	96.0	39.0	153.5	134.5	50.0	115.0	101.5	85.0	75.0	80.0	82.0	78.0	76.2	149.5	76.0	51.0	84.4	37.0	0.0	18.0	66.0
1981	47.0	7.9	59.2	3.0	32.6	32.2	51.0	10.0	0.0	55.4	36.7	43.3	23.0	24.1	28.6	28.6	30.5	28.9	17.8	47.5	24.5	0.0	20.0	24.4	13.2	28.0	123.0
1982	137.0	97.8	140.6	48.5	22.6	83.4	105.0	45.5	132.0	25.0	103.0	40.0	13.0	37.0	27.0	45.0	12.0	26.0	40.5	128.5	86.5	62.0	86.0	38.0	3.3	61.0	174.0
1983	26.0	40.2	66.1	24.0	25.7	51.6	51.0	26.4	73.0	105.5	70.0	24.5	44.5	15.0	13.0	25.0	11.0	14.0	25.5	68.0	88.0	35.0	0.0	15.0	1.0	16.0	15.0
1984	174.0	52.8	157.1	58.0	176.4	182.2	353.8	100.8	191.5	381.0	202.0	78.5	186.5	225.0	236.0	180.0	37.0	47.0	134.0	176.0	334.8	119.0	156.0	96.0	32.0	144.3	250.0
1985	110.0	30.0	98.4	21.0	53.1	74.6	129.3	44.9	89.0	91.5	24.0	42.0	56.5	62.0	81.0	53.0	27.0	29.0	27.0	115.0	122.3	90.0	9.0	61.0	0.0	56.0	122.0
1986	147.5	99.6	125.9	85.5	111.5	120.9	225.9	74.4	177.0	283.5	191.0	81.5	110.0	123.0	89.0	98.0	123.2	148.0	63.0	104.5	208.7	97.0	22.0	80.0	0.0	91.0	160.0
1987	10.0	24.0	32.2	0.0	26.7	22.8	48.0	2.4	49.0	41.0	39.0	26.0	21.0	14.0	24.0	22.0	22.5	0.0	0.0	37.0	52.5	6.0	9.0	7.0	8.0	5.0	24.0
1988	24.5	46.0	29.8	2.6	12.7	13.1	14.0	9.7	31.0	49.5	59.0	88.0	9.2	2.0	0.0	0.0	16.0	79.0	0.0	20.0	31.0	25.0	10.0	18.0	0.0	15.0	29.0
1989	44.0	116.0	51.3	37.7	83.5	84.5	125.9	37.1	100.5	130.5	90.0	75.0	103.0	67.0	66.0	83.0	90.0	58.0	43.0	91.5	96.5	69.0	85.4	42.0	19.0	38.0	107.0
1990	7.0	36.0	10.9	0.0	12.4	5.5	25.0	2.0	5.5	41.5	12.0	42.0	13.0	6.0	13.0	11.0	25.0	40.0	0.0	5.0	14.2	7.0	4.0	8.0	0.0	13.0	22.0
1991	11.0	47.0	13.4	0.0	20.5	21.0	47.2	0.9	8.0	10.0	22.0	39.0	0.0	8.0	11.0	13.0	44.5	33.0	38.0	7.5	0.0	25.0	5.0	28.0	11.0	10.0	8.0
1992	17.5	76.0	25.2	42.7	64.4	64.1	115.7	32.3	48.5	212.0	95.0	65.5	73.3	81.0	92.0	64.0	104.5	47.0	0.0	44.5	23.8	110.0	25.0	92.0	20.0	38.0	39.0
1993	140.0	112.0	137.6	60.2	127.8	92.2	62.4	81.4	123.5	211.5	204.0	82.5	100.0	83.0	98.5	113.0	115.5	182.0	85.8	87.5	130.3	104.0	93.5	107.0	11.0	81.0	134.0
1994	181.0	286.0	204.8	145.8	224.5	295.4	431.3	199.6	221.5	665.5	668.0	213.0	309.0	232.0	279.5	207.0	314.5	237.0	256.5	285.5	437.2	282.0	187.0	233.0	148.0	219.0	209.0
1995	39.0	0.0	43.2	0.9	2.3	10.3	7.2	9.2	0.0	9.5	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	15.0	26.9	10.0	13.0	0.0	0.0	19.0	34.0
1996	0.0	28.4	3.0	19.6	20.5	7.8	21.9	3.3	2.5	23.5	2.5	0.0	8.0	2.0	8.5	14.0	14.5	18.0	22.0	13.0	6.1	6.0	1.0	7.0	0.0	10.0	11.0
1997	111.0	28.8	112.0	25.9	102.9	79.3	86.0	28.4	113.2	187.5	191.0	66.0	151.0	126.0	124.5	92.0	69.0	65.0	101.0	105.0	112.8	63.0	75.0	54.0	67.0	70.0	111.0
1998	28.0	13.2	22.8	0.8	31.0	32.1	37.0	5.8	37.4	46.0	25.0	6.0	18.0	33.0	28.0	36.0	21.5	0.0	72.0	47.0	42.6	18.0	30.0	16.0	7.0	34.0	36.0
1999	28.4	60.4	30.3	86.1	48.4	30.4	55.0	19.2	34.4	111.2	71.3	84.6	47.9	49.7	57.5	54.5	59.5	55.6	15.7	30.7	39.3	29.3	21.3	22.0	28.7	20.0	36.4

Table 12. December precipitation (mm) in the upper KRB.

Year	Shilan	shaza	Sanandaj	Malayer	Khoramabad	Kermanshah	Ilam	Hamedan	Cheshma ravansar	Keshvar	Cham chit	Vanaii	Jelogir	Pol dokhtar	Afrina	Cham anjir	Sarabe seid ali	kakareza	Holilan	Doab merek	Karkhana ghand bisotoon	Aran	Aghajanbalaghi	Firooz abad	Pol dehloran	Pol shah	Piran
1965	1.6	18.0	14.6	10.0	13.0	9.0	7.5	12.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1966	16.0	18.0	46.4	10.5	23.6	50.9	31.0	35.1	61.0	78.0	63.0	19.9	5.0	30.0	14.0	18.0	82.0	36.0	25.0	63.5	76.0	34.0	69.5	27.3	0.0	47.6	0.0
1967	0.0	4.5	27.8	2.5	48.0	15.0	120.0	8.0	29.0	53.0	27.0	83.5	23.0	21.0	32.0	26.0	24.0	14.0	38.0	38.0	60.0	16.0	25.5	5.0	10.0	0.0	0.0
1968	61.0	19.0	99.3	22.0	64.0	59.1	205.9	42.0	47.0	138.0	106.0	52.0	36.0	61.0	66.0	53.0	79.0	88.0	47.0	67.5	90.5	49.0	50.0	43.0	32.0	63.0	52.0
1969	41.0	64.5	70.4	10.5	71.6	44.0	64.0	20.5	126.0	138.0	137.0	144.0	30.0	5.0	28.0	48.0	52.0	42.0	3.0	42.0	45.0	29.0	52.0	25.0	25.0	69.0	92.0
1970	21.0	53.0	35.6	86.5	93.0	55.4	47.0	35.0	34.0	147.5	169.2	97.5	105.0	63.0	106.0	77.0	87.0	107.0	40.0	38.0	67.0	49.0	20.0	73.0	60.0	12.0	39.0
1971	60.0	62.0	60.0	41.5	65.0	100.0	78.3	101.4	86.0	277.5	152.0	213.5	61.0	98.0	72.0	75.0	84.0	91.0	19.0	74.0	90.0	39.0	59.5	28.0	8.0	85.0	89.0
1972	86.0	40.8	58.5	17.0	60.0	79.0	82.0	33.8	88.0	196.7	78.0	107.0	136.5	114.0	104.0	82.0	90.0	77.0	52.5	56.0	120.0	47.0	72.0	73.0	70.0	64.0	73.0
1973	31.0	7.0	19.9	20.0	63.0	72.2	102.0	20.2	79.5	73.7	75.0	109.5	49.0	31.0	43.0	48.0	62.0	36.0	50.0	74.5	138.0	58.0	28.0	32.0	42.0	57.0	64.0
1974	64.0	97.5	45.7	50.5	112.9	77.0	90.0	90.2	66.0	267.2	154.0	182.5	155.0	122.0	156.0	125.0	139.0	230.0	78.0	60.5	89.0	92.0	133.0	73.0	53.0	65.0	38.0
1975	91.5	144.5	74.0	41.0	182.4	128.4	156.0	56.5	124.0	252.4	256.0	94.0	177.0	135.5	157.0	177.0	143.0	132.0	87.5	85.4	36.0	122.0	46.0	81.0	72.0	48.0	88.0
1976	46.0	45.3	58.0	36.5	57.2	75.0	74.0	30.7	61.0	157.3	87.0	55.0	63.0	94.0	70.0	54.0	65.0	70.5	53.0	58.5	100.0	92.0	42.0	0.0	37.0	25.0	52.0
1977	103.0	72.0	71.2	42.7	101.7	72.1	107.0	41.0	109.2	247.5	181.0	121.0	103.0	79.0	115.0	75.0	124.0	63.0	0.0	105.0	61.0	67.0	47.0	75.9	64.0	67.0	202.0
1978	85.0	106.2	144.6	91.0	182.0	88.9	128.5	61.0	16.0	336.5	388.0	261.0	149.0	152.0	182.0	141.0	193.0	281.6	82.1	93.0	153.2	116.0	90.6	97.5	57.0	65.0	118.0
1979	43.0	117.5	99.0	47.7	157.3	115.0	157.0	44.9	93.0	281.2	179.0	155.0	156.0	142.0	149.0	144.0	109.0	43.0	111.7	134.0	91.0	90.0	32.0	131.2	127.2	44.0	116.0
1980	40.0	61.0	57.0	24.5	74.0	51.6	137.0	26.8	54.0	137.5	74.0	95.5	65.0	102.0	85.0	73.0	64.0	94.0	39.8	60.5	92.5	63.0	46.4	76.0	0.0	10.0	105.0
1981	31.0	29.0	36.2	27.6	36.1	59.4	42.0	29.2	51.8	67.8	44.3	52.5	23.0	29.8	35.0	34.3	36.9	34.8	48.6	60.0	66.5	0.0	25.0	59.5	16.6	0.0	57.0
1982	50.0	144.2	50.4	57.3	73.0	58.9	62.0	52.4	53.5	136.5	113.0	33.0	56.0	88.0	76.0	83.0	36.0	73.0	63.5	77.5	57.5	52.0	18.0	36.0	53.0	16.0	51.0
1983	101.0	127.3	84.0	57.6	100.8	91.4	139.0	52.6	77.0	123.5	95.0	76.0	59.0	64.0	86.0	98.0	81.0	49.0	104.5	97.5	143.0	120.0	29.0	90.0	19.0	55.0	38.0
1984	50.0	156.8	52.2	49.0	94.7	70.5	120.8	45.7	29.0	137.0	87.0	25.0	62.8	56.0	72.0	91.0	21.0	70.0	71.5	64.5	117.4	72.0	45.0	65.0	34.0	35.0	73.0
1985	38.0	110.0	54.0	63.0	111.8	93.3	168.3	42.8	150.0	276.5	182.0	59.5	118.0	73.0	112.0	82.0	105.5	44.0	36.5	126.0	92.2	53.0	10.0	50.0	70.5	109.0	166.0
1986	60.0	42.0	21.3	19.8	51.3	23.0	21.7	23.1	52.0	140.5	130.0	14.5	79.5	44.0	50.0	45.0	44.5	82.0	0.0	46.0	53.0	25.0	0.0	35.0	0.0	34.0	67.0
1987	115.0	122.8	100.8	84.2	128.2	117.5	201.4	73.4	184.0	255.0	172.0	141.0	54.0	187.0	114.0	132.0	167.0	90.0	0.0	122.5	152.6	100.0	38.0	108.0	12.0	154.0	197.0
1988	52.0	59.4	57.3	23.2	85.5	85.0	154.2	25.8	120.0	161.5	119.0	148.0	9.0	67.0	52.0	75.0	80.5	143.0	77.7	88.0	165.4	55.0	22.0	41.0	65.3	77.0	89.0
1989	85.0	98.0	88.0	50.9	110.4	162.8	101.3	47.4	153.5	204.5	118.0	143.0	114.0	94.0	93.0	109.0	146.5	158.0	78.5	117.5	53.5	79.0	178.1	89.0	84.0	102.0	87.5
1990	12.0	18.5	15.7	33.2	19.4	16.5	53.0	33.6	43.5	47.5	63.0	10.0	22.0	13.0	25.0	24.0	25.5	37.0	0.0	25.0	53.5	10.0	4.0	4.0	9.0	32.0	52.0
1991	104.0	137.0	106.2	110.1	165.0	105.9	186.7	93.6	154.5	411.0	220.0	219.0	0.0	163.0	146.0	143.0	207.5	237.0	118.0	168.5	129.8	136.0	34.0	106.0	66.0	147.0	171.0
1992	64.5	92.0	85.2	41.4	134.3	70.7	105.3	48.0	65.0	333.5	96.0	81.0	184.3	136.0	169.0	108.0	107.5	97.0	0.0	86.5	77.1	87.0	32.0	70.0	121.0	93.0	120.0
1993	78.0	28.0	81.1	23.1	25.4	60.3	95.0	22.8	77.0	55.5	41.0	41.5	26.0	20.0	31.0	24.0	41.0	44.0	49.6	61.5	43.4	38.0	35.0	33.0	24.0	89.0	16.0
1994	34.0	62.0	43.8	37.3	77.1	35.3	97.5	40.6	53.5	177.0	122.0	32.0	124.0	52.0	64.0	73.0	79.5	103.0	51.5	51.0	57.9	67.0	44.0	41.0	51.0	59.0	79.0
1995	5.0	25.0	0.8	4.8	30.3	13.0	35.9	23.2	3.2	33.5	22.0	68.0	26.0	29.0	33.0	30.0	39.0	24.0	19.0	7.0	22.3	30.0	16.0	27.0	11.0	27.0	38.0
1996	123.0	40.0	104.6	22.7	64.8	73.0	96.8	20.4	82.3	82.5	43.0	70.0	50.0	57.0	71.0	67.0	79.0	99.0	26.0	69.5	87.2	45.9	66.0	45.0	26.0	39.5	44.2
1997	63.0	39.4	48.8	17.2	65.7	52.5	93.1	31.9	119.0	135.5	109.3	35.5	84.0	43.0	61.5	73.0	67.0	80.0	34.0	89.0	86.3	30.0	61.0	25.0	20.5	62.0	166.0
1998	1.0	5.2	0.3	0.5	0.6	1.5	1.5	4.6	0.0	23.5	56.0	7.0	4.0	0.0	0.0	0.0	3.0	0.0	0.0	0.0	0.0	7.0	3.0	1.0	0.0	0.0	0.0
1999	19.2	46.0	24.9	52.4	70.3	51.7	33.0	24.2	72.6	188.4	119.4	141.8	82.7	85.1	97.5	90.6	99.8	92.7	39.9	68.7	80.8	63.6	46.5	49.5	50.3	48.7	80.2

Appendix III. SPI-values for different time scales.

Table 13. SPI values for one-month time scale in Alashtar station.

Year	JAN	FEB	MAR	APR	MAY	OCT	NOV	DEC
1965								
1966	0.9	–0.05	–0.03	–0.6	–0.57	0.93	–1.35	0.17
1967	–1.46	0.58	–1.63	–0.6	1.03	0.18	1.16	–1.39
1968	–1.09	0.09	–0.5	0.97	1.37	0.45	1.14	0.12
1969	2.38	–0.35	1.39	1.61	1.16	–0.3	–1.35	–0.47
1970	–0.49	–1.38	–0.74	0.76	–0.57	–0.3	–0.29	0.26
1971	–1.03	–0.37	1.27	1.22	–0.57	0.38	1.34	0.21
1972	–0.26	–1.12	1.31	0.88	1.64	–0.3	1.11	0.32
1973	–0.26	–0.73	–1.59	–0.02	–0.43	–0.3	–0.5	–0.23
1974	1.32	1.1	0.52	0.38	–0.57	–0.3	–0.62	1.06
1975	0.15	0.56	–1.82	–0.15	0.95	–0.3	–0.32	1.11
1976	1.44	–0.09	0.03	–0.51	0	0.15	–0.66	–0.17
1977	–0.39	–2.12	0.46	0.1	–0.57	1.77	–0.44	0.85
1978	–1.03	–0.37	–0.21	–1.01	–0.39	0.18	–0.84	1.7
1979	0.17	–0.54	–0.13	–0.6	0.38	0.12	–0.27	0.63
1980	0.52	1.55	0.39	0	0.27	–0.3	0.73	–0.19
1981	0.95	1.1	–0.31	–0.45	–0.57	1.47	–0.28	–0.91
1982	1.94	1.54	0.26	–0.68	1.06	0.63	–0.88	–0.94
1983	0.32	–1.01	–1.12	–0.51	–0.57	–0.3	–0.92	0.15
1984	–1.9	–1.47	–1.3	–0.69	–0.03	–0.3	–0.11	–1.53
1985	–1.61	–0.76	–1.51	–1.9	–0.57	–0.3	–0.38	0.58
1986	–1.18	0.33	–0.58	0.97	2.23	0.25	1.29	–0.68
1987	–0.67	0.48	1.15	–0.82	–0.57	2.29	–0.51	1.41
1988	–0.17	1.47	0.52	0.65	–0.38	0.55	–0.73	0.15
1989	0.1	–0.41	0.88	–0.51	0.03	0.29	0.85	1.16
1990	–0.34	0.29	–0.76	0.67	0.54	0.89	–0.44	–1.33
1991	0.25	0.24	0.28	–0.34	–0.45	–0.02	0.06	1.85
1992	–0.54	1.56	0.88	0.8	0.59	–0.3	1.05	0.61
1993	0.61	1.62	0.27	1.37	0.98	0.42	1.19	–0.78
1994	0.33	0.43	0.3	0.12	0.75	1.93	2.97	0.13
1995	–1.42	–0.08	–1.15	1.48	0.83	–0.3	–1.35	–0.84
1996	0.72	1.09	1.82	1.67	0.06	–0.28	–0.78	0.12
1997	0.44	–2.24	1.31	0.85	0.3	0.31	0.53	–0.13
1998	0.7	–0.32	1.66	–1.07	0.06	–0.16	–0.54	–3
1999	0.27	–0.24	–0.5	–1.05	–0.51	–0.3	0.36	0.48
2000	0.55	–0.32	–0.83	–1.89	–0.57			

Table 14. SPI values for one-month time scale in Kermanshah station.

Year	JAN	FEB	MAR	APR	MAY	OCT	NOV	DEC
1965						1.20	0.04	–1.98
1966	0.08	0.64	0.63	–0.28	–0.04	1.89	–2.30	–0.15
1967	–1.06	0.38	–1.06	0.03	1.57	–0.18	0.89	–1.52
1968	0.36	0.14	–0.92	1.66	1.73	0.50	1.26	0.05
1969	1.74	0.27	0.99	2.78	0.72	0.79	0.29	–0.34
1970	1.24	–1.85	0.75	1.49	–1.32	–0.47	–0.34	–0.04
1971	–1.62	0.89	0.09	1.85	0.71	–0.26	1.15	0.86
1972	0.09	0.75	1.77	0.23	1.32	–0.32	–0.48	0.48
1973	0.16	0.21	–1.94	–0.35	–0.87	–0.70	–0.79	0.34
1974	1.37	1.66	2.34	0.31	–0.73	–0.90	–0.54	0.44
1975	0.61	1.23	–0.80	0.54	1.55	–1.07	0.45	1.30
1976	0.04	–0.22	–0.21	0.57	0.25	0.52	–1.56	0.40
1977	0.39	–1.25	–0.39	–0.19	–0.03	1.10	0.38	0.34
1978	0.13	–0.85	–0.40	–1.19	–0.06	–0.90	–0.94	0.67
1979	0.05	–1.90	0.13	–2.91	0.15	–0.30	–0.73	1.10
1980	0.70	1.31	0.39	–0.48	–0.78	–0.36	0.68	–0.13
1981	0.47	1.00	0.50	–0.62	0.34	1.04	–0.27	0.06
1982	–0.40	0.77	–0.09	–0.34	0.71	1.19	0.67	0.05
1983	–1.14	–0.56	–0.48	0.17	0.14	–1.07	0.16	0.71
1984	–1.74	–1.74	–1.08	–0.36	0.31	0.47	1.72	0.31
1985	0.20	–0.45	–0.39	0.41	–1.21	–1.07	0.55	0.75
1986	–1.30	0.30	–0.21	–0.02	1.09	0.18	1.13	–1.10
1987	–2.53	–0.01	1.65	–0.33	–0.41	1.64	–0.55	1.14
1988	0.98	1.54	–0.26	0.15	–1.29	0.77	–0.95	0.60
1989	0.40	–0.19	0.83	–1.22	–0.85	–0.60	0.69	1.76
1990	0.71	0.33	–0.40	–0.29	–1.20	0.57	–1.48	–1.43
1991	0.48	0.33	0.59	–0.70	–1.48	0.89	–0.61	0.96
1992	–0.59	0.67	0.75	–0.46	0.76	–1.07	0.38	0.31
1993	–0.03	–0.05	–1.28	1.37	2.10	0.79	0.79	0.08
1994	0.87	0.53	–0.67	–0.36	–0.97	1.40	2.54	–0.61
1995	–2.59	–0.85	–1.24	0.28	0.70	–1.07	–1.10	–1.66
1996	0.77	0.63	1.38	0.58	–0.03	–0.95	–1.28	0.36
1997	0.13	–1.25	0.70	–0.02	0.29	0.10	0.62	–0.11
1998	0.38	–0.22	1.03	–0.41	–0.56	–0.83	–0.27	–3.26
1999	0.59	0.32	–1.68	–0.85	–1.31	–0.02	–0.32	–0.13
2000	0.31	–1.37	–1.08	–1.09	–1.53			

Table 15. SPI values for three-month time scale in Kermanshah station.

Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	OCT	NOV	DEC
1965										–0.15
1966	–1.24	–0.63	0.59	0.39	0.10	–0.35	–0.12	2.05	1.06	0.71
1967	–2.01	–0.60	–0.91	–0.50	0.00	0.78	1.51	–0.28	0.48	–0.30
1968	0.03	–0.71	–0.39	0.56	1.17	1.97	1.73	0.47	1.08	0.89
1969	1.79	1.03	1.36	2.24	2.41	2.49	0.68	0.82	0.49	0.08
1970	0.38	–0.52	0.34	0.67	1.02	0.91	–1.41	–0.60	–0.83	–0.87
1971	–1.44	–0.30	–0.10	1.37	1.29	1.68	0.68	–0.16	0.72	0.94
1972	1.35	0.91	1.44	1.40	1.59	0.82	1.38	–0.25	–0.90	–0.51
1973	–0.26	0.32	–0.83	–1.10	–1.74	–0.72	–0.95	–0.85	–1.36	–0.84
1974	0.26	1.78	2.63	2.18	1.58	–0.10	–0.82	–0.49	–0.98	–0.65
1975	–0.06	1.15	0.36	0.35	0.38	1.07	1.49	–0.31	0.04	0.62
1976	1.02	0.78	–0.33	–0.05	0.10	0.44	0.17	0.51	–0.69	–0.47
1977	–0.54	–0.30	–0.66	–0.98	–0.55	–0.27	–0.09	1.12	0.79	0.72
1978	0.23	–0.34	–0.66	–1.28	–1.02	–0.92	–0.04	–1.05	–1.55	–0.62
1979	–0.35	–0.69	–0.84	–1.78	–0.82	–1.40	0.08	–0.41	–1.12	–0.08
1980	0.49	1.72	1.00	0.51	–0.33	–0.81	–0.87	–0.48	0.23	–0.06
1981	0.39	0.57	0.82	0.37	–0.01	–0.37	0.29	1.06	0.36	0.17
1982	–0.78	0.11	0.05	0.00	–0.15	0.01	0.64	1.24	1.07	0.86
1983	–0.18	–1.09	–1.12	–0.57	–0.34	0.07	0.06	–1.19	–0.38	–0.02
1984	–0.35	–1.23	–2.35	–1.72	–0.90	–0.23	0.24	0.43	1.50	1.44
1985	1.74	–0.14	–0.47	–0.33	–0.42	–0.10	–1.31	–1.19	0.03	0.30
1986	0.17	0.01	–0.56	–0.16	0.11	0.45	1.03	0.15	0.83	0.22
1987	–0.49	–2.01	0.54	0.85	0.82	–0.55	–0.11	1.72	0.91	1.27
1988	0.74	2.03	0.92	0.55	–0.54	–0.37	–1.39	0.81	–0.18	0.00
1989	–0.22	0.33	0.50	–0.10	–0.23	–1.44	–0.94	–0.74	0.20	1.14
1990	1.88	1.77	0.11	–0.37	–0.88	–0.76	–1.29	0.54	–0.64	–1.55
1991	–1.67	–0.46	0.57	0.08	–0.35	–1.20	–1.55	0.89	0.04	0.45
1992	–0.23	0.68	0.47	0.42	0.38	0.14	0.94	–1.19	–0.14	–0.13
1993	0.14	–0.05	–0.83	0.15	1.06	1.95	2.11	0.78	0.85	0.66
1994	0.84	0.63	0.16	–0.43	–1.07	–0.76	–1.06	1.49	2.70	2.52
1995	1.98	–2.38	–2.19	–0.98	–0.40	0.50	0.78	–1.19	–1.75	–2.68
1996	–1.38	–0.12	1.34	1.23	1.06	0.34	–0.07	–1.09	–1.93	–1.00
1997	–0.68	–0.50	–0.03	–0.13	0.36	0.01	0.25	0.03	0.31	0.03
1998	0.30	–0.23	0.64	0.28	0.25	–0.67	–0.31	–0.66	–0.78	–2.23
1999	–1.30	–0.68	–0.46	–1.19	–2.09	–1.30	–0.26	–0.10	–0.59	–0.77
2000	–0.55	–0.84	–1.14	–1.95	–1.87	–1.57	–1.62			

Table 16. SPI values for three-month time scale in Alashtar station.

Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	OCT	NOV	DEC
1965										
1966			0.3	–0.46	–0.66	–0.86	–0.57	0.93	–0.3	–0.22
1967	–1.51	–0.33	–1.06	–0.84	–0.72	0.18	1.01	0.18	0.91	0.08
1968	–0.48	–1.3	–0.75	0.2	0.7	1.23	1.36	0.45	1	0.73
1969	2.04	1.36	1.76	1.43	1.82	1.55	1.15	–0.3	–1.57	–1.57
1970	–1.51	–1.3	–1.23	–0.54	–0.25	0.31	–0.57	–0.3	–0.69	–0.38
1971	–0.73	–0.64	0.19	1.11	1.11	0.69	–0.57	0.38	1.15	0.9
1972	0.68	–0.63	0.26	0.77	1.59	1.35	1.71	–0.3	0.68	0.57
1973	0.55	–0.42	–1.26	–1.25	–1.16	–0.29	–0.45	–0.3	–0.89	–0.88
1974	0.34	1.04	1.21	0.8	0.19	–0.02	–0.57	–0.3	–1.01	0.13
1975	0.33	0.81	–0.45	–0.7	–0.61	0.34	0.93	–0.3	–0.72	0.29
1976	1.24	1.27	0.63	–0.4	–0.38	–0.44	–0.04	0.15	–0.62	–0.67
1977	–0.91	–1.24	–0.57	–0.42	0.01	–0.26	–0.57	1.77	0.82	0.99
1978	–0.3	–0.2	–0.79	–0.86	–0.89	–1.05	–0.42	0.18	–0.72	0.79
1979	0.81	0.87	–0.3	–0.74	–0.37	–0.26	0.35	0.12	–0.34	0.09
1980	0.35	1.23	1	0.82	0.15	0.05	0.24	–0.3	0.31	–0.01
1981	0.68	0.83	0.69	0.06	–0.79	–0.73	–0.57	1.47	0.65	–0.03
1982	0.69	1.49	1.62	0.54	0.15	0.16	1.04	0.63	–0.34	–0.95
1983	–0.94	–0.86	–0.82	–1.46	–1.33	–0.78	–0.57	–0.3	–1.27	–0.76
1984	–1.66	–1.66	–2.45	–1.85	–1.28	–0.58	–0.07	–0.3	–0.52	–1.42
1985	–2.1	–2.22	–1.92	–2.19	–2.44	–1.9	–0.57	–0.3	–0.77	–0.17
1986	–0.58	–0.12	–0.7	0.26	1.13	1.68	2.24	0.25	1.05	0.44
1987	0.06	–0.56	0.51	0.48	0.14	–1.05	–0.57	2.29	1.22	1.61
1988	0.5	1.37	0.77	1.11	0.39	0.28	–0.4	0.55	–0.32	–0.25
1989	–0.42	–0.22	0.29	0.03	0.2	–0.42	0	0.29	0.69	1.09
1990	0.88	0.55	–0.49	–0.02	0.05	0.64	0.52	0.89	0.12	–0.71
1991	–0.97	–0.46	0.23	–0.04	–0.29	–0.56	–0.47	–0.02	–0.16	1.13
1992	0.95	1.61	0.89	1.4	0.93	0.8	0.67	–0.3	0.62	0.69
1993	1.09	1.31	1.02	1.46	1.09	1.33	1	0.42	1.04	0.39
1994	0.41	–0.12	0.36	0.25	0.34	0.38	0.73	1.93	3	2.72
1995	1.88	–0.74	–1.28	0.28	0.6	1.36	0.89	–0.3	–1.57	–1.93
1996	–0.73	0.47	1.61	2.15	1.81	1.23	0.03	–0.28	–1.12	–0.72
1997	–0.23	–0.52	0.37	0.59	1.12	0.67	0.27	0.31	0.42	0.12
1998	0.42	0.04	1.06	0.51	0.64	–0.75	0.03	–0.16	–0.79	–2.25
1999	–1.38	–1	–0.32	–0.99	–1.16	–1.17	–0.4	–0.3	–0.06	0.15
2000	0.57	0.28	–0.33	–1.49	–1.8	–1.89	–0.57			

Table 17. SPI values for six-month time scale in Kermanshah station.

Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	OCT	NOV	DEC
1966			0.24	–0.38	–0.34	0.22	0.27	1.91	1.04	0.75
1967	0.37	0.43	–0.18	–1.50	–0.40	–0.25	0.08	0.66	0.45	–0.34
1968	–0.31	–0.28	–0.71	0.38	0.53	1.01	1.02	1.18	1.10	0.85
1969	1.59	1.51	1.68	2.65	2.41	2.49	2.17	0.81	0.48	0.07
1970	0.56	–0.15	0.20	0.65	0.48	0.70	0.36	–1.73	–0.90	–0.91
1971	–1.79	–1.02	–0.85	0.44	0.82	0.94	1.36	0.06	0.75	0.96
1972	0.96	1.08	1.79	1.75	1.66	1.49	1.59	0.57	–0.74	–0.49
1973	–0.57	–0.52	–1.23	–1.01	–0.92	–1.14	–1.30	–1.55	–1.45	–0.88
1974	–0.19	0.65	1.86	1.86	2.12	2.11	1.88	–1.23	–1.06	–0.62
1975	–0.45	0.19	–0.29	0.16	0.87	0.82	0.74	0.64	0.00	0.66
1976	0.62	0.43	0.13	0.51	0.46	–0.10	–0.06	0.25	–0.76	–0.48
1977	–0.44	–0.94	–1.07	–1.10	–0.64	–0.77	–0.98	0.79	0.77	0.69
1978	0.68	0.28	–0.01	–0.79	–0.98	–1.09	–1.23	–0.80	–1.54	–0.65
1979	–0.79	–1.67	–1.33	–1.48	–1.06	–1.44	–1.61	–0.52	–1.20	–0.11
1980	0.09	0.66	0.67	0.59	0.80	0.41	0.26	–1.26	0.19	–0.09
1981	–0.01	0.41	0.52	0.43	0.26	0.42	0.35	0.87	0.33	0.13
1982	–0.15	0.17	0.03	–0.49	–0.12	–0.05	0.12	1.20	1.06	0.84
1983	0.46	0.16	–0.16	–0.59	–0.93	–0.90	–0.57	–0.71	–0.44	–0.05
1984	–0.79	–1.47	–1.82	–1.44	–1.44	–1.95	–1.49	0.20	1.50	1.40
1985	1.53	1.23	0.83	0.81	–0.46	–0.52	–0.60	–1.96	–0.02	0.26
1986	–0.29	–0.19	–0.33	–0.09	0.01	–0.25	0.13	0.49	0.82	0.19
1987	–0.63	–0.64	0.48	0.36	–0.32	0.10	0.70	1.51	0.97	1.30
1988	1.64	2.08	1.64	0.76	0.90	0.50	0.24	0.08	–0.23	0.01
1989	0.06	–0.09	0.28	–0.27	–0.04	–0.22	–0.34	–1.48	0.16	1.11
1990	1.38	1.34	0.93	0.89	0.54	–0.36	–0.64	–0.27	–0.70	–1.58
1991	–1.34	–1.04	–0.56	–0.84	–0.59	–0.09	–0.22	0.16	–0.01	0.41
1992	0.11	0.34	0.60	0.13	0.60	0.35	0.59	0.04	–0.04	–0.16
1993	–0.32	–0.37	–0.92	0.12	0.74	0.75	0.88	1.64	0.87	0.65
1994	0.92	1.00	0.53	0.15	–0.36	–0.31	–0.67	1.02	2.73	2.50
1995	2.39	1.98	1.26	0.64	–1.61	–1.25	–0.65	–0.09	–1.56	–2.72
1996	–1.79	–1.20	–0.10	0.33	0.71	1.16	1.06	–0.83	–1.97	–1.02
1997	–1.11	–1.59	–0.88	–0.54	–0.06	–0.12	–0.12	–0.12	0.29	0.00
1998	0.04	–0.12	0.42	0.31	–0.01	0.13	0.13	–0.94	–0.70	–2.01
1999	–1.67	–1.31	–1.93	–1.71	–1.81	–1.06	–1.22	–0.56	–0.34	–0.56
2000	–0.79	–1.33	–1.70	–1.72	–1.82	–1.77	–2.21			

Table 18. SPI values for six-month time scale in Alashtar station.

Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	OCT	NOV	DEC
1966			0.56	0.03	–0.73	–0.18	–0.64	0.14	–0.26	–0.22
1967	–0.92	–0.49	–1.00	–1.36	–0.68	–0.78	–0.39	0.68	0.90	0.08
1968	–0.48	–0.39	–0.60	–0.16	–0.20	0.18	0.57	1.15	0.99	0.73
1969	1.87	1.44	1.67	1.95	1.92	2.06	1.50	0.51	–1.89	–1.57
1970	–1.65	–1.85	–1.89	–1.15	–0.94	–0.81	–0.71	–1.19	–0.66	–0.38
1971	–0.92	–0.91	–0.16	0.40	0.41	0.42	0.82	–0.50	1.13	0.90
1972	0.63	0.18	0.64	0.80	0.80	0.89	1.16	1.09	0.74	0.57
1973	0.30	–0.02	–0.55	–0.41	–0.98	–1.22	–1.33	–1.12	–0.87	–0.88
1974	0.10	0.47	0.51	0.65	0.70	0.88	0.53	–1.19	–1.00	0.13
1975	0.09	0.23	–0.35	–0.27	0.13	–0.25	–0.32	0.29	–0.69	0.29
1976	0.95	0.70	0.54	0.45	0.56	0.23	–0.43	–0.27	–0.58	–0.67
1977	–0.87	–1.36	–0.91	–0.79	–0.72	–0.68	–0.60	1.04	0.81	0.99
1978	0.48	0.23	0.04	–0.74	–0.69	–1.19	–0.96	–0.57	–0.69	0.79
1979	0.68	0.36	0.18	0.01	0.29	–0.47	–0.59	0.04	–0.31	0.09
1980	0.25	0.78	0.73	0.66	0.81	0.72	0.72	–0.44	0.33	–0.01
1981	0.42	0.70	0.43	0.36	0.07	0.20	–0.16	0.72	0.65	–0.03
1982	1.07	1.37	1.20	0.66	0.97	1.29	0.72	0.99	–0.31	–0.96
1983	–0.67	–0.92	–1.26	–1.47	–1.36	–1.12	–1.58	–1.19	–1.33	–0.76
1984	–1.79	–2.01	–2.26	–2.11	–1.83	–2.24	–1.70	–0.77	–0.48	–1.42
1985	–2.21	–2.04	–2.36	–2.55	–2.83	–2.53	–2.26	–1.19	–0.75	–0.18
1986	–0.77	–0.51	–0.72	–0.16	0.66	0.58	1.02	1.84	1.03	0.44
1987	0.03	0.15	0.53	0.29	–0.28	–0.04	0.23	1.58	1.19	1.61
1988	1.36	1.57	1.45	0.94	1.02	0.64	0.86	–0.15	–0.28	–0.25
1989	–0.27	–0.41	–0.01	–0.24	–0.05	–0.05	–0.04	–0.11	0.69	1.09
1990	0.78	0.68	0.29	0.44	0.31	–0.09	0.08	0.79	0.15	–0.71
1991	–0.54	–0.38	–0.27	–0.55	–0.50	–0.14	–0.22	–0.84	–0.13	1.13
1992	0.76	1.15	1.22	1.35	1.48	0.99	1.34	0.02	0.68	0.69
1993	0.81	1.22	1.06	1.46	1.40	1.39	1.48	0.82	1.04	0.39
1994	0.40	0.42	0.39	0.33	0.10	0.37	0.37	1.79	2.98	2.72
1995	2.24	1.83	1.29	1.21	–0.03	0.01	0.45	0.25	–1.70	–1.93
1996	–0.92	–0.22	0.62	1.22	1.46	1.76	1.87	–0.63	–1.13	–0.72
1997	–0.43	–0.96	–0.16	0.23	0.47	0.54	0.52	0.12	0.43	0.12
1998	0.37	0.15	0.80	0.50	0.39	0.52	0.39	–0.50	–0.76	–2.25
1999	–1.44	–1.25	–1.31	–1.40	–1.36	–0.81	–1.07	–1.08	0.03	0.19
2000	0.32	0.10	–0.26	–0.51	–0.73	–1.01	–1.60			

Table 19. SPI values for 12-month time scale in Kermanshah station.

Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	OCT	NOV	DEC
1966								0.57	0.23	0.52
1967	0.32	0.25	–0.35	–0.23	0.21	0.21	0.21	–1.19	–0.25	–0.55
1968	–0.25	–0.32	–0.25	0.50	0.56	0.58	0.58	0.74	0.94	1.20
1969	1.65	1.74	2.25	2.74	2.54	2.52	2.51	2.68	2.18	2.05
1970	2.03	1.72	1.58	0.80	0.54	0.53	0.53	0.15	–0.08	0.01
1971	–0.75	0.01	–0.27	–0.03	0.27	0.27	0.28	0.30	0.95	1.22
1972	1.54	1.55	2.19	1.54	1.70	1.72	1.71	1.73	1.06	0.90
1973	0.96	0.84	–0.57	–0.75	–1.30	–1.35	–1.35	–1.52	–1.54	–1.59
1974	–1.19	–0.54	1.25	1.38	1.41	1.40	1.40	1.44	1.43	1.43
1975	1.29	1.18	–0.36	–0.24	0.28	0.28	0.28	0.27	0.60	0.93
1976	0.84	0.42	0.60	0.60	0.27	0.26	0.26	0.44	–0.06	–0.50
1977	–0.44	–0.69	–0.71	–0.98	–1.05	–1.04	–1.04	–0.77	–0.21	–0.24
1978	–0.35	–0.26	–0.23	–0.44	–0.45	–0.43	–0.43	–1.16	–1.62	–1.42
1979	–1.55	–1.97	–1.59	–1.72	–1.68	–1.70	–1.69	–1.74	–1.61	–1.31
1980	–1.17	–0.12	0.03	0.30	0.18	0.18	0.18	0.14	0.62	0.15
1981	0.08	–0.04	0.04	0.01	0.19	0.19	0.19	0.63	0.23	0.28
1982	0.07	–0.01	–0.24	–0.15	–0.06	–0.06	–0.06	0.00	0.40	0.38
1983	0.26	–0.11	–0.22	–0.05	–0.18	–0.18	–0.18	–0.94	–1.20	–0.88
1984	–1.05	–1.37	–1.51	–1.66	–1.63	–1.62	–1.61	–1.40	–0.15	–0.32
1985	0.03	0.30	0.50	0.71	0.55	0.54	0.54	0.30	–0.57	–0.37
1986	–0.76	–0.54	–0.43	–0.57	–0.14	–0.14	–0.14	–0.03	0.34	–0.21
1987	–0.38	–0.48	0.50	0.41	0.10	0.10	0.16	0.91	0.18	0.84
1988	1.45	1.95	1.15	1.24	1.19	1.18	1.13	0.61	0.53	0.28
1989	0.11	–0.54	0.00	–0.32	–0.29	–0.28	–0.28	–0.77	–0.11	0.46
1990	0.57	0.73	0.25	0.43	0.42	0.41	0.41	0.64	0.03	–1.24
1991	–1.43	–1.46	–0.88	–0.96	–0.99	–0.98	–0.98	–0.87	–0.68	0.06
1992	–0.23	–0.10	0.01	0.07	0.38	0.45	0.45	0.00	0.34	0.06
1993	0.18	–0.04	–0.78	0.02	0.49	0.44	0.46	0.79	0.96	0.86
1994	1.13	1.32	1.42	0.81	0.11	0.09	0.07	0.45	1.76	1.58
1995	1.14	0.86	0.73	0.88	1.13	1.16	1.15	0.44	–2.22	–2.47
1996	–1.69	–1.19	0.05	0.17	0.02	–0.01	–0.01	–0.05	–0.06	0.39
1997	0.22	–0.25	–0.63	–0.85	–0.78	–0.77	–0.77	–0.71	–0.06	–0.23
1998	–0.19	0.05	0.24	0.14	0.01	0.01	0.05	–0.09	–0.47	–0.92
1999	–0.92	–0.75	–1.90	–1.97	–2.09	–2.08	–1.96	–1.98	–1.90	–1.34
2000	–1.55	–2.16	–1.87	–1.86	–1.90	–1.89	–2.05			

Table 20. SPI values for 12-month time scale in Alashtar station.

Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	OCT	NOV	DEC
1966								0.01	–0.82	–0.38
1967	–1.07	–0.90	–1.29	–1.22	–0.76	–0.76	–0.76	–0.99	–0.28	–0.72
1968	–0.64	–0.86	–0.53	–0.01	0.10	0.10	0.10	0.14	0.14	0.41
1969	1.43	1.41	1.85	1.98	1.87	1.87	1.87	1.78	1.39	1.36
1970	0.43	0.28	–0.49	–0.91	–1.33	–1.32	–1.32	–1.35	–1.12	–0.99
1971	–1.12	–0.96	–0.10	0.10	0.11	0.11	0.11	0.21	0.69	0.70
1972	0.83	0.75	0.74	0.60	1.00	1.02	1.02	0.91	0.85	0.92
1973	0.92	1.01	0.20	–0.08	–0.58	–0.61	–0.61	–0.63	–1.21	–1.59
1974	–0.86	–0.32	0.26	0.37	0.34	0.34	0.34	0.33	0.32	0.71
1975	0.33	0.17	–0.41	–0.54	–0.20	–0.20	–0.20	–0.22	–0.15	–0.18
1976	0.29	0.12	0.51	0.43	0.24	0.24	0.24	0.30	0.26	–0.20
1977	–0.89	–1.36	–1.06	–0.83	–0.89	–0.89	–0.89	–0.40	–0.35	–0.06
1978	–0.19	0.05	–0.16	–0.38	–0.32	–0.32	–0.32	–0.83	–0.90	–0.54
1979	–0.24	–0.30	–0.24	–0.15	0.00	0.00	0.00	–0.03	0.08	–0.46
1980	–0.34	0.30	0.46	0.57	0.54	0.54	0.54	0.46	0.71	0.51
1981	0.65	0.51	0.30	0.20	0.08	0.08	0.08	0.44	0.20	0.03
1982	0.47	0.64	0.78	0.72	0.96	0.96	0.96	0.76	0.70	0.72
1983	0.11	–0.69	–1.07	–0.98	–1.36	–1.35	–1.36	–1.65	–1.65	–1.45
1984	–2.23	–2.47	–2.37	–2.32	–2.07	–2.07	–2.07	–2.10	–1.85	–2.72
1985	–2.54	–2.46	–2.36	–2.57	–2.64	–2.63	–2.64	–2.67	–2.79	–2.09
1986	–1.97	–1.66	–1.27	–0.44	0.32	0.32	0.32	0.40	0.85	0.59
1987	0.68	0.74	1.20	0.78	0.11	0.11	0.11	0.65	0.18	0.79
1988	0.89	1.22	0.95	1.22	1.20	1.20	1.20	0.76	0.74	0.33
1989	0.40	–0.17	0.01	–0.30	–0.22	–0.21	–0.21	–0.29	0.12	0.45
1990	0.35	0.52	0.01	0.33	0.42	0.42	0.42	0.52	0.22	–0.51
1991	–0.34	–0.38	–0.02	–0.31	–0.47	–0.47	–0.47	–0.71	–0.58	0.41
1992	0.22	0.66	0.83	1.08	1.19	1.20	1.20	1.16	1.41	1.07
1993	1.31	1.39	1.15	1.30	1.33	1.32	1.32	1.41	1.47	1.28
1994	1.21	0.90	0.88	0.46	0.40	0.39	0.39	0.76	1.57	1.83
1995	1.57	1.53	1.17	1.52	1.48	1.50	1.50	1.07	–0.45	–0.80
1996	–0.22	0.13	1.07	1.12	0.96	0.94	0.95	0.94	1.02	1.25
1997	1.18	0.66	0.40	0.04	0.09	0.09	0.09	0.18	0.46	0.40
1998	0.48	0.74	0.86	0.43	0.39	0.39	0.39	0.30	0.07	–0.34
1999	–0.49	–0.50	–1.53	–1.45	–1.51	–1.50	–1.48	–1.54	–1.24	–0.67
2000	–0.57	–0.62	–0.66	–0.73	–0.71	–0.71	–0.73			

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WATER & FOOD

Benchmark river basins

The CP Water & Food is a research, extension and capacity building program aims at increasing the productivity of water used for agriculture. The CP Water & Food is managed by an 18-member consortium, composed of five CGIAR/Future Harvest Centres, six National Agricultural Research and Extension Systems (NARES) institutions, four Advanced Research Institutes (ARIs) and three international NGOs. The project is implemented at nine river basins (shown above) across the developing world. The Karkheh River Basin (KRB) in western Iran is one of the selected basins. The program's interlocking goals are to allow more food to be produced with the same amount of water that is used in agriculture today, as populations expand over the coming twenty years. And, do this in a way that decreases malnourishment and rural poverty, improves people's health and maintains environmental sustainability.

Improving On-farm Agricultural Water Productivity in the Karkheh River Basin Project (CPWF PN 8)
Strengthening Livelihood Resilience in Upper Catchments of Dry Areas by Integrated NRM (CPWF PN 24)

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