Water and water shortage in Iran

Case study Tashk-Bakhtegan and Maharlu lakes basin, Fars Province, South Iran

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To my husband who supported me and light up my life

Abstract

Tashk-Bakhtegan and Maharlu lakes' basin in Fars province in south of Iran is facing a harsh water shortage in recent years. Semi-dry and dry conditions are prevailing climate conditions in the basin and the wet condition can only be seen in the small part of the north. Groundwater is the main source to provide water for different purposes such as agriculture, industry and drinking. Over-exploitation of water more than aquifers potential caused exploitation of prohibited water and prevailing the critical condition in vast part of basin. Kor and Sivand rivers are the only permanent rivers in the basin and they flow only in some parts of basin and they supply part of the water demand. Some factors such as geological setting, the rate of evaporation, existence of two salt lakes and Salt Lake's intrusion from the lakes has caused a decrease in water quality especially in the south of the basin.

In this study for the first time a complete research was carried out to understand the hydrologic circle of Tashk-Bakhtegan and Maharlu lakes' basin. In this study those basins were evaluated in terms of meteorology, surface water, groundwater, water quality, and water balance was carried out. Although the agriculture section was evaluated as the most water consumer. The main reasons behind the study area water scarcity includes; decrease in rainfall, over-exploitation of groundwater resources, using traditional irrigation methods and low irrigation efficiency resulting in huge amount of water being wasted, incorporated crop pattern that does not match climate conditions and water resources.

One of important and effective step to be taken for dealing with the water shortage in this basin is selecting suitable crop pattern. In the south of the basin base on water quality and climate condition developing gardening and growing pomegranate and pistachio as two plants that has low water demands and also tolerate high salinity is recommended.

Finding the suitable lands to cultivate rain-fed products such as wheat (as the most water consumer crop in the basin) corresponding to ecological condition could be helpful to increase productivity. Based on the result of studies, Marvdasht-Kherameh, Shiraz, Beiza-Zarghan and Dozkord- Kamphiroz are suitable places to cultivate this product. Only with these important changes in the cultivation of field crops can a balanced water balance be achieved.

Zusammenfassung

Das Taschk-Bakhtegan- und Maharlu-Seenbecken, welches in der Fars-Provinz im Süden des Irans gelegen ist, erleidet seit einigen Jahren eine extreme Wasserknappheit. Im Gegensatz zum Norden des Beckens, wo humide Bedingungen vorzufinden sind, beherrschen halbtrockene bis trockene klimatische Bedingungen das Becken. Grundwasser dient als Hauptquelle für die Trinkwasserbereitstellung und Wasserversorgung in der Landwirtschaft und Industrie. Eine Überbeanspruchung des Grundwasserleiters in den letzten Jahren einschließlich der Entnahme von verbotenen Grundwasserreserven führte zu der momentan kritischen Situation in weiten Teilen des Beckens. Die Flüsse Kor und Sivand, welche als einzige das gesamte Jahr über Wasser tragen, durchfließen nur einen Teil des Beckens, weswegen deren Flusswasser nur bedingt zur Deckung des Wasserbedarfs beiträgt. Zusätzlich zur Wasserknappheit ist eine Verschlechterung der Wasserqualität, insbesondere im Süden, vorzufinden. Diese Qualitätsabnahme ist vor allem durch Faktoren, wie geologischen Beschaffenheit, Verdunstungsrate sowie Salzwasserintrusion aus zwei Salzseen in den Untergrund zurückzuführen.

Die vorliegende Studie führt eine erstmalige Untersuchung zum besseren Verständnisses der Wasserkreisläufe des Tashk-Bakhtegan und Maharlu Seenbeckens durch. Hierbei wurde das Becken hinsichtlich Meteorologie, Oberflächenwasser, Grundwasser, Wasserqualität und Wasserhaushalt bewertet. Obwohl sich die Landwirtschaft als Hauptwasserverbraucher resultierte, konnten folgende Hauptgründe der herrschende Wasserknappheit im Untersuchungsgebiet identifiziert werden: Niederschlagsabnahme, Übernutzung der Grundwasserressourcen, Verwendung von traditionellen Bewässerungsmethoden mit geringer Bewässerungseffizienz und einer enormen Wasserverschwendung, sowie für die die klimatischen Bedingungen und vorhanden Wasserressourcen ungeeignete Anbaumethoden.

Ein wichtiger und effektiver Schritt zur Bewältigung des Wassermangels im Untersuchungsgebiet ist die Auswahl geeigneter Anbaumethoden. Im Süden des Beckens wurden in Abhängigkeit der Wasserqualität und des Klimas Granatapfel und Pistazien angebaut, die einen geringen Wasserbedarf aufweisen und einen hohen Salzgehalt tolerieren.

Die Identifizierung von geeigneten Anbauflächen für regenabhängige Produkte wie Weizen, einem der Hauptwasserverbraucher im Untersuchungsgebiet, könnte zur Steigerung der Produktivität beitragen. Basierend auf den Ergebnissen der Studien sind Marvdasht-Kherameh, Shiraz, Beiza-Zarghan und Dozkord-Kamphiroz geeignete Orte, um Weizen unter

den gegebenen ökologischen Bedingungen zu kultivieren. Nur mit diesen wichtigen Veränderungen im Anbau von Feldfrüchten kann eine ausgeglichene Wasserbilanz für das Taschk-Bakhtegan- und Maharlu-Seenbecken erreicht werden.

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A	Area
Aj	Aghajari formation
As	Asmari formation
ºC	Centigrade Degree
Cl	Chloride
CMC	Cubic Million Meters
DEM	Digital elevation model
E	Evaporation
EC	Electrical Conductivity
GIS	Geographic Information System
Gu	Gurpi formation
H	Height
Ha	Hectare
Ja	Jahroum formation
km^2	Square Kilometer
Ksv	Sarvak formation
m	Meter
mm	Millimeter
m/y	Meter/year
mg/lit	Milligram/Liter
MCM/Y	Million Cubic Meter/Year
Mr	Razak formation
N	Number
nb	Number data more than average
na	Number data lower than average
P	Precipitation
Q	Discharge

R	Regression
T	Return Period
TDS	Total dissolved solids
T/ha	Tone/hectare
Sa	Sachon formation
UTM	Universal Transverse Mercator
µs/cm	Micro Siemens /Centimeter

1. Introduction

Iran is situated in the arid and semi-arid climate of Middle East. With an area of 164 million square kilometers, it is the second largest country in the Middle East (after Saudi Arabia) and the 18th largest country in the world.

Iran enjoys vast climatic variability, being mainly affected by the subtropical high-pressure belt. It has a complex climate ranging from subtropical to sub-polar and this is why temperature can vary significantly (from -20 to+50 °C) throughout the country and during the year. January and July are respectively the coldest and hottest months of the year in most of the country. For example, in summer, the temperature varies from 1 c in the northwest to 50 at the head of the Persian Gulf.

Precipitation also varies greatly, ranging from less than 100 mm/year in the central and southeast to about 1000 mm/year in the Caspian region. The annual average is about 271 mm (Ardakanian, 2003), less than one-third of average annual precipitation at the global level.

The study of the spatial distribution of rainfall in the country indicates that only 25 % of country's area has higher than 300 mm annual average precipitation and in the rest of the country, the amount of annual precipitation is less than 300 mm. Thus it seems quite uneven. The considerable spatial and temporal precipitation variability in Iran has been the main motivation to construct numerous dams and large reservoirs to regulate water flows (Madani, 2014).

In the current climate, 71 % of precipitation is evaporated. The main water source in Iran highly depends on precipitation, 70 % of which has to do with rainfall and the rest is in the form of snowfall. The amount of water resulting from precipitation is about 417 billion cubic meters, 299 million of which is evaporated.

Most (65%) of the country's total area is considered to be arid, 20% of which is semi-arid, and the rest is humid or semi-humid. This thesis focuses on Tashk-Bakhtegan and Maharlu lakes' basin in Fars province in southeast of Iran, Iran's climate map is shown in figure 1-1.

There is a vastly extended network of rivers in Iran. Only one river (Arvand River) is navigable, and the others are too steep and irregular. Some permanent rivers run from Alborz or Zagros mountains to the Caspian Sea, Persian Gulf and Oman Sea. Some temporary rivers either run into body of water or get dried before reaching any watershed. They normally flood in spring (with the ability to create some damage), but have little or no water in summer.

Rivers across Iran are divided into 12 watersheds with regard to drainage. Iran's watersheds and important river are as follows:

1- Caspian Sea watershed (Aras, Sefid Rud, Haraz, Atrak)
2- Persian Gulf and Oman watershed (Arvand, Karun, Zohre, Mond)
3- Uremia lake watershed (Zarineh Rud)
4- Qom Salt Lake watershed (Gharehchai, Shor)
5- Esfahan and Sirjan watershed (Zayanderud)
6- Neyriz or Bakhtegan watershed (Kor, Sivand)
7- Jazmurian watershed (Halilrud)
8- Dasht-e- Kavir watershed (Hablerud, Kalshor Jajarm)
9- Kavir-e-Lut watershed (Tahrud)
10- Ardestan- e- Yazd watershed
11- Qaraqom watershed (Kashfrud Jajarm)
12- Hamun watershed (Hirmand)

According to the hydrological division of Iran Water Resources Management Company, water resources are divided into six major catchments: Caspian Sea, Persian Gulf and Oman sea, Uremia lake, the Central Plateau, Eastern border of the Qareqom and Serakhs. The resources are also divided into thirty sub catchments. (Figure 2: shows Iran sub catchments).

This dissertation provides an overview of water and its shortage in Iran. It is argued that Iran is experiencing significant water challenge that has made water security problem to a national priority at the moment (Madani, 2014).

1.1 Water resources and water shortage in Iran

In recent years drying lakes, declining groundwater level in most of plains, land subsidence, water contamination, reducing level of agricultural productivity and damage to agriculture have emerged new developments. Agriculture losses, surge in rate of unemployment and ecosystem damages are among the developments which have caused increased migration to the cities.

Given the water shortage and irregular precipitation, ancient Iranians learned to build dams, irrigation network and Qanat. They are proud of their significant contribution to hydraulic engineering by inventing Qanat.

The Qanat system is seen as one of the most balanced water recovery methods. The Qanat has been a traditional method of water supply in Iran. In arid regions, Qanat was invented to deal with water shortages, while water supply is provided through springs and wells. Qanats have been effective for nearly 3000 years and are still being used as one of the major methods of procuring water for irrigation and agricultural activities (Mahmudi et al, 2017). In the recent years, however, rapid socioeconomic development has created a serious water crisis for this nation. In the northwest of the country, Lake Uremia has been shrinking for the last 15 years and its area has decreased from 6100 to 4750 km^2 (Jalali, 2010) resulting in about 6 m drawdown in water level. This lake has significantly shrunk as a result of frequent drought and intensive agricultural activities, anthropogenic changes to system (Aghakochakian et al., 2015). Drying lake of Uremia has had tragic consequences including salinization of water wells, decreasing soil quality, changing farmlands to desert, influence on residents' livelihood and finally spread of diseases that threatens the health of residents.

Hamun lake, located in south east of Iran, consists of transboundary wetlands between Iran and Afghanistan that are fed by Hirmand river and a unique freshwater wetland that has a remarkable local, national and international significance. This wetland has a great ecological economic and cultural value and offer livelihood to a significant proportion of human population in the Sistan basin.

Over the last decade drought seems to have occurred here more frequently than before. The vegetation cover has dramatically decreased. The degradation of the ecosystem is of great concern to the authorities and the local people, who see their livelihood threatened. Between 2001 and 2005, Hamun lake has been completely dried up most of the time. Hence, people lost their source of income from fisheries, reed harvest, grazing and bird harvesting. Likewise, agriculture suffered from severe shortage of water. Reasons for this vast degradation are associated with occurrence of droughts and decreased discharge of the Hirmand river due to increased water use in Afghanistan and over-exploitation of natural resources by the growing local population (Najafi & Vatanfada, 2011).

Zayandeh-Rud river supplies important part of drinking, agriculture and industry usage in Gavkhoni basin in central Iran. Since early 2010, however, the river dried out completely, imposing extensive pressure on the agriculture, industries and urban population. Several reasons should be blamed for causing the river to dry which includes: industrial development in Esfahan province, cropping pattern with high water requirement, drinking water use more than standard, low irrigation efficiency, excessive use of grass for green space in Esfahan city, overexploitation of groundwater resources and negative effect of interbasin water transfer.

In south of Iran, Bakhtegan lake has been a home and suitable habitat to many residents and migratory birds. In addition, it played an important role in Fars province ecosystem. This lake, however, is now completely dry due to decrease in rainfall, overexploitation of groundwater in upstream and dam in construction upstream during recent years.

Uremia, Hamun and Bakhtagn lakes are not the only drying water bodies in Iran. Parishn lake as one of the important fresh water lake in Fars province, in south of Iran, Shadegan and Gavkhoni wetland are another water bodies which have dried up one after another in recent years.

Similar to the lakes and wetlands, rivers have been victims of aggressive human developments for enhancing regional economics (Madani, 2014). Karun River as the only navigable river in Iran has reached a critical situation. The main reason behind this condition is construction of 24 dams in the river's basin. Constructing dams without attention to ecosystem and water right in the basin has caused numerous problems in the country.

The Iranian water tragedy is not limited to surface water. In fact, deteriorating condition of 80 % of plains in Iran display their dangerous situation with regard to underground water. There are totally 609 plains in Iran, 290 of which are in critical condition and the remaining ones require immediate care and careful planning to preserve them. Illegal use of groundwater resources, inappropriate cultivation with regard to climate condition in each region, changing in climate condition, population growth and low irrigation efficiency are among the most notable reasons for this condition. Changing in water extortion and water use in agriculture, drinking and industry use is shown in chart (1-3).

As can be seen over the last few decades, there has been a dramatic increase in water use in Iran. Accounting for over 90 % of water consumption, agriculture is the most significant consumer of water resources in Iran.

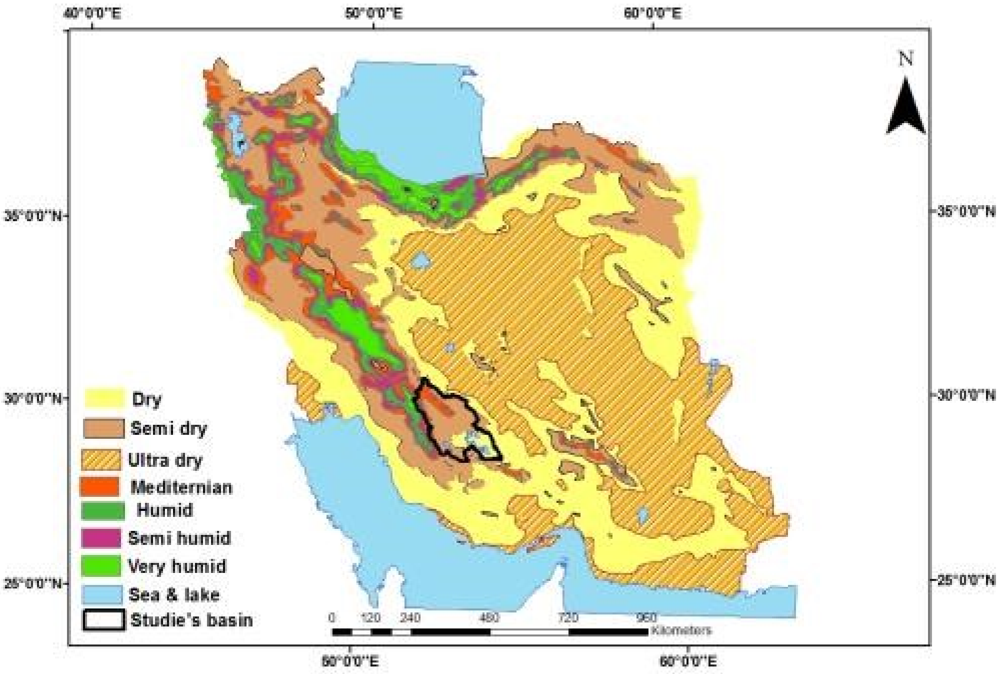

Figure 1-1: Iran's climate map

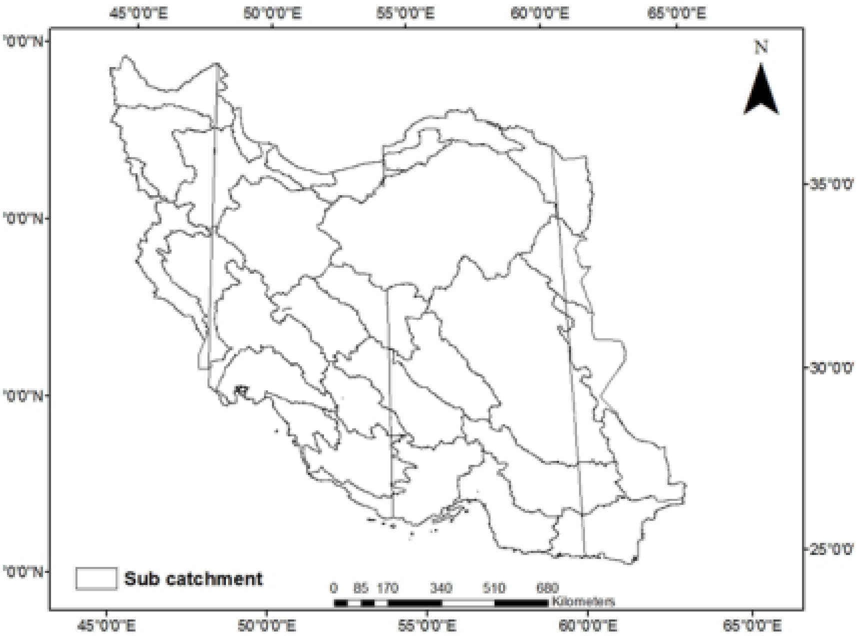

Figure1- 2: Iran’s sub catchment

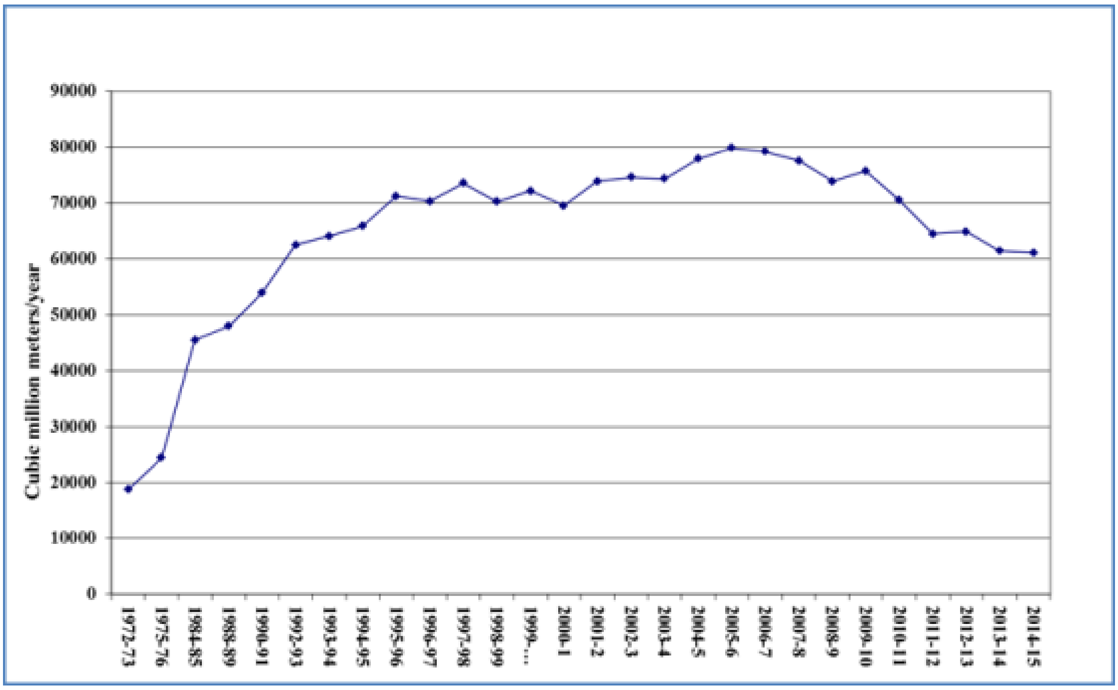

Figure 1-3: Water consumption trend in Iran

1.2 Location of the study

The study area is located in Tashk-Bakhtegan and Maharlu lakes' basin in Fars province in southeast of Iran. The first reason for selection of this area is that it is facing a harsh water shortage in recent years and this is also seen one of important part of Iran in terms of agriculture.

1.3 General information of study area

Task- Bakhtegan and Maharlu Lakes basin - an area of 31492 Km² is located in Fars province, South of Iran. The study area that is situated in the northwest, southeast and parallel to Zagros Mountains, consists mainly of two distinct parts which are called "Tashk–Bakhtegan lake basin" and "Maharlu lake basin" (Figure1-4-Maharlu-Bakhtegan Lake position in Iran). The area is located between 51º-42´ and 54 º-31´ east longitude and 29º to 31º-14´ north latitude.

According to the latest census (2011), cities, that are located in this basin, are the following: Shiraz, Sarvestan, Neyriz, Estahban, Safashahr, Sivand, Arsanjan, Kharameh, Marvdasht, Saadat Shahr, Abade Tashk, Seyyedan, Zarghan, Lapoie, Kovar, Meshkan, Beiza and Kamfiruz.

According to Iran Water Resources Management, the study area constitutes 27 areas including: Tavabe Arsanjan, Arsanjan, Seyyedan - Farogh, South of Tashk lake, Jahanabad Bakhtegan, Khanekt, Khir, Estahban, Neyriz, Tange Hana, Marvdasht- Kharameh, Darian, Saadatabad, Sarpaniran, Ghaderabad - Madar Soleyman, Dehbid, Namdan, Beiza - Zarghan, Dozkord - Kamfiruz, Khosroshirin, Asopas, Bakan, Shiraz, Gharebagh, Kavar maharlu, Sarvestan and Goshnegan. Population growth rate in the basin area (1.08% per year (Jamab, 2011)).

In morphological and topographical perspectives, the lake and Zagros mountain share similar characteristics. Study area lies in direction of Zagros folds (northwest-southeast trend), being located in the southern part of this mountain range. Zagros folds are parallel and the multiple faults have disorganized its continuous structure. Extended synclines, among long and high anticlines, that are stuffed by sediments of erosion have created the basin's plains.

The other Morphological characteristics of Bakhtegan- Maharlu are inland lakes and closed basin. The surface areas of Bakhtegan, Maharlu and Tashk lakes are respectively 739.03, 416.83 and 243.45 km^2.

The maximum height of the lakes' catchment is 3941 meters (Sefid mountain peak in Sivand river basin) and the maximum height of the Maharlu lake is 3003 meters (mountain top Qalat). The minimum height of Tashk Bakhtegan and Maharlu lakes' basin is 1525 and 1455 meters respectively (Figure1-5- DEM map of the basin).

According to hydrometric stations located in the catchment area, the main rivers' slope in tashk-Bakhtegan and Maharlu varies between 4.8-18.4 %.

The climate of the basin is mostly semi-dry (about 63.9 %) and to a lesser extent dry climate. The rest of the area has the Mediterranean climate and to a lesser degree humid climate.

According to the rainfall map, the highest record of average annual rainfall in the catchment is more than 800 mm in the northwestern areas. The amount of rainfall decreased up to 200 mm per year in the East.

The absolute minimum temperature was -28 ^{0}C, which was recorded at Kaftar station in December 1995 and January 1996. The absolute maximum temperature was 45 ^{0}C which was recorded at Abasabad station in June 1994.

Land cover in the basin is composed of mountain, dunes, plain-wetland, plain salt marsh. In mountainous regions, juniper and woody plants, in dunes between 1700 to 2500 meters altitude oak, pistachio and almond, in plain-wetland with less than 1700 meters altitude wheat and in plain salt marsh Tamarisk are among the trees that are mostly found. (Figure 1-6- land cover in the basin).

In general, due to agricultural, industrial and urban usage, the land cover in this area have been widely destroyed. This has resulted in low density of vegetation and degradation of pastures and forests which in their part have caused soil erosion in the basin and transfer of large amounts of sediment to the river.

Agricultural land in the study area is largely dedicated to growing crops, rice, sugar beets, oil seeds, potato.

- Tashk- Bakhtegan lakes basin

Kor River is the main permanent river in this area that has several branches. Sivand is the largest river originating from the highlands of the northeast and northwest areas that flows into Kor river in south. The main cities in this area are Marvdasht, Estahban, Neyriz and Dehbid.

- Maharlu lake basin

This basin has no permanent river and only Khoshk and Chenarrahdar river of Shiraz plain and Nazarabad river of Sarvestan plain lead to this lake. The main cities in this area are Shiraz and Sarvestan.

1.4 Field studies

Tashk-Bakhtegan and Maharlu lakes basin contain 27 studies areas. The geographical characteristics, size and the name of each of the major rivers are indicated in details in table 1(app (a)). Most of fields, other than Marvdasht- Kherameh, Saadatabad, Ghaderabad-Mdarsoliman, Dehbid-Namdan, Dozkord-kampiruz, Khosroshirin, Asopas and Shiraz, have no permanent river.

Maharlu-Bakhtegan basin is explored in five different parts including meteorology, hydrology, and groundwater, quality of water and balance of water. The figures presented are based on statistics data from 1970-2013 (Figure1-7-field studies map).

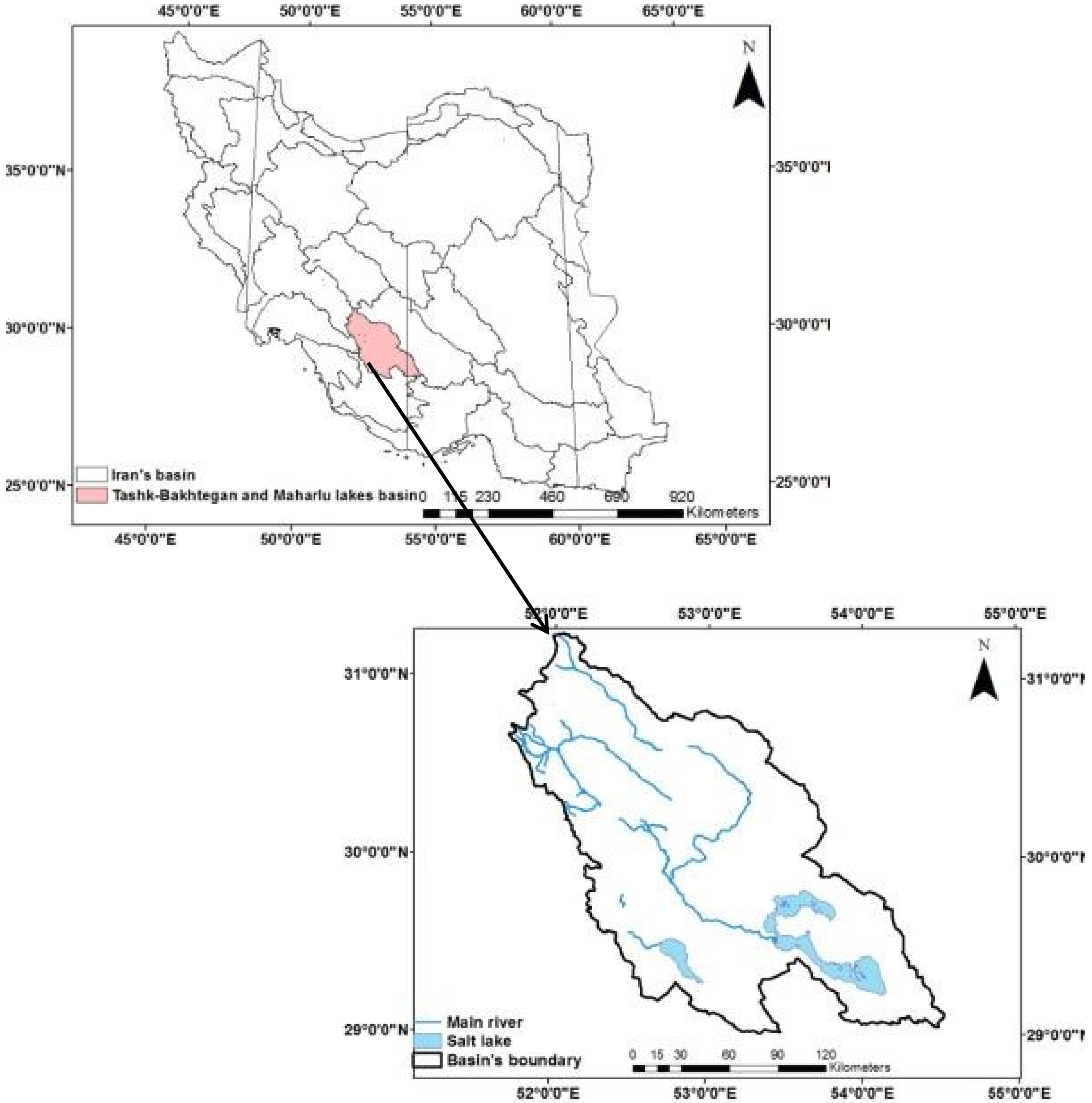

Figure1-4: Tashk-Bakhtegan and Maharlu Lakes basin position

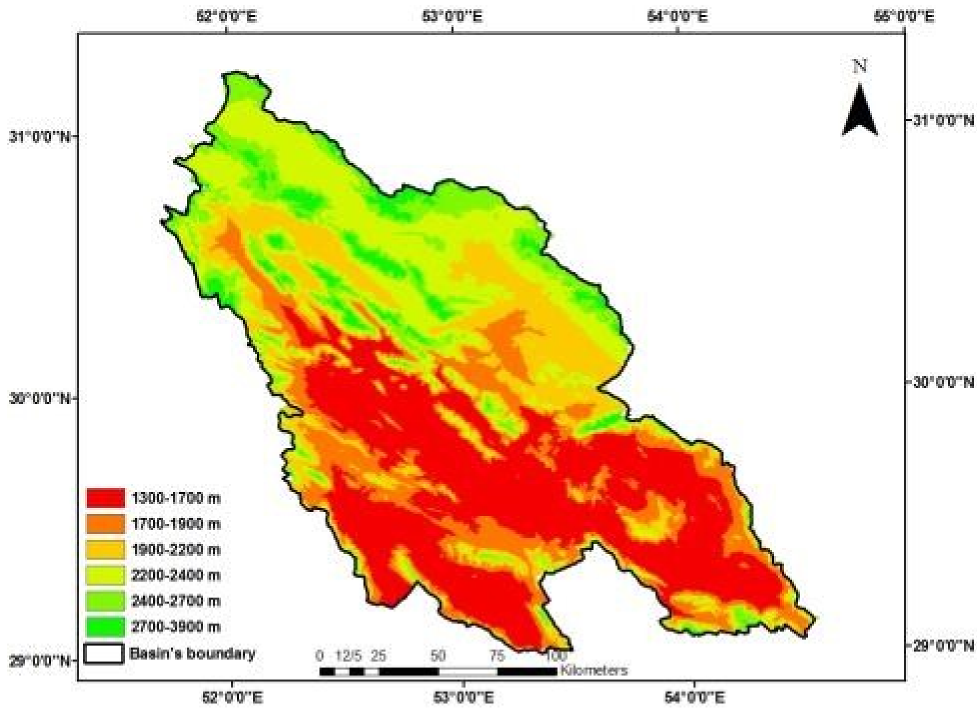

Figure1-5: Dem map of basin

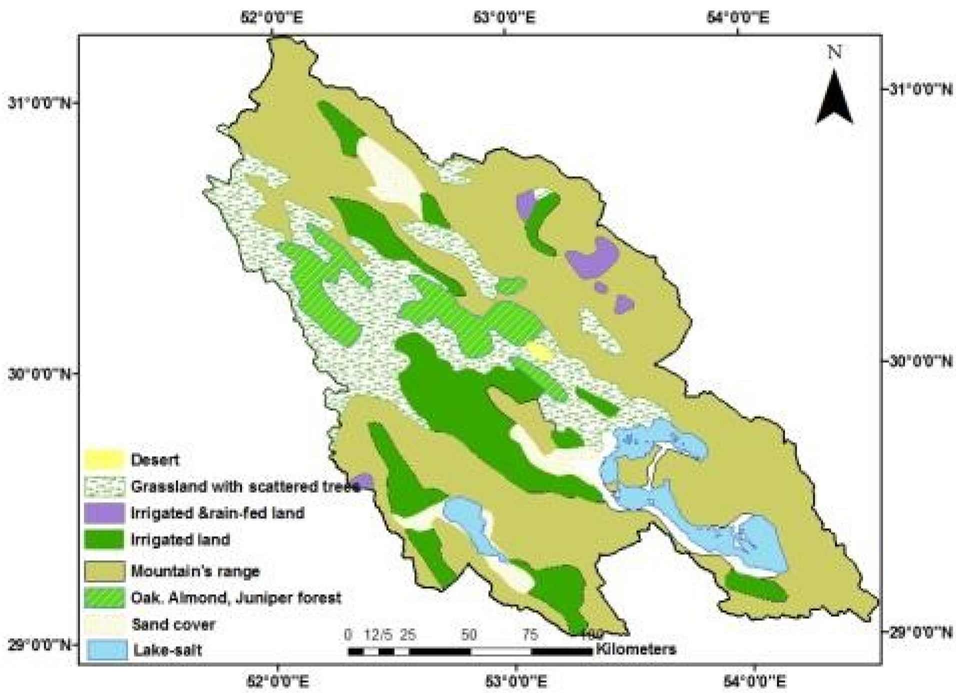

Figure1-6: Land cover map of basin

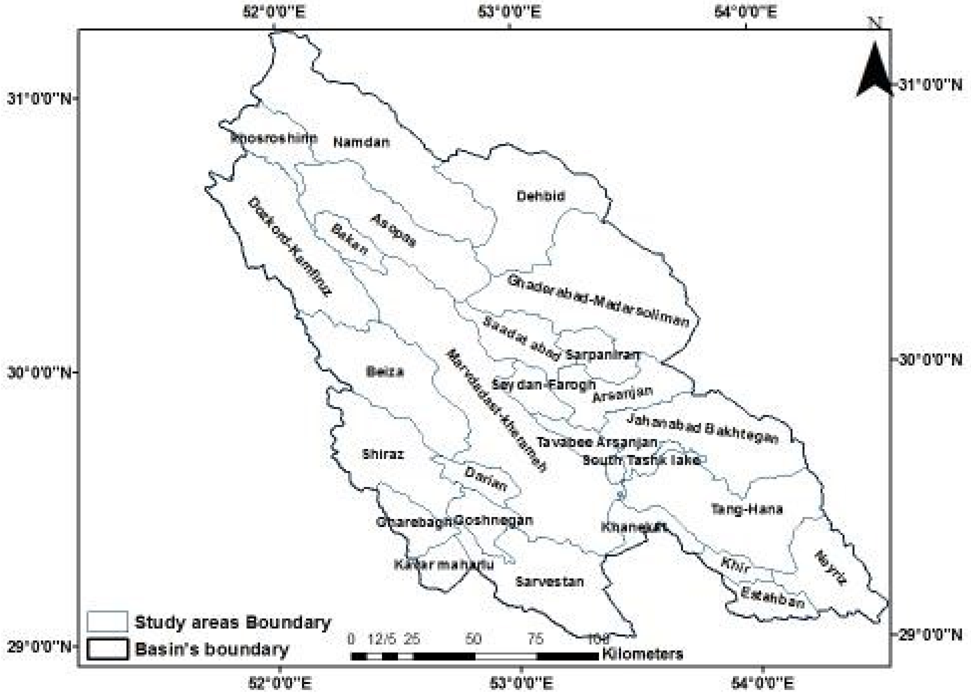

Figure1-7: Study areas map

1.5 Study objectives

The main objective of the current PhD thesis is to evaluate water resources and to determine crop pattern that are proportionate to available water and climate condition in Tashk-Bakhtegan and Maharlu lakes basin. Hence this research aims to:

- Evaluating climate parameters include temperature, precipitation and evaporation.
- Evaluating surface water and calculating runoff in the basin.
- Evaluating groundwater resources and investigating their changes.
- Evaluating groundwater and surface water quality.
- Calculating water balance based on hydrogeological statistics and determining water shortage in the basin.
- Evaluating agriculture as a major water consumer in the basin and presenting the best crop pattern. In order to assess the role of agriculture, the research has conducted a survey among 100 farmers of the area.

- Simulating Dynamic model of Drodzan dam as an important water supplier for agriculture and drinking of two meteropolices cities Shiraz and Marvdasht.

1.6 General study approach

This research is divided into various chapters. The first chapter begins with an introduction which briefly presents the research problem and the purposes of the study. The next four chapters, which is considered the first phase of this study, discuss and analyze meteorology, surface water, groundwater and quality of water in the basin.

The second phase of this study, which begins with the sixth chapter, calculates the water balance of the basin based on hydrological statistics. Evaluation of the crop pattern based on available water resources and climate condition is presented in the chapter seventh.

Eighth chapter of this research is dedicated to a general discussion of the study's findings and conclusion. The list of references cited in the research is presented in the last chapter of the thesis.

2. Meteorology

General

Iran is a vast country, and has different types of climate: mild and quite wet on the coast of the Caspian Sea, continental and arid in the plateau, cold in high mountains, desert and hot in the southern coast and in the southeast. Generally, Iran is an arid country.

In the west and the north, rainfall, however, is a bit more abundant than in the east and the south. The only rainy area is the Caspian Sea coast. Summer is sunny everywhere. The annual average of precipitation in Iran is about 271 mm (Ardakanian, 2003) that is less than one-third of average annual precipitation at the global level. Another point is that majority of precipitation falls in months which do not match with agriculture requierments.

Meteorological parameters include temperature, relative humidity, wind; precipitation and evaporation are important factors influencing on hydrological cycle. These elements affect directly or indirectly on the amount and intensity of surface flows, erosion and sediment of basins and also groundwater reserves. Detailed scientific analysis of these parameters plays an important role in understanding of hydrological phenomena for effective use of groundwater resources (especially in the south, east and central parts of Iran).

Tashk- Bakhtegan and Maharlu lakes basin consist of northern, central and southeastern parts of Fars province in the south of Iran. This is why the meteorological parameters vary widely in the basin. For example, in the cold area with minimum temperature of -28 ° C in the north and northwestern parts to the tropics area in south and southeastern part with temperatures above 45° C.

In this part of the dissertation, meteorological parameters including temperature, precipitation and evaporation are studied and analyzed. The tables and diagrams are also applied to better present the research results.

2.1 Temperature

Temperature is an objective comparative measurement of how hot or cold something is. Due to reception of irregular solar energy by the earth, the temperature varies on the surface which leads to change in other climatic elements. Temperature is a significant factor in many aspects of daily life, as well as all fields of natural science including physics, geology, chemistry, atmospheric sciences, medicine and biology.

The air temperature does not remain constant during the day. In fact, before sunrise it reaches the minimum, and in afternoon it reaches to maximum and then it drops again. In order to calculate the daily mean temperature, the average of temperature readings at specific times is assessed. In addition to the constant changes in daily temperature, the temperature doesn't remain same during the year, so that the maximum and minimum temperature is respectively in summer and winter. In order to measure the temperature at a specific location, different temperature parameters are calculated and analyzed. These parameters include mean tempreture, absolute maximum, absolute minimum, average maximum and average minimum. The specific statistical period both monthly and annually are calculated as well.

In order to study basin’s temperature, the data related to synoptic, climatology and evaporation stations affiliated to the Ministry of Energy and Department of Agriculture will be employed. Before analysis of temperature statistics, statistical quality is controlled by means of statistics from the nearby stations and is corrected if necessary. In order to gain monthly temperature information, the data provided by the nearby stations is used.

Table 2 (app (a)) summarizes the monthly record of temperature compiled from 25 stations during ten years. The climate information also contains five elemnts of tempreture including absolute maximum tempreture, absolute minimum tempreture, mean maximum tempreture, mean minimum tempreture and mean temperature.

2.1.1 The relationship between altitude and temperature (temperature gradient)

In order to investigate the relationship between altitude and temperature, the long term mean temperature should be explored. Given the fact that the information related to the base period might not be fully available, the 10-year is considered instead of 42-year relevant information. But before that, a comparison was made between the temperature average in ten years in stations with long-term information and the temperature average during long term and then the %age difference was explored. In Zarghan, Chamriz, Kaftar, Abbas Abad and Mehrabad Ramjerd stations, the mean temperature average was calculated in a 10-year period between 2003-2013. The temperature average was respectively 16/8, 14/9, 19/9, 16/1 and 16/3 degree, while the long term temperature average for these stations were respectively 16/4, 14/5, 19/4, 15/7 and 15/8 ° C. According to presented statistics, the difference between 10- year temperature average and long-term average is approximately 2% which is a negligible amount. Therefore, in order to estimate the relationship between temperature and altitude, rather than the temperature average of the base period, we can use the temperature average of the stations with more than 10-year record.

The long-term temperature average and altitude of stations in Tashk-Bakhtegan and Maharlu Lakes basin are listed in table 3 (app (a)). In this table, the annual temperature average changes along with altitude were determined for entire basin and are presented in figure 1 (app (b)).

Given the distribution of stations in figure 1 app ((b)), two separate gradients may be taken into account for investigating the relation between temperature and altitude in basins Station. The first gradient includes Abade Tashk, Ahmadbad Ramjerd, Ahmadabad, Arsanjan, Bajgah, Bajgah (Department of Agriculture), Jahanabad-Bakhtegan, Chamriz, Zarghan, Drodzan dam, Shiraz, Abasabad, Aliabad kamin, Godzereshk, Madarsoliman, Marvdasht, Mehrabad Ramjerd, Neyriz and Horgan stations that are located on the left side of the Figure 1(app (b)).

The second gradient is related to Tangeboragh, Dehbid, Sade and Kaftar stations that are located on the right side of the Figure. According to the stations' position in figure (app (b)), the first gradient covers the entire basin except northern part.

The results are presented both as monthly and annual temperature gradient in the table 4 a and b app ((a)) for the north and rest of the basin. According to these equations, the variation of annual temperature is 1.28 °C per 100 m height. Monthly temperature change is calculated between 0.22-0.37 (in northern part of basin) and 0.78-1.8 ° C (in rest of basin except the north) per 100 m height. According to the obtained gradients, variation in temperature with altitude is quite strong. In addition to the connection between temperature and height, temperature also changes with UTM. These relevance offeres two formulas for the basin: one for the basin’s north and another for the rest of basin, as the following:

Equation (2-1) north’s gradient $T = 1.869E\text{-}5X + 2.348E\text{-}5Y - 0.13H - 25.905$

Equation (2-2) rest of basin's gradient $T = 0.006X - 0.012Y + 0.45H + 43091.7$

In these formulas, the average annual temperature (T) is measured in centigrade, H represents height in meters and X and Y respectively represents latitude and longitude. It should be noted this relationship woulde be used in drawing iso-temprature map.

2.1.2 ISO temperature map

Iso temperature map is drawn using the station’s annual temperature average and general relationship between mean annualy temperatures. Iso temprtaure map in Figure (2-1) indicates that the temperature decreases as moving from the south to the north. The maximum temperature is 18.9 °C at the Dobaneh station and minimum temperature is 10.7°C at the Chambaian station. The annual temperature at Tange hana-Pichacan, Khir, South Tashk lake is around 13.4 °C, at Sarpaniran, Tavabe Arsanjan, Estahban, Neyriz, Abade tashk and Khanekat is around 12.5°C, at Seydan, Saadatabad and Arsanjan is over 10°C and in Ghaderabad-Madarsoliman and Dehbid is respectively 9°C and 7°C.

According to the temperature map, isothermal contours vary between 2 to 20°C in the basin. However, all of temperature contours in the northern part are 10°c or less and in the southern part are 10°C or more. Study of the temperature and topographic maps of the basin indicates that the difference between temperature in the north and south of basin is associated with the difference in height in these locations. This is because most of areas in the north have height of more than 2500 m and this amount in the southern part is 2500 m or less.

As mentioned before, Tashk- Bakhtegan and Maharlu lakes basin is divided into two separated areas, based on the temperature in the south and north. Lower temperature of the northern part is mainly because of its higher altitude compared to the southern part. This explains why Chambaian and Dobaneh stations located in the north and south of the basin displays respectively the minimum and maximum temperature.

2.1.3 Representative temperature stations

Based on isothermal map and network of synoptic, climatology and evaporation stations, some stations selected as representative stations. These stations have been chosen such that both represent the surrounding area and cover the whole of the basin. However, in some part of the basin, especially at uplands area, the number of stations for measuring temperature isn’t sufficient. This is why the stations, that both have long-term record of information and cover the whole of the basin, were chosen as representatives. In case of this basin, 15 stations were selected as representatives that are shown in table (2-1).

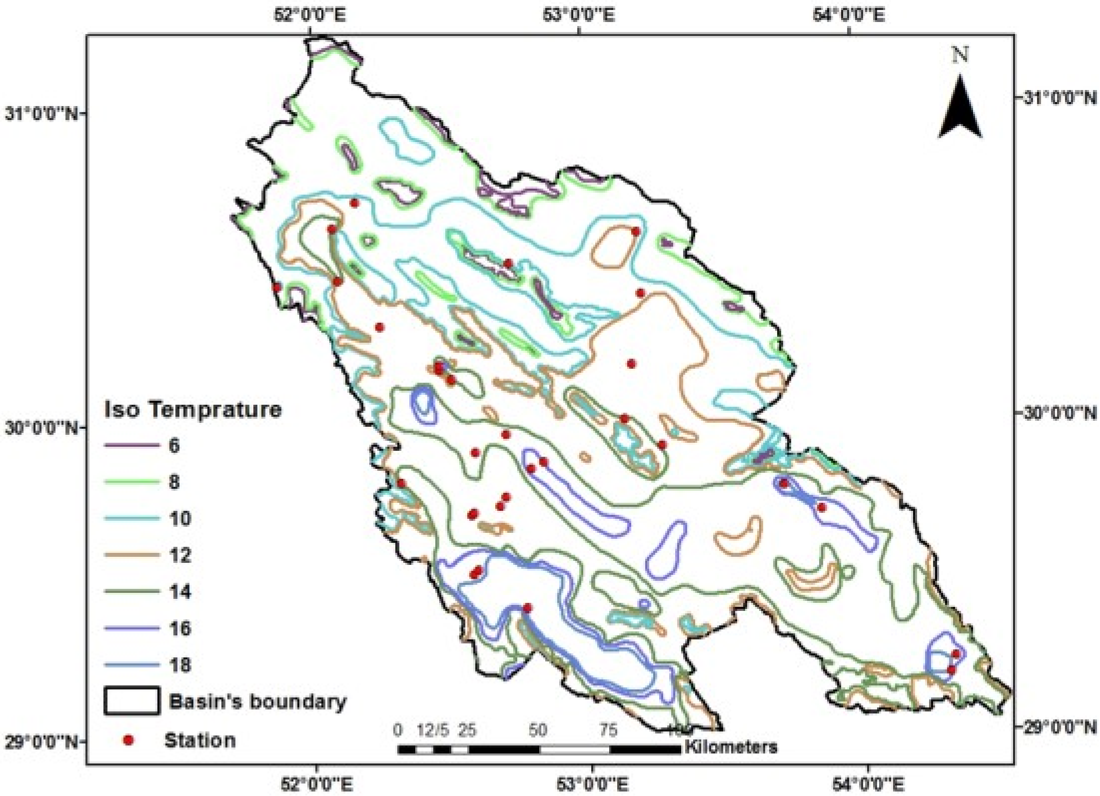

Figure 2-1: Iso temperature of the basin

Table 2-1: Representative temperature stations

C0lumn	Station	Basin	UTM			Statistic Duration (year)
			Elevation (m)	Latitute	Longitute	
1	Jahanabad Bakhtegan	Abade Tashk	1580	29-43-10	53-51-46	30
2	Chamriz	Chamriz	1840	30-28-03	52-06-06	42
3	Dbaneh	Sarvestan	1490	29-25-14	52-46-56	35
4	Dehbid	Aiaghloo	2260	30-37-00	53-12-00	17
5	Zarghan	Doshmanziari	1596	29-46-47	52-42-15	25
6	Drodzan dam	Polekhan Drodzan	1620	30-11-07	52-27-56	39
7	Sadeh	Abbalangan	2160	30-43-30	52-10-30	36
8	Shiraz	Khoshkerood	1488	29-32-47	52-36-13	56
9	Abasabad	Chamriz	1700	30-19-05	52-15-17	38
10	Aliabadkamin	Sivand 1	1790	30-01-23	53-08-24	35
11	Ghalat	Khoshkerood	2080	29-49-08	52-19-40	42
12	Kaftar	Shadkam	2315	30-31-00	52-44-00	33
13	Madar Soliman	Sivand 2	1850	30-11-25	53-10-47	29
14	Mehrabad Remjerd	Polekhan Drodzan	1616	29-58-25	52-42-02	42
15	Neyriz	Neyriz	1620	29-12-00	54-18-58	42

2.2 Precipitation

Precipitation is the primary mechanism for transporting water from the atmosphere to the surface of the earth. There are several forms of precipitation, the most common of which for arid and semi-arid region is rain. Other forms of precipitation include; hail, snow, sleet, and freezing rain. Rainfall is the primary source of water for agricultural production in most of the world. Three main characteristics of rainfall consist of amount, frequency and intensity, the values of which vary from place to place, day to day, month to month and also year to year. Precise knowledge of these three main characteristics is essential to draft a plan for its full utilization (FAO). As the most of the precipitation in the study area is in form of rainfall, in what follows the research will focuse merely on the assessments of rainfall.

2.2.1 Rainfall stations

In order to investigate and analyze precipitation in the basin, the rainfall data collected from Iran's Meteorological Organization, Iran's Ministry of Energy and Shiraz University's faculty of agriculture, have been employed. In assessing the rainfall record, the research attempts to make use of the station's information with record of more than 10 years. Therefore, many of existing stations have been disregarded due to lack of adequate data in long time.

2.2.2 Annual rainfall

Annual rainfall is one of the effective and important indexes to determine weather condition and also to calculate balance of water. In this study, annual rainfall is evaluated. At first, data homogeneity is tested through Run Test method then data reconstructed and completed in the base period between 1970-2013. In the table 5 app ((a)) the data related to 50 stations, which is applied for prolonging rainfall record, is presented. The correlation coefficient and number of years for which the data are available is shown in the table as well.

Rainfall data related to the base period in Chamriz, Dashtbal, Mehrabad Ramjerd, Drodzan dam, Shiraz, Neyriz and Horgan stations is completed and doesn’t need any prolongation.

- **Rainfall gradient**

The rainfall gradient in the basin is investigated through annual average rainfall in the 50 selected stations table 6 (app (a)); figure 2 app ((b)) shows variation of annual average rainfall with altitude. Within the study area, beside the height, longitude and latitude are of especial importance, as well. Thus, in order to calculate rainfall gradient, each of three parameters of height, longitude, and latitude should be taken to account at the same time.

According to studies, it is necessary to consider two separate gradients in the basin to evaluate rainfall variation along with height, longitudes, and latitudes.

The relationship between height, longitudes, and latitudes for the entire basin, other than the northern part, is as the following:

Equation (2-3) $$P = 9.487E\text{-}5X + 0.001Y + 0.075H - 3122.695$$

In this equation, P represents average annual rainfall in the base period (millimeters), H represents height (meter), X and Y represent longitudes and latitudes (UTM).

The second gradient is related to the northeast part of the basin, including Dehbid, Ghaderabad- Madar soliman and Namdan. This gradient is calculated as the following:

Equation (2-4) $$P = -0.006X - 0.0012Y + 0.45E + 44019.729$$

- **ISO rainfall map and average rainfall in the basin**

Iso rainfall map is the best way to evaluate rainfall distribution and trend in the basin. Iso rainfall map of the basin is presented in figure (2-2). As can be seen in figure (2-2), maximum average annual rainfall in the basin is more than 800 mm in the northwest. The amount of rainfall decreases to 200 mm from the west to the east of basin. With simultaneous assessment of rainfall and topographic (DEM) map, study area can be divided into three parts:

The eastern part of the basin which (2000-3500 m) has low average rainfall in spite of high height (mostly 200-400 mm).

The second part including northwest of the basin with high height (2,000-3,500 m) shows high average rainfall (mostly 400-800 mm).

The third part includes part of the southwest with relative height of 1500-2500 mm; (mostly 400-600 mm).

Given the relationship found when exploring rainfall gradient and considering the reverse relationship between rainfall and longitudes and latitudes, the low amount of rainfall in the eastern part of basin is understandable. This is mostly because of higher longitudes and approximity of this area to the kavir (desert).

Based on the rainfall gradient effect of longitudes is 12.3 times of latitudes, that's why the difference of rainfall between the east and west is higher than the difference between the north and south of basin. The average rainfall measured through Iso rainfall map in all of the study areas and subbasins are separately calculated for plains and heights and presented respectively in tables 7 and 8 app ((a)). In general, rainfall in the heights is more that plains. The comparative result of calculated rainfall in the plains and heights of basin shows that the lowest amount of rainfall is related to the plains in the south such as Neyriz, Abadetashk, Kheir, South of Tashk lake and Tangehana Pichakan and then Namdan and Dehbid areas which are located in the northeas. The highest amount of rainfall is related to the Dozkord Kamphirouz and Bakan in the southwest.

- **Representative rainfall stations**

In study area some stations are selected as representative rainfall stations. This selection is based on the rainfall map and rainfall stations network. The selected stations represent the surrounding area, covering a total surface of the basin. In this basin 24 stations selected as representative stations, which are presented in table (2-2).

- **The annual rainfall regime**

One application of the annual rainfall record is related to determine drought and wet periods. Since the annual rainfall shows fluctuations in different years, the best way to determine drought and wet period is to use the moving average technique. In this investigation, a three-year moving average of annual rainfall in representative stations was calculated. Figures (2-3) to (2-5) display annual rainfall variation and moving average of rainfall respectively in the basin (average rainfall in index period), Neyriz station in the Southeast of basin and Chobkhaleh station in the North of basin. The following results were obtained based on this graph: In general, during the base period three drought and wet periods have been occured. Drought periods occurred in 1970-74, 1981-89, 1997-2000, 2006-2013 and wet periods occurred in 1974-80, 1990-97, 2001-2005.

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- **The frequency of annual rainfall**

To assess annual rainfall frequency in the basin, rainfall records of the representative stations in the base period were employed. In drawing frequency curves, the issue of data homogeneity is highly important. This is why at the beginning, statistics homogeneity has been assessed and confirmed through Run Test method, then the best statistical distribution has been calculated by using Smada softwater. Normal, log-normal and gamma were chosen as the best statistical distribution. Frequency curves in representative stations of Abade tashk(as a sample station in the south basin) and Chamriz (sample staion in the north of basin) are presented in figures (2-6) and (2-7). The annual rainfall of representative stations in different return periods is shown in the table 9 (app (a)).

2.2.3 Monthly rainfall

Monthly rainfall is an important parameter in assessing rainfall; monthly rainfall is the best criteria for exploring rainfall history. To investigate rainfall in the study, rainfall parameters including average, minimum, maximum, standard deviation and variation coefficient of rainfall were calculated. The table 10(app (a)) displays rainfall parameters of monthly rainfall. According to the results, rainfall in the basin started from November and continued utill August. The amount of rainfall in another month of year is quite low, so that in summer it almost reachs to zero. January is the rainiest month, while Julay, August and September have rather the lowest amount of rainfall in the basin. In stations located in the south of basin, such as Estahban, Neyriz, Sarvestan, rainfall in less rainy months is more than another parts of basin. This change could also be seen in southern provinces of Iran like Hormozgan. The areas are actually affected by Tropical currents of Indian ocean.

2.2.4 Frequency of storm (IDF curve)

Intensity–duration–frequency (IDF) relationship of rainfall amounts is one of the most commonly used tools in water resources engineering for planning, designing and operating of water resources projects.

Rainfall intensity–duration–frequency IDF curves are graphical representations of the amount of water that falls within a given period of time in catchment areas (Dupont and Allen, 2000). IDF relationship is a mathematical relationship between the rainfall intensity i, the duration d, and the return period T (or, equivalently, the annual frequency of exceedance f typically referred to as 'frequency' only). Indeed the IDF-curves allow for the estimation of the return period of an observed rainfall event or conversely of the rainfall amount corresponding to a given return period for different aggregation times (Koutsoyiannis et al., 1998 ;Koutsoyiannis, 2003). In the study area, IDF curves were drawn at 11 stations for different return periods. Figures 3to13 (app (b)) indicate these curves.

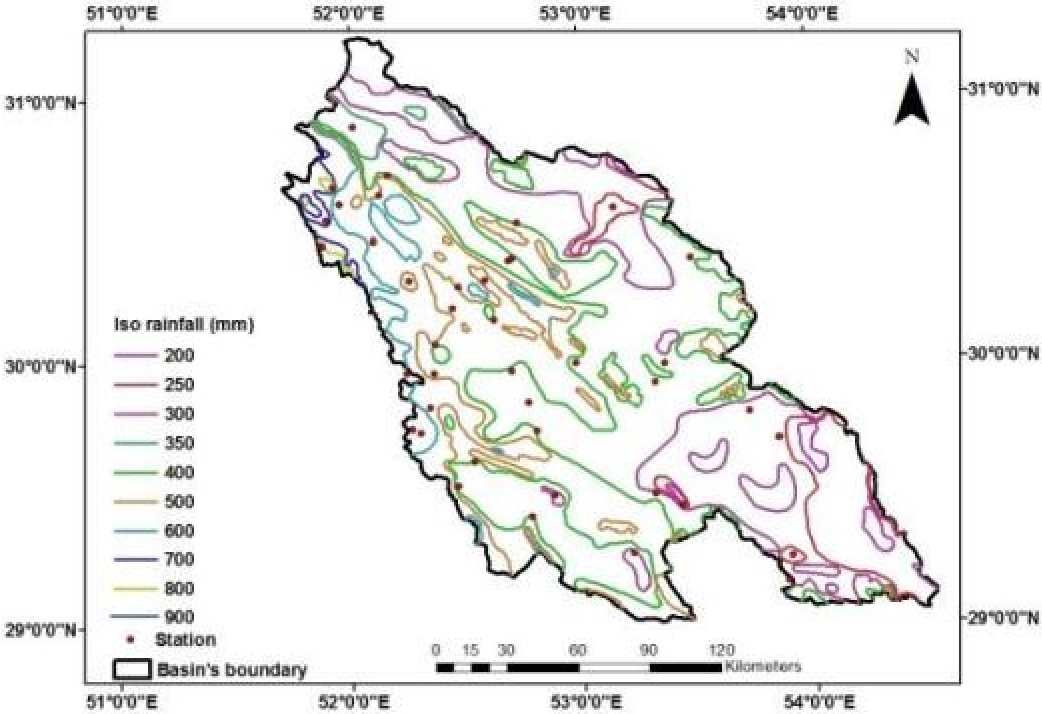

Figure 2-2: ISO rainfall map in the basin

Table 2-2: Representative rainfall stations

Column	Station	Basin	UTM			Foundation year
			altitude (m)	latitude	longitude	
1	Abade Tashk	Abade Tashk	1650	29-48-40	53-43-37	1972
2	Arsanjan	Middle Arsanjan	1663	29-54-40	53-18-24	1972
3	Estahban	Sarab Estahban	1700	29-07-00	54-04-00	1979
4	Polekhan kor	Doshmanziari	1590	29-52-00	52-47-00	1964
5	Jamalbeig(shirin)	Shorshirin	1880	30-36-30	51-57-13	1967
6	Jahanabad Bakhtegan	Abade Tashk	1580	29-43-10	53-51-46	1976
7	Jahanabad Kherameh	Marvdasht-Kheramed	1530	29-33-00	53-23-00	1967
8	Chamriz	Chamriz	1840	30-28-03	52-06-06	1967
9	Chobkhale	Shorshirin	2000	30-32-51	51-53-58	1970
10	Hosseinabad Sarab	Doshmanziari	1680	29-57-53	52-22-05	1972
11	Dashtbal	Sivand	1660	30-00-27	52-58-39	1979
12	Dobaneh	Sarvestan	1490	29-25-14	52-46-56	1971
13	Dehbid	Aiaghloo	2300	30-36-48	53-11-41	1972
14	Dehkade Sefid	Sefid river	2100	30-39-47	52-06-42	1970
15	Drodzan Dam	Polekhan drodzan	1620	30-11-07	52-27-56	1972
16	Sivand	Middle Sivand 1	-	30-10-12	52-51-00	1973
17	Shiraz	Khoshkerod	1500	29-37-48	52-32-01	1972
18	Abbasabad	Chamriz	1700	30-19-05	52-15-17	1967
19	Ghalat	Khoshkerod	2080	29-49-08	52-19-40	1970
20	Kaftar	Shadkam	2315	30-31-00	52-44-00	1980
21	Kohnejan	Sarvestan	1464	29-12-00	52-55-12	1969
22	Madarsoliman	Middle sivand 2	1850	30-11-25	53-10-47	1984
23	Mehrabad Ramjerd	Polekhan Drodzan	1616	29-58-25	52-42-02	1963
24	Neyriz	Neyriz	1620	29-12-00	54-18-58	1964

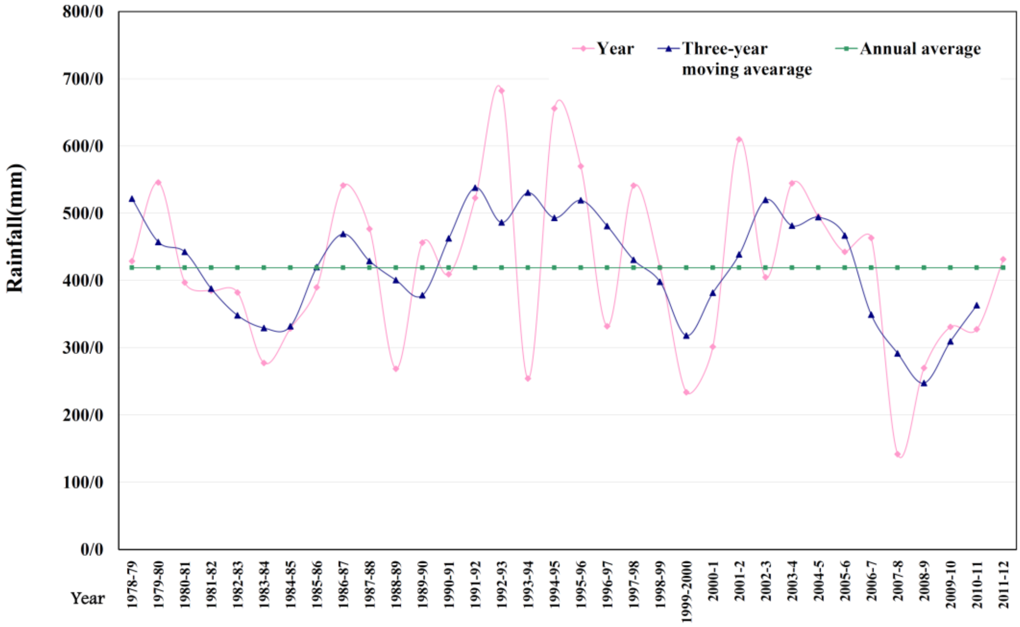

Figure 2-3: Three -year moving average of basin

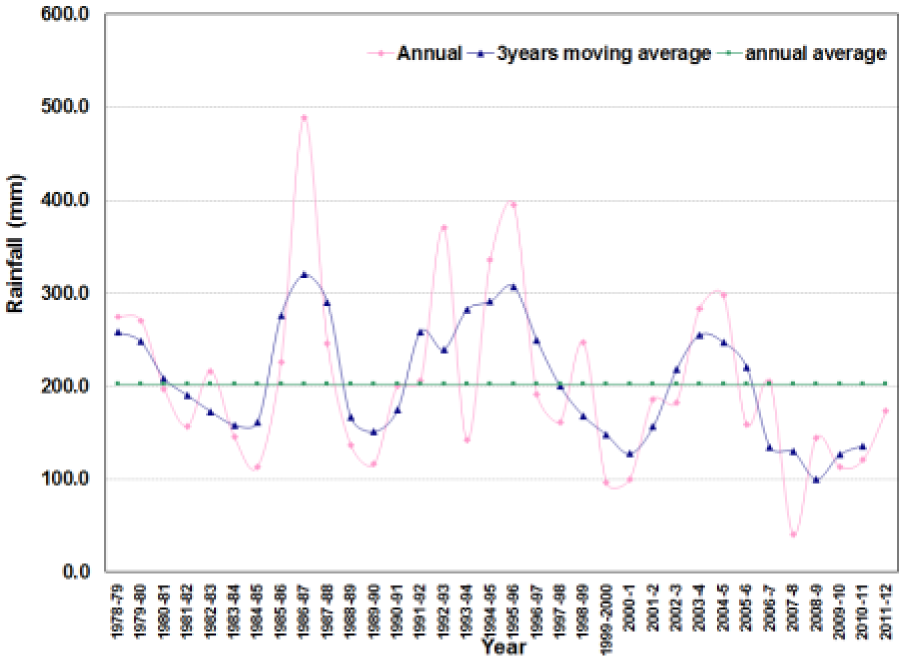

Figure 2-4: Three-year moving average of Neyriz station

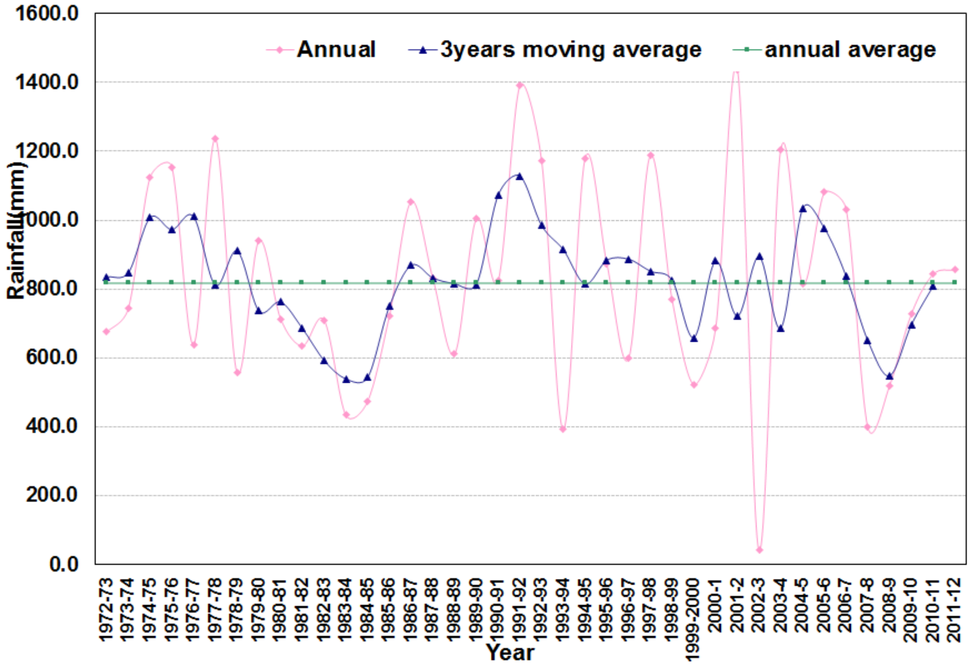

Figure 2-5: Three-year moving average of Chobkhaleh station

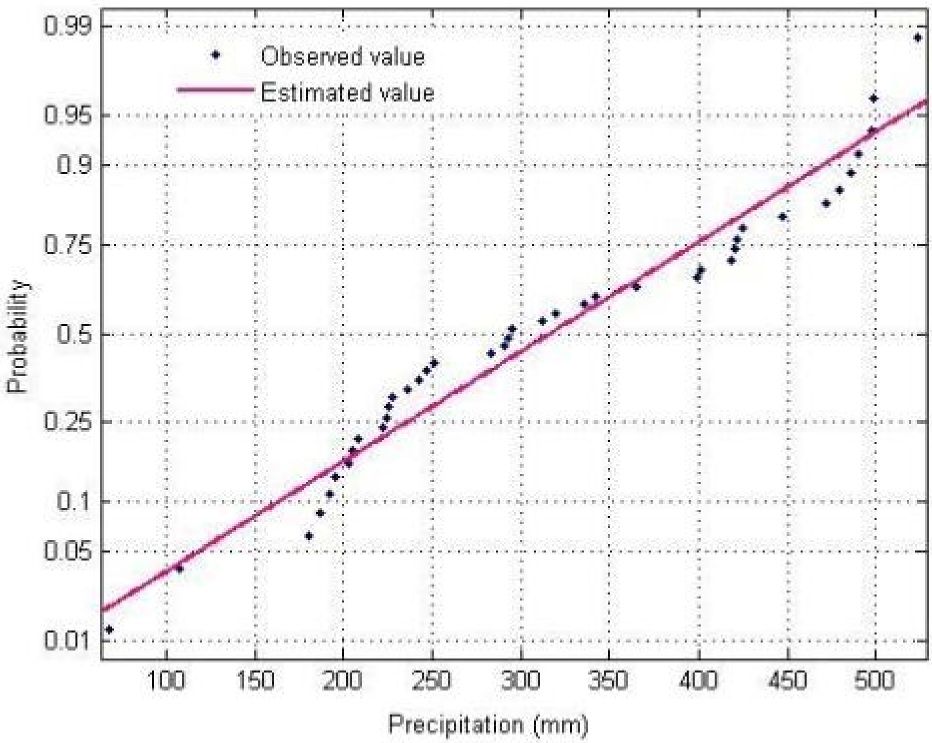

Figure 2-6: Frequency curve of Abade Tashk station

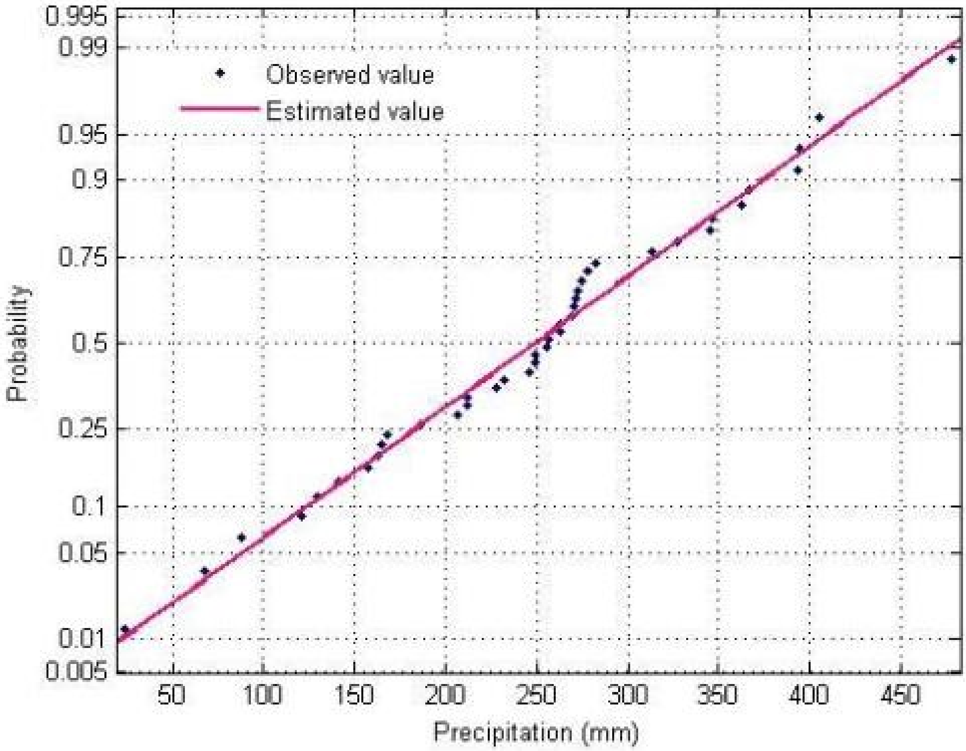

Figure 2-7: Frequency curve of Chamriz station

2.3 Evaporation

Evaporation is an important process in the global water cycle. Evaporation takes place at different locations: from water surfaces, from soil and from plant pores (transpiration). The total evaporation is called "evapotranspiration". Evapotranspiration depends on the air temperature and the amount of water present in the soil. Higher air temperature results in an increase in maximum possible (potential) evaporation. This means that for an increase of actual (real) evaporation, first, there must be enough water present in the soil. Evaporation estimations are needed in a wide array of problems in hydrology, agronomy, forestry and land resources planning, such as water balance computation, irrigation management, river flow forecasting, investigation of lake chemistry, ecosystem modeling and etc. Of all the components of the hydrological cycle, evaporation is perhaps the most difficult to estimate owing to complex interactions between the components of the land-plant-atmosphere system (Singh and Xu, 1997).

Iran is located in arid climat condition, therefore has high rate of evaporation. Total amount of annual rainfall in Iran is 413 billion cubic meters, of that about 296 billion cubic meters

(72%) is evaporated. In order to evaluate evaporation in Tashk-Bakhtegan and Maharlu basin, the statistics recorded by the evaporation stations of the ministry of energy, the faculty of agriculture, the University of Shiraz, and also synoptic stations have been employed. Evaporation stations in the basin are Ahmadabad, Bajgah, Polekhan, Tangeboragh, Jahanabad Bakhtegan, Chambaian, Chamriz, Dashtbal, Dobaneh, Sade, Abasabad, Ghalat, Kafrtar, Kamhar, Koshk, Godzereshk, Madarsoliman, Maron and Mehrabad ramjerd. Records of few stations such as Polekhan, Dashtbal and Maron haven't been used by the study, since they are stations with less than 10 years of record. Synopthic stations include Zarghan, Shiraz and Drodzan dam. To determine the relationship between evaporation-altitude, in addition to stations inside of the basin, the data retrieved from Mazijan station (located in the eastern border of basin) and Roniz (located in the southern boundary) have been applied. Before analysis of data related to evaporation, quality of data in all stations was investigated and for those stations that lacked information, data were reconstructed. Then, monthly average evaporation of stations was investigated and the results were presented in table 12(app (a)). After reconstructing the data, data homogeneity was evaluated by using the Run-Test method, and then statistics in stations was extended for the base period. Extension of the data length was carried out through the base station that has a complete data and also similarity in alttitude. Annual evaporation data is presented in table 13 app ((a)).

2.3.1 Evaporation gradient

Evaluating evaporation gradient done by means of the annual evaporation statistics in base period of 42 years. To identify the relationship between evaporation and altitude, the average evaporation of the base period was used. Given the climatic conditions in the basin, to identify the relationship between evaporation and altitude, the stations were divided into two parts and the relationship for each part was provided individually. The first relationship is related to the north stations and the second relationship is related to the rest of basin. In addition, evaporation gradient for the basin (figure 2-8) and annual evaporation-altitude relationship for each part is presented in figures (2-9and 10).

Evaporation-altitude relationship in the north of basin, based on Kamhar, Sadeh, Chambaian and Mazijan stations, is as the following:

Equation (2-5) $$E = -0.002X - 0.004Y - 0.862E + 18619.75$$

Evaporation-altitude relationship in the rest of basin based on statistics in Jahanabad-Bakhtegan, Bajgah, Tangeboragh, Chamriz, Dobaneh, Roniz, Zarghan, Shiraz, Koshkak, Madar soliman and Ahmadabad Ramjrd is as the following:

Equation (2-6) $E= 0.001X+0.016Y-0.327E-50879.546$

In this formula, E evaporation represents the term millimeters and H altitude represents the term meter.

2.3.2 Iso evaporation map

Iso evaporation map of the basin was prepared through statistics of stations and also evaporation gradient relationship (figure 2-11 evaporation map). The amount of evaporation is higher in the plains and shows a decrease in heights. The average annual evaporation in the basin varies between 1000-2500 millimeters. The maximum evaporation is in the south and southwest of basin and the minimum amount is in the west and northwest of basin (upstream of the Kor river basin). As mentioned earlier, the study area is divided into northern and south parts through simultaneous reviewing of evaporation curves and topography. Average evaporation in the northern part with the altitude of more than 2500 meters is over 600-2200 millimeters, while in the southern part with altitude of less than 2500 mm; average evaporation is 1000-3500 millimeters.

This classification matches with temperature classification so that in the north of basin with lower temperature, there is lower rate of evaporation. Evaporation in each area of study was calculated for plain and height through evaporation-altitude relationship and also average altitude table 14 (app (a)). According to results which presented in the table 14 (app (a)), the highest evaporation can be seen in Shiraz, Gharebagh, Goshnegan and Kavar Maharlu which located in the southwest of basin and the lowest evaporation can be seen in Bakan in the north of basin. As indicated in the table table 14 (app (a)), the highest and lowest amount of heights evaporation belonged to the south of Tashk lake and Bakan with 2657.1 and 1380.8 millimeters respectively and the highest and lowest amount of plains is related to Khanekat and Bakan with 2766.4 and 1577.2 millimeters respectively.

2.3.3 Representative evaporation stations

Representative evaporation stations were selected in the basin by reviewing evaporation stations' location. In Tashk-Bakhtegan and Maharlu Lakes basin, there are totally 20 evaporation stations among which several stations are closed or lack enough statistics. These stations don’t cover the whole of the basin. In north of the basin, number of the evaporation stations aren't enough and that is why Mazijan station, situated in proximity to the basin, is designated to calculate the evaporation gradient. There is also shortage of stations in the south of basin and this is why Roniz station, located out of basin, is selected to evaluate evaporation. Thus, based on the available data, 8 stations have been selected as representative stations whose charctrestics are presented in table (2-3). These stations include Jahanabad-Bakhtegan, Madarsoliman, Kaftar, Mehrabadramjerd, Chamriz, Dobaneh, Koshk and Shiraz.

2.3.4 Evaporation from free water surface and evaporation potentiality

Evaporation is the primary process of water transfer in the hydrogical cycle. The water is tranformed into vapour and transported of to the sky.

The evaporation plus transpiration from a vegetated surface with unlimited water supply is known as potential evaporation or potential evapotranspiration (PE) and it constitutes the maximum possible rate due to the prevailing meteorological conditions. Thus, PE is the maximum value of the actual evaporation (Et): PE = Et when water supply is unlimited.

Actual evaporation is the amount of water which is evaporated a normal day. It means that if for instance the soil runs out of water, the actual evaporation is the amount of water which has been evaporated, not the amount of water which could have been evaporated if the soil had had an infinite amount of water to evaporate. Because of the variability of region and seasons, water managers who are responsible for planning and adjudicating the distribution of water resources need to have a thorough understanding of the evapotranspiration process and knowledge about the spatial and temporal rates of evapotranspiration.

There are many different ways of measuring evaporation. One of the most common methods is to use the irrigated lysimeter. Other ones are the use of an atmometer and the standardised US Class A pan. There are a lot of standardized pans for measuring evaporation and the US Class A pan is probably used alot. The water level is measured every day. This measurement indicates the difference between the present level and the initial level of water in the pan. If the water level in the pan is measured, the amount of water existing in the pan will be specified. Due to that, the sun hits the sides of the pan and consequenctly the temperature gets higher that means the evaporation gets higher than the actual evaporation. To correct this value, evaporation value from the pan multiplies with a coefficient, called pan coefficient, that depends on the climate region and different months of year (Ward & Robinson, 1999). This coefficient for tropical area varies between 0.55-0.75 and in the cold climate varies between 0.65-0.90. This amount for study area is on average 0.7. In the table 15(app (a)) evaporation in the plains and heights of the areas of study is presented. According to obtained result, maximum evaporation is occurred in Shiraz, Gharebagh, Goshnegan and Kavar Mahrlu in the south of basin and minimum amount of evaporation is related to Bakan in north of basin. In the area without evaporation station, evaporation could be calculated with potential evapotranspiration. Evapotranspiration of representative stations calculated with different methods which described as below:

- **The Hargreaves- Samani method**

In this method, potential evapotranspiration is calculated using the following

Formula:

Equation (2-7) $ETp=0.0023\ Ra\ (T+17.8)\ TR\ 0.5$

Where ETp represents potential evapotranspiration (mm/day), T means temperature (degrees Celsius), TR represents the difference between the maximum and minimum average temperature (centigrad) and Ra indicates the amount of radiation (mm) per day which reachs to the atmosphere.

- **Shiraz university methods**

In methods applied by the Shiraz University, values of potential evapotranspiration is calculated by using monthly temperature, station elevation and atmospheric radiation and based on below formulas:

Equation (2-8) first method $ETp = e-7.38 \times Ra1.11\times TR0.38\times (T+25)\ 1.32$

Equation (2-9) second $ETp= e-7.9506\times Ra \times (T+25)\ 1.683\times (El+25)\ 0.072$

In above formulas, ETp represents potential evapotranspiration rate (in millimeters per day), T represents average monthly temprature (in degree centigrad), TR shows difference between the maximum and minimum temperature (in degree centigrade), Ra indicates amount of radiation (in millimeters per day) which reaches to atmosphere and El shows station’s elevation above the sea level (in meters).

- **Pan method**

In this method, potential evapotranspiration multiplies evaporation value from the pan with a coefficient using the following formula:

Equation (2-10) $ETp = Kp \times Ep$

ETp potential evapotranspiration (mm per month) and Kp correction coefficient.

The result of calculated potential evapotranspiration with mentioned methods is presented in the tables 16 to 23(app (a)).

In pan evaporation method, potential evapotranspiration is calculated through multiple coefficients to evaporation of the pan, it should also be noticed that constant coefficient cause error in the data. In Hargreaves-Samani and Shiraz university methodes, reults of caclulated potential evapotranspiration are closer together.

The data obtained with these methods show less difference with monthly data of stations. So that potential evapotranspiration which obtained using these methods (Shiraz University and Hargreaves-Samani) was considered as a potential evapotranspiration in representative stations.

Actual evapotranspiration was calculated in representative stations using Torrent White method, this method was developed for the first time in east of the US and monthly mean temperature was just used to determine potential evapotranspiration. Torrent White relationship is the following: (Safavi, 2009)

Equation (2-11) $\mathrm{ET_P} = \mathrm{L_a}\left(\frac{10\mathrm{T_a}}{\mathrm{I_t}}\right)1^{\mathrm{a}}$

$\mathrm{ET_P}$ is the monthly potential evapotranspiration(cm), $\mathrm{L_a}$ is modifying coefficient for number of light hours and month numbers depending on geographical width, T is the monthly temperature based on °C, $\mathrm{I_t}$ is sun of 12 month thermal indexes and thermal index is

$$i = (\frac{\overline{T_a}}{5})^{1.514}$$

a: empirical constant obtained from following relationship:

$a = 6.75 \times 10^{-7} I_T^3 - 7.71 \times 10^{-5} I_t^2 + 1.792 \times 10^{-2} I_t + 0.4924$

In Torrent White method, the main hypothesis is that there is a fine correlation among temperature, solar radiations, air humidity, and wind, so just temperature is used to determine evapotranspiration (Safavi et al, 2015). The results of actual evapotranspiration are presented in the tables 16 to 23 (app (a)).

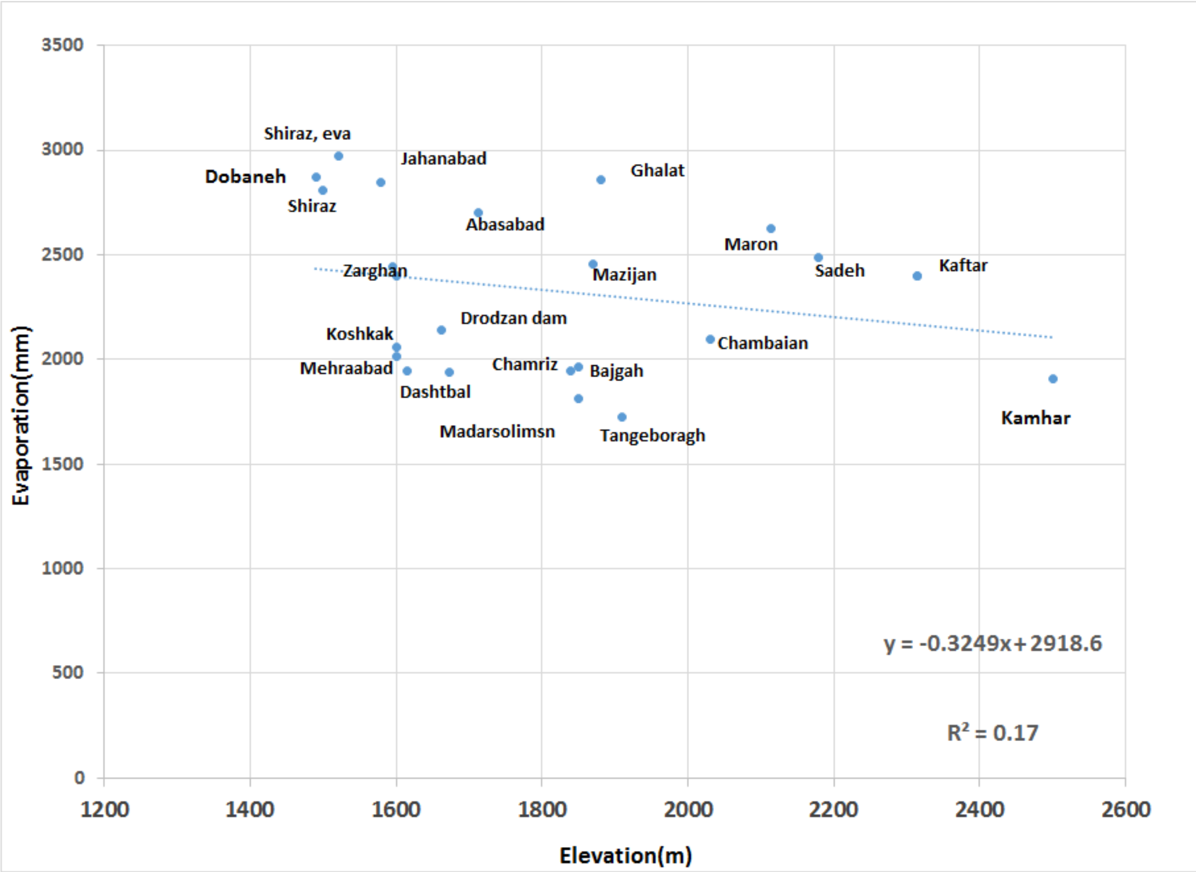

Figure 2-8: Evaporation gradient with elevation in whole of the basin

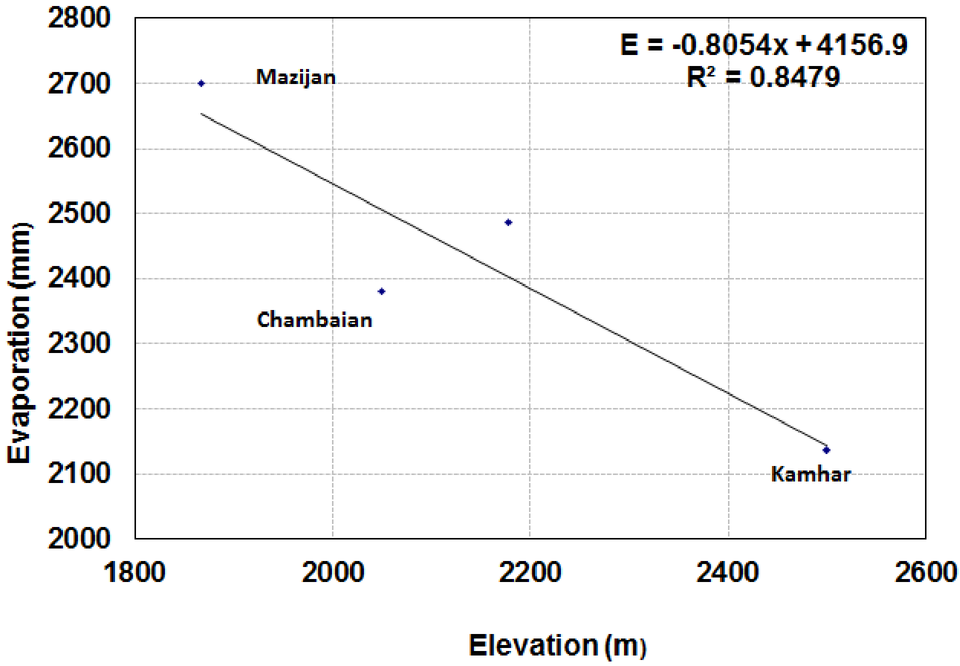

Figure 2-9: Evaporation gradient for north of the basin

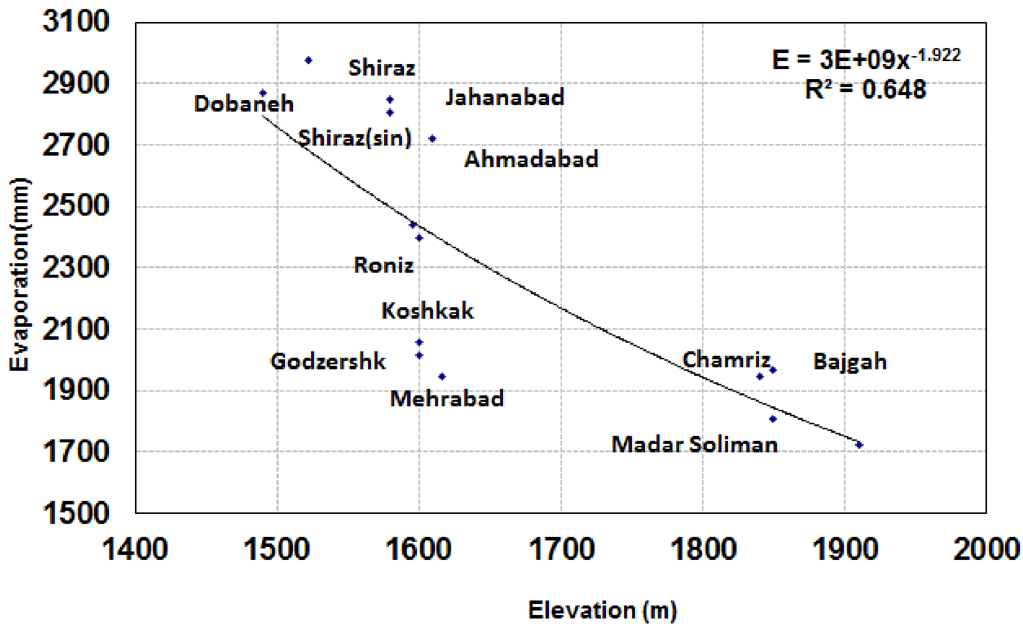

Figure 2-10: Evaporation gradient for rest of the basin

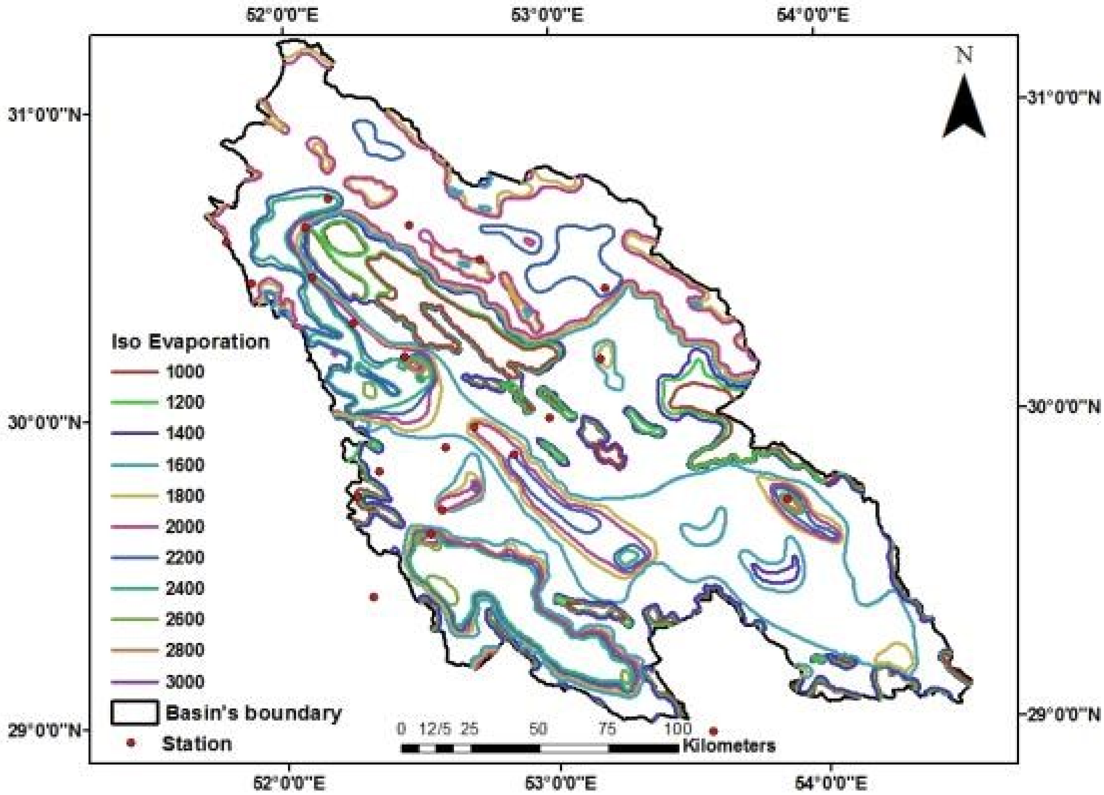

Figure 2-11: ISO evaporation map in the basin

Table 2-3: Representative stations in the basin

Column	Station	Basin	Geographic information			Foundation year	Available statistic
			Longitute	Latitute	Heigh(m)		
1	Jahanabad Bakhtegan	Abade Tashk	53-51-46	29-43-10	1580	1976	30
2	Chamriz	Chamriz	52-06-06	30-28-03	1840	1964	39
3	Dobaneh	Sarvestan	52-46-56	29-25-14	1400	1970	35
4	Shiraz	Chenar Rahdar	52-32-01	29-37-48	1500	1971	14
5	Kaftar	Shadkam	52-44-00	30-31-00	2315	1981	22
6	Koshkak	Marvdasht-Kherameh	52-51-00	29-53-00	1600	1975	30
7	Madar soliman	Middle sivand 1	53-10-47	30-11-25	1850	1985	22
8	Mehrabad Ramjerd	Polekhan Drodzan	52-42-02	29-58-25	1616	1962	42

2.4 Climate

Climate changes in two basins are affected by precipitation, temperature and relative humidity that are essentially affected by fronts entering the area.

In general, the amount of precipitation in the basin decreases from the west to the east. The temperature declines from south to north, showing two different trends in south and north of basin. Average annual temperature in the north varies between 6-12 °C and in the south of basin varies between 14-20°C. Figure (2-12) shows different types of climate in the basin. According to this map, semi-dry and dry conditions are prevailing conditions in the basin and the wet condition can only be seen in the small part of the north.

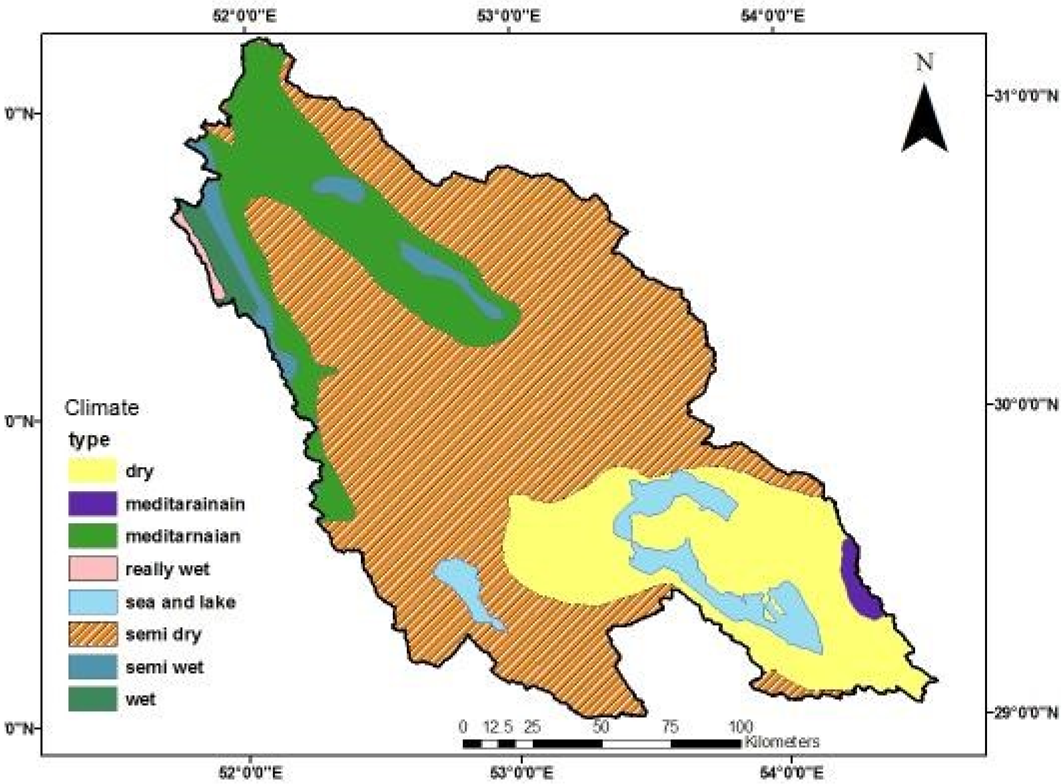

Figure 2-12: Climate types in the basin

3. Surface water

General

Surface runoff is one of the important components of water balance. Surface runoff is determined either through measuring daily and moment runoff in the hydrometric stations or via regional and experimental relationship.

Based on information obtained from the stations (active or closed), surface water flow of parameters including annual and monthly discharg and the frequency of monthly and annually discharge were measured and analyzed in this section. Analysis of the records and information of surface water is of a great importance. Runoff of basins, base and flood flow, input and output volume of water to the areas of study determined in this section, has been applied as initial information in the study of water balance of the basin.

Kor and Sivand rivers are the most important permanent rivers of Tashk-Bakhtegan and Mahrlu lakes basin. These rivers originate from the heights of the north and northwest of the basin that flows in Bakhtegan lake after crossing Polekhan. The main important rivers in the south and southwest of basin are Khoshk and Chenarrahdar. Koshk river originates from northwest of Maharlu lakes basin and during the path receives water from spring and Qanats of Ghasrghomshe. Thus, in wet seasons the river has permanent flows and during dry seasons it is dry in most part of the path. In general, south and southeast of basin has seasonal rivers. Rivers' discharge regime was evaluated by using chart of classe discharge and daily hydrograph in the wet and dry years in the representative stations. Based on this chart, the discharge in the Kor basin is more than Sivand and Maharlu.

3.1 Surface water in the basin

There are 72 hydrometric stations in the basin, of which 52 stations are located on rivers, 11 stations are located on springs, 5 stations are located on drainages and 4 stations are located on lakes. Out of these 72 stations, 45 stations have been closed and currently 27 stations are active. Hydrometric stations' propertis and their positions in the basin are presented in the table 24(app (a)) and figure (3-1). From hydrometric stations, 8 stations have no statistics, 34 stations have statistics less than 10 years, 21 stations have statistics between 10-24 years and 15 stations have statistics more than 25 years.

Kor river is the main river of the basin. This river originates from northwest and north highlands and also forms from several branches that joins together. Sivand river is the most important river inputing into the Kor river. It originates from northern and northeastern heights of the basin, passing through the different plains such as Marvdasht-Kharameh areas and finally flows into Kor river where Polekhan is located.

The branches of this river and the most important hydrometric stations which are located on Kor river includes Dehkadesefid (Gavgodar), Dehkade Sefid (sefid), Jamal beig (Shorkharestan), Jamalbeig (Shirin), Chamriz, Drodzan dam(output), input Drodzan dam, Polekhan (Kor), Menjan, Badamak and Tangeboragh(Kor).

Dehbid, Chambaian, Didegan, Didegan, Ghaderabad, Mashad morghab, Tangeboragh, Tangebolaghi, Rahmat abad and Dashtbal stations are the stations which are located on Sivand river.

The most important stations in Maharlu lake basin includes Chenarsokhte (Nahreazam), Chenarsokhte (Khoshk), Eghbalabad, Polefasa, Chenarrahdar, Aliabad (Paskohak), Aliabad (Maron), Aliabad (Khoshk), Maron (Maron), Maron (Gozdan) and Polesafa. It should be noted that among the above hydrometric stations, some stations closed or have a short period of records.

In order to study the quality and discharge statistics of hydrometric stations, the shortcomings and errors were initially identified and corrected. For this purpose, discharge statistics in terms of homogeneity was evaluated with Run-Test method and non-homogeneity statistics was primarily modified with Double Mass Analysis.

3.2 Representative discharge stations

Given the base period, accuracy of statistics, station’s location and equipment, 12 hydrometric stations were selected as representative station in Tashk-Bakhtegan and Maharlu lakes basin. These stations include Polefsa, Chenarsokhte (Khoshk), Dehkadesefid (Sefid), Tangebolaghi, Dashtbal, Jamalbeig (Shorkharestan), Jamal beig (Shirin), Polekhan (Kor), Chamriz, Drodzandam, Dehkadesefid (Gavgodar) and Chenarsokhte (Nahrazam).

It should be noted that the following points are the determining criteria of representative stations in the area:

- Active stations
- Station equipment
- Statistical discharge period
- Accuracy of information
- Location of stations (input and output of plains, input and output to the dams)

All Stations considered as representative stations were active Dehkadesefid on Gavgodar river (that have statistics until 2003-2004). During the base period, all representative stations have had statistics for more than 20 years and their information showed enough accuracy based on statistics tests. In addition, the representative stations selected to cover whole of basin would also represent the surrounding area. These stations are presentd in the table (3-1).

3.3 Annual discharge

For the purpose of calculating the annual average discharge of stations in the base period (1970-2013), records of stations with more than 10 years of statistics were reconstructed and prolonged through establishing correlation between these stations and representative stations. Annual discharge of stations is presented in table 25(app (a)). Statistical characteristics of representative stations includes minimum, maximum, mean, standard deviation, skewness and coefficient variation of annual discharge in the base period which is presented in table 26 (app (a)).

According to this table, the maximum and minimum annual average discharge of stations in the base period are respectively 29.69 cubic meters per second in Polekhan station on Kor river and 0.41 cubic meters per second in Aliabad station on Khoshk station. The maximum annual discharge in the base period is 96.63 cubic meters per second in Polekhan(Kor) station in 1992 and minimum annual discharge is 0.12 cubic meters per second in Chenarsokhte station in 1977. The minimum standard deviation, variation coefficient and skewness in the base period respectively are 0.41, 0.51 and 0.17 that are related to Chenarsokhte (Nahrazam). As can be seen, the maximum discharge belonges to the Kor river that is the most important river in the basin. The river originated from the mountains in the north of basin that receive more precipitation. Minimum discharge is related to the southwest of basin that has no permanent river and has lower level of precipitation compared to the north of basin. Statistics of annual discharge in stations with records of 10 years and more (except stations on springs and drainage) were reconstructed by using correlation between them and base stations. In table 27 (app (a)) the correlation employed to construct annual discharge is indicated.

3.3.1 The relationship between annual discharge and area of hydrometric stations

In this section the correlation between the stations' annual discharge in the base period and their catchment area is determined. In the studied basin, logarithmic, exponential and linearly relationships associated with the correlation between area and stations' annual discharge in Kor, Sivand and Maharlu basins are evaluated and presented in figures (3-2) to (3-4).

The equation (3-1) shows the best relationship between the catchment area and annual discharge of stations which are located on Kor catchment (before Drodzan dam):

Equation (3-1) Q=0/0067A+1/0368

R=0. 92

N=14

The best relationship obtained between discharge and basin's area of stations located in Sivand's basin (before joining to Kor river) is as follows:

Equation (3-2) Q=0/0005A1/0125

R=0.86

N=9

In the Maharlu basin (Khosk river), the best relationship between basin' area and annual discharge of hydrometric stations which are located in this basin is as follows:

Equation (3-3) Q=0/4912 Ln A-1.511

R=0.92

N=11

In this formula, Q indicates the annual discharge in cubic meters per second, basin area is calculated in square kilometers, r shows correlation coefficient and n represents the number of data.

3.3.2 Annual discharge in the basins without data

Different methods were used to estimate annual discharge in the basins without statistics. To calculate the runoff of rainfall in stations, flood discharge and base flow was seprated and the relationship between the annual flood, area and precipitation is determined. This relationship for stations which are located on Kor river (before Drodzan dam) is as follows:

Equation (3-4) $Q = 1.03 \times 10^{-9} \times A1.1 \times P2.26$

$R = 0.92$

$N = 8$

As for hydrometric stations that are located on Sivand river (before joining to the Kor river), the relationship is the following equation:

Equation (3-5) $Q = 1.5 \times 10^{-10} \times A1.02 \times P2.46$

$R = 0.99$

$$N = 3$$

As for stations with no statistics in Maharlu lake basin (Khoshk river), the following relationship is obtained:

Equation (3-6)

$$Q = 1.13 \times 10^{-9} \times A0.96 \times P2.37$$

$$R = 0.99$$

$$N = 4$$

In presented equations, Q is annual flood (cubic meters per second), A is basin area (square Kilometers) and P is annual precipitation during the base period (millimeters).

Another relationship which is used to calculate runoff in the basins withouth statistics is Justin method. Justion equation is as follows:

Equation (3-7)

$$R = KS^{0.155} \frac{P^2}{1.8T + 32}$$

$$S = \frac{H_{max} - H_{min}}{\sqrt{A}}$$

Equation (3-8)

In this formula, R represents annual runoff in cm, K represents Justin coefficient, S represents average slope of basin (calculated from equation (3-8)), P represents annual precipitation in cm and T represents average temperature of basin (°C). Justin formula was calculated for stations located on Kor river (before Drodzan dam), Sivand (before joining to Kor river) and Maharlu basin and findings are presented in tables 28 to 30 (app (a)). Averages K (Justin coefficient) are respectively 0.27, 0.065 and 0.227.

According to the table 31 (app (a)), there is no significant difference between results of Justin method and relationship of area-rainfall and annual discharge. Therefore, the relationship between area-rainfall and annual average has been applied to calculate runoff in the basin with no statistics relevant to water balance calculation.

Annual average discharge parameters in the base period are presented in the table 32 (app (a)). These parameters include annual average discharge, specific discharge, average rainfall of basin and their runoff coefficient in the basin. If there is a hydrometric station in the outlet, the statistics of the station will be used in order to calculate the annual average discharge of basin. In the basins that have the hydrometric station near the outlet, the annual average discharge of that station is evaluated and corrected in proportion to the area of the basin.

Given that, the statistics of below stations were used in order to calculate annual discharge of the different basins:

The statistics of Polefasa station is used for Babahaji basin. The statistics of Dashtbal station's statistics is used for Sivand 1 basin. The Tangebolaghi station's statistics is used for Sivand 2 basin. The statistics of Chambaian station is used for Aiaghlo basin. The statistics of Dehkadesefid (Sefid station) is used for Sefid river basin's. The statistics of Gavgodar station is used for Ablangan basin. The statistics of Maein staion is used for Maien basin. The statistics of Polekhan station is used for Polekhan drodzan. The statistics of Polekhan station is used for Paiabsivand. The statistics of Jahanabad-Kherameh is used for Marvdasht-Kherameh basin. The statistics of Tangeboragh station (Dozkord) is used for Tangeborgh basin. The statistics of Jamalbeig (Shorkharestan) station is used for Shor & Shirin basin. The statistics of Khanmin Station is used for Chamriz basin. The statistics of Drodzan dam outlet is used for Shol basin. The statistics of Chenarsokhte station (Nahrazam) is used for Khoshkerud, and statistics of Chenarrahdar station is used for Chenarrahdar basin.

Annual discharges of basins having no statistics were determined through the relationship of discharge-rainfall and area of basin. Thus, the annual discharge of basins that have no statistics were calculated through the mentioned relationship and presented in the table 32(app (a)).

3.3.3 Changes in mean annual discharge

Changes in mean annual discharge and three-year discharge moving the annual average of representative stations are presented in Figures (3-5) and (3-6) for Polekhan and Chamriz as sample for hydrometric stations. These figures indicate that in general four droughts and also three wet periods are observed in most of the stations.

According to mentioned figures, there has been drought from 1970-71 to 1973-74 and immediately there has been wet period from 1974-75 to 1980-81. The second drought period occurred from 1981-82 to 1990-91 and the second wet period ocurred from 1991-92 to 1998-99. The third drought period started from 1999-2000 to 2001-2002 and the third wet period began from 2001-2002 until 2003-2004. The fourth drought period started from 2004-2005 and continued until 2012-2013. In some station, the above mentioned condition didn't exist so that in Chenarsokhte stations (Khoshk and Nahrazam) the first drought period continued until 1977-78, and in Jamalbeig (Shirin), Polekhan(Kor), Chamriz and Dehkadesefid(Gavgodar) stations the third drought period started from 1977-78.

3.4 Annual discharge frequency

Annual discharge of representative surface flow stations for different return periods of 2, 10, 25, 50, 100, 500 and 1000 years was calculated through fitting statistic distribution including normal, log normal II and III parameters, GamaII parameters, Pearson, Log-Pearson and Gambel (using Smada software). Given the amount of mean deviation, the best fitted distribution was selected and result is presented in table 33(app (a)). Based on the obtained results in Polefasa and Jamalbeig (Shirin) stations, log normal III parameters is the best fitted distribution. In addition, in stations such as Chenarsokhte (khoshk), log-pearson, Dehkadesefid (Sefid and Gavgodar), Tangebolaghi, Dashtbal, Jamalbeig (Shorkharestan), Polekhan (Kor), Chamriz, Drodzandam and Chenarsokhte (Nahrazam) stations, Gama II parameter distribution is considered to be the best fitted distribution. This table also shows mean, standard deviation and coefficient skewness of annual discharge in representative stations. In this table x, Sn-1 and g are respectively, average discharge, standard deviation and coefficient skewness.

According to the results, maximum discharge of 200-year return period is related to Polekhan (Kor) station with 105.6 cubic meters per second and minimum discharge is related to Chenarsokhte (Nahrazam) station with 2.57 cubic meters per second. To determine annual discharge of representative stations in the wet and dry periods with different return periods, annual discharge of hydrometric stations in the base period was fitted with various statistical distributions and annual discharge was fitted with different return period based on the best fitted distribution determined in table 34(app (a)).

In hydrological studies, one of required information is the annual drainage yield with different retun periods in the regions and stations with no data. In order to determine this amount, the below steps have been taken:

A) The basins having statistics were divided into three parts given the different discharge including Kor, Sivand and Maharlu basins. In general discharge of Kor basin was more than Sivand and Sivand's discharge is more than Maharlu (Kor>Sivand>Maharlu).
B) Relationship between annual average discharge (discharge with 2 years return period) and area of the basin were determined in each basin and this relationship is (3-9) to (3-11) respectively for Kor, Sivand and Maharlu basin.

Equation (3-9) $$Q_2 = 0.0067A + 0.9107$$

$$r = 0.927$$

$$n = 11$$

Equation (3-10) $$Q_{2=}0.00009A^{1.2745}$$

$$r = 0.983$$

$$n = 3$$

Equation (3-11) $$Q_2 = 0.0017A + 0.1699$$

$$r = 0.951$$

$$n = 5$$

In the above equations, A is the basin's area (in square kilometers) and Q2 is discharges with 2 years return periods (in cubic meters per seconds).

C) Ratio of discharge with different return periods to discharge of 2 years return period was determined and their average was calculated for Kor, Sivand and Maharlu basins table 35 (app (a)).

3.5 Monthly discharge

Monthly and seasonal average discharge changes: monthly and seasonal average discharge is presented in table36 (app (a)) in the form of %age of annual discharge.

According to the table of results, March is the wettest month at Polefasa, Chenarsokhte (Khosk), Tangebolaghi, Dashtbal, Chamriz, Dehkdesefid (Gvgodar) and Chenarsokhte (Nahrazam). This is mainly due to precipitation and melting snow in this month, at Plokhan (Kor) and Drodzan dam stations. The lattest, however, is under the influence of the role curves and also upstream basin.

The driest month of year (low water) are July-August and September at Polefasa, Chenarsokhte (Khoshk), Tangebolaghi, Dashtbal and Chenarsokhte (Nahrazam).

At Dehkadesefid (Sefid), Jamalbeig (Shorkharestan), Jamalbeig (Shirin), Chamriz and Dehkadesefid (Gavgodar) the driest months are August-September and October. At Polekhan (Kor) and Drodzandam stations the driest months start from October and continue until December.

At hidrological stations, other than Jamalbeig (Shirin) station and Drodzan, winter is the wettest season of the year. At these two stations, spring is the wettest season because of melting snow in highlands. Drodzandam station is also affected by Drodzan dam in winter, water is saved on dam reservoir and in spring it is relased because of filling dam and demand of downstream to water for agriculture. The driest (low water) month is summer in the representative stations other than Polekhan (Kor) and Drodzandam. Polekhan (Kor) is located in downstream of Drodzandam and also affected by dam. Thus, fall is the direst season at Polekahn (Kor) and Drodzandam stations.

3.6 Hydrograph and classified discharge (Classification curve)

To evaluate the rivers discharge regime, classified discharge graph and daily hydrograph of wet, average and dry years in the representative stations were explored and results are presented in figures (3-7) and (3-8) repestively for Polekhan and Chamriz stations, for rest of representative hydrometric stations graphs show in figures 23 to 33 (app(b)) . Specific discharge of 10,30, 60, 90 and 180 days were provided by using classified discharge graphs for wet, average and dry years and is shown in the table 37(app(a)).

In this table, in addition to mentioned data, information related to the base and flood flow of wet, average and dry years are presented. In order to calculate base and flood low, the daily discharge of hydrometric stations was used. For this purpose, minimum monthly discharge was considered as a monthly base flow. Given this table, the maximum specific discharge in dry year is 90 and 180 days and the base flow is related to Chamriz station. The maximum specific

discharge is 10, 30 and 60 days and flood flow is related to the Polekhan (Kor) station. Morever, in the average and wet years, the maximum specific discharge and also base and flood flow is related to the Polekhan (Kor) station.

In wet year, the minimum specific discharge is 10, 30, 60 and 90 days and also base flow is related to the Chenarsokhte (Nahrazam). Other discharges are related to the Chenarsokhte (Koshk) station. In average and dry year, the minimum specific discharge for all periods (10, 30, 60, 90 and 180 days) as well as the base and flood flow is related to the Chenarsokhte (Khoshk) station.

With comparing the base and flood flow in hydrometric stations, in general the average base and flood flow of Kor basin is more than Sivand basin and Sivand is more than Maharlu basin (Kor> Sivand> Maharlu).

3.7 Streams

Investigating streams of study basin shows that the most floods have occurred in December to April. Basin's stream is mainly due to rainfall and in March and April, it is affected by snow melting.

Evaluation statistical of momental discharge**:** among hydrometric stations, 34 stations had statistics for less than 15 years and 13 stations had momental discharge stations for more than 15 years. Given this available statistics, the maximum momental and maximum daily discharge was investigated and their homogeneity was controlled by using Run-Test method. The results are presented in the table 38 (app (a)), based on which 13 stations were chosen as a representative station. The representative stations have adequate (at least 15 years) and homogeneous statistics and they were selected to cover whole of Mahrlu-Bakhtegan basin.

To complete the maximum momental discharge in the years without statistics either of below methods is applied:

A) The correlation between the maximum momental and daily discharge at the same station is employed table 39(app (a)).

B) The correlation between the maximum momental discharges of stations without data with adjacent stations is employed table 40(app (a)). In table 41(app (a)), the maximum momental discharge of representative stations and the reconstructed data by using mentioned relationship are presented.

3.7.1 Flood frequency

Study of the momental maximum discharge of hydrometric stations in the basin shows that the longest statistical period is related to the Chamriz station which is located in the northwest of basin. Investigating the statistics shows that in most part of the basin (especially in the south and southeast) there aren't any hydrometrics stations or they have statistics for less than 5 years. The assessment of maximum momental discharge of hydrometric stations in the base period shows that the maximum amount belonges to Polekhan (Kor) station with more than 2000 cubic meters per second discharge.

The maximum momental discharge was fitted with different statistical distribution including normal, log-normal II and III parameters, gamma II parameter, pearson and log pearson (by using Smada statistical software) and considering the amount of mean deviation, the best fitted distribution is selected.

According to that, at Chenarsokhte (Nahrazam), Dashtbal, Polekhan (Kor), Rahmatabad and Tangebolaghi log-normal II parameters, at Dehkadesefid (Sefid), Dehkadesefid (Gavgodar), Chenarsokhte (Khoshk), Jamalbeig (Shorkharestan) and Jamalbeig (Shirin) gama II parameters, at Chenarrahdar and Chamriz stations log-pearson and at Tangeboragh (Kor), Gambel were the best fitted distribution. Statistical parameters and maximum momental discharge of stations with different return periods are shown in the table 42(app (a)).

Estimating the maximum momental discharge with different return periods is one of important required data in hydrological studies in the basins without statistics. In order to determine the needed relationship, the following steps are taken:

A) with using the maximum momental discharge of homogeneous stations, the relationship between maximum momental discharges of 100 years return period (Q100) with the area of the hydrometric stations is obtained (3-12). The reason of selecting this return period is that the maximum momental discharge with 100 years return period has the best correlation with the basin area.

Equation (3-12) $Q_{100=6.48A}^{0.6109}$

r=0.83

n=13

In the (3-12) equation, A is the basin area (in square kilometers) and the maximum momental discharge with return period 100 years (in cubic meters per seconds).

B) The ratio of the maximum momental discharge with different return periods to 100 years return period was determined for homogenous stations and calculated their average table 43(app (a)).

C) According to the figure (3-9) the best correlation between achived information in clause (B) and different return periods (T) is determined.

Equation (3-13): $$\frac{Q_T}{Q_{100}} = 1.58\,(T)0.8854$$

$r = 0.99$

In this eqaution QT is the maximum momental discharge with return period T.

With using these relationships, the maximum momental discharge with required return period for the basins without statistics is provided.

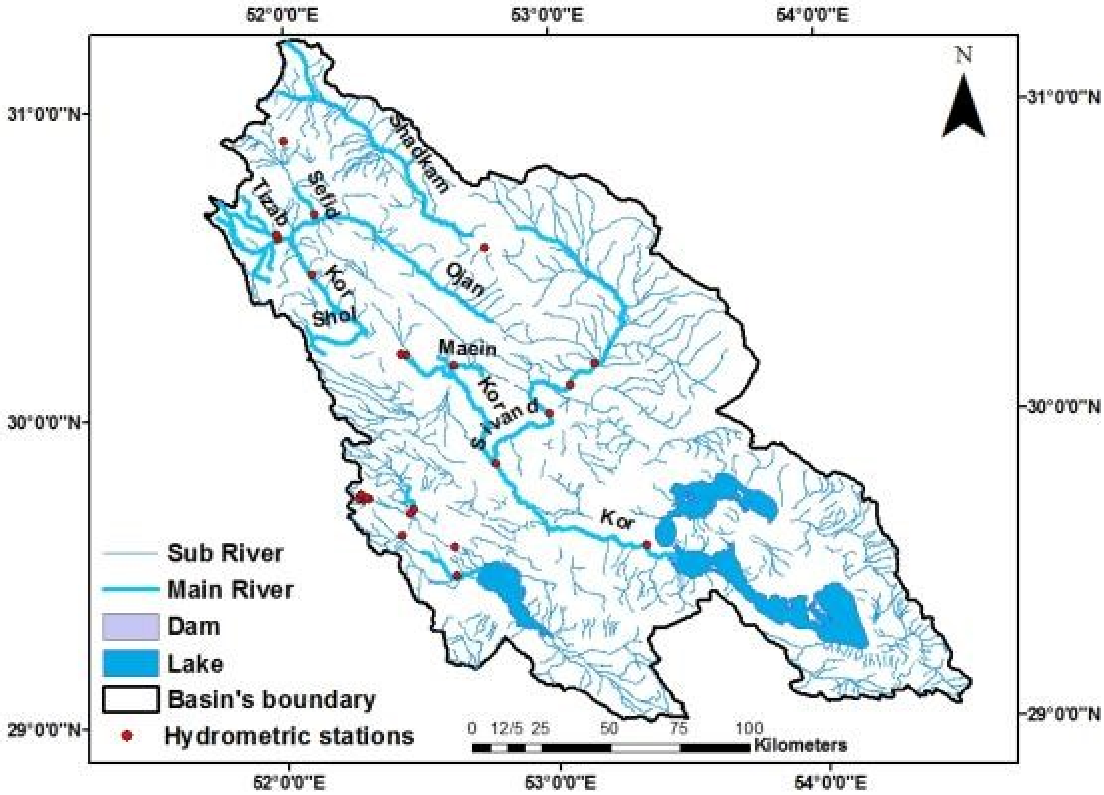

Figure 3-1: Hydrometric stations position in the basin

Table 3-1: Representative stations

Column	River-Station	Geographic information			Available data(year)
		Longitude	Latitude	Height(m)	
1	Babahaji-Polfasa	52-38-08	29-29-12	1476	34
2	Khosk-Chenarsokhte	52-27-31	29-41-30	1650	37
3	Sefid-Dehkadesefid	52-06-41	30-39-52	2100	36
4	Sivand-Tangbolaghi	53-09-14	30-10-02	1820	27
5	Sivand-Dashtbal	52-58-52	30-00-34	1660	43
6	Shorkharestan-Jamalbeig	51-58-06	30-35-54	1900	39
7	Shirin-Jamalbeig	51-58-19	30-35-05	1880	37
8	Kor-polekhan	52-46-15	29-51-19	1590	43
9	KORIchamriz	52-06-05	30-28-00	1840	48
10	Kor-Drodzan dam	52-25-57	30-12-33	1646	29
11	Gavgodar-Dehkade Sefid	52-07-14	30-39-15	2100	31
12	Nahraezam-Chenar Sokhte	52-28-12	29-42-22	1650	38

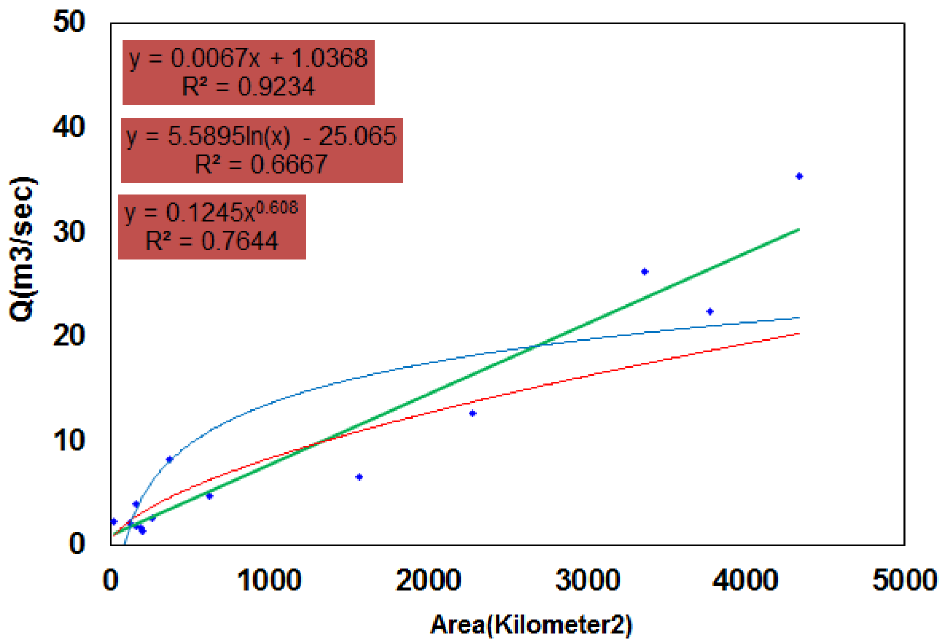

Figure 3-2: Area and annual discharge relation in Kor river basin

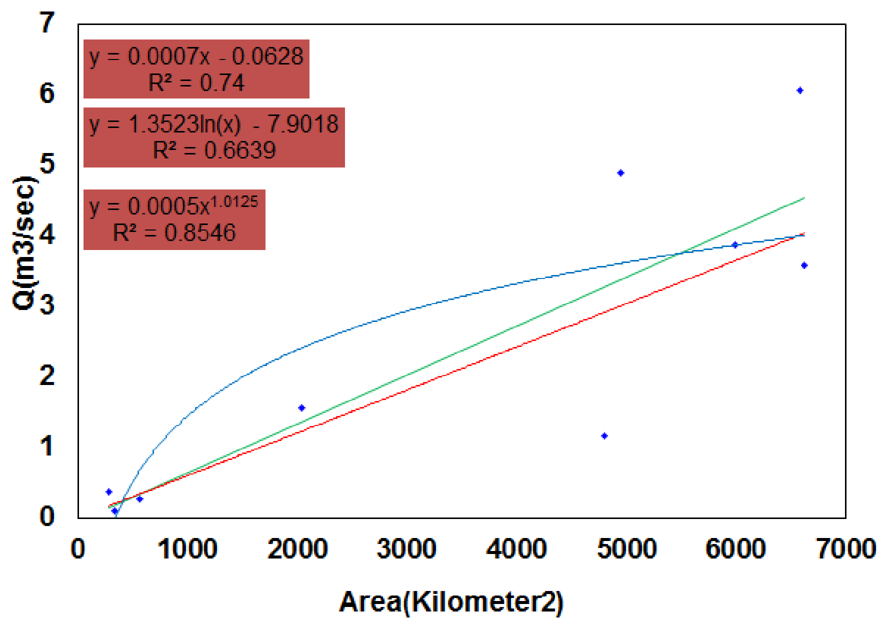

Figure 3-3: Area and annual discharge relation in Sivand river basin

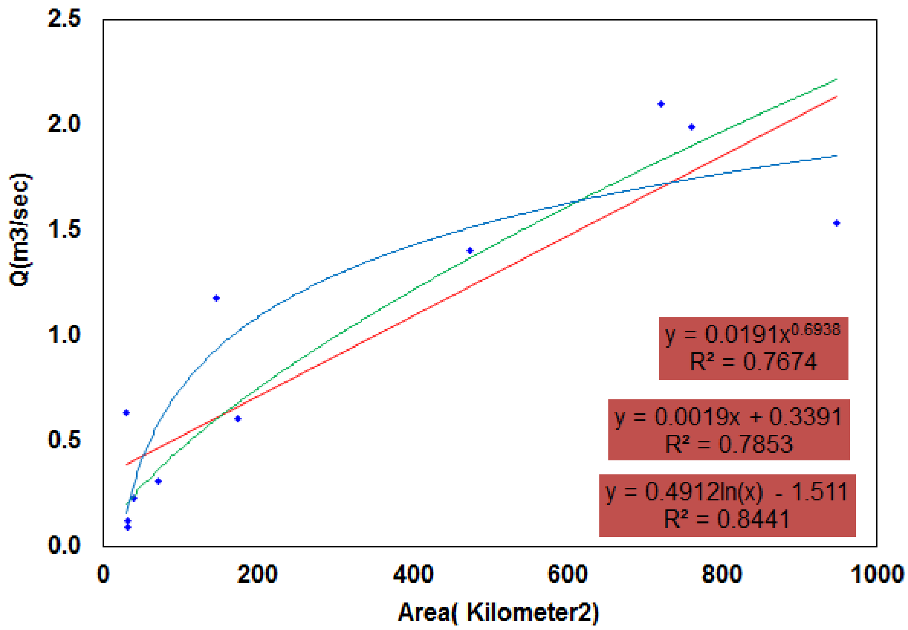

Figure 3-4: Area and annual discharge relation in Khoshk river basin

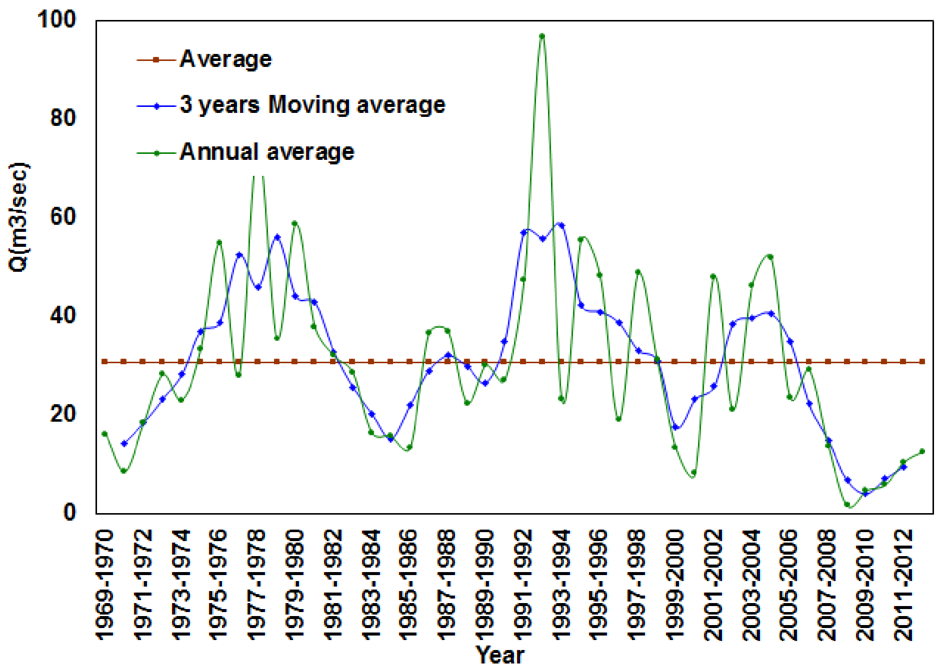

Figure 3-5: Moving average in Polekhan station

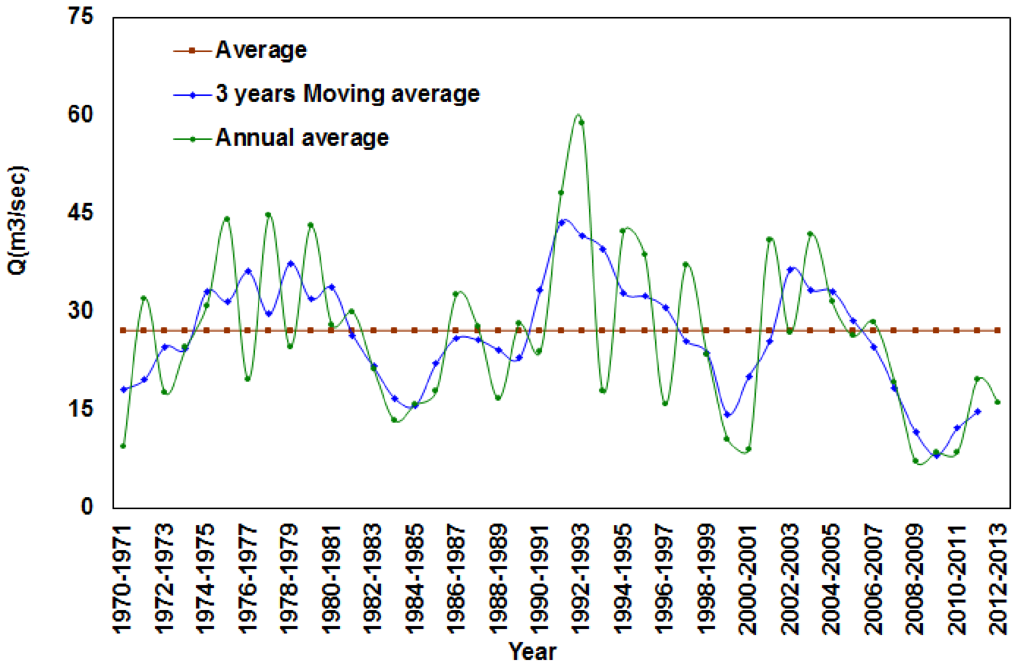

Figure 3-6: Moving average in Chamriz station

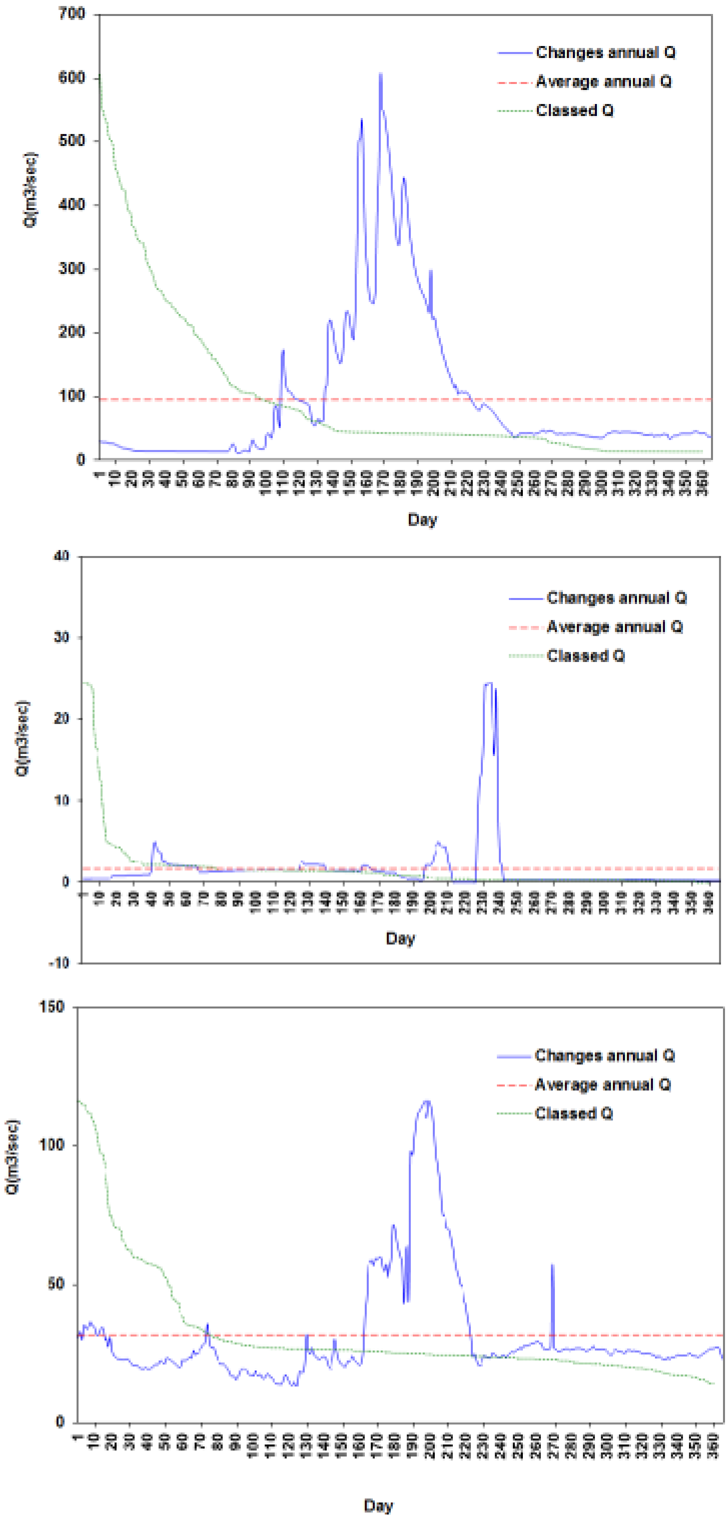

Figure 3-7: Changes in annual discharge and discharge classed curve at Polekhan station respectively for wet, dry and average years

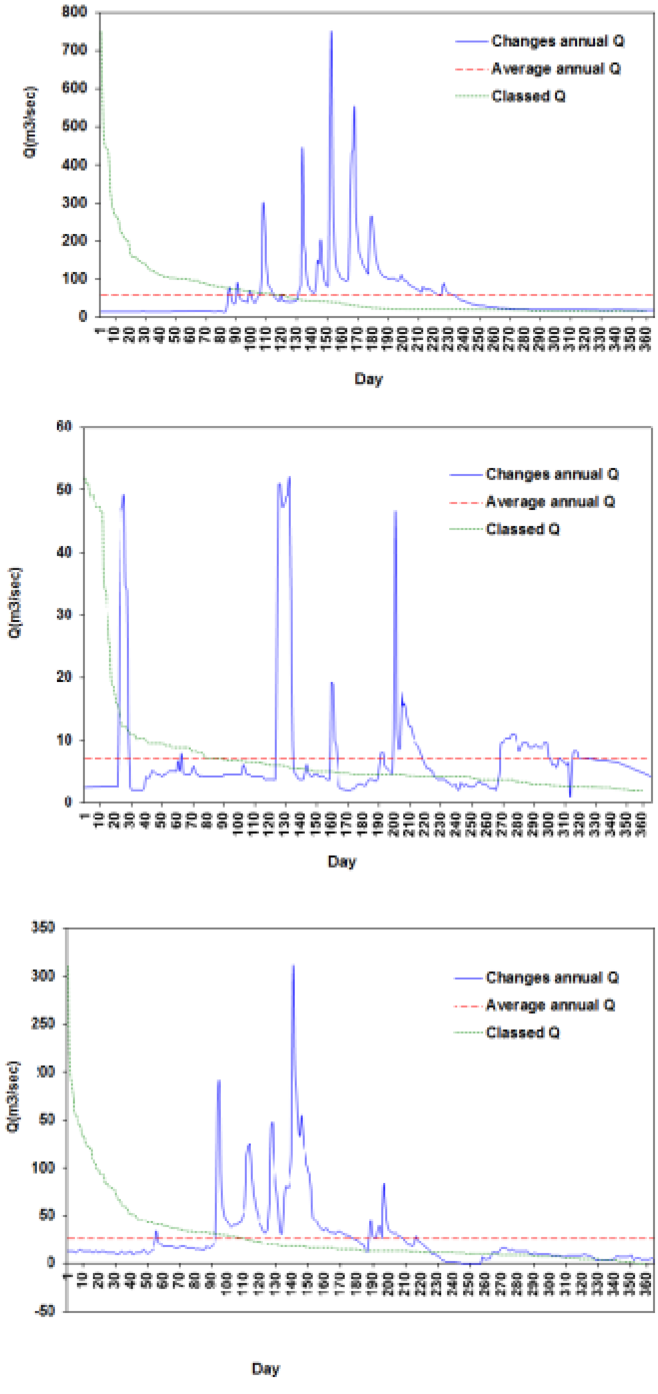

Figure 3-8: Changes in annual discharge and discharge classed curve at Chamriz station respectively for wet, dry and average years

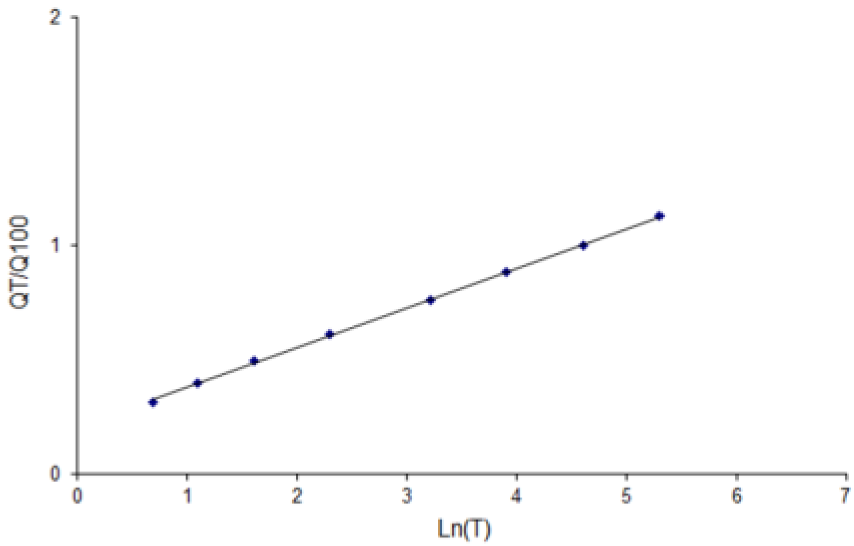

Figure 3-9: Flood correlation chart with return period of T and 100 years

4. Ground water

General information

Groundwater plays an important role in sustainable development of human society. In most regions of the country, except the northern and western regions, permanent surface water flow is very limited and due to the effect of saline geological formations (especially in the south of Iran), most of the river don't have a good quality. Therefore, since many years ago ground water has been used for different purposes such as drinking, agriculture, and industry. Actually, Iranians' interest in groundwater exploitation goes back to more than 2,500 years, when the "Qanat" system was developed that is still underway until now (English 1968; Beekman et al. 1999). In Iran, rapid growth of population and low irrigation efficiency in the agricultural sector have increased the demand for groundwater resources. Due to easy access and use of groundwater, exploitation of groundwater has been increasing dramatically in recent years and in most parts of the country. Thus, Iran will expose to crisis in near future, if this trend continues. There are several factors that affects on increasing groundwater resources' crisis, the most important of which are the followings (Assadolahi, 2009):

- Drought (decrease precipitation and increase average temperature).
- Population growth and agricultural development.

- Excess of water withdrawal from permitted water wells.
- Water withdrawal from unpermitted wells.
- Improper use of groundwater resources.
- Pollution through industrial activities and houses sewage.
- Limitation and difficulties in carrying out water rules and regulation.

Mahrlu-Bakhtegan lakes basin located in the south of Iran has been facing water shortage and declining in groundwater level during last decad. According to the unit aquifer hydrograph, groundwater level has been dropping in all field studies.

In the basin, the first area of study which enforeced prohibition of water withdrawal was Neyriz in 1983. In order to strengthen alluvial aquifers, artificial recharge projects were implemented at plains like Kharameh, Estahban, Sarvestan, Neyriz Arsanjan and Dehbid. In most of the study area, the basin's groundwater is the main source to provide water for different purposes such as agriculture, industry and drinking. Kor and Sivand rivers are only permanent rivers in the basin and they flow only in some parts of basin and they supply part of the water demand. In the study areas, similar to other parts of country, over-exploitation of water more than aquifers potential caused exploitation of prohibited water and prevailing the critical condition in some plains. Effective use of available groundwater resources needs precise knowledge of alluvial aquifers and hard rock reservoirs in term of quality and quantity. Realization of this depends on accurate and sufficient statistics of all water resources and also constant control.

Tashk-Bakhtegan and Maharlu Lakes basin have 27 studies areas, all of which has alluvial aquifer. The exploitation of alluvial aquifers in the basin was equal to 4018.784 (MCM) in the water year 2012-2013 which this amount increased 32 % compare to water year 2000-2001(2810 MCM). Out of this amount, 3441.30 (MCM) (85.63%) was withdrawal from alluvial wells and respectively 224.62 and 352.86 MCM (5.6 and 8.8%) were withdrawal from Quants and springs. Marvdasht-Kherameh study area, with 3941square kilometers is the vastest area in the basin. In this study area, overall 866.23 MCM was extracted from alluvial aquifer that is considered the highest rate of extraction. Then,the most volume of groundwater withdrawal belonges to the Beiza-Zarghan and Namdan. Hard rock formation especially carbonate formation has an adequate expansion in the basin and considerable volume of water supplies from these formations.

The expansion of carbonate rock in the basin is about 9053.11 square kilometer, of which approximately 65.27 % consists of the hard rock formation. In the basin, the entire withdrawal from hard rock formation until the end of 2013 was about 856.66 MCM, of which 416.84 MCM (48.16%) wells, 78.57 MCM (9.1 %) Qanats and 370.21 MCM (42.77%) were supplied from springs.

4.1 Alluvial aquifer

As mentioned earlier, groundwater resources are the main water supplier in the basin because of limitation of surface water. Alluvial aquifers in the basin are formed enclosed between heights and they mostly formed in the northwest to the southeast direction. With comparing the rate of exploitation from the alluvial aquifer (4018.78 cubic million meters) and hard rock formation (865.66 cubic million meters) it becomes clear that the volume of discharge from alluvial aquifer in the basin is 3.9 times more than hard formation which shows significant alluvial aquifer in the basin. In the most of the study areas at the basin, the main part of groundwater supplies with alluvial aquifer and portion of surface water and hard rock formation is negligible (figure 4-1: aquifer boundary in each studies area).

4.1.1 Number of resources and amount of discharge

According to the last census results, there were 12958 deep alluvial wells, 23373 semi deep wells and the total amount of withdrawl from deep and semi deep wells were 3441.30 (MCM) in 2013. Amount of withdrawl from groundwater resources in the basin is shown in the table 44(app (a)).

4.2 Aquifer characteristics

Folded Zagros is formed by long anticlines and deep synclines. Due to tectonic phenomena that regularly have changed the base level of erosion, diverse sediments with different age and thickness deposited in the synclines and low lands and formed alluvial aquifers. (Figure 4-2 shows anticline and syncline distribution map in the basin).

One characteristic of Zagros Folded system is its stepped structure. This structure is under influence of Arabian shield movement and they were formed as result of drowning Zagros folded system beneath Iran’s central part, so that in the junction of two continents Zagros Thrust fault has been formed.

This fault has a northwest-southeast trend and in parallel to that, there are large numbers of thrust faults which are often seen on the southern flank of the anticlines that formed stepped structure. The faults' height decrease from the northeast to southwest and toward the Persian

Gulf. The highest elevation in the Zagros is situated in the western parts of Maharlu-Bakhtegan basin and the lowest elevation is located in the Persian Gulf. This phenomenon also can be seen clearly in the western parts of Mahrlu-Bakhtegan basin, so that in northwest direction ther are flat plains with the clear and distinct difference to each other. For example, after passing through Marvdasht plain via Chahoo defile in Drodzan area Bakan closed plain is located that indeed is considered a developing Polijeh and rising due to tectonic movements. Bakan plain has a higher altitude compared to Marvdasht plain whose surface (Bakan seasonal lake) and groundwater currents are going out via fractures in Sarvak limestone (Dashtak anticline) and the springs in upstream of plain. After Bakan plain and behind of Mahgan defile, Asopas plain is suited with northwest-southeast trend. This plain one of the main branches of Kor river and has a higher altitude compared to the downstream plains. Namdan plain is suited after Asopas heights via Asopas defile. Namdan is a flat plain and precipitation in this plain is collected in the southeastern part in Kaftar lake and in the years with high precipitation overflow currents to Sivand river. Timarghan defile is the last stepped structure in the basin that has a higher altitude to the mentioned defile. Timarghan defile is located close to Zagros fault and connects Zagros system to the Sanandaj-Sirjan and Iran's central.
Another characteristic of this basin is faults with northeast-southwest trend. These faults are often caused breakdowns in anticlines whose clear sample is the mentioned defiles.

Bain's plains are mostly syncline amonh which are Shiraz, Sarvestan, Marvdasht-Kherameh, Darian, Asopas, Namdan, Arsanjan, Tavabe Arsanjan.

The existing rivers such as Kor, Sivand, Maeen, Khoshk and another drain was very effective in formation of alluvial plains and evolution of sedimentation. The existence of permanent and seasonal lakes likes Tashk, Bakhtegan, Mahrlu, Kaftar and Bakan caused depositing of lake's sediment and also evaporation area of groundwater in the basin. The thickness and extension of sediment forming alluvial aquifer in the basin varies to a great degree. Some plains like Shiraz, Sarvestan, Marvdasht-Kherameh, Beiza-Zarghan, Assopas and Namdan have a considerable extension and sediments thickness. Plains like Darian, Saadatabad, Ghaderabad, Sarpaniran, Seidan-Farogh, Neyriz and Arsanjan are the plains with average extend and alluvial aquifer thickness. Kamphiroz, Khosroshirin, Kheir, Khanekat and Goshnegan are the main small plains in the basin.

4.2.1 Aquifer water quality

In addition to precipitation, the permanent river's currents and drainage which often have a good quality are effective in the feeding of alluvial aquifers. Expansion of hard rock formation in the basin, especially in the border of plains, is one of the important elements in the feeding of aquifers. The suitable quality of water in water supplier resources of aquifers causes improving aquifer water quality especially in the border of plains and rivers so that they can be used for drinking, agriculture and industrial purposes.

The main sources of limitation of alluvial aquifer's quality in the plains are Salt lakes, Marchs, and evaporative areas. Evaluation of groundwater quality in the study areas shows that in the north and northwest part of basin, such as Dozkord-Kamphiroz, Khosroshirin, Asopas, Bakan, Namdan, Dehbid, Saadatabad, Ghaderabad-Madarsoliman and Seidan-Farough, the groundwater has a suitable quality and doesn't have any limitation for different purposes because the lack of salinity factors alluvial and hard rock formations.

In the center, south, east and southeast of the basin, the groundwater doesn’t have suaitable quality because existence of Tashk, Bakhtegan and Maharlu lakes, as well as the salt dams and formations such as Razak and Sachon that degrade the water quality. This condition can bee seen obviously in Abadetashk-Jahanabd, Arsenjan, Tangehana-Pichakan, Marvdasht-Kherameh, Sarvestan, Shiraz, Goshnegan, Neyriz, Tavabee Arsanjan, Kheir and South of Tashk lake. In some of these areas groundwater isn’t suitable even for agriculture.

4.2.2 Hydrodynamic coefficient

In order to investigate the hydraulic conductivity of the aquifer and to determine hydrodynamic coefficient, information of 118 observed wells and 130 wells in which pumping test were taken, have been used. All operation wells are entirely alluvial, 83 of which are alluvial and 35 wells have hard rock formation. In south of Tashk lake, Sarpaniran, Goshnegan and Dozkord-Kamphirouz study areas, no experiment has been conducted in order to determine hydrodynamic coefficients. However, despite taking pumping test in few plains such as Khosroshirin and Ghaderabad-Madrasoliman, no hydrodynamic coefficient has been calculated. Transmissivity map of the basin is presented in the figure (4-3).

According to figure (4-3), transmissivity curve was drawn in Shiraz, Darian, Kavar Maharlu, Bakan, Abadetashk, Namdan, Dehbid, Seydan-Farough and Marvdasht-Kherameh study areas.

Due to lack of data or appropriate distribution of pumped wells in the aquifer, in study areas such as Neyriz, Estahban, Khir, Gharebagh, Tangehana, Saadatabad, Beiza-Zarghan, Sarvestan and Khanekat, it hasn't been possible to expand transmissivity coefficient and to provide Iso transmisivity curves map. As the figure (4-3) shows, in the plain of Namdan, Bakan and Shiraz, Iso transmissivity curves 3000, 2000, 1500 and 1000 (m^2/day) are observed that indicates the good transmissivity of ground water in several parts of these plains. In Shiraz plain, transmissivity curves are decreased from northern limestone heights toward the south and southeast of plain (outlet). In Bakan plain, transmissivity decreases from heights toward the center of plain. Moreover, in Namdan plain this amount reduces from northern heights to the south (Shadkam river). In addition, in Kavar Maharlu reducing the particles diameter in the outlet of the plain decreases the transmissivity, so that 1000 (m^2/day) curve in the south of plain and 750 (m^2/day) curves in the plain outlet can be observed. In Dehbid plain, due to low thickness of aquifer and spreading small sediments, the minimum transmisivity in the T in the north of plain is observed. In Marvdasht-Kherameh plain, maximum transimisvity is suited in the center of palin close to the junction of Kor and Sivand rivers with 1000(m^2/day). This is due to coarse sediment in this part. In the most part of plain transmisity has a low amount (lower than 300 m^2/day).

4.3 Iso groundwater level map

Iso groundwater level map of basin's aquifers is presented in figure (4-4) to (4-23). Iso groundwater map wasn't drawn in South Tashk lake, Abade Tashk-Jahanabd, Khanekat, Tangehan, Sarpaniran, Dozkord-Kamphirouz, Khosro shirin and Goshnegan areas of study. This is mainly due to the lack of observing well network. In other areas of study Iso groundwater map was provided. In what follows, the groundwater map and direction at areas of study are explained.

Tavabee Arsanjan plain

In figure (4-4), Iso groundwater level map at Tavabee Arsanjan is shown. According to this map, the groundwater flow direction is from northwest heights to the south of plain. In other word, input groundwater flow is from northwest, north and east of plain and output groundwater flow is from south of plain toward Marvdasht-Kherameh plain. There isn't permanent surface flow in this plain.

Arsanjan plain

Iso groundwater level curves (figure 4-5) from 1600 to 1520 m cover the whole of this plain. Recharge zone of groundwater is in the northwest of plain and groundwater direction is from northwest to the east and west of plain.

Seydan Farough plain

Figure (4-6) shows Iso groundwater level map of Seydan Farough plain. According to this map, the maximum curve is 1600 (m) in the north and minimum 1580 (m) in the southeast of plain. Thus, the main recharge zone of alluvial aquifer is located in the northwest highland and outlet area (discharge) of ground water is located in southeast part of aquifer. Groundwater direction is also from northwest to the southeast.

Khir plain

According to the groundwater level map of Kheir plain figure (4-7), the maximum and minimum groundwater level curve are respectively 1545 and 1520 (m) in the south and east of plain. According to the map, recharge area of alluvial aquifer in located in the south of plain and output area (discharge) of aquifer is located in the east and north. The groundwater flow in this palin is from south to the north and finally flows into the Bakhtegan lake. In this area, there is'nt any recharge or drainage of surface water

Estahban plain

Estahban plain is situated in the southeast of basin. The groundwater level curves in this plain are between 1600 (m) in the west to1665 (m) in the east of plain (figure 4-8). Therefore, groundwater flow in this plain is from east and southeast heights to the northwest (outlet of Estahban plain and output of Kheir plain). Hydrulic gradient increases from the east to west of the plain. On this basis, the eastern heights recharge alluvial aquifer and the western part is output of groundwater. Due to lack of permanent river in this plain, there isn't drainage from groundwater.

Neyriz plain

Neyriz groundwater level map is shown in figure (4-9). According to this map, the groundwater flow is from south to the center of the plain. The north and southeast part of the plain feed this area. Hydraulic gradient in the western part is less than others, in which the groundwater doesn't discharge to another area.

Marvdasht-Kherameh plain

This study area is the vastest part of the Tashk-Bakhtegan and Maharlu lakes basin. This area is divided into two parts including Kherameh and Marvdasht palins.

Kherameh plain

Figure (4-10) shows groundwater level in Kherameh plain. According to these map, the groundwater level varies between 1520-1585 (m). In this plain, southwest heights recharge the alluvial aquifer and the groundwater flow is from southwest of plain toward the east and north of plain (Bakhtegan lake).

Marvdasht plain

This vast plain includes four smaller plains that are ordered respectively from northwest to southeast (Kherameh): Dashtak-Drodzan, Maien-Bidkal, Dashtbal – Lanetavos and Marvdasht - Korbal. According to groundwater level map, western and northern heights recharge alluvial aquifer. This is the reason why groundwater movement is from north and west heights to the southeast of plain (Kherameh and then Bakhtegan lake). Kor river and its branches including Main and Sivand are permanent river in this plain which are feeding upstream of plain. In downstream of plain, this river play role as a drainage of groundwater (figure 4-11).

Darian plain

General direction of groundwater flow in this plain is from west to the east. The westen and southwest heights recharge alluvial aquifer and the eastern and southeast parts discharge groundwater to the Marvdasht-Kherameh area. Due to lack of permanent river in this area, there isn't any drainage in groundwater (figure 4-12).

Saadatabad plain

Figure (4-13) shows Iso groundwater level in the Saadatabad plain. According to this map, groundwater flow direction is from eastern heights to the south and southeast of plain. The hydraulic gradient is higher in east side and gradually declines toward the west. Because of Sivand river's currents in this plain, river flow drainages groundwater and groundwater flow matches to the river flow.

Ghaderabad and Madarsoliman plain

As can be seen in figure (4-14), in this area groundwater level curves varies between 1805-1870 (m). The groundwater direction in this area is from north heights and also west and east of plain. In other word northern heights recharge the alluvial aquifer and groundwater discharges from east of plain. Besides, in this area there isn't permanent river flow.

Dehbid plain

According to groundwater level map (figure 4-15), groundwater level varies between 2150 to 250 (m). Northwest, north and northeast part of plain feed alluvial aquifer and groundwater's alluvial aquifer is evacuated in the southern part of the plain and flow into the Ghaderabad-Madarsoliman study area. In this plain, due to existence of permanent river, drainage of groundwater is performed. Groundwater direction is from north, northeast and northwest toward the center and south of plain.

Namdan plain

In this plain groundwater flow direction is from northwest to the center and south of plain and finally to the Kaftar lake. Therefore, northwest and esat heights recharge the alluvial aquifer. Hydrulic gardients is lower in the center of plain compared to the end of plain (figure 4-16).

Beiza-Zarghan plian

This plain consists of Beiza and Zarghan plains. In Beiza plain, groundwater level varies between 1590-1640 (m) and flows from west and south of plain to the east and southeast (Zarghan plain). Hydrulic gradient in the center of plain is lower than the western part.

In Zarghan plain, groundwater flows from south, southeast heights toward the north of plain. Hydraulic gradient in this plain is higher in the southwest of plain (figure 4-17).

Asopas plain

Groundwater level curves in this plian fluctuate between at least 2160 (m) to 2340 (m) (figure4-18). General direction of ground water flow in this palin is from southeast to the northwest. A large outcrop of limestone formations is seen around this area. Northeast, north and northwest heights are feeding aaluvial aquifer.

Bakan plain

Groundwater flow direction is from northwest and north of plain to the south (figure 4-19). Northern and west heights feed alluvial aquifer. This plain is surrounded by limestone. Bakan plain is a closed basin that is considered a Polijeh, in terms of morphology. Surface and ground water is collected in southeast of plain (particularly in autumn and winter) and makes up a lake. Lake's water flows via cracks in the limestone mountain to out of the basin. Due to the lack of permanent river in this area, groundwater drainage doesn't occure (figure 4-19).

Shiraz plain

Groundwater level curves in this plain varies from 1550 (m) in the west to 1450 (m) near Maharlu lake in the southeast of plain. On this basis, groundwater flows from northwest and west to the southeast of plain. Limestones heights in the west of Shiraz city feed alluvial aquifer and groundwater discharges to Maharlu lake (figure 4-20).

Gharebagh plain

This plain is surrounded by Asmari-Jahrom formation (limestone formation). Groundwater flow is from west, south, southeast and north of plain toward the center. Southern heights recharge alluvial aquifer. Groundwater flows to Gharebagh plain from Kavar Mahrlu plain in the east (figure 4-21).

Kavar Maharlu plain

In this plain, groundwater flows from west to the east of plain and from the center toward the southeast of plain. In the border of plain, groundwater flow is toward limestone heights because of existence of wells or drainages of alluvial aquifer with limestone heights. Groundwater from west of aquifer flows to the Gharebagh plain. In this plain, also because lack of permanent river there isn't groundwater drainage (figure 4-22).

Sarvestan plain

In this plain groundwater flows toward Maharlu lake, eastern and southeast heights recharge the alluvial aquifer. Hydraulic gradient in the center of the plain is less than east and northwest parts. Groundwater flows in the northwest of plain could be due to pumped wells or recharges of limestone from alluvial.

Evaluating the groundwater level curves' map in the plains of basin shows the following results:

- General direction of groundwater flow is in the most plains in the northwest-southeast direction and toward the Tashk-Bakhtegan and Maharlu lakes. The only exception is the groundwater flow direction in Asopas plain due to tectonic condition is in the opposite direction (southeast to northwest).
- In general, groundwater flow direction in alluvial plains adheres to topography and that is from border of heights toward center and outlet of plains.
- The most important determinative of groundwater flow direction after topography is the tectonic conditions in different areas.

- In some plains, such as Shiraz, Sarvestan and Kavar Maharlu groundwater level curves show the flow from plain to heights. The main reason for this phenomenon is the existence of pumping wells in the border of heights.

4.4 Groundwater level fluctuation and unit hydrograph

To evaluate fluctuation of the groundwater level and identify the period of rising and falling of groundwater level especially decline of groundwater level in the statistical period the unit hydrograph of basin's plains is drawn. To provide unit hydrograph of plains with observed wells network, all available data was used. Based on this, plains' unit hydrograph with rainfall changes (at the nearest representative station) is drawn in the study areas including Tavabee Arsanjan, Arsanjan, Seydan-Farough, Khir, Estahban, Neyriz, Marvdasht-Kherameh (includes: Dashtak-Drodzan, Maien-Bidkal, Dashtbal-Lane Tavos, Marvdasht-Korbal and Kherameh plains), Saadatabad, Ghaderabad-Madarsoliman, Dehbid, Namdan, Beiza-Zarghan (includes Beiza and Zarghan plains), Asopas, Bakan, Shiraz, Gharebagh, Kavar Maharlu and Sarvestan. In figures 34 to 55(app (b)) unit hydrographs of these plains are shown.

The unit hydrographs appearance shows that a minimum level of groundwater belongs to September and October (due to reducing precipitation and used water for agriculture) and the maximum level is in April and May (due to precipitation or melting snow). Given that the basis of calculating water balance is groundwater level changes (positive or negative) in the base period, this changes are calculated based on groundwater level difference in the fist year to the last year of statistics period. Studies show that the groundwater level has declined in all plains in which provision of unit hydrograph were possible. According to the trend of groundwater decline, Neyriz is the first plain of the basin that applied the ban of groundwater extraction (1983) then Arsenjan plain banned this in 1984. in addition to these plains, currently Darian, Kherameh, Kavar Maharlu and Sarvestan are banned plains. It is worth explaining that Darian, Kherameh and Neyrize are banned plains due to the crisis. In the Kherameh plain, because of salt water intrusion from Bakhtegan lake the groundwater quality has been deteriorated. Due to decline in the groundwater levels in other plains such as Seydan-Farough, Tavabee Arsanjan, Khir and Gharebagh, preparation for banding water extraction is necessary to prevent more groundwater level declines.

Tavabee Arsanjan unit hydrograph was drawn based on available data, from November 1992 to 2013. On this basis, groundwater decline in Tavabee Arsanjan plain was around 14.87 m (figure 34(app (b))). The average annual decline of plain was 0.68 (m) during this period (21 years).

Figure 35(app (b)) shows unit hydrograph in Arsanjan plain from 1991-92 to 2012-2013. The hydrograph groundwater level shows 35.97 m decline during statistics period, thus average annual loss was 1.8 m during the 21 years.

The statistical period that used in Seydan-Farough hydrograph was 17 years from 1994-95 to 2012-2013. Unit hydrograph shows groundwater level decline. Groundwater level decline was approximately 14.39 m. The average annual groundwater decline was 0.85 m durind 14 years figure 36(app (b)).

Khir plain unit hydrograph shows 18.8 m decline in groundwater level during 18 years (1995-2013), so the average annual drop was 0.89 m figure 37(app (b)).

According to statistical period, 18 years was drawn Estahban plain unit hydrograph. The decline in groundwater level at the end of period was 20.3 m and average annual drop was 1.15 m during this period figure 38(app (b)).

Figure 39(app (b)) shows Neyriz unit hydrograph during 20 years. According to the drawn hydrograph amount of groundwater, decline was 18.31 m. The average annual decline was 0.21 m in the plain.

Figure 40(app (b)) shows Kherameh hydrograph during 22 years (since 1991-92 to 2012-13). According to hydrograph, the groundwater level has declined for about 0.24 meter. In this plain, before 2009 water year groundwater level showed rising. The main reason for that was salt water intrusion from Bakhtegan lake but during recent years, groundwater level has dropped because of drying of Bakhtegan lake and lack of rainfall in this area.

Figure 41 to 44 (app (b)) shows unit hydrographs in Marvdasht plain including Dashtak-Drodzan, Maien-Bidkal, Dashtbal-Lanetavos and Marvdasht-Korbal. According to them, the groundwater level decline has been mostly in Dashtbal-Lanetavos (2.04 m/y), Maien-Bidkal (1.18 m/y), Marvdasht-Korbal (0.44 m/y) in Dashtak-Drodzan plain (1.15 m/y) during the statistical period.

Darian plain unit hydrograph from 1991 to 2013 was presented in figure 45(app (b)). Groundwater level decline was 12.4 m (0.59 m/y).

Figure 46(app (b)) shows unit hydrograph in Saadatabad plain for 17-year period. According to the hydrographm, the groundwater level has declined 11.92 m (0.7m/y).

Figure 47 (app (b)) shows Gaderabad-Madarsoliman unit hydrograph during 12 years (2001-2013). According to that, the groundwater level has dropped 9.75 m (0.89 m/y) during this period.

Hydrograph in Dehbid plain is shown in figure 48(app (b)). Based on the hydrograph, the groundwater level has declined 0.25 m (0.03 m/y) during 14 years.

Namdan plain uint hydrograph is presented in figure 49(app (b)) that shows groundwater level has declined 5.37 m (0.33 m/y) during 20 years.

As in figure 50 (app (b)), the Beiza-Zarghan plain unit hydrograph is seen that indicates 6.09 m (1.02 m/y) decline in groundwater level.

Groundwater level recording have been starting in Asopas plain since 1995-1996 water year figure 51(app (b)). Unit hydrograph of plain shows 4.96 m (0.45 m/y) groundwater decline during statistical period.

According to digging observed wells in recent years in Bakan plain, the information related to groundwater level was gathered from August 2004 to the end of 2012. Unit hydrograph of Bakan plain figure 52(app (b)), shows that groundwater level has dropped 13.21 m in this plain.

Figure 53(app (b)) shows groundwater level during the period of about 21 years. Shiraz plain hydrograph indicates 5.09 m (0.25 m/y) drop in the mentioned period.

Figure 54 (app (b)) shows hydrograph in Ghareebagh plain. Drawn hydrograph in this plain shows groundwater level has dropped 11.04 m (0.55 m/y).

Drawn hydrograph in Kavar Maharlu plain figure55(app (b)) shows that groundwater level has declined 21.47 m (1.26 m/y).

The groundwater level in Sarvestan plain in 21 years (since 1990 to 2012) was used to prepare unit hydrograph. Drawn hydrograph shows 8.45 m (0.40 m/y) decline in groundwater level figure 56(app (b)).

According to unit hydrographs and their evaluation, the maximum groundwater level decline belongs to Kavar Maharlu-Seydan-Farough, Arsanjan and Estahban and the minimum amount of water level decline can be seen in Marvdasht-Kherameh, Dehbid, Asopas and Shiraz plains.

The groundwater level hydrographs show dramatics decline in water level in recent years because of reduces precipitation in the study area.

4.5 Water reservoir in hard rock formation

In Tashk-Bakhtegan and Maharlu lakes basin, a significant expansion of hard rock formation especially carbonate formation is seen. Due to high potential of groundwater storage in these formations, they have suitable aquifers and feed several springs in the basin. In this basin, because of Zagros mountains' structure, plains have been created in the form of separated synclines among anticlines. They are functioned as a center for population's residence and industrial and agricultural activities. In most of plains existing in this area, carbonate formation forms the heights in the border of plains and this is why water resources is easily accessible.

Since many years ago, the ability of hard formations especially carbonate formations for supplying water in the basin has been known, so that extracted water from these formations are currently the main sources of drinking water in the major cities in the basin, especially in Shiraz (center of Fars province). Because importance of supplying drinking water and its significance for maintaining groundwater of hard rock formation, they have been used just for drinking and their usage for agricultural and drinking purposes is forbidden. In this basin, carbonate formations such as Sarvak, Darian, Fahlian, Tarbour and Asmari –Jahroum are permeable formations that mainly form karstic aquifer. Razak, Gorpi, Gadvan and Kajdomi are also considered as semi-permeable or not-permeable formations.

4.5.1 Statistics and information

Water resources of hard rock formations in Tashk-Bakhtegan and Maharlu lakes basin includes springs, wells, and Qanats. According to statistics of the base period, there are 835 springs, 264 Qanats and 4812 active wells in the hard rock formation. It should be noted that the basis of determining the type of water resources (hard rock formation or alluvial) was the information of census and the location of resources in GIS map. According to this information, 865.66 (MCM) hard rock formations are extracted (Table 45(app (a)) shows number of water resources and the amount of discharge from hard rock formation).

4.5.2 Number and rate of discharge

Based on last census in the basin, there are 835 springs in hard rock formation with discharge of 370.21 (MCM). There are 4812 wells in these formations and as mentioned, most of them supply water for drinking purpose in the cities.

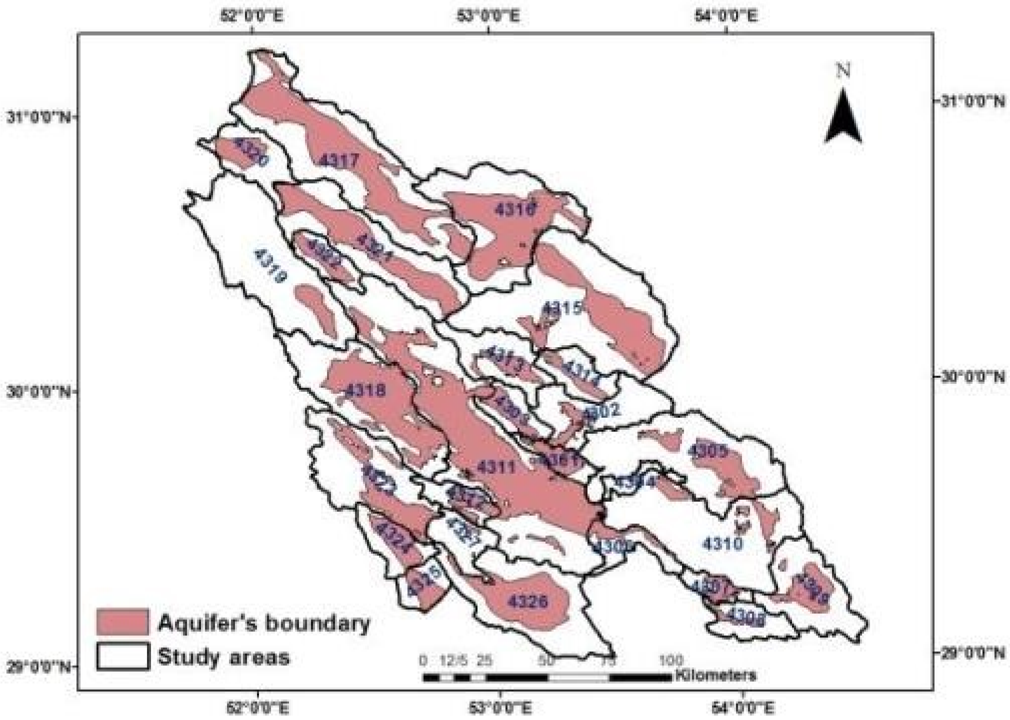

Figure 4-1: Aquifer boundary in study areas

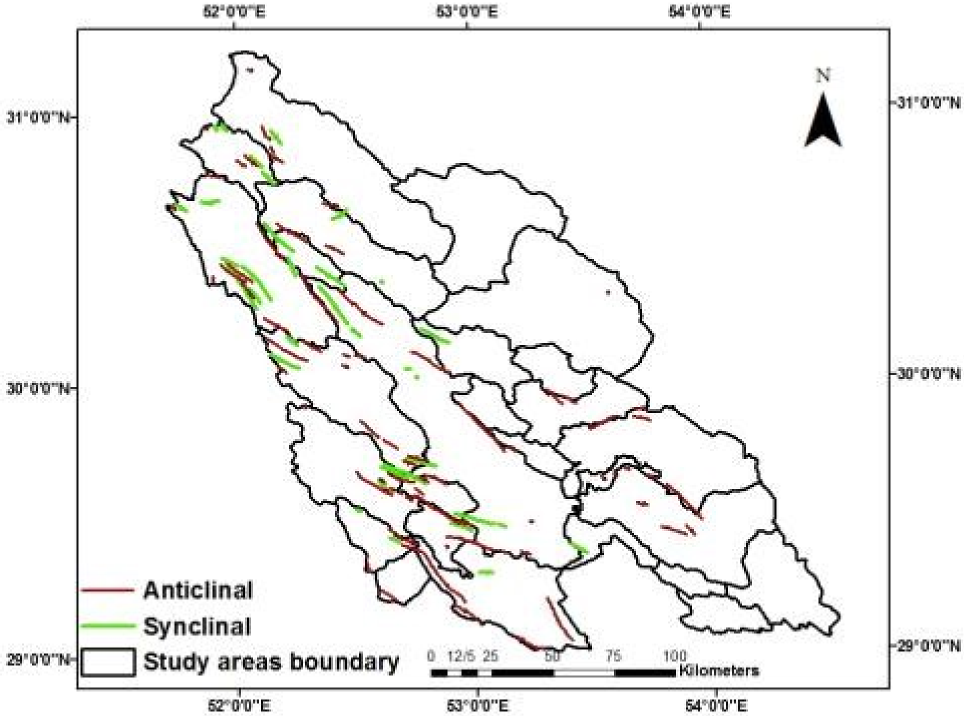

Figure 4-2: Anticlines and synclines in the basin

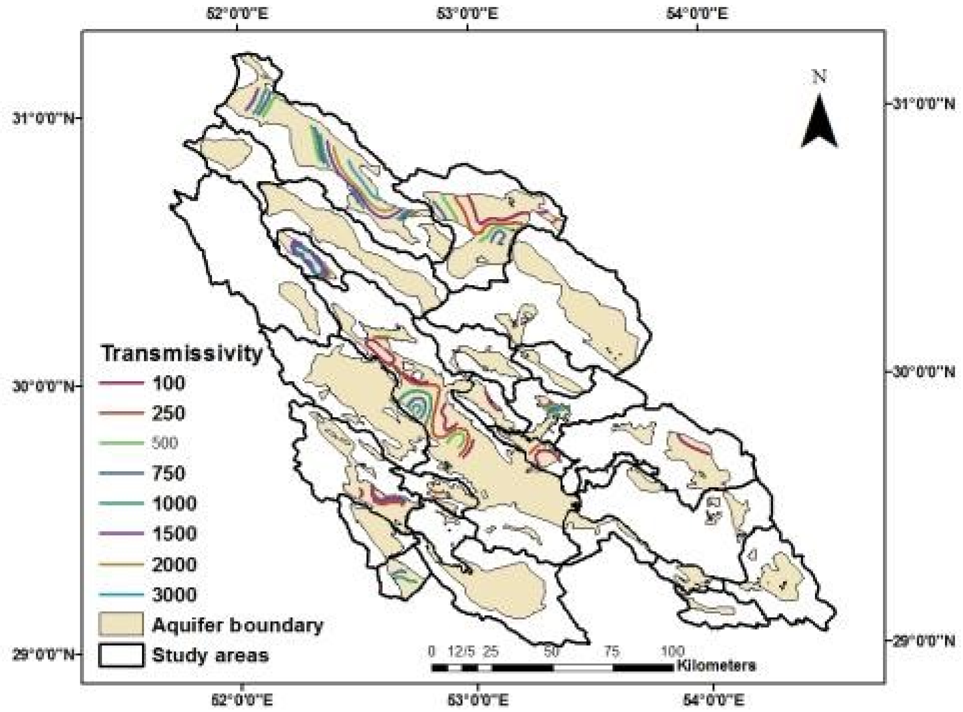

Figure 4-3: Transmissivity (T) map

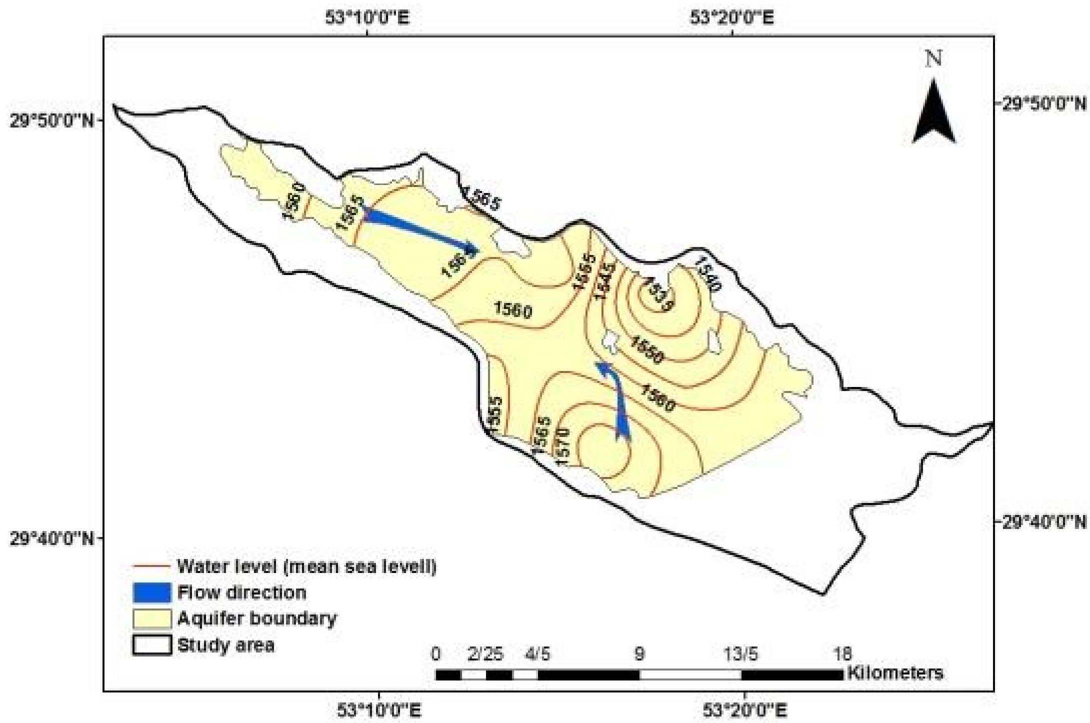

Figure 4-4: ISO groundwater level in Tavabee Arsanjan

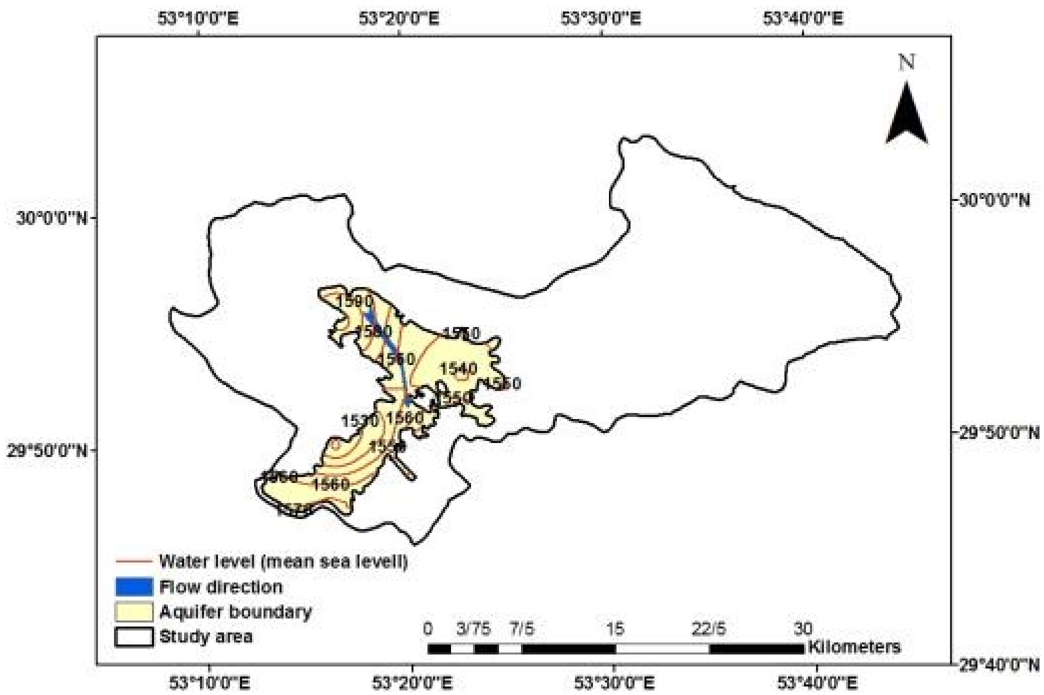

Figure 4-5: ISO groundwater level in Arsanjan

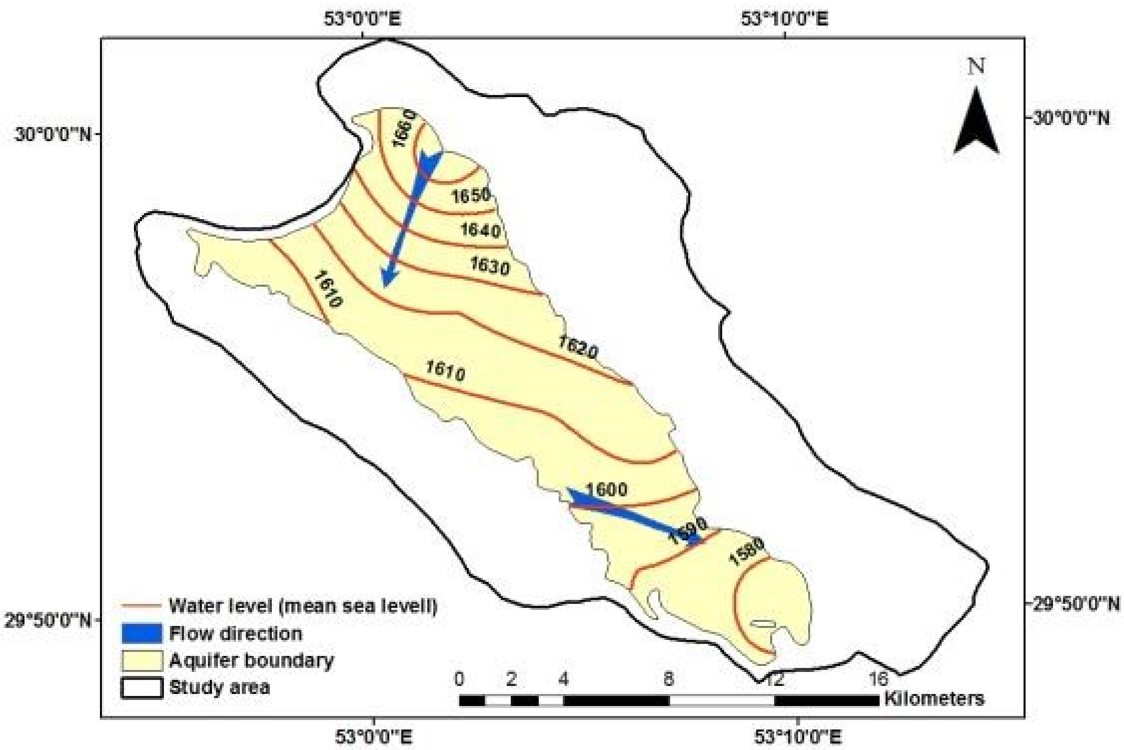

Figure 4-6: ISO groundwater level in Seydan-Farough

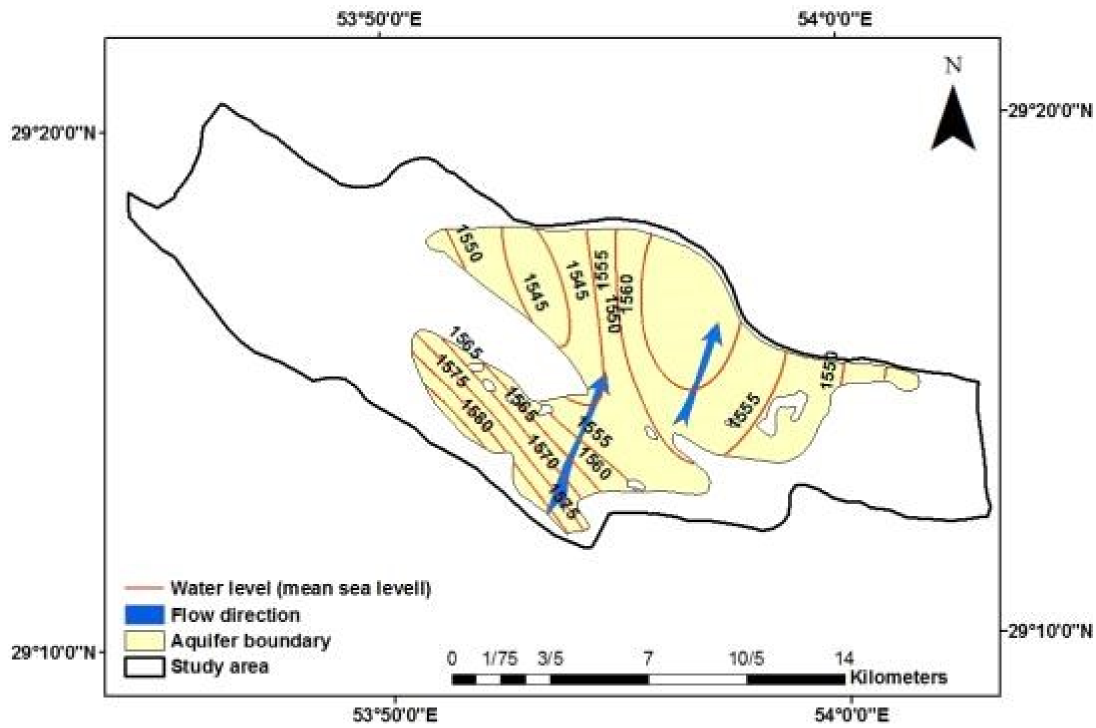

Figure 4-7: ISO groundwater level in Khir

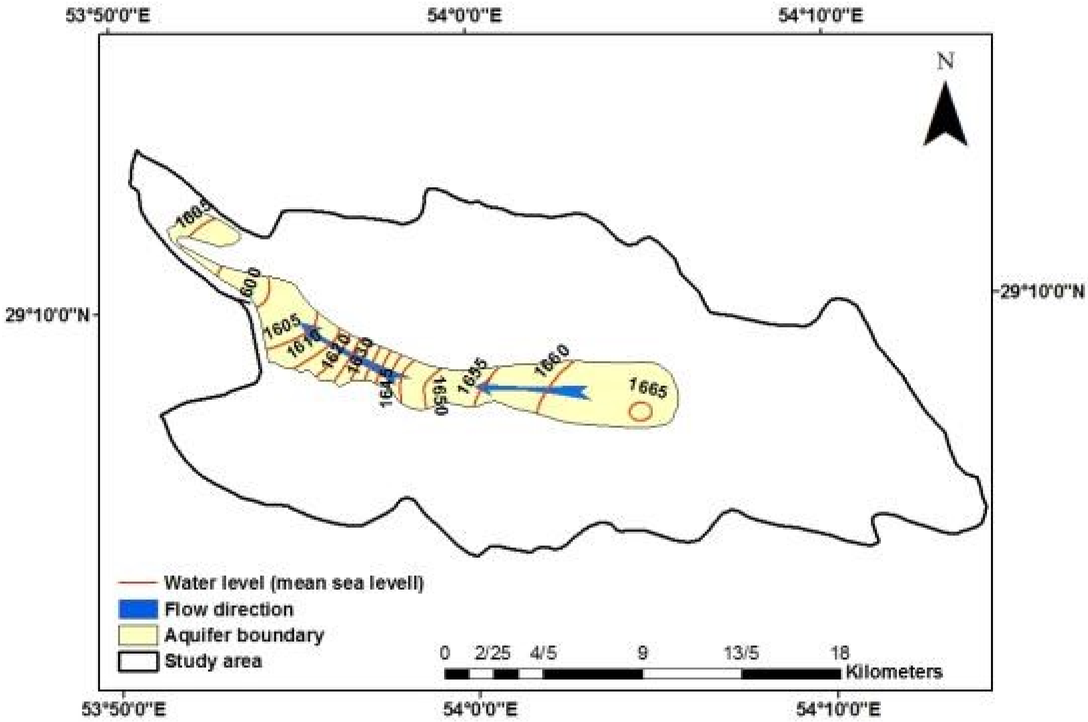

Figure 4-8: ISO groundwater level in Estahban

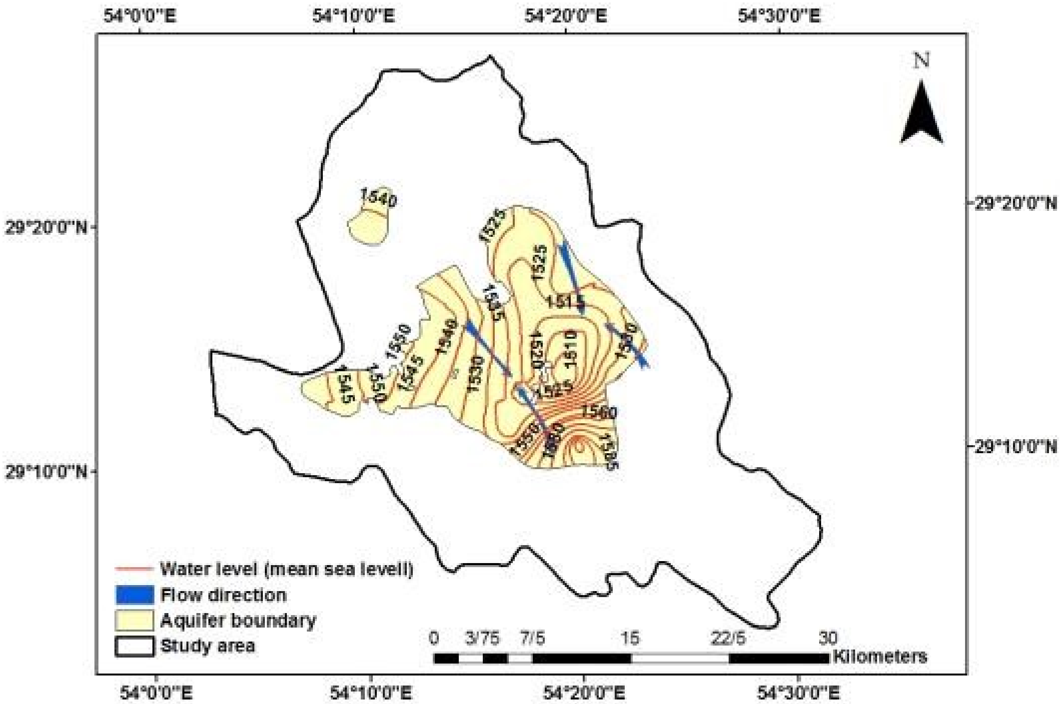

Figure 4-9: ISO groundwater level in Neyriz

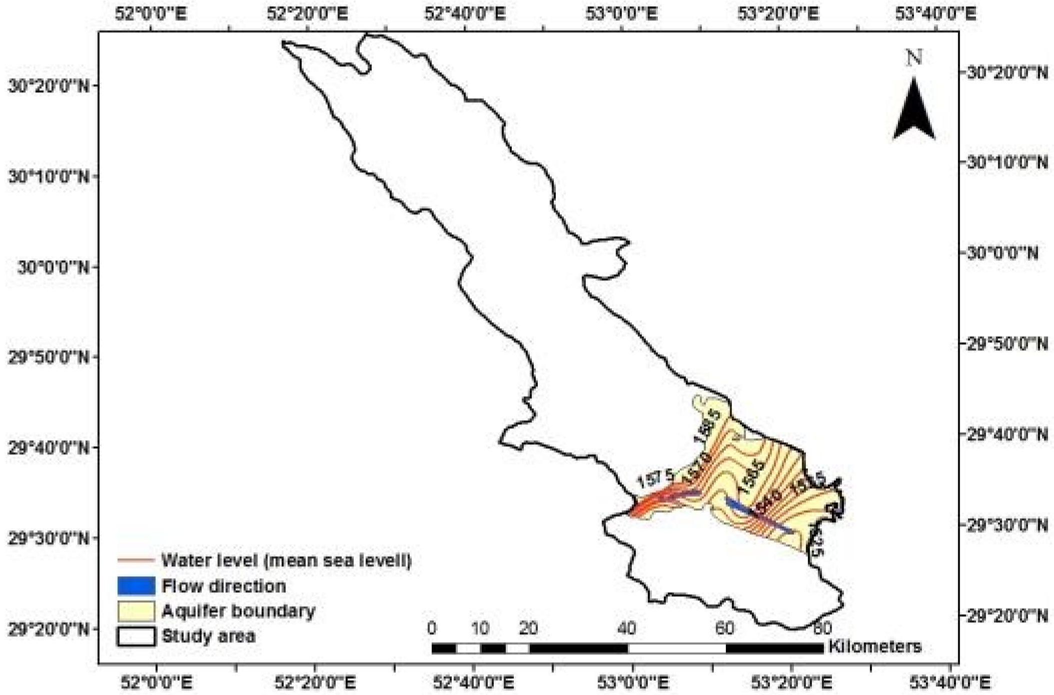

Figure 4-10: ISO groundwater level in Kherameh

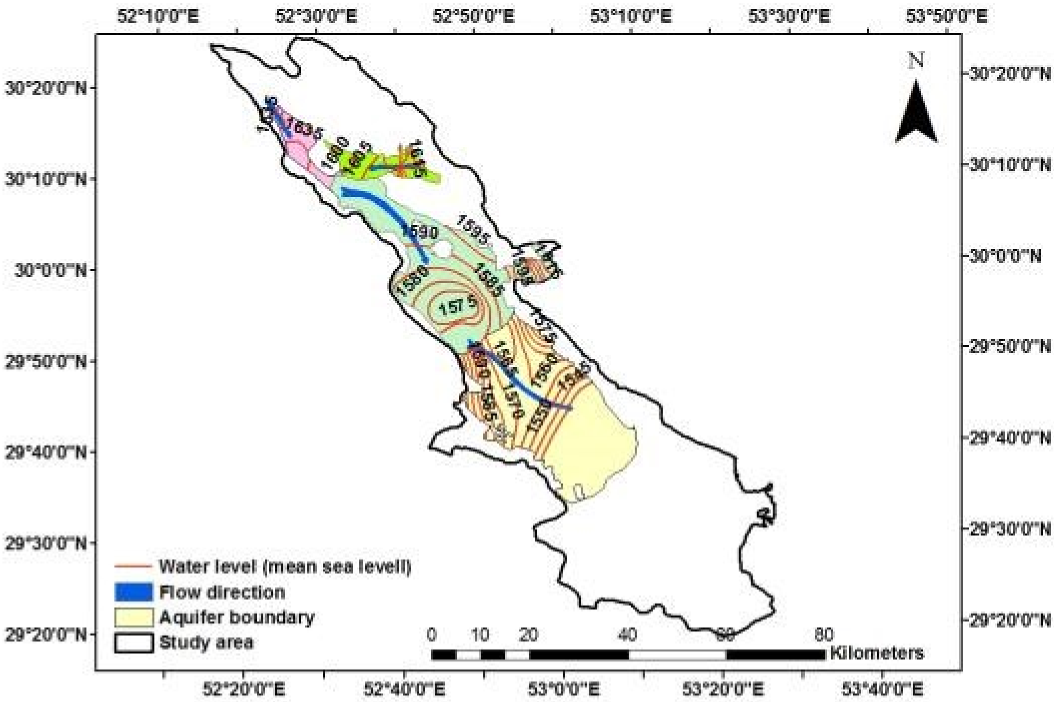

Figure 4-11: ISO groundwater level in Marvdasht

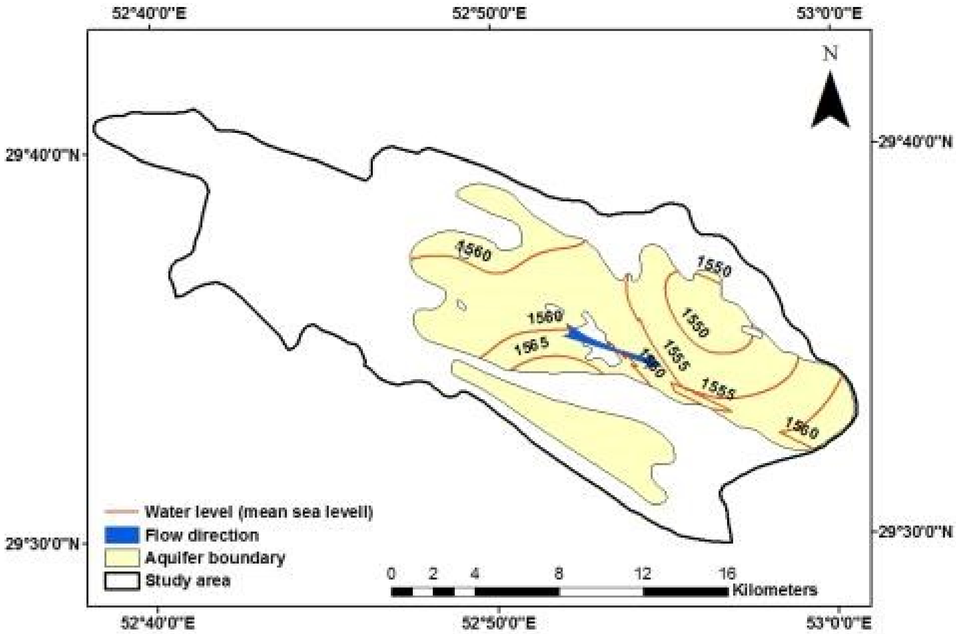

Figure 4-12: ISO groundwater level in Darian

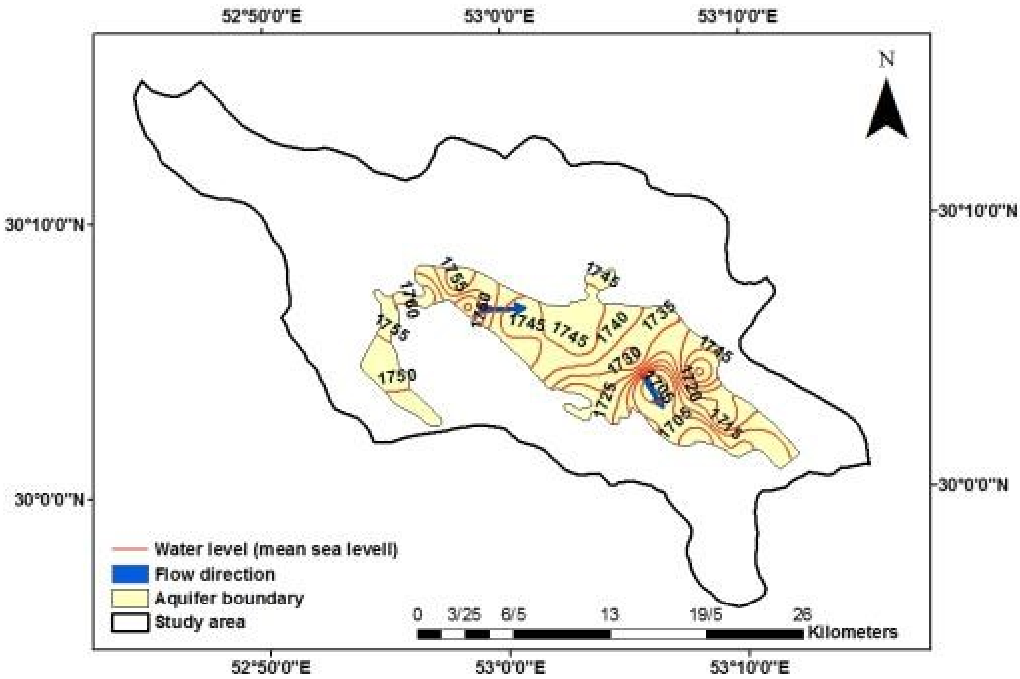

Figure 4-13: ISO groundwater level in Saadatabad

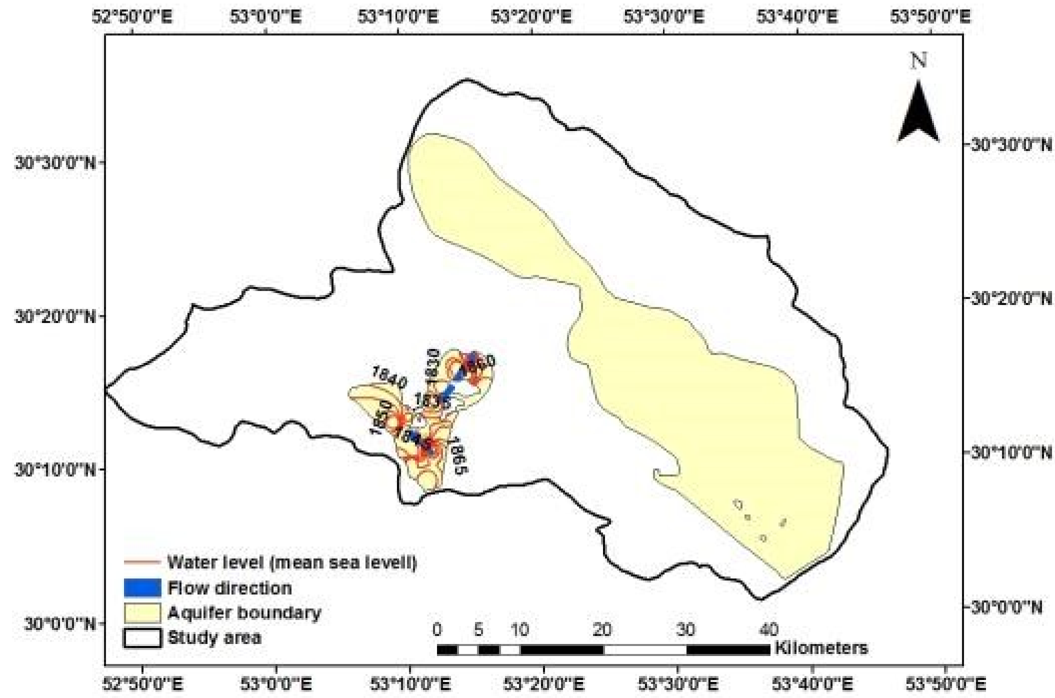

Figure 4-14: ISO groundwater level in Ghaderabad Madarsoliman

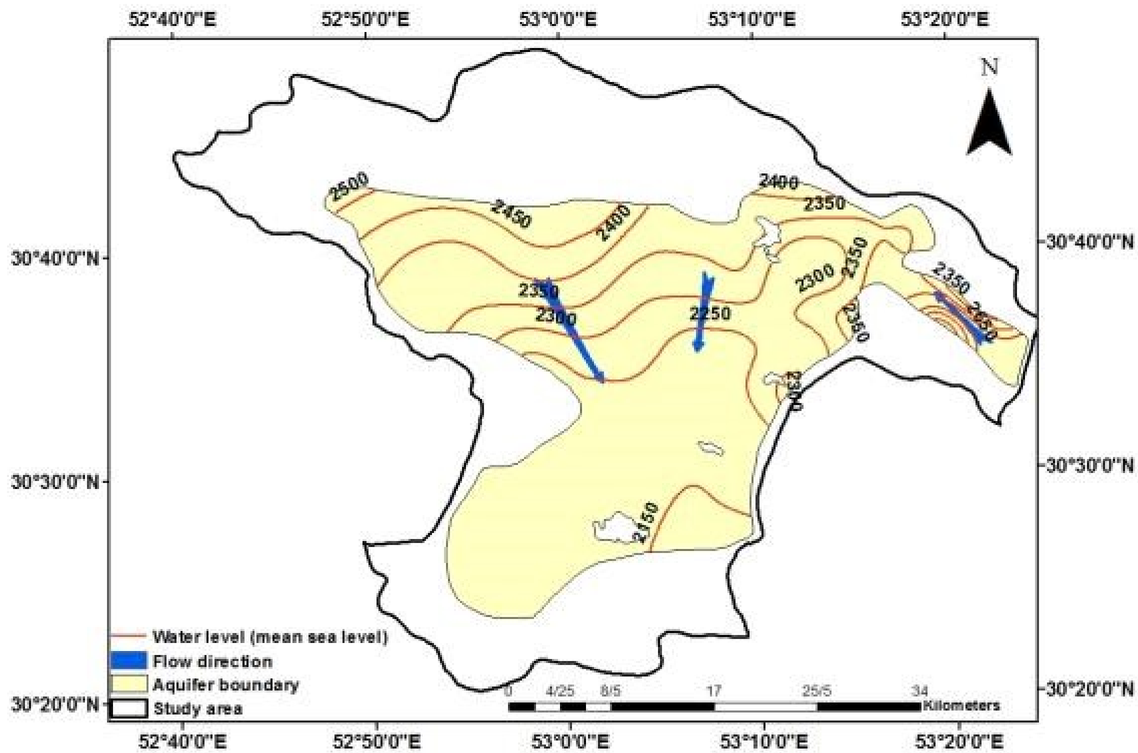

Figure 4-15: ISO groundwater level in Dehbid

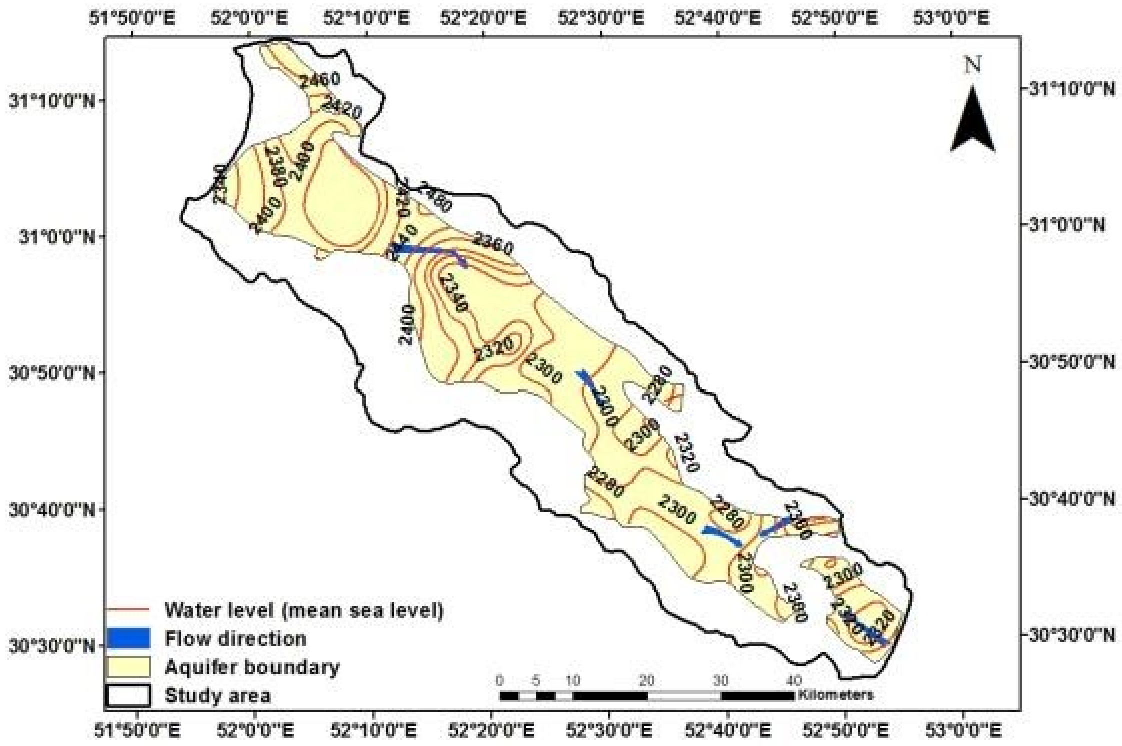

Figure 4-16: ISO groundwater level in Namdan

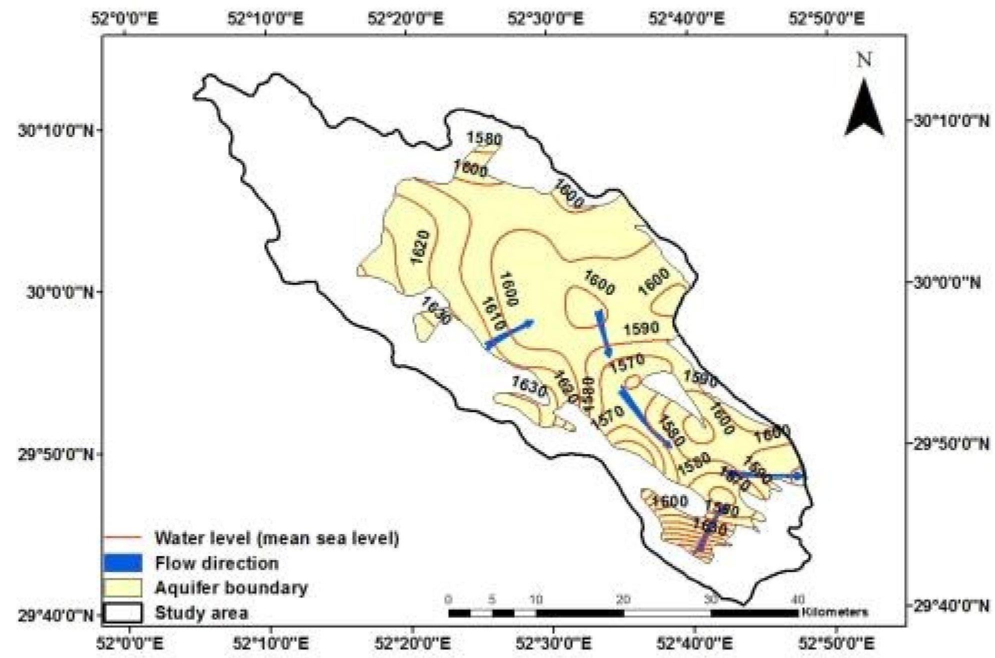

Figure 4-17: ISO groundwater level in Beiza-Zarghan

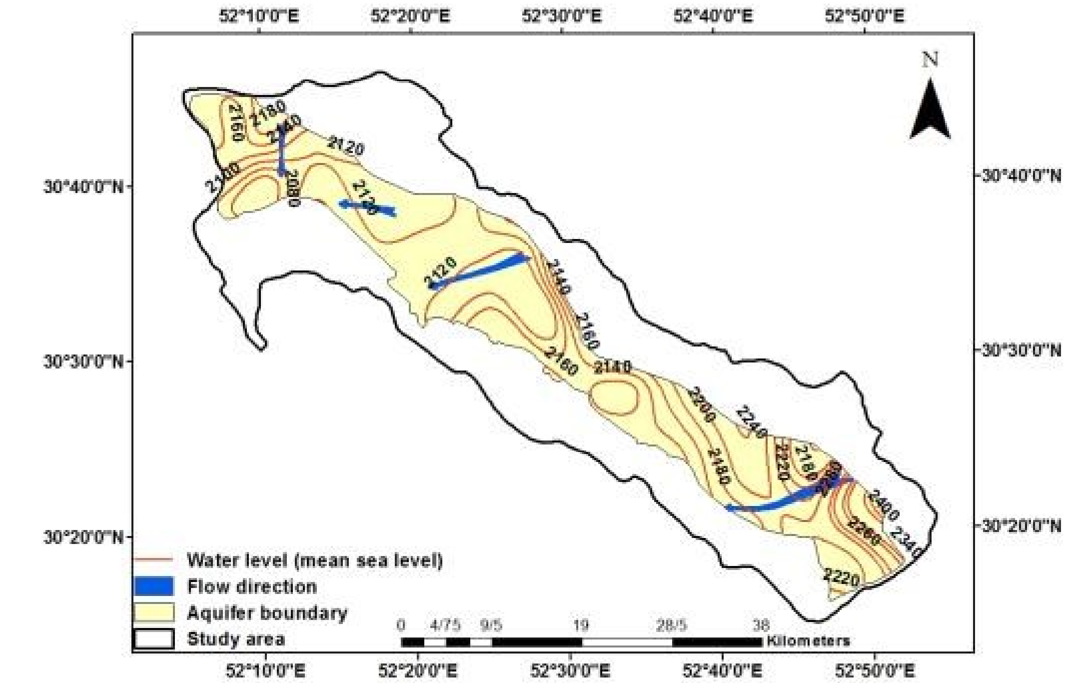

Figure 4-18: ISO groundwater level in Asopas

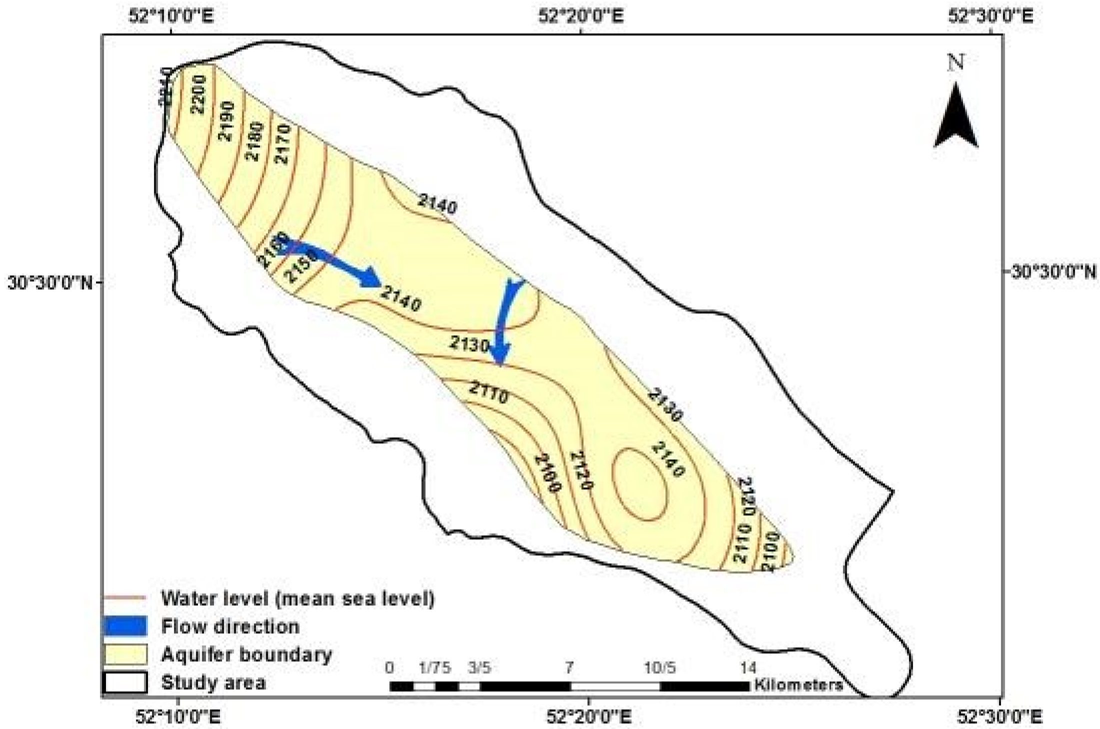

Figure 4-19: ISO groundwater level in Bakan

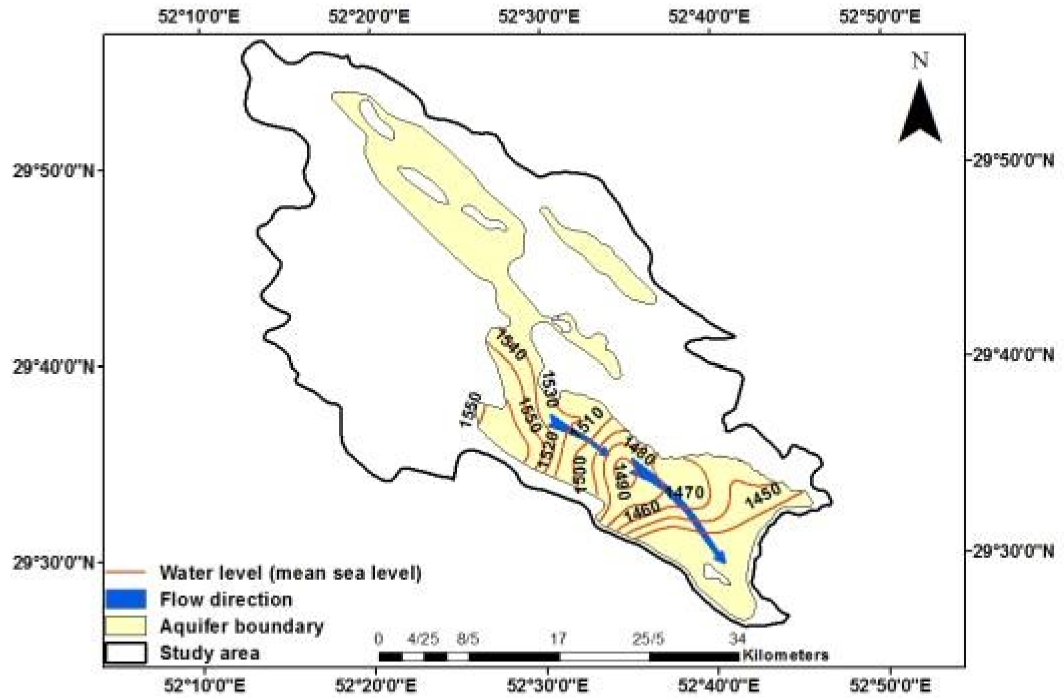

Figure 4-20: ISO groundwater level in Shiraz

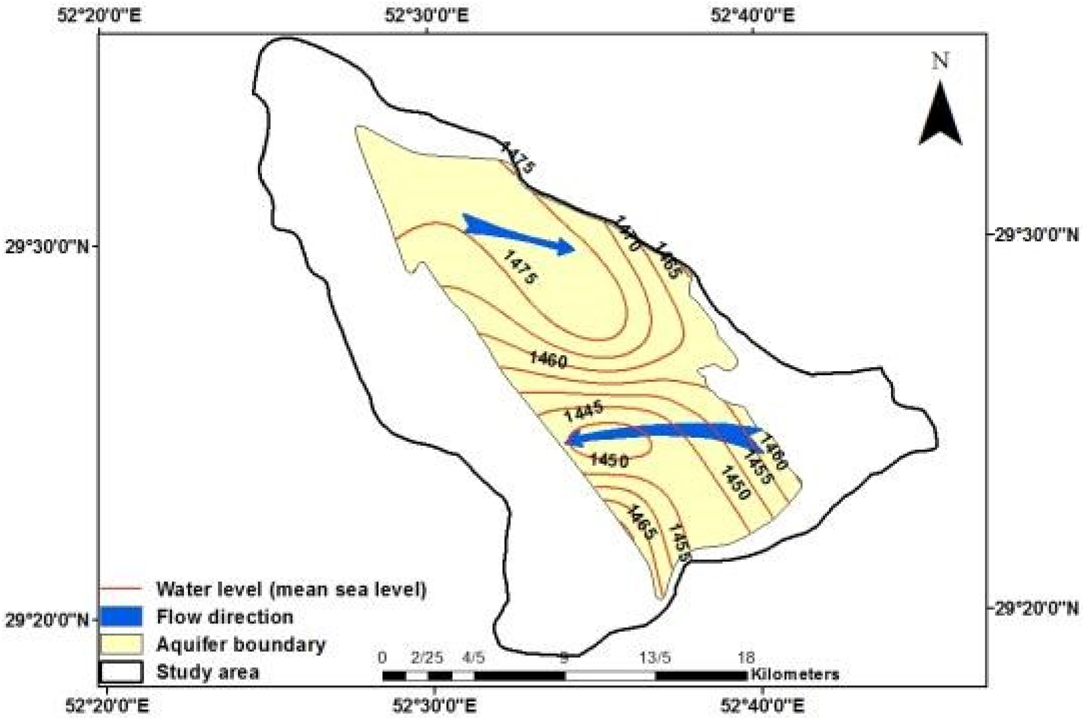

Figure 4-21: ISO groundwater level in Gharebagh

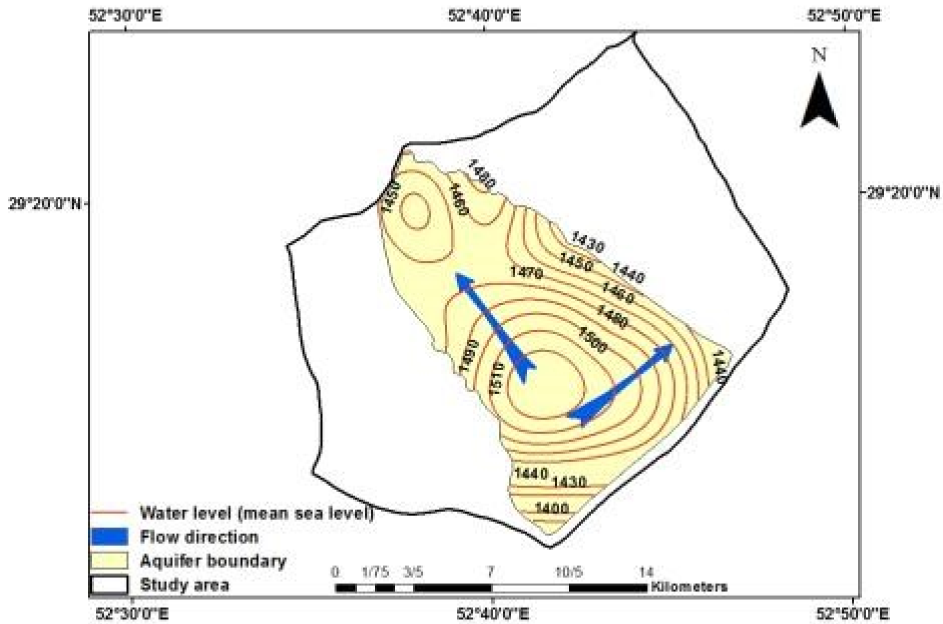

Figure 4-22: ISO groundwater level in Kavar Maharlu

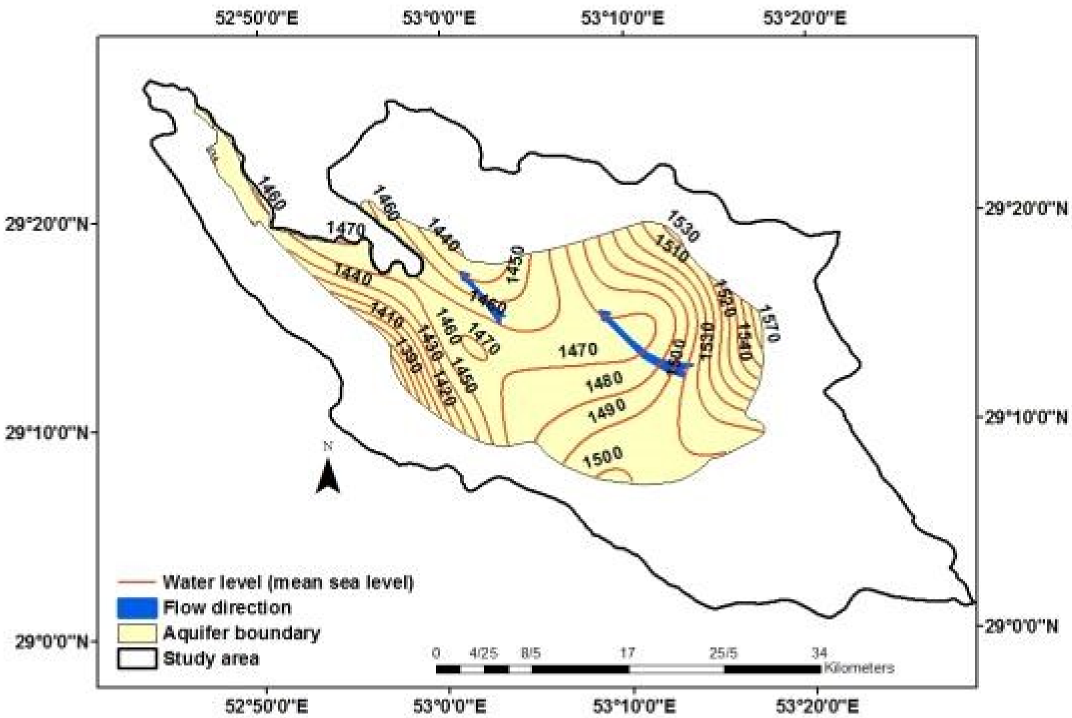

Figure 4-23: ISO groundwater level in Sarvestan

5. Chemical quality of water resources

General

Chemical quality is one of the important characteristics of surface and groundwater. The first condition to use water for different purposes such as agriculture, industry, and drinking is the chemical quality. Investigation shows that is difficult to supply water with suitable quantity in the various part of Iran especially in the south, southeast and southwest but the main limiting factor is water quality. Evaluation of water quality is really important to use water for different projects and plans. The urgency of water supply for all development activities make water quality related studies highly necessary.

Mahralu-Bakhtegan is located in the south of Iran. Some factors such as geological setting, the rate of evaporation, existence of two salt lakes and Salt Lake's intrusion from the lakes has caused a decrease in water quality especially in the south of the basin. To study groundwater quality, the number of samples including wells, springs, and Qanat are selected. They are sampled periodically and analyzed chemically. In the study of surface water quality, sampling in hydrometric stations in different times during the years has been taken.

Of 27 study areas in Tashk-Bakhtegan and Maharlu lakes basin, 22 study areas have sampling network of water resources. South tashk lake, Sarpaniran, Dozkord-Kamphiroz, Kosro shirin and Bakan are study areas without sampling network.

Normally sampling of qualitative sources is performed twice a year (dry and wet seasons) and a thorough chemical analysis will be conducted as well. It should be noted that in some study areas, sampling chemical tests have not been performed completely in some cases (for example determination of EC, PH, Chloride concentration and etc.)

According to research, there is only unconfined aquifer in most of study areas, and only in few areas such as Shiraz, Dehbid and Ghaderabad-Madarsoliman confined aquifer have been identified. However, the sampling of selected sources isn’t taken individually in each of study area. According to archived results, the best groundwater quality belongs to the north and northwest of the basin and toward the south and east (in general direction of groundwater flow) electrical conductivity increases (EC) and water quality decreases. In some study areas, groundwater level obviously drops due to over exploitation of groundwater resources. The decline in precipitation in some plains such as Neyriz, Kherameh, Tavabee Arsanjan and Arsanjan has increased water salinity that has caused several problems for using water in these plains. The main reasons for increasing salinity in these plains are dropping groundwater level, penetration of saline water from deep layers and effect of Bakhtegan lake.

It is notable that to evaluate gases or other elements existing in the water, such as Fluoride, taking relevant test is necessary. Such experiments' results, however, isn't available in this basin. Evaluation of groundwater quality sampling network in the basin shows that the distribution of selected resources isn't adequate in terms of number and distribution. For example, currently there isn’t qualitative sampling network in the large part of Marvdasht-Kherameh plain and also the number of selected quality recources isn’t enough in some plains. For example, in Shiraz plain, there are only 13 quality selected samples (11 alluvial wells and 2 hard rock wells), while in Beiza-Zarghan, Neyriz and Namdan there are respectively 30, 30 and 20 quality selected samples. Due to lack of suitablae quality network, it isn’t possible to provide quality map in some field studies. Therefore, one of the important steps in this basin is preparation of quality sampling network.

In Tashk-Bakhtegan and Maharlu lake basin, in addition to groundwater quality sampling network, the surface water sampling and chemical analysis at hydrometric stations has been performed.

5.1 Analyzing of water quality

As mentioned above, quality information of water in the basin includes surface and groundwater data. Surface water quality related data includes result of sampling from rivers, springs and drainage at 58 hydrometric stations (active or closed stations). The most quality analysis of these samples was taken and just in few cases incomplete tests were taken. Groundwater quality information includes samples of selected resources from the study areas.

5.2 Surface water quality

Chemical quality analysis of surface water in the basin is conducted based on sampling results in 58 hydrometric stations. According to available data, merely three stations such as Chamriz, Dashtbal, Polekhan-Kor have complete information in the base period (1970-2013). Other stations have information less than the base period. According to quality information of hydrometric station, the minimum and maximum of quality parameters were calculated and presented in the table 46(app (a)). The following results were obtained from the analysis:

- The Minimum electrical conductivity (EC) in the base period is 112 µs/cm that belongs to Ghadamgah station at 02.06.1980.

- The maximum electrical conductivity (EC) in the base period is 70300 µs/cm that belongd to Polefasa station at 26.06.1984.
- The maximum difference between the maximum and minimum EC is related to Polefasa station. In this station, the maximum and minimum measurement EC are respectively 70300 and 529 µs/cm and their difference is 69771µs/cm.
- The maximum Chloride concentration is 3127 mg/L and is related to Polefasa station on 26.06.1984. The minimum amount is also 5.3 mg/L in Khanmin station on 13.03.1977.
- The Maximum and minimum amount of TDS is related to Polefasa and Ghadamgah stations respectively with 60587 and 56 mg/L.
- The maximum Sulphat ion concentration is 6624 mg/L and is related to Airport drainage and minimum is 2.4mg/L belonging to Nasrabad station.
- The Maximum and minimum PH are respectively 9.1 and 6.3 at Drodzan dam station.

Evaluation of the chemical quality of surface water in the basin shows that in general surface water has a suitable quality and doesn't have any limitation for different uses such as agriculture, drinkinig and industrial use. Inappropriate quality can be observing only a few cases that most of them are drainage. The main reasons for the low quality are drianaging water via rivers or releasing wastewater into rivers.

5.2.1 The result of chemical analysis of surface water

According to the results, %age of different quality parameters was specified and presented in the table 47 (app (a)). According to the results, frequency of bicarbonate, sulfate and chloride in the samples of hydrometric stations were respectively 71, 6 and 23 % of samples. Moreover, of all samples 59 % had calcic facies, 10 % had magnesium and 31 % had sodic facies. 67 % of samples were good for drinking, 10 % were acceptable and only 2 % were inappropriate for drinking and the rest of 10 % could be used in the emergency condition. In terms of agriculture, only 17 % of the samples were inappropriate and could be used only in especial circumstance for particular crops. Evaluating surface water quality of the basin shows that in general rivers don't have any limitation for different uses and stations with inappropriate quality are suited on drainage of the basin (end of Shiraz and Kherameh plains). In these drainages, water quality is low due to enterance of irrigation wastewater and drainage of toxin (table 5-1- different quality parameters).

5.3 Groundwater quality

To evaluate the chemical quality of groundwater, quality sampling network has started in 1993 and developed gradually in different study areas. Sampling of water is taken twice a year (in wet and dry season). It should be noted that the available selected network often belongs to alluvial well and only a few hard rock formation wells, spring and Qanat participated in this network.

Based on available information there is selected sampling network in all study areas, other than south Tashk lake, Sarpaniran, Dozkord-Kamphirouz, Khosroshirin and Bakan. There are totally 390 selected wells, springs and Qanats in the basin.

- Selected quality sample of alluvial aquifer well

To evaluate groundwater quality in alluvial aquifer, the latest sampling related data was used (spring 2013). Evaluation of groundwater chemical quality in alluvial aquifer was investigated for different parameters such as maximum, minimum, average quality parameters and types of water and facies. To evaluate water quality Iso EC map was provided. In this section, various plots such as Schoeller and Wilcox diagrams were also provided and investigated.

- Evaluation of groundwater resources quality statistical parameters (mean, minimum, maximum, standard deviation and coefficient of variation)

Table 48 (app (a)) shows statistical characteristics of groundwater chemical quality in the basin. This table presents statistical parameters of chemical quality elements including TDS, EC, pH, cations sodium, magnesium and calcium and sulfate anions, chloride and bicarbonate. The achieved results are evaluated as follows:

The maximum amount of EC (EC is the salinity index of groundwater in study area) was 67406 µs/cm in Sarvestan.

The Minimum EC (salinity) of groundwater was 182 µs/cm in Neyriz plain (spring in Palangan).

The PH amount didn't show a significant difference in the basin that varies between 6.03-8.98. The minimum and maximum amount belongs to the Dehbid and Sarvestan study areas.

The maximum Cl concentration was related to Abadeh Tashk- Jahanabd with 8100 mg/L and minimum amount was related to Namdan area with 120 mg/L The results related to Chloride ion also shows that the Tashk -Bakhtegan lakes are the most important factor in water salinity in the basin. Thus, the maximum amount of Chloride belonged to around of these lakes and all selected samples in this area had a high Chloride concentration.

The maximum Sulvate ion in the basin was 11900 mg/L in Tangehana-Pichakan (because outcrop of Sachon formation that contains Gypsum) and minimum amount was recorded 0.3 mg/L in Namdan and Saadatabad.

Average bicarbonate ion in the basin didn’t have significant changes compared to other anions, so that the minimum amount was 22 mg/L in Asopas and the maximum amount was 110 mg/L in Beiza-Zarghan.

Evaluation of the chemical quality of selected alluvial wells indicated that the alluvial aquifer in the north and northwest of basin have more suitable quality than the south and south of basin. In general, water quality is decreased from north to the south and south east, so that the maximum amount of electrical conductivity is related to the Sarvestan, Neyriz, Tangehana-Pichakan, Marvdasht Kherameh and Abadetashk-Jahanabad study areas.

Studies show that the main reason for increasing the salinity of water in the basin is the existence of Tashk-Bakhtegan and Maharlu lakes, therefore the highest salinity belongs to the filed studies which are located around the salt lakes. In Sarvestan field study that is located close Maharlu lake, the salinity of groundwater is due to the performance of salt domes and also the effect of Mahrlu lake. Goshnegan plain is suited close to Maharlu lake and doesn’t have a suitable quality due to salt intrusion from lake and influence of salt water.

Type of groundwater in the basin (according to the average amount of anions) shows that in Tavabee Arsanjan, Arsanjan, Abade Tashk-Jahanabad, Khanekat, Kheir, Neyriz, Tangehana-Pichakan, Marvdasht-Kherameh, Darian, Beiza-Zarghan, Sarvestan and Goshnegan (12 study areas) study areas**, Chloride** is the dominant type of groundwater. **Bicarbonate** is the dominant type of groundwater in Seydan-Farough, Estahban, Saadatabad, Sarpaniran, Ghaderabad-Mdarsoliman, Dehbid, Namdan, Dozkord-Kamphiroz, Khosroshirin, Asopas, Bakan (11 study areas). **Solvate** is also the dominant type in Shiraz, Sarvestan and Kavar Mahrlu.

According to the average amount of cations, groundwater facies is **Sodic** in the Tavabee Arsanjan, Arsanjan, AbadeTashk-Jahanabad, Khanekat, Kheir, Neyriz, Tangehana-Pichakan, Marvdasht-Kherameh, Darian, Beiza-Zarghan, Sarvestan and Goshnegan study areas (12 study areas). **Calcic** is the dominant groundwater facies in the 14 study areas including Seydan-Farough, Estahban, Saadatabad, Sarpaniran, Ghaderabad-Madarsoliman, Dehbid, Namdan, Dozkord-Kamphiroz, Khosroshirin, Asopas, Bakan, Shiraz, Gharebagh and Kavar Maharlu.

The achived results illustrated that groundwater type and facies is **Bicarbonatecalcic** in the study areas that are located in the north and northwest of basin. The type and facies of groundwater in the upstream of Kor and Sivand rivers is Calcium bicarbonate, while in the study areas located in the downstream of these river and especially those in border of Tashk and Bakhtegan, the type and facies of groundwater is **Chloridesodic**. Among five study areas in Maharlu lake watershead, type and facies of water is **Chloridesodic.** In Ghoshnegan plain, the whole of the aquifer is suited in border of Maharlu lake. Moreover, due to simaltanueos effect of salt dam and Maharlu lake type, the facies of water is **Chloridesodic** in Sarvestan plain.

In other study areas, including Kavar Maharlu, Gharebagh and Shiraz in Maharlu lake watershead, **Cholride** isn't type of water. This is why the most of aquifers don't have direct relation with the lake. The main factor that affects on groundwater quality in these areas is groundwater formation in the border of plains, especially Sachon and Razak formations. Therefore, the average type of water is **Solvate**.

- Relationships and internal correlation coefficients of the variables in alluvial wells

One of important factor in evalauation qualitative of groundwater is relationship of quality factors and electrival conductivity. EC can is easily measurable with the minimal cost and simple laboratory operation, while measurement of the other chemical parameters with common experiment requires the lab environment and spending money and time. If a correlation is made between chemical components and EC, it will be possible to determine other chemical parameters with reasonable accuracy. In the study area, groundwater resources were classified with regarding the type of water then a correlation was made among EC, cation and anions for each of related samples. Table 49(app (a)) shows the relationship of EC and other chemical components.

- Analysis of water quality in relation to aquifer hydrogeology

In this section, chemical analysis of selected wells in the basin was investigated based on the achived results:

- Change in groundwater quality in the flow direction
- Change in the type and facies of groundwater
- Development and evolution of chemical facies and their %age

Type and facies of groundwater is presented in the table (5-2). In some study areas, especially in the north and northwest of basin such as Khosroshirin, Dozkord-Kamphirouz, Bakan, Asopas, Namdan, Saadatabad, Sarpaniran, Dehbid, Seydan-Farough and Ghaderabad-Madarsoliman and also Estahban in the south of basin, the type of water is **Bicarbonatecalcic**. Due to hydro-geological setting, lack of geological formation with salinity, lack of salt mineral sediment in alluvial aquifer and distance from salt lakes, groundwater in the most part of plain has a good quality.

- In these areas, groundwater type and facies don’t change in direction of flow. The dominant anionic frequency in this area is HCO3>SO4>Cl or HCO3>CL>SO4/. In study areas such as Sarpaniran and Khosroshirin, anionic frequency is (HCO3>Cl>SO4) and in the other study areas there are two frequencies. The cause of difference in frequency is the diversity of origins of water in different parts of aquifer. The usual cation frequency is the Ca>Mg>Na.

- **Bicarbonate calcic** is the dominant type and facies of groundwater in these field studies.

Evaluation of hydrogeologic groundwater quality in several study areas including Tavabee Arsanjan, Arsanjan, Abade Tashk-Jahanabad, Neyriz, Kheir, Tangehana-Pichakan, Sarvestan, Marvdasht-Kherameh, that are suited in border of Tashk-Bakhtegan lakes, shows the following points:

- Most part of alluvial aquifer doesn’t have suitable quality and is inappropriate for different purposes even agriculture.

- Quality of groundwater is only suitable in the border of limestone heights and in flowing area from alluvial fan to the plain and bicarbonate type is possible just in the mentioned area (such as Arsanjan, Tavabee Arsanjan, Neyriz, Kheir, Sarvestan, Marvdasht-Kherameh, AbadeTashk-Jahanabd). Type of water is in general **Chloridesodic** from center of alluvial aquifer toward outlet of plain.

- Anionic frequency is HCO3>Cl>SO4 in the area with **Biocarbonate** type. In some cases, Cl might replace with SO4. The dominant cation frequency is Ca>Mg>Na and some times Na replaces with Mg.
- In groundwater flowing direction is **Chloridesodic** because of saline sediment of lakes and this condition continues until the end of groundwater path. In this condition, the dominant anionic frequency is Cl>SO4>HCO3 and cation frequency is Na>Ca>Mg. In some cases, Mg is replaced with Ca.

The study areas that are suited in Maharlu lake Watershead include Shiraz, Gharebagh and Kavar Maharlu. There seems to be different condition in these areas:

- **Sulvate** is the groundwater type and **Bicarbonate** exists only in border of limestone heights and input of plain type of water.
- Cation frequency is the Ca>Mg>Na and just in few cases Mg>Ca>Na is observed.
- Anionic frequency in the samples with bicarbonate type is HCO3>SO4>Cl, and in chloride type is Cl> HCO3> SO4.

In Khanekat and Goshnegan study areas, all samples were **Chloride Sodic.** There, the anionic frequency is Cl>SO4>HCO3 and this is Cl>HCO3>SO4 in Goshnegan.

In different parts of the Darian study area, three types of chloride, sulfate and bicarbonate was observed. The origin of bicarbonate type is heights, the origin of sulfate is layer Sachon formation and the origin of chloride is the salt sediment in alluvial aquifer.

In the Beiza-Zarghan study area, the groundwater types are **Chloride** and **Bicarbonate**. Only a limited part located at center of plain has sulfate type. Groundwater type is bicarbonate in the northwest and border of limestone heights in north and south of plain. Because of evaporate area and salt sediment type in the southeast of plain, water is chloride. Collins diagram was used to evaluate water type in studies area figure 5-1 to 5-3 show type of water respectively in Dehbid in the north of basin with water type bicarbonate, kherameh with chloride type and Kavar Mahrlu in the south west of basin with sulfate type (Figure 5-4 shows groundwater type in the basin).

5.4 Relationship of water quality with type of geological formation

Amount and type of anion and cation in groundwater depends on the rocks and materials that the groundwater touches through its path, velocity of water flow and origin of water. Normally the amount of dissolved materials will be added gradually in groundwater from feeding side to the outlet side.

Based on effect in groundwater quality, geological formations are divided to three groups:

1. The formation that doesn't have an adverse effect on groundwater quality. In general, groundwater in these formations or adjacent alluvium has good quality and has no limition for different uses. The most important formations in this group are carbonate and conglomerate formations. Carbonate formations includes Asmari-Jahrom, Tarbor,

Fahlian and Darian. Bakhtiari formation is also the important conglomerate formation in the basin.

2. The evaporate and colloids formations might have advers effect on groundwater quality but don’t damage adjacent alluvial aquifers. These formations in the basin include Aghajari, Pabdeh- Gourpi and Kajdomi.
3. These formations are the most important factors on salinity of alluvial aquifer. In the basin Hormoz (salt dome), Sachon and Razak are the most important formation in this group. These formations with salt sediments of Bakhtegan, Tashk and Maharlu lakes are the important reason behind the inappropriate groundwater quality in the south and southeast of basin (figure 5-5- geological map of basin).

Studies show that in the north and northwest of basin, degradation formations of groundwater such as Hormoz, Sachon, Razak don’t have outcrop and this is the reason for appropriate quality of surface and groundwater in these areas. In contrast, in south and southeast due to outcrop of saline formation and expand of Maharlu, Bakhtegan and Tashk lakes, groundwater quality is highly inappropriate and in some areas available water is not even suitable for agriculture and industry.

Table 5-1: Different chemical quality parameter of surface water

Agriculture Category		Dirinking Category		Facies		Type	
2%	Very good	64%	Good	26%	Sodic	67%	Bicarbonate
48%	Good	16%	Appropriate	64%	Calcic	19%	Sulphate
24%	Appropriate	8%	Inappropriate	10%	Maniasic	14%	Chloride
16%	Inappropriate	2%	Bad				
		10%	Emergency				
		2%	Not Suitable for dirinking				

Table 5-2: Type and Facies of groundwater

Column	Plain	**Bicarbonate**			Sulphate Type			Chloride Type		
		Ca	Mg	Na	Ca	Mg	Na	Ca	Mg	Na
1	Tavabee Arsanjan		-	-	-	-	-	-	-	100
2	Arsanjan	70	-	30	-	-	-	-	20	80
3	Seydan-Farough	53	29	18	-	-	100	-	-	100
4	South Tashk lake	-	-	-	-	-	-	-	-	-
5	Abadetashk-Jahanabad	34	33	33	-	-	-	7.6	15.4	77
6	Khanekat	-	-	-	-	-	-	-	-	100
7	Khir	-	-	100	-	100	-	9	9	82
8	Estahban	80	20	-	75	25	-	-	-	-
9	Neyriz	78	11	11	33	-	67	38	9.5	52.5
10	Tangehana-Pichakan	-	-	-	-	-	100	-	12	88
11	Marvdasht-Kherameh	45	41	14	-	60	40	11	23	56
12	Darian	50	50	-	33.3	33.3	33.3	-	50	50
13	Saadatabad	67	-	33	-	-	-	-	-	-
14	Sarpaniran	100	-	-	-	-	-	-	-	-
15	Ghaderabad-Madarsoliman	37.5	62.5	-	-	100	-	-	100	-
16	Dehbid	67	27	6	40	-	60	100	-	-
17	Namdan	88	6	6	-	-	-	-	-	-
18	Beiza-Zarghan	23	77	-	16.6	50	33.4	7.6	46.2	46.3
19	Dozhord-Kamphirouz	100	-	-	-	-	-	-	-	-
20	Khosroshirin	100	-	-	-	-	-	-	-	-
21	Asopas	97	-	3	-	-	-	-	-	100
22	Bakan	97.1	2.9	-	-	-	-	-	-	-
23	Shiraz	44.5	43	12.5	50	50	-	-	-	100
24	Ghareebagh	50	50	-	-	71	29	-	100	-
25	Kavar Maharlu	50	50	-	-	100	-	-	-	-
26	Sarvestan	50	50	-	-	100	-	-	-	-
27	Goshnegan	-	-	-	-	-	-	-	12.5	87.5

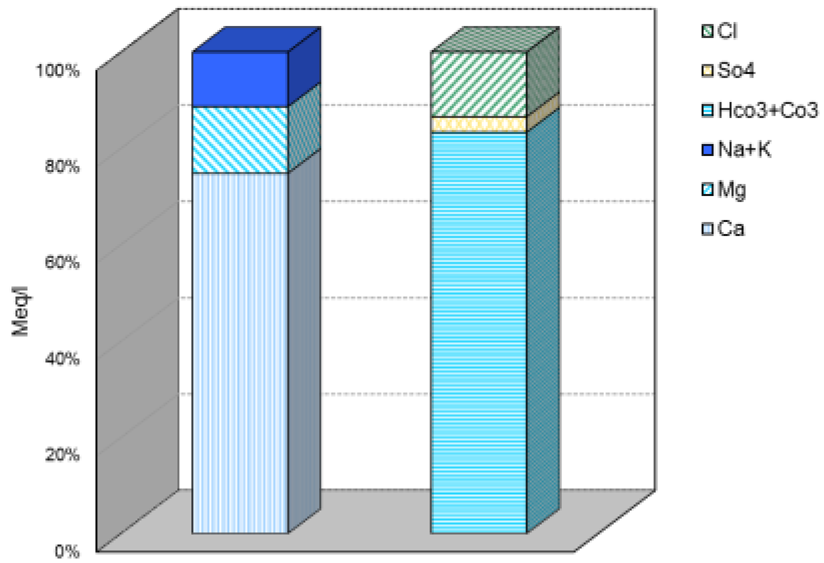

Figure 5-1: Groundwater type in Dehbid study area

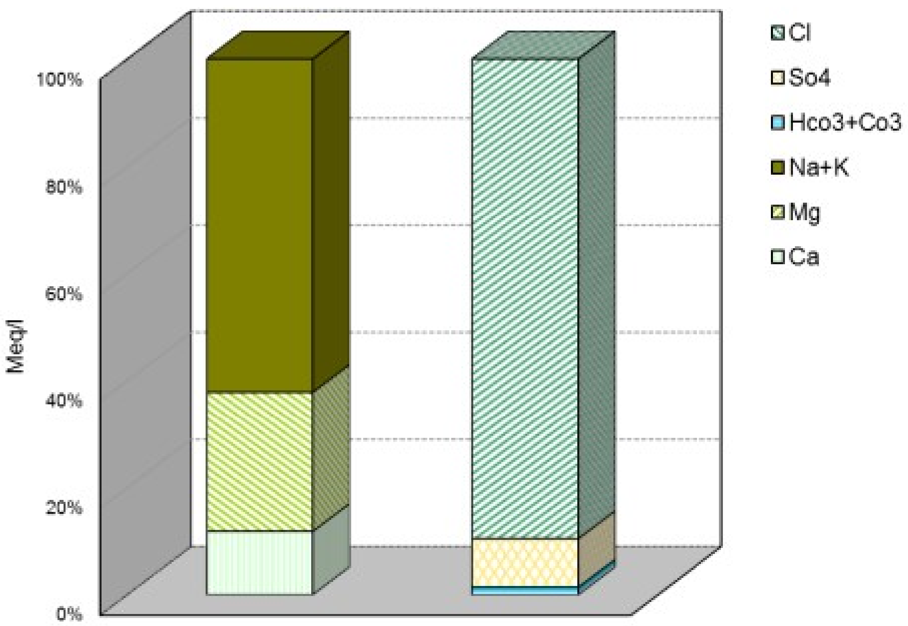

Figure 5-2: Groundwater type in Kherameh study area

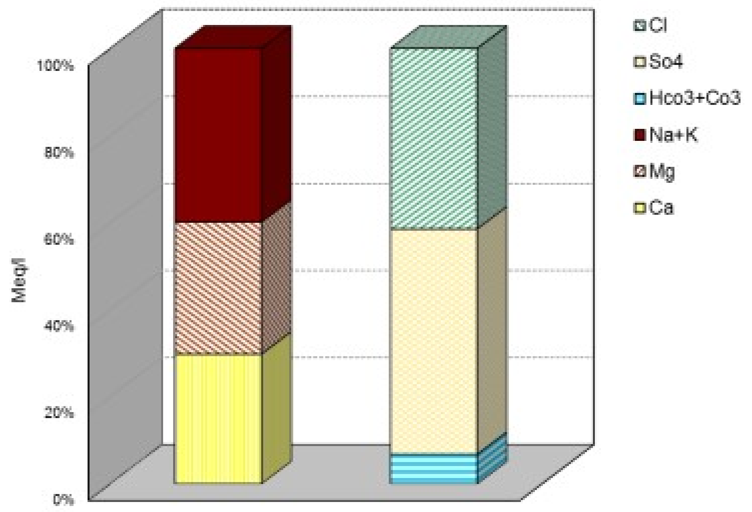

Figure 5-3: Groundwater type in Kavar Maharlu study area

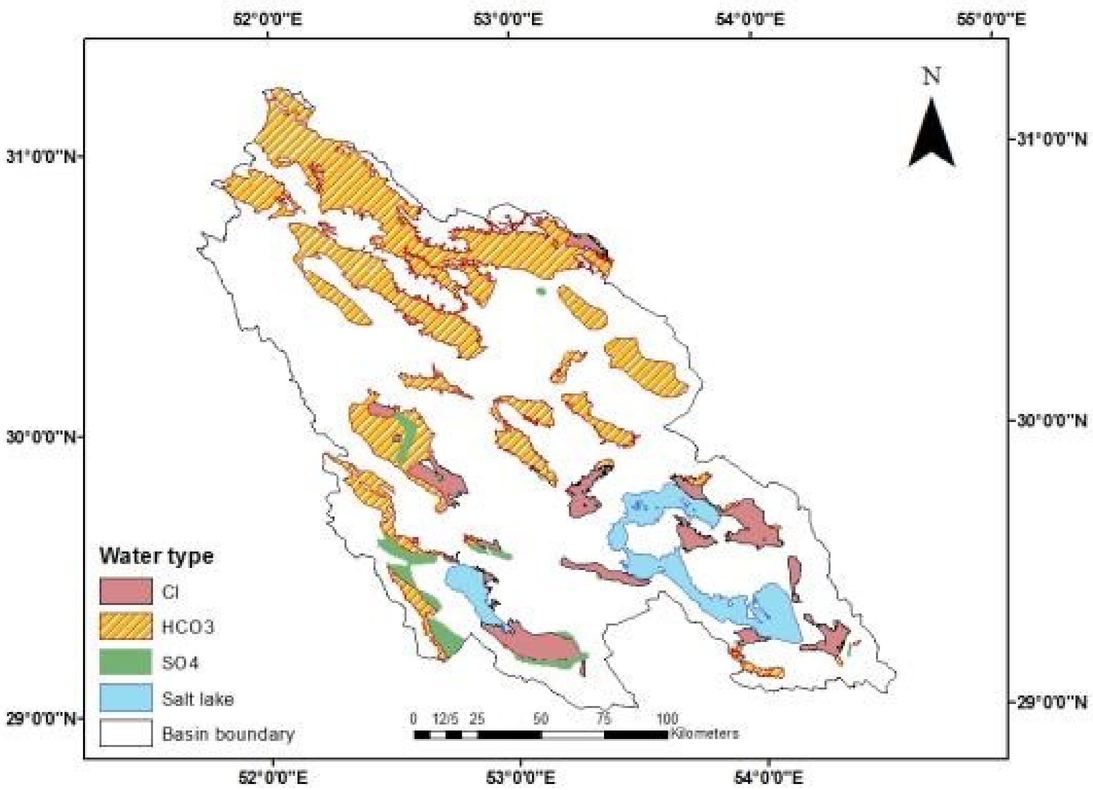

Figure 5-4: Groundwater type map of basin

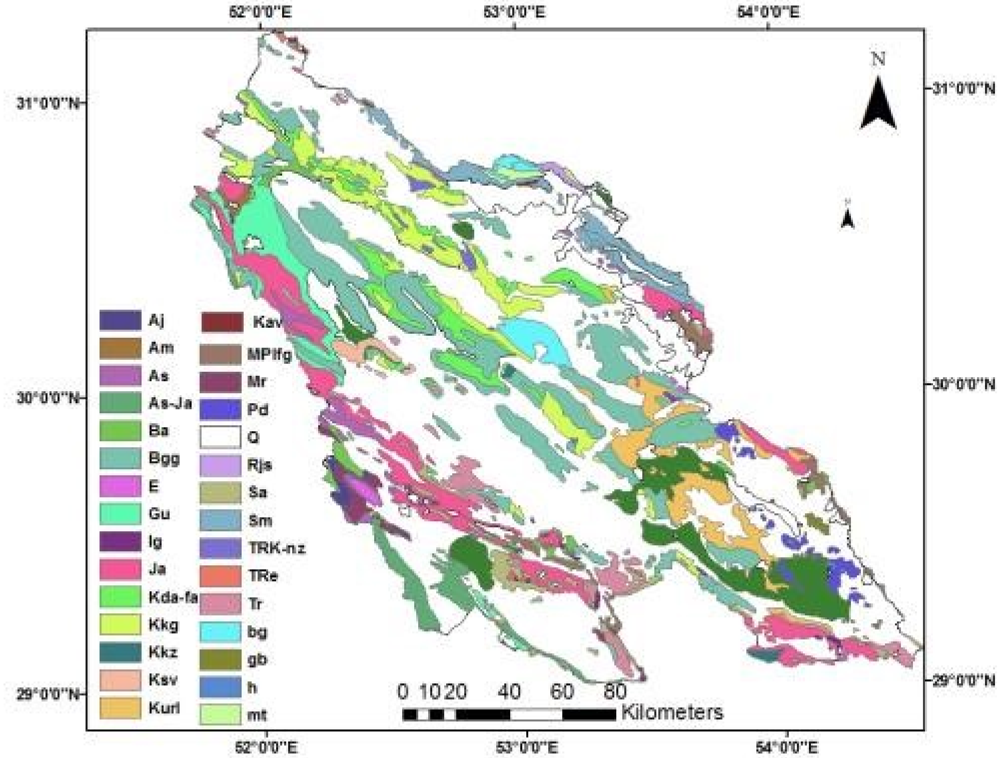

Figure 5-5: Geology map Tashk-Bakhtegan and Maharlu lake basin

6. Water balance

General

Scarcity of water is now the greatest threat facing many parts of the world, especially in arid and semi arid regions. Establishing balance between water resources and the demands in a catchment scale basis could be one of the most important strategies to overcome this problem. In this regard, determination and analysis of water balance components (inputs and outputs) would be necessary (Dastorani & Poormohamadi, 2012).

A Water Balance Analysis can be used to:

- Assess the current status and trends in water resource availability in an area over a specific period of time.
- Strengthen water management decision-making, by assessing and improving the validity of visions, scenarios and strategies (NWC, 2005).

To calculate water balance in the Tashk-Bakhtegan and Maharlu-lakes basin meteorological data, surface water and groundwater statistics in the base period (1971-2013) are employed and groundwater balance in water year 2012-2013 is calculated based on the precipitation in the base period.

Given the applied statistical period, it seems that balance factors in the surface water and meteorology have approached to average climate condition.

In the last 15 years, well observation network has been established widely in some study areas and unit hydrographs have been proivided for these areas. According to unit hydroghraphs, almost all of the areas face decline in groundwater level.

Water balance is the combination of meteorology, surface water and groundwater statistic. Therefore, different factors directly and indirectly affect on water balance calculation.

Figure (6-1) shows position of the basin and the table 50(app (a)) presents average rainfall of plain and heights in 24 study areas.

In what follows, different parameters and calculation of hydroclimatology, aquifer and general balance in the basin will be discussed.

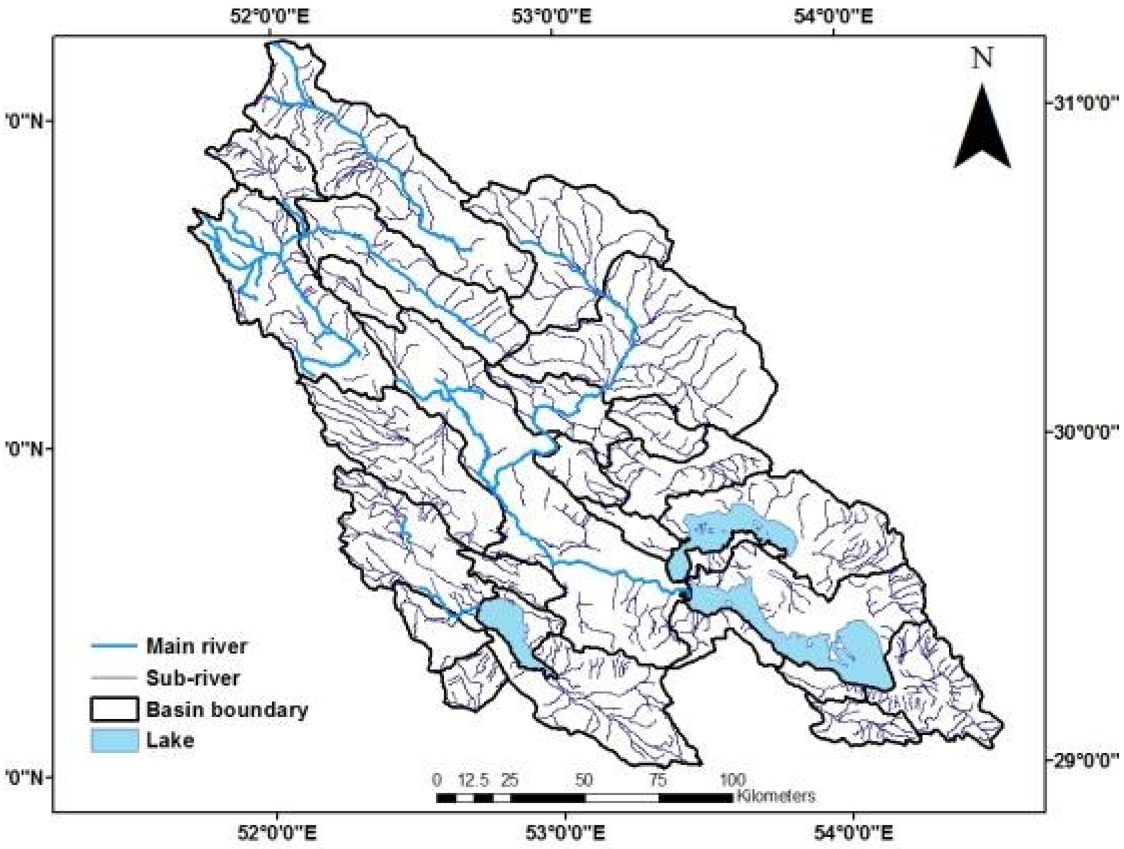

Figure 6-1: Position of Bakhtegan-Maharlu lakes basin

6.1 Hydro climatology balance

Hydoclimatology balance is the special form of general balance that investigates water exchange in the plains and heights. The general equation of hydro climatology balance is as the following:

(6-1) $$P=E+R+I$$

P: precipitation

E: actual evapotranspiration

R: runoff of rainfall

I: infilteration of precipitation

Hydro climatology balance base on three parameters includes infiltration, evapotranspiration and runoff. According to this balance, after precipitation in an area the collected water can select one of three mentioned paths. To calculate evapotranspiration amount different methods such as daily or Torent-Whit methods are used. To calculate runoff, information of hydrometric station is used and in absence of information in hydrometric stations expriments, method such as SCS, Justin etc are applied. Given the fact that calculation of infiltration amount isn't possible directly, this amount is measured through subtraction of sum of runoff and evapotranspiration from 100.

In the table 51(app (a)), the %age of required parameters of above equation is presented. These parameters were calculated in all field studies and presented in this table. In the table 52(app (a)) hydro climatology parameters are indicated. In what follows, the detail of hydro climatology balance equation will be discussed.

6.1.1 Precipitation

Precipitation is one of the important factors in balance equation because all water resources in an area is provided directly or indirectly with precipitation. According to meteorological results, an average rainfall of plain and heights are calculated based on the Iso rainfall map and the result is shown in table 50(app (a)). The total volume of rainfall was calculated separately for heights and plains.

Elevation of Tashk-Bakhtegan and Maharlu lakes basin, plains and lakes' areas are respectively 13864.2, 16131.8 and 1469 (km^2). Plains average rainfall volume is 5238.77 and heights average rainfall volume is 5125.441 (C). The total volume of rainfall in the basin is 11505.26 (MCM). The maximum amount of rainfall belongs to Marvdasht-Kherameh with 1522.02 (MCM) and the minimum amount is related to South Tashk lake with 48.96 (MCM).

6.1.2 Actual Evapotranspiration

Water is evaporated in different forms in the basin. The majority of evaporation is from precipitation in the basin and part of that is related to evapotranspiration. Part of that also belongs to free waters and lakes.

Actual evapotranspiration is the quantity of water that is actually removed from a surface due to the processes of evaporation and transpiration. To calculate actual evapotranspiration in the basin Torent-Whit method is used. Monthly temperature and precipitation are used to calculate this amount in the plains and heights.

Actual evapotranspiration of precipitation in the basin is the sum of this amount in each study. This amount in the plains and heights are respectively 3080.48 and 3495.78 (MCM) per year and total amount of evapotranspiration is equal to 63.4 % of precipitation in the basin. The maximum and minimum amounts are related to the Marvdasht-Kherameh and South Tashk lake respectively with 795.58 and 36.99 (MCM) per year.

6.1.2.1 Evaporation from free waters and lakes

There are five natural and artificial lakes in Maharlu-Bakhtegan basin. The natural lakes including Bakhtegan, Tashk, Maharlu and Kaftar are located in Tangehane-Pichakan, Abade Tashk-Jahanabad, Goshnegan and Namadan study areas respectively with areas of 739, 416.83, 243.45 and 46.2 (Km^2). In Dozkord-Kamphirouz, Drozdan dam artificial lake with an area 49.67 (Km^2) is suited. Therefore, the total area of lakes is 1495.38 km^2 and is equal to 4.75 % area of basin. Evaporation of pan in the representative stations are used to calculate evaporation of free waters. By using pan coefficient in different months, evaporation of free water is calculated. The total volume evaporation is 368 (MCM).

It should be noted that based on statistics obtained from evaporation stations (evaporation pan information), evaporation of surface water resources is considerably greater than the volume of input water such as rainfall and groundwater into lakes. This is the reason why the amount of evaporation from free water was determined equally to water entering the lakes.

6.1.3 Useful precipitation (runoff and infilteration)

Useful precipitation is the excess of precipitation after subtracting actual evapotranspiration. This amount includes both runoff and infiltration. Infiltration will be obtained after separating the amount of runoff. Actual evapotranspiration has a direct relationship with distribution and amount of precipitation, therefore actual evapotranspiration reduces in the area with low precipitation. To calculate useful precipitation, the actual evapotranspiration is subtracted from precipitation in plains and heights. Part of useful precipitation is turned into run off and the remaining part infiltrates into lower layers.

%age and volume of runoff in the height and plains are presented in the tables 51 and 52(app (a)). If hydrometric stations exist in the study area, the information of these stations will be used to calculate runoff in absence of hydrometric stations experimental methods such as Justin that is used to calculate runoff amount. The amount of runoff depends on different factors such as ground slope, land cover, type of geological formation and etc.

6.1.4 Infiltration in the heights and plain

As mentioned in the previous section, due to impossibility of calculation and estimation of direct infiltration (to the heights and aquifer), the %age of runoff after subtraction of evapotranspiration and runoff from 100 % is calculated. The amount of calculated infiltration has been matched to the area characteristics including geology, land cover, karstic potential and elevation.

6.3 Groundwater balance of alluvial aquifer

Groundwater balance is an especial form of balance that evaluates input and output amounts and also storage changes. Estimation of these factors is more complicated than general water balance, because few of factors can be measured directly. Aquifers storages changes are determined through calculation of difference between input and output flow and groundwater level fluctuation multiplied by storage coefficient. Increasing the groundwater level or decreas in discharge of springs and Qanat show the rise of recharge. In contrast, decrease in discharge of Qanats and wells and drop in groundwater level show decrease in recharge and feeding of the aquifer in a given period. The best condition for stability of aquifer is balance between input and output of aquifer. Aluvial aquifer balance is calculated according to below equation:

(6-2) $$Q_{UI} + Q_P + Q_R + Q_I + Q_{SW} - Q_{UO} - Q_{EX} - Q_D - Q_{ET} = \Delta V$$

(Q_{UI}): Input groundwater flow

(Q_P): Penetration of perecipition to aquifer

(Q_R): Feeding of surface flow

(Q_I): Penetration of agricultural uses

(Q_{SW}): Penetration of industrial and drinking water uses

(Q_{UO}): Output groundwater flow

(Q_{EX}): Evaporation of groundwater

(Q_D): Drinage of aquifer by river

(Q_{ET}): Extraction of water from well, spring and Qanat

Alluvial aquifer balance in study areas is presented in the table 53(app (a)). Based on the results obtained by alluvial aquifer balance and also unit hydrographs, drop in groundwater level throughout the study areas is remarkably seen. It should be noted that although the

Thissen network area is not completely equal to aquifer area, the result of unit hydrograph can be indicative of the behavior of the entire aquifer. The total area of alluvial aquifers in the basin is 10566.90 Km^2. According to calculations, the total amount of recharge and discharge of alluvial aquifer are respectively 4056.81 and 4895.19 cubic million meters per year.

6.3.1 Input and output of groundwater flow

Input and output groundwater flow of aquifer can be calculated by using Iso groundwater level map and also result of pumping expriments (transmissibility coefficient). Amount of input and output groundwater flow are calculated based on Darcy low's and flow pipes in the plain that have Iso groundwater level map and transmibility coefficient. Table 54(app (a)) shows the calculation of groundwater flow in Marvdasht-Kherameh area as a sample.

But sometimes the results of this method don't matched with other parameters of balance. This error can be related to the failure in transmissivity calculation.

In the regions that lack observation well network, the amount of groundwater input to the aquifer is sume of the water penetrated to the height, subtracted from the output water from the height, and the volume of water infiltrated into the area between the plain and the aquifer.

Total amount of input groundwater flow to alluvial aquifers in the basin is 1719.69 MCM/y. The maximum input flow is related to Marvdasht-Kherameh study area with 195.35 MCM/y and the minimum input flow is related to Estahban study area with 0.3 MCM/y.

By using Iso-potential ground water map, the amount of output and exchange between aquifer is calculated as follows:

From alluvial aquifer located in Tavabee-Arsanjan and Darian to Marvdasht-Kherameh 0.18 and 0.20 (MCM/y), from alluvial aquifer Seidan-Farough to Tavabee Arsanjan 6 (MCM/y), from South Tashk lake to Abade Tashk-Jahanabad 3.2 (MCM/y), from Estahban to Khir 0.1 (MCM/y), from Dehbid to Ghaderabad-Madar Soliman 13.02 (MCM/y) and from Kavar Maharlu to Gharebagh 0.85 (MCM/y) are transferred per year.

It should be noted that the precise calculation of the groundwater flow exchange among alluvial aquifers depends on a complete network of observation wells, detailed statistics of groundwater level and accurate taking of pumping test and determining the precise hydrodynamic coefficients (especially transmissivity in this area).

The volume of output groundwater flow in Asopas, Khosro-Shirin, Dozkord-Kamphirouz, Beiza-Zarghan, Ghaderabad-Madarsoliman, Saadatabad, Sarpaniran and Seydan-Farough are assumed zero because bedrock postion in the end of plains.

In South Tashk Lake, Khanekat, Khir, Marvdasht-Kherameh, Shiraz and Sarvestan groundwater output flow was toward the lakes in the South Tashk lake, Khanekat, Kheir, Marvdasht-Kherameh, Shiraz and Sarvestan study areas. Based on Iso groundwater level map in Neyriz plain, groundwater flow was from the Bakhtegan lake toward the center of plain (overexploitation and pumping of wells), therefore ground water output flow in this plain was estimated to be zero.

In the study areas with observation network, the input and output groundwater flow was calculated by using Darcy's low, while in study areas without observation network, these parameters were estimated based on input parameters and balancing water budget.

The comparison between previous statistics and recent calculation shows a decrease in the exchange between aquifers. One of the major reasons for that is increase in withdrawal from pumped wells and as result, change in groundwater flow orientation (usually flow is toward the center of plain rather than outlet).

6.3.2 Rainfall infiltration to aquifers

To calculate infilterated rainfall the below equation could be used:

$$I = P - ETC - R \qquad (6\text{-}3)$$

I= Infiltration height

P= Rainfall height

ETC= Rainfall evapotranspiration

R = Runoff height

The plain's excess rainfall is obtained by subtraction of actual evapotranspiration. Remain of rainfall is going out as a runoff from the aquifer or add to the aquifer. In total, according to basin's climate condition, actual evapotranspiration is considerable amount compared to that of rainfall in the basin. Based on sediments type, the notable amount of excess rainfall turns into run off and just small part of rainfall is penetrated into the aquifer. %age of penetrated rainfall was mentioned in the table 51(app (a)), the volume of penetrated water can be calculated based on the aquifer. The total infiltrated water to the aquifer is 1097.13 (MCM/Y), the maximum and minimum infiltrated water belongs to Marvdasht-Kherameh and South of Tashk lake respectively with 287.78 and 0.03 (MCM/Y). According to the aquifer, balance infiltrated water volume is equal to 28% of input water to the aquifer.

6.3.3 Exchange

Exchange between rivers and alluvial aquifers

Exchange between rivers and aquifer have two forms: feeding (infiltration) of surface flow and discharge (drainage) of aquifer. Drainage of groundwater is calculated in Marvdasht-Kherameh, Saadatabad, Ghaderabad-Madarsoliman, Dehbid, Namdan, Beiza-Zarghan, Dozkord-Kampirouz, Khosroshirin, Asopas, Shiraz and Gharebagh. This amount is calculated and presented in the table 53(app (a)). Kor and Sivand rivers are considered the main permanent rivers in the basin that flow inside the above study areas.

In the plains located in the study areas such as Tavabee Arsanjan, Arsanjan, Seidan-Farough, South Tashk Lake, Abade Tashke-Jahanabad, Khanekat, Kheir, Estahban, Neyriz, Tangehana-Pichakan, Marvdasht-Kherameh, Darian, Sarpaniran, Bakan, Gharebagh, Kavar Maharlu, Sarvestan and Goshnegan's that have seasonal rivers, the amount of flood is estimated based on hydrogeological relationships and depending on the aquifer condition, 10-15 % of flood volume has been considered as infiltereted surface water to the aquifer.

The total amount of surface water infiltrated into aquifers was 227.86 (MCM/y) and equal to 5.62 % of total input into the basin.

The maximum and minimum infiltrated water respectively are 63.89 and 0.31 (MCM/y) and belong to Marvdasht-Kherameh and South Tashk lake field studies. Drainage from alluvial aquifer ocurre just in the study areas with permanent rivers.

The drainage of the aquifer is estimated zero in the study areas without permanent river including Tavabee-Arsanjan, Arsanjan, Seidan-Farogh, South Tashk lake, Abade Tashk-Jahanabad, Khanekat, Khir, Estahban, Neyriz, Tangehana-Pichakan, Darian, Srpaniran, Bakan, Kavar Maharlu, Sarvestan and Goshnegan. The total drainage of alluvial aquifer in the basin is 376.28 (MCM/y) equivalent to 7.69% of basin's output.

6.3.4 Water uses and their infiltration into the aquifer

The exploited water from aquifer is used for agriculture, drinking and industry. Part of consumption will return to aquifer storage if it is used in the region. Agriculture return depends on irrigation method, soil type and permeability and kind of planet, area under cultivate and planets water requierments.

In the studied basin, irrigation method in the vast part of the basin is mostly traditional.

In the basin's study areas, different return agriculture coefficient is applied. This amount in the basin has a range between 20-30 % of agriculture water. Actually, there isn't precise information about agriculture return water in this basin and this amount is obtained based on the expert idea, previous studies and reports. Given the fact that the waste water disposal in the basin is performed manily through absorbent wells in drinking and industrial sections, 80% of consumed water in these sections has been assumed as infiltration into the alluvial aquifer.

The total amount of water consumption in the basin's plain was 5256.55 MCM, of which 95% (5029.52 MCM/y) is used for agriculture, 3% (168.59 MCM/y) is used for drinking and 2% (58.14 MCM/y) is used for the purpose of industry. In the table 55(app (a)), different usage of water in the basin is presented.

Water consume in the heights are neglibale. Water withdrawal from heights is about 728.71 MCM/y, out of which 587.95, 128.84 and 11.92 MCM/y are respectively related to agricultural, drinking and industry uses.

The agricultural return of water in the basin is 1205.37 MCM/y. This amount equivalent to 29.71 % of aquifer recharge. The maximum amount belongs to the Marvdasht-Kherameh plain with 292.20 MCM/y.

Penetration from drinking and industry uses is 226.78 MCM/y. This amount is equivalent to 5.59% of recharge to the aquifer. The maximum amount belongs to Shiraz plain with 65.47 of total recharge water to aquifers. The highest infiltrated water is related to Shiraz study area with 65.47 MCM/y.

6.3.5 Withdrawal of groundwater

The withdrawal from the alluvial aquifer depends on wells, springs and Qanats. The largest volume of water in the alluvial aquifer is withdrawal from wells compared to the springs and Qanats.

Total withdrawal of alluvial aquifers is presented in the table 56(app (a)). The total volume of exploited water is 4371.46 MCM/y, of which 3747.6 is related to wells, 293.57 is related to springs and 285.85 MCM/y is related to Qanat. The maximum and minimum amounts belong to the Marvdasht-Kherameh and South Tashk lake plain.

6.3.6 Groundwater evaporation

Iso depth map of groundwater is applied to calculate evaporation. Groundwater evaporation is measured in the areas that groundwater depth is between 0-5 m. It should be noted that in the depth of less than 5m, groundwater evaporation doesn't occur.

The total amount of evaporation in the basin was 68.73 MCM/y. These phenomena are seen in Marvdasht-Kherameh, Seidan-Farough, South Tashk lake, Namdan, Beiza-Zarghan, Asopas, Shiraz and Gharebagh study areas. Marvdasht-Kherameh with 33.37 MCM/y has had the largest amount of evaporation in the basin. This is due to fine grained sediment in the center of plain and considerable extent of evaporating zone.

6.3.7 Groundwater level fluctuations and changes in storage

Unit hydrograph is representative of groundwater fluctuations in the specific period. The goal of unit hydrograph preparation is to display groundwater level, to determine the maximum and minimum period of water level and to estimate groundwater level loss in the specific period.

In study areas with observation network of wells, unit hydrograph that is shown in the figures (34 to 56 (app (b))) is drawn. According to the hydrographs, the least water level has been in October and September (due to decline in rainfall and also extraction water for agriculture) and the most water level has been in April and May (due to rainfall and melting snow). In the other word, precipitation and groundwater extraction are the major reasons behind groundwater fluctuation in the basin. Based on unit hydrograph, in all of study areas groundwater level decline is considerable.

According to the table 53 (app (a)) groundwater balances in alluvial aquifers of the basin is totally -838.38 MCM/y. Unit hydrographs also shows dramatic drop in groundwater level.

6.4 General water balance in the basin

General water balance determines the portion of each input and output factors in the basin. The input factors include the volume of surface and transmitted water. Input groundwater flow and the output factors include evapotranspiration, surface and groundwater flow to areas outside or neighboring area. The general water balance equation is as follows:

(6-4) $$P + Q_{SI} - Q_{UI} - E - Q_{SO} - Q_{UO} = \pm\Delta$$

P= The volume of precipitation in the balance range

Q_{SI}= Volume of surface or transmitted flow to the balance range

E = Evapotranspiration in different forms

Q_{SO}= Volume of out going surface and transmitted flow from the balance range

Q_{UO}= Volume of groundwater out going flow

$\pm\Delta$= Changes in storage of groundwater or surface water

The result of general water balane is presented in the table (6-8).

6.5 Input factors

6.5.1 Precipitation

Precipitation is one of the important factors in water balance. The amount of precipitation is calculated based on the weight method using the Iso precipitation map in GIS. According to the statistics of the base period (1970-2013) and precipitation map, precipitation is calculated in the plains and heights and is inserted into the table 57(app (a)). The total volume of that is 6576.26 MCM/y, of which 3080.48 and 3495.78 MCM/y is related to the plains and heights.

6.5.2 Surface water

Input water doesn't limit to precipitation. The surface and groundwater flows from adjacent area also enters the area and participate in input water. On the other hand, a plain's output is an input of plain in the downstream. Input surface flow to the area can be calculated by using hydrometric station statistics if there is a permanent river in the study area. Input surface flow is calculated in the study areas without permanent river by using discharge-area-precipitation relationship. The study area is a close basin and there isn't any input and output surface flow from another basin. Surface water is transmitted only between basin's plains.

Input and output surface flow is showen in table 57(app (a)). Discharge-area-precipitation relationship is used to calculate surface flow in Tavabee-Aranjan, Khir, Tangehana-Pichakan and Goshnegan. Hydrometric stations' statistics are used to calculate surface flow of Marvdasht-Kherameh, Saadatabad, Ghaderabad-Madarsoliman, Dehbid, Dozkord-Kamphirouz and Ghareebagh. The maximum input flow is 707.69 MCM/y belongs to Marvdasht-Kherameh plain in which surface flow enters the plain from Dozkord-Kamphiroz, Saadatabad, Darian and Beiza-Zarghan. The maximum output flow also belongs to Marvdasht-Kherameh with 442.62 MCM/y. Surface flow from this plain enters the Bakhtegan lake.

6.5.3 Input groundwater flow

Input groundwater flow is the combination of water transferring from aquifer to aquifer or from height to height. Groundwater flow is calculated by using Darcy low. Groundwater level map and transmissibility coefficient (T) are used to calculate groundwater flow. There is groundwater flow transferring between heights of filed studies in the basin as below:

Water from Tavabee Arsanjan's heights flows into Seidan-Farough and Abade Tashk study area. From Estahban's heights water enters Kheir. From Ghaderabad-Madarsoliman and Sarpaniran heights water flows into the Saadatabad. Groundwater flows from Saadatabad and Marvdasht-Kherameh into Seydan-Farough. Moreover, water flows from Seydan-Farough into Tavabee-Arsanjan. Groundwater flows from Namdan's heights into the Khosroshirin and Dehbid. Water flows from Dozkord-Kamphirouz into Beiza Zarghan.

Groundwater flow transfers between alluvial aquifers of study areas as below:

From Seydan-Farough flows into Tavabee-Arsanjan. Marvdasht-Kherameh receives groundwater flow from Tavabee-Arsanjan and Darian. From Khanekat-Kheir and Marvdasht-Kherameh water flow into the Tangehana-Pichakan. Groundwater transfres from Shiraz and Sarvestan into Goshnegan (Maharlu lake).

Due to overextraction of groundwater in Neyriz, salt water from Bakhtegan lake flows into the plain and this phenomenon causes deteroration of groundwater quality.

6.5.4 Transfering water to study areas

In the Tashk-Bakhtegan and Maharlu lakes basin, there is no output from heights and aquifers located outside the basin that flows into the basin.

6.6 Output factors

6.6.1 Evapotranspiration

Evapotranspiration is one of the important output factors in water balance. Evapotranspiration occurs as an output in different forms including evapotranspiration of precipitation, aquifer and free waters.

6.6.1.1 Evapotranspiration of precipitation

Evapotranspiration of precipitation is calculated by using Torent-White method. The total amount of that is 6569.4 MCM/y that constitutes 84.74% total amount of evapotranspiration.

The maximum and minimum amount belong to Marvdasht-Kherameh and South Tashk lake with 795.58 and 37 MCM/y respectively.

6.6.1.2 Evaporation of free water

In the study areas with natural or artificial lakes, evapotranspiration of surface water is calculated by using statistics of representative evaporation stations. This amount is calculated in study areas such as AbadeTashk-Jahanabad (**Tashk lake**), Tangehana-Pichakan (**Bakhtegan lake**), Namdan (**Kaftar lake**), Goshnegan **(Maharlu lake**) and Dozkord-Kamphirouz (**Dorodzan dam lake**).

The total amount of free water evaporation in the basin is 1144.48 MCM/y that constitutes 14.7% of total evapotranspiration. Since Bakhtegan lake is the vastest lake in the basin, the maximum amount of free water evaporation belongs to this lake with 722.44 1144.48 MCM/y. The amount of evaporation from Tashk, Kaftar, Mahrlu and Drodzam dam lakes are 108.50, 60.7, 81.01 and 171.83 1144.48 MCM/y respectively. It should be noted that the above amounts are actual evaporation from free waters based on input to the lakes. It is clear that in the drought period, the actual evaporation is lesser due to decrease in precipitation and input rate to the lakes.

6.6.1.3 Groundwater evapotranspiration

Groundwater evapotranspiration is calculated in the aquifers that water level depth is less than 5 meters. This amount is calculated in Seydan-Farough, Abade Tashk-Jahanabad, Marvdasht-Kherameh, Namdan, Beiza-Zarghan, Khosroshirin, Asopas, Shiraz, Gharebagh and Sarvestan. In total, the groundwater evapotranspiration is 69.03 MCM/y that constitutes less than 1 % of the entire basin's evapotranspiration.

6.6.2 Pure consumption

Pure consumption of water is a type of evapotranspiration from different parts including agriculture, drinking and industry. Water consumption for different purposes is presented in the table 55(app (a)). It should be noted that because of lack of detailed information in area under cultivation and crop pattern, net consumption can't be calculated precisely. Net consumption is measured through subtraction of infilteration from total consumption. The obtained amount might have certain extent of miscalculation which is considered inevitable.

6.6.3 Output flow of Surface, underground and transferred water

6.6.4 Output surface flow

Output surface flow is presented in the table 57(app (a)). The surface flow is calculated in the study areas with permanent river, given the statistics of hydrometric stations. Experimental relationship is used to calculate output surface flow in study areas without hydrometric stations. Other than Abade Tashk-Jahanabad, Tangehana-Pichakan, Bakan and Goshnegan study areas in which output surface flow is zero, in the other study areas water enters the basin's lakes.

6.6.5 Underground output flow

Groundwater is transferred to the basin through different forms such an aquifer to adjacent aquifer or from heights to the adjacent heights. There is underground flow from heights of Arsanjan, Seidan-Farough, South Tashk lake, Estahban, Marvdasht-Kherameh, Saadatabad, Ghadeabad-Madarsoliman, Namdan, Dozkork-Kamphiroz and Bakan study areas' heights into the heights of adjacent area. Meanwhile, there is underground flow from aquifer of Tavabee Arsanjan, Seidan-Farough, South Tashk lake, Estahban, Drian, Dehbid, Kvarar Maharlu study areas into adjacent alluvial aquifer. There is underground flow from from South Tahk lake, Khanekat, Khir, Marvdasht-Kherameh, Shiraz and Sarvestan into the closed lakes.

6.6.6 Transferred flow

From Dozkord-Kamphirouz (Drodzan dam lake) 31 MCM/y water is transferred to Shiraz, and from Marvdasht-Kherameh 154.45 MCM/y water is transferred via a channel to the Beiz-Zarghan study areas.

6.7 Changes in water reserves

Hydrograph of alluvial aquifer is used to calculate changes in water reservers. The hydrographs show dropping in groundwater level especially during recent years. It isn't possible to draw hydrograph in study areas without observation wells network such as Kanekat, Sarpaniran, Khoshroshirin, Goshnegan, Dozkord Kamphirouz, South Tashk lake, Abade Tashk- Jahan abad. Based on table 57(app (a)), water balance in the basin in water year 2012-2013 for 42 years precipitation is -838 MCM. This amount actually shows shortage of water in the basin.

7. Agriculture

Islamic Republic of Iran (IRI) is located on arid and semi-arid regions of the world. The average annual precipitation is 252 mm (one-third of the world average). While, 179 mm of precipitation is lost directly through evaporation. In other words, 71% of precipitation is lost due to evaporation; the annual potential evaporation varies between 1500 to 2000 mm.

Drought and water shortage is a climate fact in Iran due to increasing needs to water in different parts; drought problem will be harsher in the coming years. So that, according to the International Water Management Institute (IWMI), in order to maintain its current position in 2025, Iran should increase extracted water resources by 112%. The main reason for water shortage are population growth, decrease in precipitation, over-extraction of groundwater resources, using traditional irrigation methods, low irrigation efficiency resulting in huge amounts of wasted water, incorporate crop pattern that does not match to climate condition and water resources.

Therefore, in such circumstances, one of effective and practical solution to manage water is an efficient use and saving in water consumption.

Agriculture sector plays a key role in Iran's economy and consumes more than 90 % of water in Iran. About 37 million hectare (Mha) of the 165 million hectare (Mha) of the country's land areas are suitable for irrigation and agriculture. The areas include 20 Mha irrigated and 17 Mha dry-land. Moreover, about 18.5 Mha are currently devoted to horticulture and field crops production. The total cultivated distribution is as follows: 6.4 Mha are under annual irrigated crops, 2 Mha horticultural crops, about 6.2 million Mha under annual dry-land crops and the remaining 3.9 Mha are fallow (Abassi & Sohrab, 2011). Due to inefficiency of traditional irrigation methods and poor efficiency of water conveying systems; about 60% of the valuable water is lost and only 40% of available water is practically utilized for agricultural production purpose. The overall irrigation efficiency in Iran varies between 31 to 57% for the different provinces (Abbasi et al., 2006), which is lower than the world irrigation efficiency average. This amount is 45% and 60% in developing and developed countries respectively.

To evaluate agriculture water consumption and suggest a management plan, it is necessary to identify the main characteristics of water management and quantify these characteristics with an appropriate method. Irrigation efficiency, agriculture water use efficiency, water consumption in agriculture sector and sustainable development of modern irrigation techniques are the most important key indicators in strategic planning of supplying, allocating and proper use of water in different sections including agriculture.

To evaluated agriculture water consumption and suggest a management plan, it is necessary to identify the main characteristics of water management and quantify these characteristics with appropriate methods. Irrigation efficiency, agriculture water use efficiency, water consumption in agriculture sector and the sustainable development of modern irrigation techniques are the most important key indicators in strategic planning related to water supply, allocation and proper use of water in different parts including agriculture.

In this chapter agriculture, optimum crop pattern and effective parameters of water consumption in agriculture in Tashk-Bakhtegan and Maharlu lakes basin are evaluated. For this purpose, Marvdasht-Kherameh palin is selected as objective because this plian is the vastest plain in the bain. It is, moreover, an important part of Iran in terms of agriculture. (Figure 7-1 shows Marvdasht-Kherameh position in the basin).

7.1 Marvdasht-Kherameh plain

Located in Fars province, south of Iran, Marvdasht-Kherameh plain is an important agricultural area in Iran. The total area is 3941 Km^2 of which 2452.50 km^2 is plain and 1488.50 km^2 heights. The average annual precipitation is 404 mm and the average temperature is 16.2ºC. Two important rivers -Kor and Sivand- current in this plain. Kor and Sivand rivers are two important rivers that current in this plain. Kor is a valuable river in the south of Iran originating from mountains in the north of Fars province and flows into the Bakhtegan lake. It has always played an important role in the economy, agriculture and providing drinking water supply and has had an important effect in environmental issues, particularly in Bakhtegan lake ecosystem.

This plain is bounded from southeast to South Tashk lake and Khanekat, from south to Sarvestan, from southwest to Goshnegan, from west to Darian and Beiza-Zarghan, from northwest to Dozkord-Kamphirouz and Bakan, from north to Asopas, from northeast to Saadatabad and from east to Seidan-Farough, Tavabee Arsenjan and Tangehana-Pichakan.

The most important cities located in this palin are Marvdasht, Kherameh, Ezadkhast, Takhtjamshid and Emamzadeesmael (Marvdasht-Kherameh position is shown in figure (7-1)).

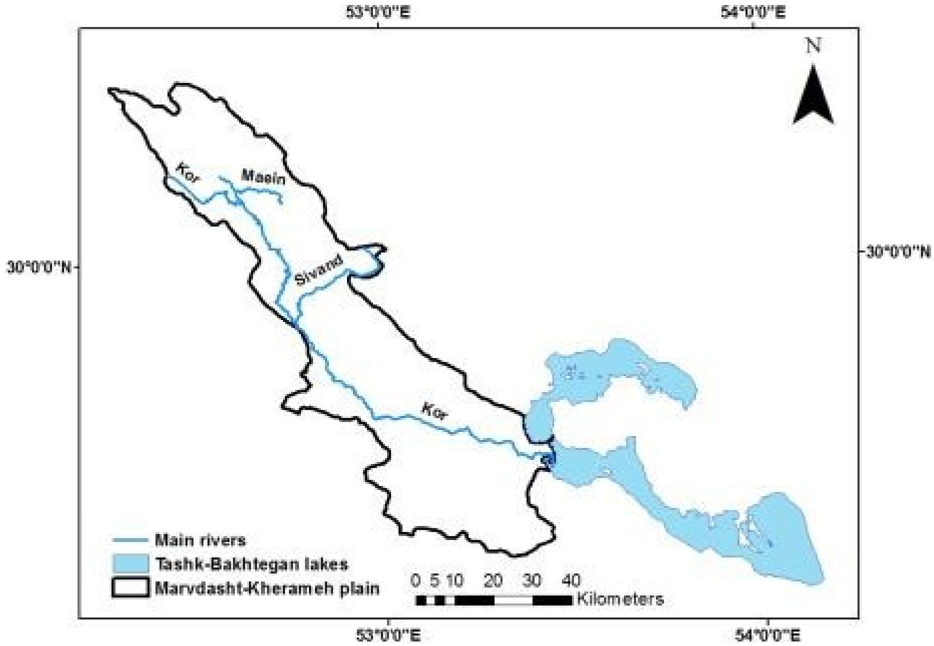

Figure 7-1: Marvdasht-Kherameh plain setting

7.1.1 Groundwater balance of Marvdasht-Kheramah area

Knowledge of water balance is necessary to develop water resources and evaluate the feasibility of civil and agricultural development projects. Water balance is result of meteorology, hydrology and hydrogeology related studies. Therefore, different parameters directly or indirectly are involved in this calculation. Balance water may be positive or negative, or equal to input and output.

Marvdasht-Kherameh plain is divided into two parts including Marvdasht and Kherameh. Kherameh plain is located in the south of this area and is close to Bakhtegan lake. Therefore, groundwater is not of good quality and towards the lake, there is a dramatic increase in salinity due to high rate of evaporation and salt water intrusion.

Marvdasht plain is a vast plain divided into four smaller plains: Dashtak-Drodzan, Maien-Bidkal, Dashtbal- Lanetavos and Marvdasht-Korbal from northwest to southeast respectively (figure7-2: shows aquifers of Marvdasht-Kherameh plain). According to the map of groundwater level, groundwater direction is from northwest to the southeast of plain toward Bakhtegan Lake. Kor and Sivand are two permanent rivers that feed this plain and play an important role in its agricultural fertility. Ground water exploitation has increased in this area in recent years due to increasing need to supply food for the growing population.

To evaluate groundwater changes, hydrograph of plain – demonstrated in Figures (41to44(app (b))) was provided using water level in 60 observation wells located in this area. According to the hydrograph in Kherameh area, groundwater level has declined in recent years due to a drop in precipitation and overexploitation of groundwater. In Marvdasht plain the hydrograph shows a decline in groundwater level in all four plains, especially in Marvdasht-Korbal and Dashtbal-Lanetavos located in the south of plain. Decrease in precipitation and high demand and overuse of groundwater in this plain has resulted in this drop in groundwater level.

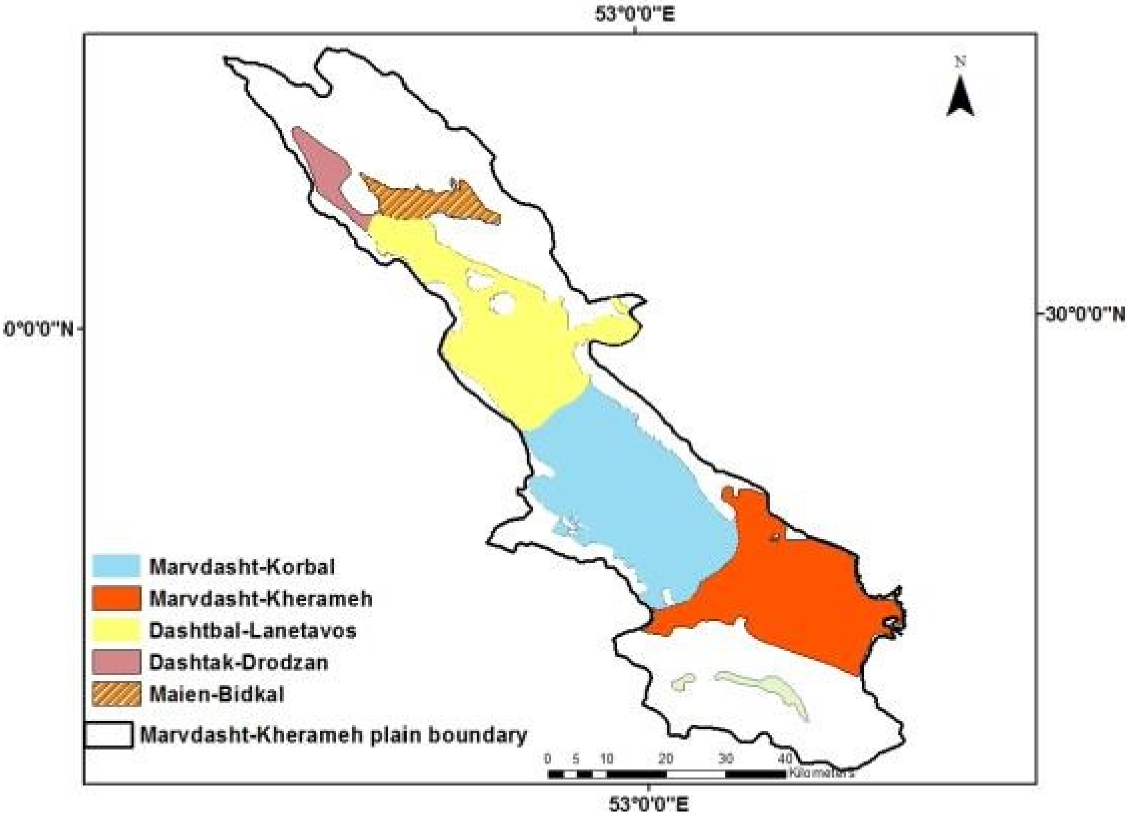

Figure7-2: Aquifers of Marvdasht-Kherameh plain

7.1.1.1 Hydroclimatology balance

% of rainfall infilteration, runoff and evapotranspiration in plain and height are shown in the table 58(app (a)). Hydro climatology balance is presented in the table 59(app (a)). %age of hydro climatology parameters were determined based on geological characteristics, land cover, land use, slope ….

7.1.1.2 General water balance

General water balance calculated by using hydro climatology and alluvial aquifer balance and the result is presented in table 60(app(a)). Based on the balance, recharge and discharge are 2260 (MCM/y) and 2297.9 (MCM/y) respectively. Thus this aquifer faces water shortage of -38.7 (MCM/y). Water cycle diagram is presented in the figure (7-3).

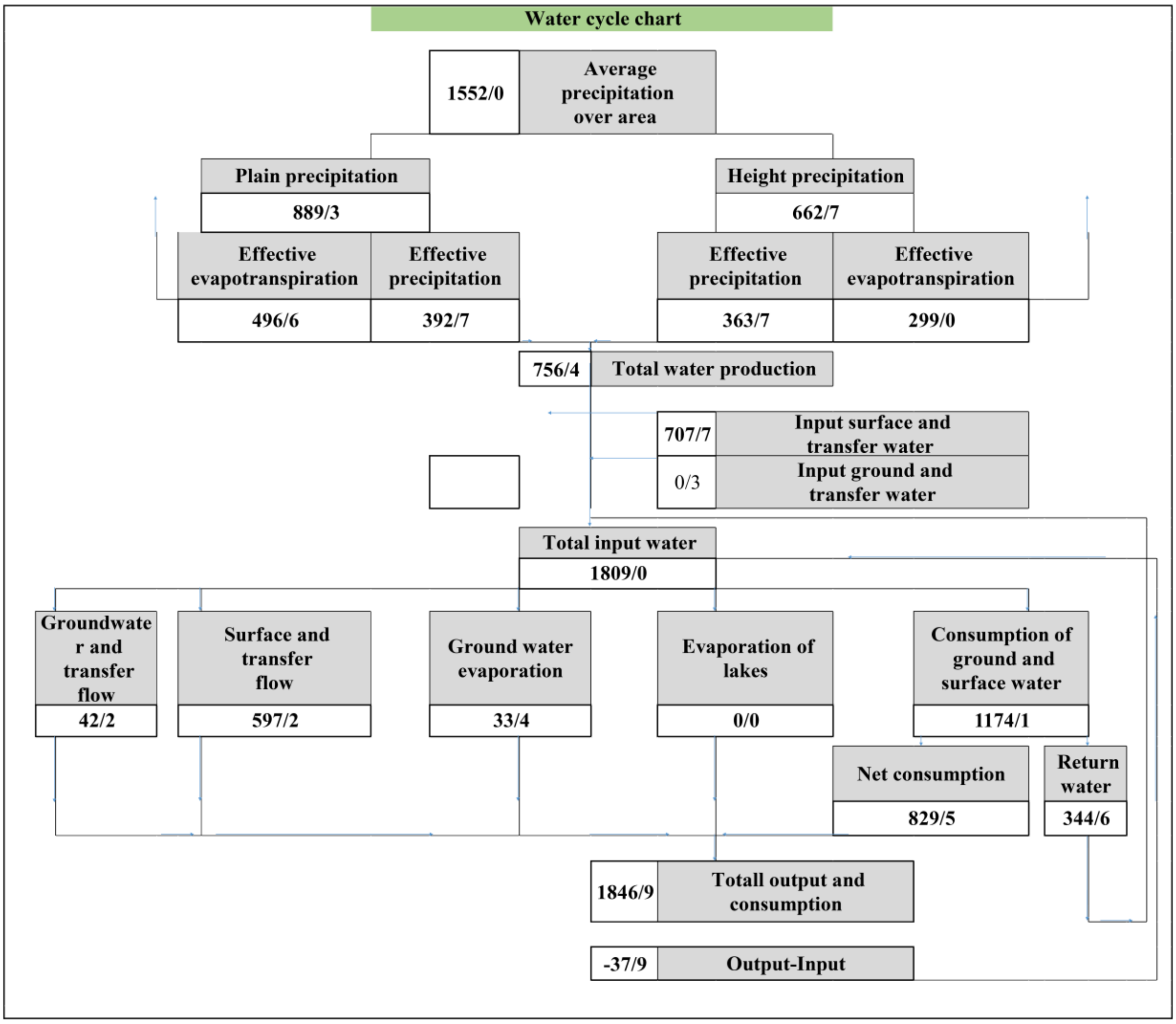

Figure 7-3: Water cycle graph in Marvdasht-Kherameh plain

7.1.2 Quality of water resources (surface and groundwater)

Study area is located in the vast part of Tashk-Bakhtegan and Maharlu lakes basin and from the east is bordered to Bakhtegan lake. The wide extent and strain of area caused that area in north western part with Dozkord-Kamphirouz, Asopas and Bakan bordered (these study areas have the best water resources quality in the basin) while, in the southeast due to bordering with Bakhtegan lake, the quality is not appropriate. Kor and Sivand rivers are the main river in this area that flow into Bakhtegan lake (figure 7-4 shows river path in study area).

Kor river is the largest and wateriest river in the basin originated from mountains in Dozkord-Kamphirouz and enters Marvdasht-Kherameh and finally flows into Bakhtegan lake. Sivand river originated from Saadatabad lain and enters Marvdasht-Kherameh basin. Sivand and Kor river join each other in center of plain.

Kor river has always played an important role in the economy, agriculture and providing drinking water supply and has had an important effect in environmental issues, particularly in Bakhtegan lake ecosystem. Given the importance of Kor river, a hydrometric station has been established on this river in order to gather chemical and hydrologicl data.

Based on statistics, Kor river has a good quality from enterance point of the plain to Polekhan (joint place of Kor and Sivand river). Calcic Bicarbonate is type and facies of water. Based on Shuller diagram, the river's water quality for agriculture is good (C2S1), while drinking water quality is classified as group II. This is while Sivand river is located before Polekhan doesn’t have suitabale quality for drinking and type of water is Sodic Bicarbonate.

The main reason for Sivand river's unsuitable water is the waste water entering Sivand river from Ghaderabad-Madar soliman, Saadatabad, Sarpaniran and Seidan-Farough.

Water quality reduced in path of Kor river toward Bakhtegan lake. Type of water in end of plain turns into to Sodic Coloride. In Kherameh (end of plain) water can be use only in an emergency condition for drinking and just is used for agricultural purposes in special condition.

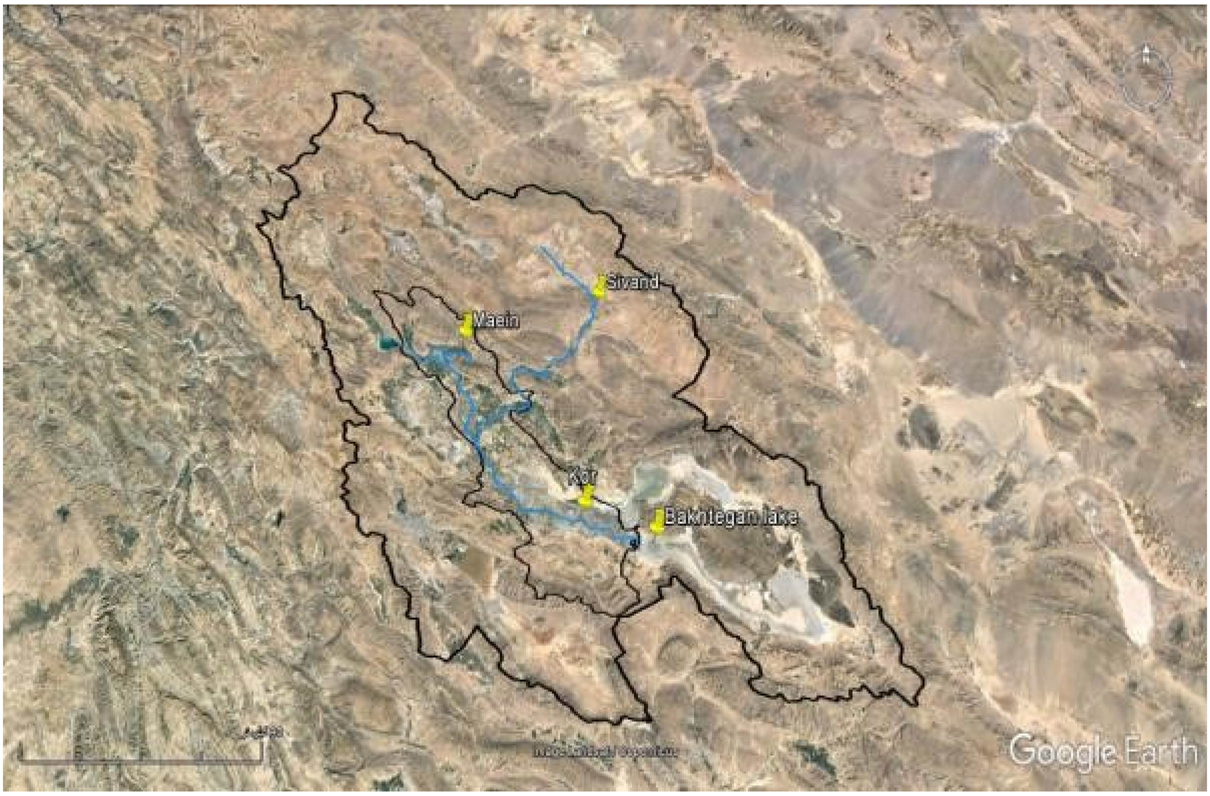

Figure 7-4: Rivers path in study area

7.2 Assessment farm and garden land extension in study area

7.2.1 Assessment of farm land extension

Table (7-1) presents extension of irrigated and rain fed land. The total extend of farm land in study area is estimated 104508 ha of which 101292 and 3217 ha are irrigated and dry farming land respectively. In other words, irrigated land occupied 97% of area which represents superiority irrigated farming to rain fed farming and the main reason behind this is lack of precipitation in this area.

Table 7-1: Extension of irrigated and rain fed land

Study area	**Irrigated agriculture**		**Dry farming agriculture**		**Total**	
	Extend	**%**	**Extend**	**%**	**Extend**	**%**
	101292	97	3217	3	104508	100

7.2.1.1 Irrigated lands extension

Table (7-2) shows the extension of irrigated land for different types of crops. As mentioned above, the total extension of irrigated land is 101292 ha of which 58.63% is allocated to wheat, 15.75 and 11.11 % is respectively allocated to rice and barley.

Table 7-2: Extend and type of product

Product	**Area(hectares)**	**%**
Wheat	59389	58.63
Barley	11257	11.11
Rice	15940	15.74
Maize	2478	2.45
Sugar beet	2547	2.51
Cereals	25	0.02
Cucumber	410	0.4
Tomato	3500	3.45
Onion	227	0.22
Corn silage	3346	3.3
Alfalfa	1722	1.7
Potato	69	0.07
Total	10292	100

7.2.1.2 Rain fed farming land extension

Due to low amount of precipitation rainfed farming doesn't play an important role in agriculture in this area and only 3217 ha of farming land belongs to rainfed farming. Wheat, barely, pea and lentil are crops that are cultivated in this area as a dry farming. Lentil and barley with 51.45 and 38.2 % are the driest farming products.

7.2.2 Assessment of garden land area

Table (7-3) shows garden lands. The total area of garden is 5703 ha of which 4756 ha (83.4 %) is irrigated garden and 947 ha (16.6 %) is rain fed garden. Most irrigated garden area belongs to pomegranate, apple and olive with 26.1, 20.61 and 14.67 % respectively. In this area, only almond and grapes are planted as rain fed.

Table 7-3: Garden extension in study area

	Irrigated garden		**Rain fed garden**		**Total**	
	Area (hectares)	%	Area (hectares)	%	Area (hectares)	%
Study area	4756	83.4	947	16.6	5733	100

7.3 Assessment of crop pattern in study area

The total area of agricultural lands (both irrigated and rain fed) is 110241 ha of which annually 108878 ha is under cultivate. The planet density in this area is 98%, that reflects the fact that study areas are serious and continuously under cultivate.

Table 61(app (a)) shows crop pattern in irrigated area. In study area, 94.8% of area is under cultivation crop and 5.5 % is gardens. Wheat is the dominant crop and apple is dominant garden product.

7.3.1 Irrigation calendar

Table 62(app (a)) represents irrigation calendar of the study area. Irrigation scheduling for each product is indicated at this table. At the mentioned times irrigation is necessary. As the table shows, the most of products don't need irrigation from October to February because these periods are rainy months.

7.3.2 Plant water requirement

The crop water need (ET crop) is defined as the depth (or amount) of water needed to meet the water loss through evapotranspiration. In other words, it is the amount of water needed by the various crops to grow optimally.

The crop water need always refers to a crop grown under optimal conditions, i.e. a uniform crop, actively growing, completely shading the ground, free of diseases, and favorable soil conditions (including fertility and water). The crop thus reaches its full production potential under the given environment.

The crop water need mainly depends on:

- The climate: in a sunny and hot climate crops need more water per day than in a cloudy and cool climate
- The crop type: crops like maize or sugarcane need more water than crops like millet or sorghum
- The growth stage of the crop; fully grown crops need more water than crops that have just been planted (FAO, 2009 and George et al., 2000).

7.3.2.1 Influence of climate on crop water requirement

The major climatic factors that affect crop water needs are:

- Sunshine
- Temperature
- Humidity
- Wind speed

The highest crop water needs are thus found in areas which are hot, dry, windy and sunny. The lowest values are found when it is cool, humid and cloudy with little or no wind.

The influence of the climate on crop water needs is given by the reference crop evapotranspiration (ETo). The ETo is usually expressed in millimeters per unit of time, e.g. mm/day, mm/month, or mm/season. Grass has been taken as the reference crop.

There are several methods to determine the ETo They are either:

- Experimental, using an evaporation pan
- theoretical, using measured climatic data, e.g. the Blaney-Criddle, Penman-Monteith methods

7.3.2.1.1 Evaporation pan

In this method, different kinds of pans are used to measure the crops water requirements. Kp represents the pan coefficient depending on the kind of pan, solar radiation, wind, humidity and the surroundings environment.

Equation (7-1) $$ET_O = K\ pan \times E\ pan$$

7.3.2.1.2 The Penman equation

ET_0 the reference rate is calculated by using the Penman Equation which is related to the climatic parameters includes temperature, solar radiation, wind speed and humidity.

A variation of this equation, published by the FAO is:

Equation (7-2): $$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma\frac{900}{T+273}u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)}$$

Where

ETo: reference evapotranspiration [mm day-1],
Rn: net radiation at the crop surface [MJ m-2 day-1],
G: soil heat flux density [MJ m-2 day-1],
T: air temperature at 2 m height [°C],
u2: wind speed at 2 m height [m s-1],
es: saturation vapour pressure [kPa],
ea: actual vapour pressure [kPa],
es-ea: saturation vapour pressure deficit [kPa],
D: slope vapour pressure curve [kPa °C-1],
g: psychrometric constant [kPa °C-1].

7.3.2.1 3 Blaney-Criddle Method

Another method to calculate reference crop evapotranspiration (ETo) is:

Equation (7-3): ET_o = p (0.46 T mean +8)

ETo= Reference crop evapotranspiration (mm/day)

Tmean= mean daily temperature (°C)

p= mean daily %age of annual daytime hours.

As we may notice from the above equation, in this method only temperature and daytime houres are used. Therefore, it is not a very accurate estimation of the reference evapotranspiration rate.

7.3.2.1.4 Estimating the water requirements of the crop

To evaluate water requirement of plants and crops, meteorological statistics of stations located at the plain have been collected from meteorology organization of Fars province. Information on area under cultivation, type of products and irrigation methods have been collected from agriculture organizations of Fars province.

The amount of water required for agriculture in the study area has been calculated using CROPWAT program.

CROPWAT is a program for calculating crop water and irrigation requirements based on soil, climate and crop planning time. In addition, the program allows the development of irrigation schedules for different management conditions and the calculation of water supply scheme for various crop patterns. CROPWAT 8.0 can also be used to evaluate farmers' irrigation practices and estimate crop performance under both rain fed and irrigated conditions.

In 1996, Iran's government developed the Iranian Water Directive "IWD" (Netwat) for all basins in the whole of its territory. In this document, ET based on the average meteorological data and some standard FAO parameter is calculated (Alizadeh and Kamali, 2007). The implementation of this method has not been successful due to a number of major shortcomings, including:

- Lack of adaption of some parameters in CWR, such as crop coefficient (Kc), to local conditions
- Using fixed amount of crop water requirement for every year (dry, wet & normal years)
- No consideration of CWR distribution in space all over the basin
- Using one meteorological station as a reference station for whole of the basin (Agdasi, 2010).

Water requirement for each product calculated from CROPWAT software. Irrigation efficiency is below 50 %, being 44 % for crop products and 60 % for garden products as irrigation method in most parts of the plain, which is considered traditional. It can be drawn from previous studies and experts' comments that agricultural return water is about 25 %.

Water requirement for agriculture in the study area was calculated using equation (7-4), where ET is the net irrigation water required for plants (cubic meters per hectare) extracted from CROPWAT8.0 and Ea is the irrigation efficiency.

Equation (7-4): $$CWRi = \frac{\mathrm{ET}}{\mathrm{E}a}$$

After calculating the amount of water required for each agricultural product in the study area, water consumed for crops and garden products is calculated using equation (7-5), and the results regarding crops and garden products are presented in tables 63 and 64(app (a)) respectively.

Equation (7-5): $$VWCi = \frac{\mathrm{CWRi}}{\mathrm{Yi}}$$

Y is the average rate of production in the study area. The total water consumption for each product is calculated by water consumed for each kilogram of products multiplied by area under cultivation.

The amount of water required for growing crops and garden products in the study area was 1179.32 and 61.87 million cubic meters respectively. Totally, 1232.72 (million cubic meters) was used for agriculture that has been provided from groundwater (914 million cubic meters) and surface water (318 million cubic meters). Thus, groundwater is the main source of water for agriculture and determining the best crop pattern and efficient irrigation system is really important to manage water. Tables 2 and 3 show water consumed for growing crops and garden products in agriculture sector. Regarding crops; wheat, rice and barley consume 56, 20 and 8.5 % of water respectively. Apple is the most water consumer among the garden products. Tables 7-4 and 7-5 show water consuming in crop and garden products.

Table 7-4: Water consumption in crop products

column	Product	Area under cultive (ton)	Water requirement (m3 / hec)	Yield (kg/hec)	Consuming water (m3/kg)	Total consuining waterc(milion m3)
1	Wheat	59389/30	11164/77	3631/21	3/07	663/07
2	Barley	11256/50	9000/00	3461/28	2/60	101/31
3	Rice	15940/30	14863/64	5721/03	2/60	236/93
4	Maize	2478/20	12051/14	7608/51	1/58	29/87
5	Pea	2/50	8829/55	1432/34	6/16	0/02
6	Beans	22/10	10977/27	1217/24	9/02	0/24
7	Lentil	0/00	11079/55	153/76	72/06	0/00
8	Cucumber	410/40	17284/09	13943/62	1/24	7/09
9	Oil seed	111/70	5965/91	5471/00	1/09	0/67
10	Potato	69/00	9107/39	30492/59	0/30	0/63
11	Onion	227/20	9920/45	96263/01	0/10	2/26
12	Tomato	3500/10	10315/91	54079/22	0/19	36/11
13	Another vegtable	380/20	12426/14	42305/38	0/29	4/72
14	Alfaalfa	1722/40	10568/18	11474/27	0/92	18/20
15	Corn silage	3346/00	17028/41	86275/67	0/20	56/98
16	Suger beet	2547/30	8335/23	64262/10	0/13	21/23

Table 7-5: Water consumption in garden products

column	Product	Area under cultive (ton)	Water requirement (m3 / hec)	Yield (kg/hec)	Consuming water (m3/kg)	Total consuining waterc(milion m3)
1	Apple	980/49	14337/50	20807/56	0/69	14/06
2	Quince	47/30	13037/50	13529/99	0/96	0/62
3	Plum	38/77	10262/50	330/71	31/03	0/40
4	Sparkling Peach	291/25	9300/00	11240/97	0/83	2/71
5	Apricot halves	240/50	11900/00	11559/93	1/03	2/86
6	Nectarines	29/83	7112/50	14980/45	0/47	0/21
7	Grape	428/90	9300/00	9090/43	1/02	3/99
8	Pomegranate	1239/53	12025/00	12166/27	0/99	14/91
9	Persimmon	20/95	9012/50	9547/16	0/94	0/19
10	Pistachios	31/06	11212/50	225/36	49/75	0/35
11	Almonds	1067/32	11425/00	683/97	16/70	12/19
12	Walnut	546/66	10175/00	2194/20	4/64	5/56
13	Olive	697/83	5462/50	475/93	11/48	3/81
14	Rose	3/34	5650/00	1497/38	3/77	0/02

7.5 Investigation of parameters affecting on water consumption in agricultural use

7.5.1 Irrigation efficiency

Irrigation efficiency is a critical measurement of irrigation performance in terms of the required water to irrigate a field. The value of irrigation efficiency and its definition are important to the societal views of irrigated agriculture. Irrigation efficiency is defined in terms of: 1) the irrigation system performance, 2) the uniformity of the water application, and 3) the response of the crop to irrigation. Each of these irrigation efficiency measures is interrelated and will vary with scale and time.

Irrigation efficiency affects the economics of irrigation, the amount of water needed to irrigate in a specific land area, the spatial uniformity of the crop and its yield, the amount of water that might percolate beneath the crop root zone, the amount of water that can return to surface sources for downstream uses or to groundwater aquifers that might supply other water uses, and the amount of water lost to unrecoverable sources (salt sink, saline aquifer, ocean, or unsaturated vadose zone). Irrigation efficiency is a substantial engineering term that involves understanding soil and agronomic sciences to achieve the maximum benefit from irrigation. The boost understanding of irrigation efficiency can improve the beneficial uses of limited and declining water resources to enhance crop and food production from irrigated lands.

Today despite progress made in science and technology and using modern irrigation techniques, in Iran and many countries in the world, even in developed countries, the main parts of agricultural land are still irrigated with surface and traditional irrigation methods. So that in Iran more than 85 % of lands are irrigated by surface irrigation methods that have low irrigation efficiency.

By increasing irrigation efficiency, considerable amount of water can be returned to the production cycle and large part of agricultural water demand and other sectors is retuned to production cycle. A large part of agricultural water is supplied from this way. It is quite clear that in order to achieve this goal, the first and most important step is to determine the efficiency of existing irrigation systems, to evaluating them to make decision related to optimize water use and cropping pattern and finally to reduce the loss of irrigation water. In developing countries and especially in Iran, much of attention has been paid to physical development of irrigation systems. This is why, issues such as the operation of the network, participation of farmers in the management, maintenance and operation of the network have been less considered. The consequence of such attitude is the reduction of irrigation efficiency to about 30 % and destruction of physical infrastructure network.

Fatemi & Shokrolahi (1994) evaluated network irrigation efficiency in period of 9 years (1982-1990) whose findings have shown that in this period maximum irrigation efficiency was 26 %, minimum and average were 21 and 18 % respectively. These values are less, compared to the planned amount by consulting (54 %). The reason behind low irrigation efficiency are factors such as non-irrigation overnight, lack of land leveling and sub network, low level of integrated land and low knowledge of farmers.

The range of irrigation efficiency in some provinces in 1999 showed at least 24.7% to 55% and in average 50.9 % that are regarding to farmer management, irrigation method, different stage of plant growth and product type and finally average irrigation efficiency (Dehghan et al.1999).

Some experts have suggested that the first step in preventing water crisis is growing water efficiency. By increasing irrigation efficiency, the water use in different parts including agriculture, industry and urban can reduce to 10-50, 40-90, 30-32 % respectively, without change in quality of life.

Therefore, reformation of the irrigation system, proper management in the time and amount of irrigation water, equipping, modernization and integration of land are all essential to improve irrigation efficiency.

In general, irrigation efficiency is the relationship between the actual volumes of water required for a specific uses and the volume of transferred water or the water taken from independent sources. Irrigation efficiency depends on several parameters including water requirement, irrigation method, type of the path for water transmission, water losses due to deep percolation or evaporation from water surface. Therefore, irrigation efficiency is considered an indicator for operation of water transmission path in irrigation network that can increase by 100 %.

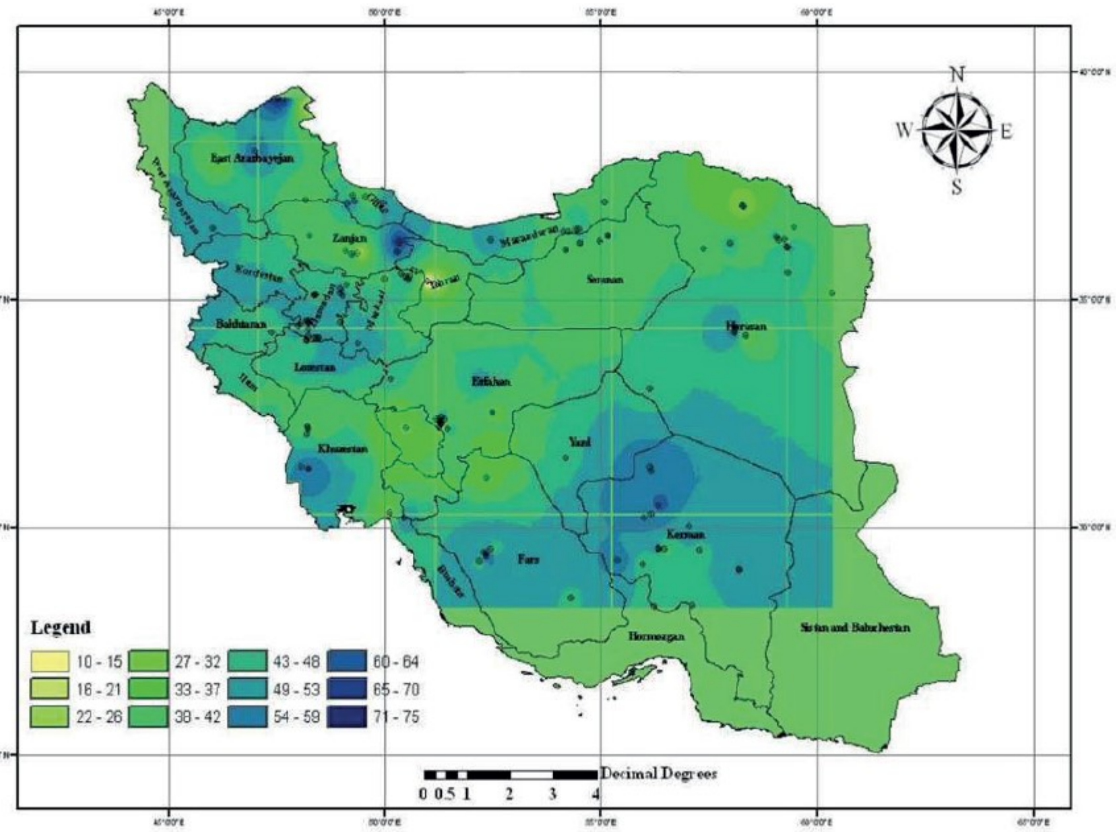

Figure 7-5: ISO efficiency map of Iran (Abassi & Sohrab, 2011)

7.5.1.1 Irrigation efficiency in Bakhtegan-Tashk and Maharlu lakes basin

In this basin the most frequently used irrigation method is traditional and flooding irrigation methods. In total, the irrigation efficiency is in average about 40 %.

In regions with low irrigation efficiency, the water is either evaporated or its deep percolation is far away from plant root. The percolated water will be returned to groundwater if groundwater level is relatively low. The returned water can use again and this phenomenon may increase irrigation efficiency by 40 % (it should be noted that the returned water doesn't have intial quality).

However, irrigation efficiency in this basin is below 50 % and varies between 40-50 %. The main reasons behind that are applying traditional irrigation method, high rate of evapotranspiration and depth of groundwater level.

Water losses isn't merely the loss of precious water, but also caused serious damages such as: salinization, soil erosion, loss of soil fertility and reduction of quality and quantity of agricultural products that ultimately lead to pollution of surface and groundwater.

7.5.2 The most important reasons for low irrigation efficiency in Fars province

- Soil and non-technical water transmission and distribution pathway
- Lack of water management in farms
- Limited use of modern irrigation methods
- Irrigation drainage network that is not equipped with new measurement technologies
- The volume of delivered water to farmers
- Lack of water users related organizations for official water use
- Failure to follow appropriate crop pattern in different regions of basin, due to climate conditions
- lack of legal requirements to force farmers to follow suggested crop pattern

Due to the absence of compensatory support system in order to offset declining water resources and consolidation of current area under cultivation, there is no way other than to optimize utilization of water extraction. This optimization is only possible through different methods to increase irrigation efficiency, proper management and careful scheduling and planning.

7.5.2.1 Solutions for increasing irrigation efficiency

Irrigation efficiency can increase by 20 % with land leveling, regular irrigation and drainage network. Equipping, renovation and land consolidation are the major infrastructures to optimize and provide the perfect platform for applying proper management of irrigation system. Additionally, by adjusting the amount of agricultural inputs such as seeds, fertilizer, pesticide and energy on average 15-20 % of production costs will be saved.

- Using modern irrigation methods

In addition to promotion and education in improving the water use in farms and gardens and modifying traditional irrigation methods to reduce water losses, the development of pressurized irrigation methods may have highly valuable effects. The desired result can be expected by implementing the moder pressurized irrigation (drip, sprinkler, tape, etc.). It may increase the efficiency of water usage in farms and gardens and ultimately lead to saving in water consumption.

Moreover, application of modern irrigation methods will cause facilitation of fertilization, the rise of yield product, improvement in product quality and prevention of pest and weed grow which cause significant reduction in production cost.

In this regard, with implementation of drip and tape irrigation system and proper management in farm, the total current irrigation output would be 90-95 % while with implementation of sprinkler irrigation method, the total output would be 70 %.

- Volumetric water delivery

In Fars province irrigation networks, there are over 4700 intakes that aren't equipped with measurement instruments and don't provide the ability to measure delivered water based on crop water demand. This makes low irrigation efficiency in subordinate networks. Therefore, in order to optimize utilization of surface water in terms of low irrigation efficiency in these networks, it is essential to equip the intake with the accurate measurement tools.

- Water management in farm

Lack of proper management of farms in the basin is the most important factor in poor productivity of water produced water. For example, some of gardens that are equipped with a drip irrigation system may have low irrigation efficiency. Therefore, education and extension methods for efficient use of water in gardens and farms can play an important role in improving irrigation efficiency.

7.5.3 Agriculture return water

To calculate agricultural return water, area under cultivates and type of product should be determined. Then, the net amount of required water is measured based on crop and plant water requirement. Finally, subtracting the volume net water requirement from used water for agriculture defines water losses that includes agriculture return water and waste water.

Unfortunately, the detailed statistic and information of area under cultivation and type of products don't exist in the basin. Thus, from previous studies and experts' comments, it can be drawn that agricultural return of water is about 20-30 % of used water for agriculture.

7.5.4 Area under cultivation

Area under cultivation is one of the important factors that has a major impact on water consumption. In fact, the area under cultivation depends on several factors such as economic value of grown crops, food security and need to crop, climate condition and irrigation system. In recent years, area under cultivation has increased considerably due to the population growth and the need to provide food.

7.6 Productivity indicators of agricultural water

To determine productivity indicators of agriculture water, the costs and income of main cultivated products are chosen and examined. In order to analyze the cost of agriculture products statistics of Iran's agriculture ministry in 2012-2013 has been taken into account.

Agricultural water productivity indicators include the following items:

CPD indicator

This indicator measures the relative value of product to volume of consumed water:

CPD=TP/TWC

TP is total product per ha regardless of rainfall (kg) and TWC is total consumed water per ha (m^3). According to this indicator, corn silage, onion, sugar beet, tomato and potato are crops that produce more product than consumed water. Due to low yield product, wheat and rice have a low amount of CPD compared to another product.

BPD indicator

The gross profit or revenue per unit of consumed water volume. According to this policy, the gross profit obtained is higher than the consumed water. In this method, however, the cost of crop production isn’t taken into account.

BPD=TR/TWC

TR= the total income from sell minor and major products per ha (10 rails).

According to this indicator onion, oil seeds, sugar beet and rice are crops with higher net profit than consumed water.

NBPD index

This index assesses the amount of profit per unit of consumed water volume. Moreover, this index is an important one in planning for combination and crop pattern in arid areas facing severe water restrictions. This is because by this way, we can devote scare water resources to the cultivation products with the lower water consumption and higher profit.

NBPD: NB/TWC

NB= net profit in each ha (10 rial)

Based on that indicator, corn silage, oil seed, sugar beet, potato, onions are crops with more net profit than volume of consumed water. Water productivity indicators are shown in table 65(app (a)).

7.7 Crop pattern

Crop pattern is to determine a sustainable agriculture system with economic benefit in accordance with the country's policies, the indigenous knowledge of farmers, the principles of ecological agricultural production in order to preserve the environment and optimum utilization of the natural capacities of region such as climate condition, water resources, soil, etc. and.

Climate conditions, negative water budget of plains and the need for sustainable production lead to modify crop patterns in order to maintain and improve underground water aquifer and to increase water use efficiency.

At the moment, in most parts of the country regular methods of agricultural production are associated with the excessive use of ground water. Therefore, it is necessary that agriculture production policies in these areas are directed toward the optimization of the water uses and high productivity as much as possible.

Optimal crop pattern, choosing a mix of products for cultivation in a given farm based on the characteristics of various crops, anticipation of their price in the market, the volume of demand, available soil and water resources, human resources, capital, agricultural equipment in order to maximize profits with respect to this model by farmers are all the elements that eventually can be effective on reducing the poverty of the rural and agriculture area.

Selecting a suitable crop pattern is an important way to manage water in the study area, because the water balance is negative and more than 90 % of water is used for agriculture. As mentioned, studies show that the amount of water used for agriculture purpose is 1232.72 million cubic meters. Groundwater constitutes 900 million cubic meters. Wheat, rice and barley consumed 1000 million cubic meters (about 80 %).

Wheat consumes more than 50 % of agriculture water. Wheat is an essential and strategic crop in Iran regarding food security and also self-sufficiency policy of the Iranian government. Wheat yield is 3.6 (ton/hectare) in this region which is reasonable compared to average wheat yield in Iran (3.5 (ton/hectare)). However, it is very far from the average wheat production in industrial countries such as Germany and France (7.5 (tons/hectare)).

In this plain, if the area under wheat cultivation reduce only by 10%, the water consumed for agriculture will be decreased to 67 million cubic meters lower than calculated amount. By increasing yield of wheat per hectare, the amount of consumed water remarkably is reduced and this leads to water saving.

Due to lack of water resources, rather than increasing the cultivated land that raise the water consumption, performance should be expanded in cultivated land. The performance should be boosted by using new method and promoting irrigation efficiency.

Rice is the second water consumer crop in this plain. Given the hight amount of water required for this, one of the best ways for saving water might be reducing rice cultivation. About 8 million cubic meters can be saved if the area under rice cultivation is reduced by 30 %.

Potato, Onion and oil seed are good replacements for rice as they have higher yields and need lower amount of water. So that if the areas under rice cultivation allocated to these products, only 5 million cubic meters will be added to water consumption.

One of the most important factors to improve the status of water resources in this area is improving irrigation efficiency by using the modern irrigation methods and mechanized agriculture.

7.8 General overview of agriculture in Marvdasht-Kherameh plain

Agriculture performance fluctuations in this plain during (2001-2012) has been between 7 to 11 (t/ha) that is relatively large. The area under cultivation has also fluctuated, and in total the extent of performance and the area of cultivation are corresponded with dry and wet years during this period. In 2007-2008 year that is one of driest years of this period, the amount of production and area under cultivate has significantly declined.

In this area, similar to the majority of the country's lands, due to climate condition and lack of precipitation, most of crops are irrigated. The distribution of monthly rainfall in the region shows that from May to November dry climate is prevailed and only in January and February there is good condition in term of moisture. In the rest of spring, summer and even early fall, evaporation and evapotranspiration of the plants goes higher. Thus, the need to pay for water grows and given the climate condition, cultivation should be performed in wet season.

In order to determine the suitable crop pattern in this region and the rest of country, it is essential to investigate soil properties such as soil acidity, salinity of the soil (soil electrical conductivity), soil texture, water holding capacity and soil calcium carbonate to determine accurately land capacity.

Figures (7-6) to (7-9) show climate condition, land cover, land use and geological map of Marvdasht-Kherameh plain.

According to figure (7-6), the prevailed climate condition is semi- arid and only in small part in the northeast, there is Mediterranean climate. In South and Southeast of plain and close to Bakhtegan lake, the climate is dry with high rate of evapotranspiration. This is mostly for Bakhtegan lake that has increased salinity of soil and water. In the south of plain, pomegranate and pistachios are suitable plants due to low rate of water requirement and their resistance agaist salinity.

Figures (7-7) and (7-8) show plain's land use and land cover. As can be seen in this plain, there is a great diversity from forest to salt marsh, that is related to size and location of this plain. Major part of plain is also allocated to irrigated land.

Figure (7-9) shows geological map and distribution of geology formation. Quaternary alluvium covers the main part plain that provides suitable bed for farmland. Sarvak and Khami Group formations are the water reservoir.

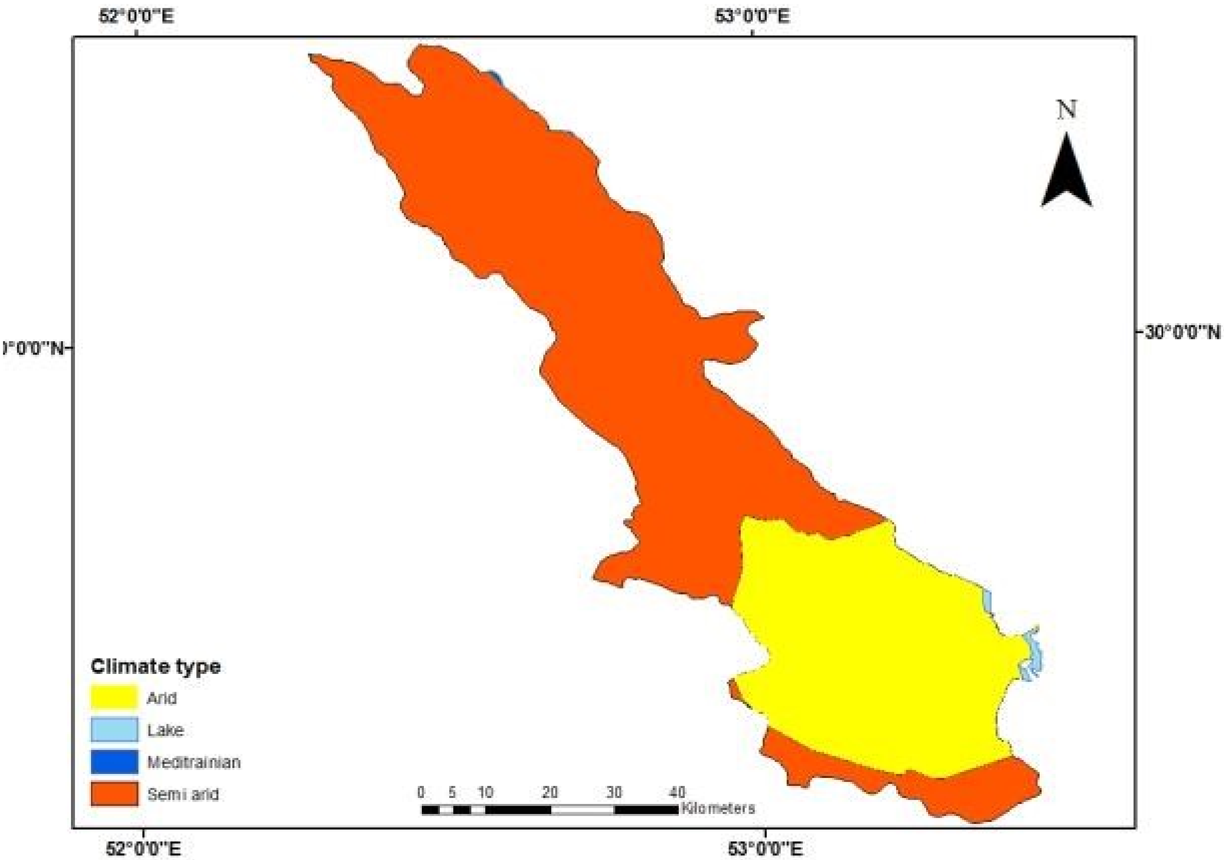

Figure 7-6: Climate condition map in the plain

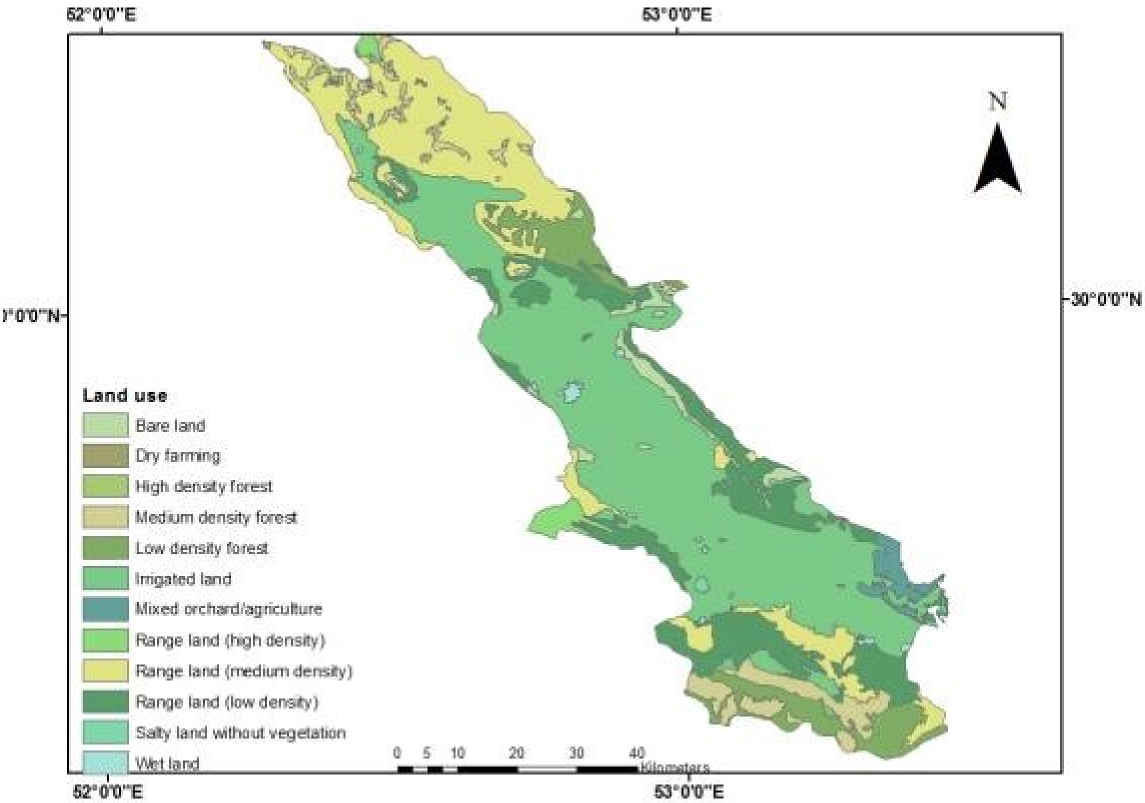

Figure 7-7: Land use map

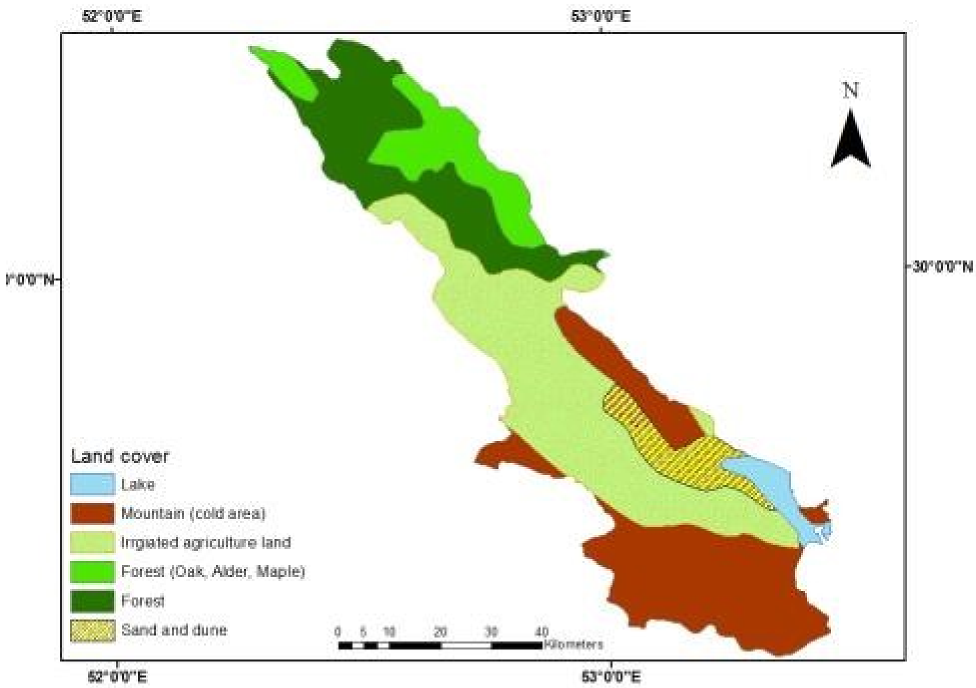

Figure 7-8: land cover of study area

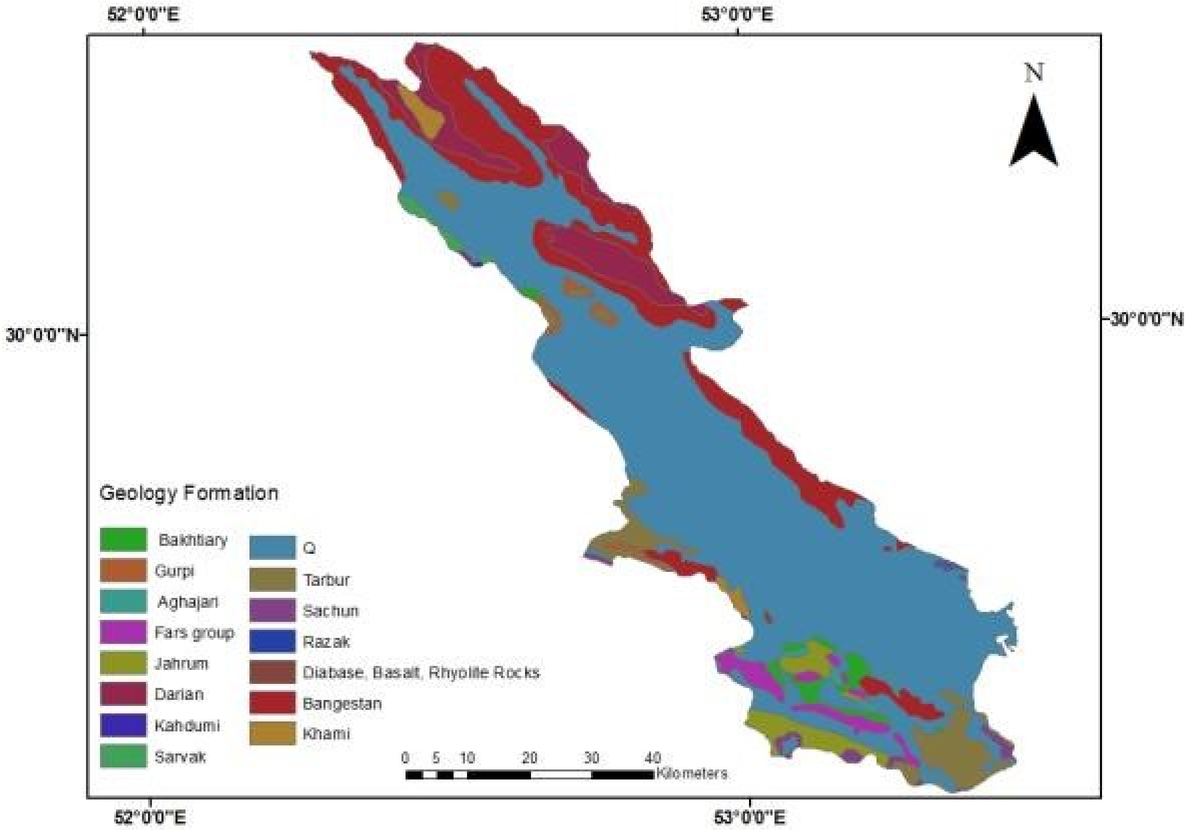

Figure 7-9: Geology formation

7.9 Farmers' importance and participation in agricultural development

Farmers are one of important factor in sustainable agriculture. In this study, a survey among 100 farmers in the south of basin has been conducted. The main goal of the survey was to gather information from farmers as an essential pillares of sustainable agriculture. Random sampling method was adopted in the selection of the respondents who entirely were male. The results show that the average age of respondent was 46. 23, indicating that they are fairly young and ready to train and make changes for use modern agriculture methods. Concerning literacy level, 75.3 % of the respondents had less than high school diploma degree, 24.7 % had high school diploma or higher degrees. These results indicate that low literacy level caused difficulties in application of optimal methods.

The average farms area was 7.7 ha, 6 ha of which belongs to 60% of respondents and the reast belongs to 40% of them. The main source of irrigatation of land is groundwater and more that 90% of land is irrigated via wells. Concerning Irrigation method, about 85% of farms irrigated using traditional methods including flood, surface and basin irrigation. Irrigation through modern method (drip irrigation method) consititute only 10% of land.

The main ways to transfer water from source to the land were soil irrigation channel, pipe and sulice. Here, 60% of land recived water via soil irrigation channel.

In this area among the samples, pomegranent, pistachio and grap are planted in 80% of lands and in the rest, wheat, barely and cotton are cultivated.

All respondents claimed that there is no official support by the government to use new agriculture methods and hence, there is no facility such as provision of loan to improve the irrigation system.

7.9.1 Result and discussion of survey results

The finding showed that agricultural planning in their farms is without any certain planning. The most barriers include lack of resources in village. Farmers believe that their villages have many potentials for development of sustainable agriculture, but they don't have financial resource and new techniques. Respondents often complained about lack of organizational support to provide adequate facilities and agricultural requirements. Farmers belived that lack of capacity of local and governmental organizations are the reasons behind the failure of investment in agricultural development. The participants indicated that there is no plan to educate farmers to use new method of agriculture and most of them chose farming as heritage from decendents. Decision making in agricultural policy is mostly made by state organizations but here the farmers are the ones who decide to change crop pattern due to decline of groundwater level and inadequate rainfall during recent years. They have planted wheat, barely and cotton for long years but during last 8 years, farmers have planted pomegranent, pistachio and grap instead. This shift is because these products have less water requirement and tolerate to water salinity. According to survey results, most of farmers didn't have enough knowledge to use new methods therefore they need more educational programs and support from government. This highlights the significance of the local organizations' role to train farmers in rural area.

New irrigation method and improvement of irrigation efficiency are notable solutions to increase productivity and also saving water. In this area, however, more than 90% of land irrigated with traditional methods. Soil irrigated channel has been the dominant way to transfer water from resource to the lands since this way of water transferring caused high amont of water loss.

In conclusion in this part of basin and also the rest of basin, using modern irrigation methods and educational planning for farmers can be a good solution to develop sustainable agriculture.

Figure 7-10: Agriculture land in Marvdasht-Kherameh study area

Figure7-11: Pomegranate and Pistachio garden in Neyriz plain

7.10 Zoning of basin and finding the suitable land in term of rain-fed wheat cultivation

Understanding the climate and climatological needs and assessments are the most important factors in crop production. Having Knowledge of climatology parameters and their effects on crops is an important parameter to increase productivity. This issue is quite significant especially in dry farming, because climate is the most effective factor for productivity in dry farming.

Agro climatic zoning enables farmers to adapt agricultural operation according to climatology condition (Sari Saraaf et al., 2009). Optimized use of land corresponding to ecologic condition is a principal way to improve agricultural activities. Wheat is one of the important and strsategic crop both in the world and in Iran. According to agricultural organization of the Fars province provided data, area under cultivation of wheat in 2012 was 389346 ha of which 311585 ha is irrigated and the rest is dry lands. Finding the suitable lands to cultivate rain-fed wheat that is copmatible to ecological condition could be helpful to increase productivity, profit of farmers and also saving more water. In order to identify suitable field for rain-fed wheat, different layers of information that contained morphological data (elevation, slope, soil and land use) and climate data (precipitation) are combined. By zoning the similar units, the potentiality of suitable land to cultivate rain-fed wheat in the basin is determined. The geographic Information System (GIS) is applied to combine the information layers and to analyze spatial data. In what follows, information layers which are used to evaluate the potentialities of a suitable land is explained.

7.10.1 Precipitation

Annual precipitation is the most important parameter for rain-fed wheat cultivation which requires at least 250 to 300 mm of rain during the growing period (Sari-Sarraf et al., 2009). Rainfall distribution in term of time and space during growth period can influence on crop yield. As it can be seen in figure (7-12), the north, northwest and midland part of basin have good rainfall in term to the amount of annual precipitation. The appropriate regions are Marvdasht-Kherameh, Dozkork-Kamphiroz, Beiza-Zarghan, Dehbid and part of Shiraz study areas. The reason for this, is the fact that these regions are mountainous and are therefore cold in their climate.

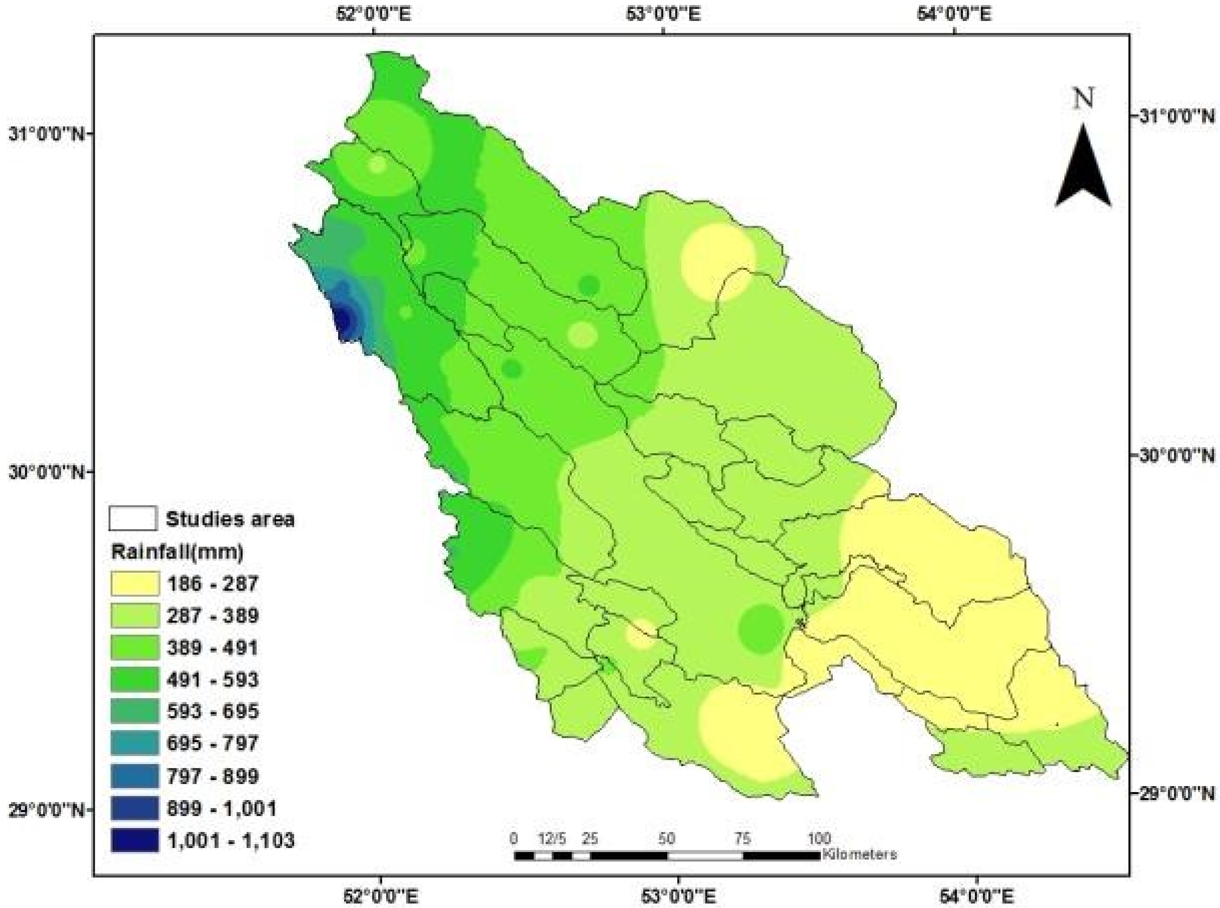

Figure 7-12: Annual precipitation of basin

<u>7.10.1.1 Fall rainfall distribution</u>

Rain-fed wheat in the basin is planted in October. Winter wheat should have at least 3 or 4 tiller by late fall (before frost), in order to tolerate sub-zero temperature during the winter (Zarin, 1999). The germination and formation of tillers should have reached an appropriate level by the end of autumn. To germinate, wheat seed normally absorb water by approximate amount 50-55% of the total seed weight. The best amount of fall rainfall is 45 to 95 mm (Givi, 1997). Figure (7-12) shows fall rainfall classification in term of distribution and amount. According to this map, the regions wherein rainfall occur mostly in fall and winter are the north-western and midland of the basin.

<u>7.10.1.2 Spring rainfall distribution</u>

Rainfall in spring is suitable if it ranges from 115 to 170 mm during the flowering and grain stage. For rain-fed wheat cultivation, suitable fraction of rainfall in spring is 37-40% of the total annual precipitation, without reference to the amount of rainfall (Bazgir, 2000). In the study basin, May is the time of flowering, therefore, the rainfall in the spring is more beneficial and effective for rain-fed wheat. Figure (7-14) shows spring rainfall classification. According to this map north-western, north and midland parts of basin such as Marvdaht-Kherameh, Dozkork-Kamphiroz, Arsanjan, Dehbid and part of Shiraz study areas receive suitable spring rainfall for growing rain-fed wheat.

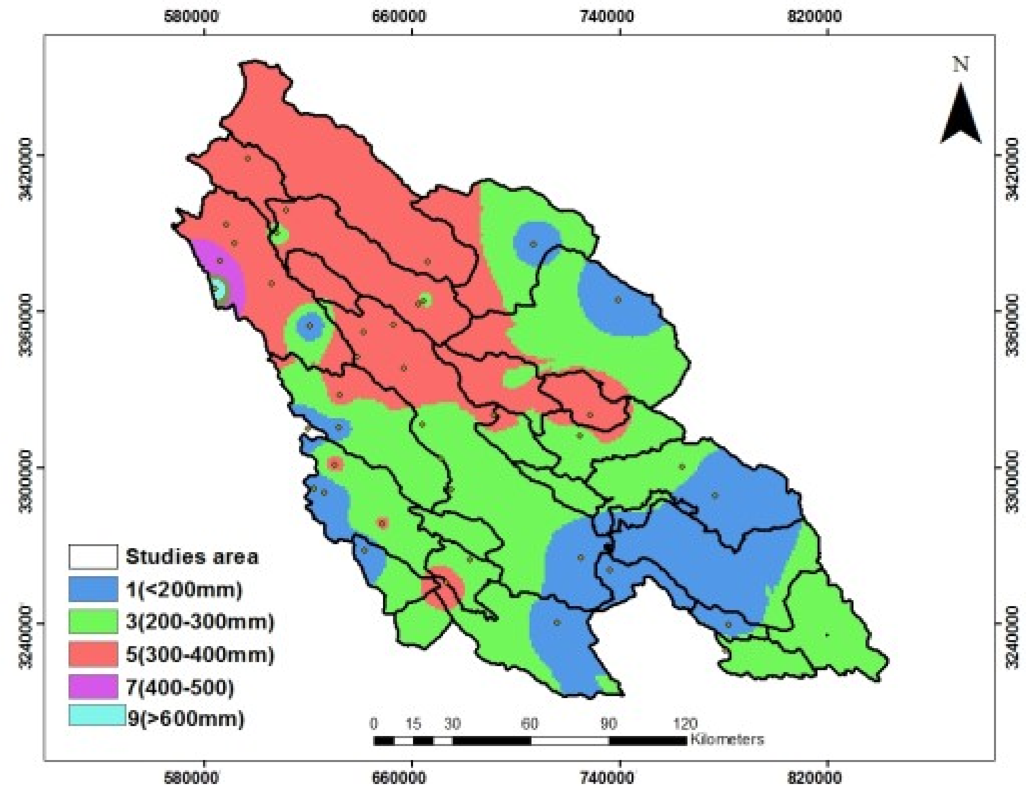

Figure 7-13: Fall and winter rainfall classification

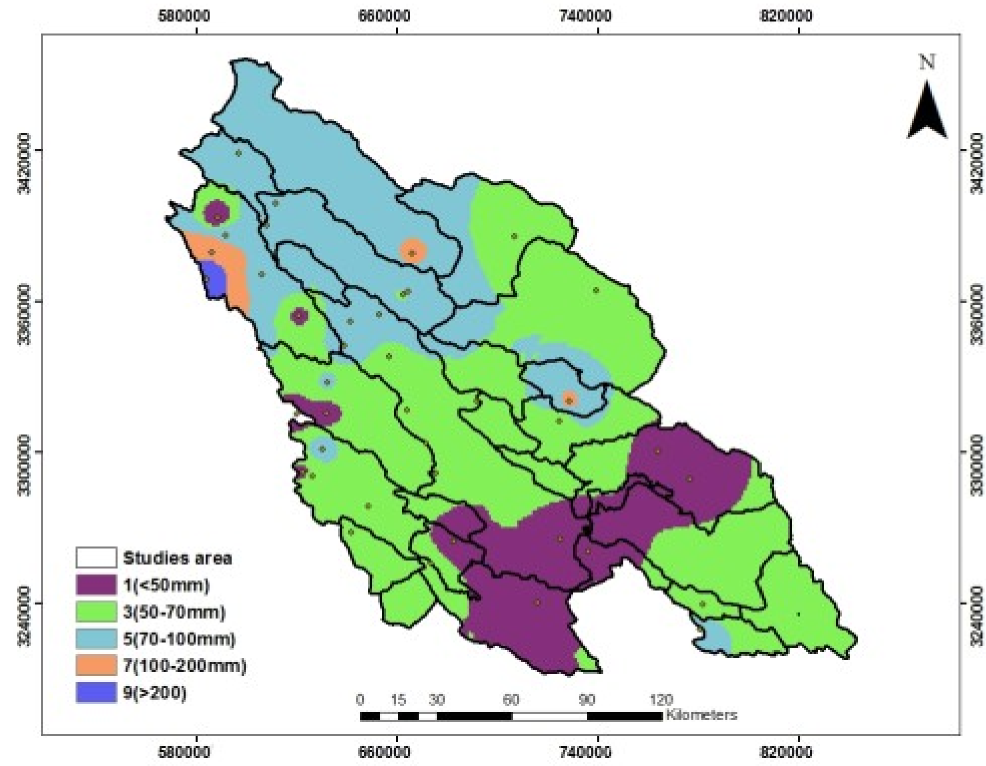

Figure 7-14: Spring rainfall classification

7.10.2 Planting date

In arid and semi-arid regions where water is a limiting factor for cultivation, the planting harvest dates and also the duration of rainfall should be critically considered to optimize water consumption in irrigated farming. Nonetheless, rain-fed cultivation of wheat can benefit from supplementary irrigation at critical stages of growth. Successful cultivation of winter wheat depends on two variables: rainfall and temperature (Mohammadi, 2005). The appropriate selection of a planting date can have dramatic impact on both the quantity and quality of crop yield (Gul et al., 2008). As the water needed for rain-fed crop is logically provided by precipitation only; the planting date should be planned to correspond with the starting date of precipitation. The best date for autumn rain-fed wheat cultivation is when the rainfall is likely to start and when temperatures begin to decline (Lotfi et al., 2008). The most suitable temperature for germination is 8 to 14 °C. Thus, the planting date map of the basin for the cultivation of rain-fed wheat has been prepared based on the temperature requirements and precipitation (figure 7-15).

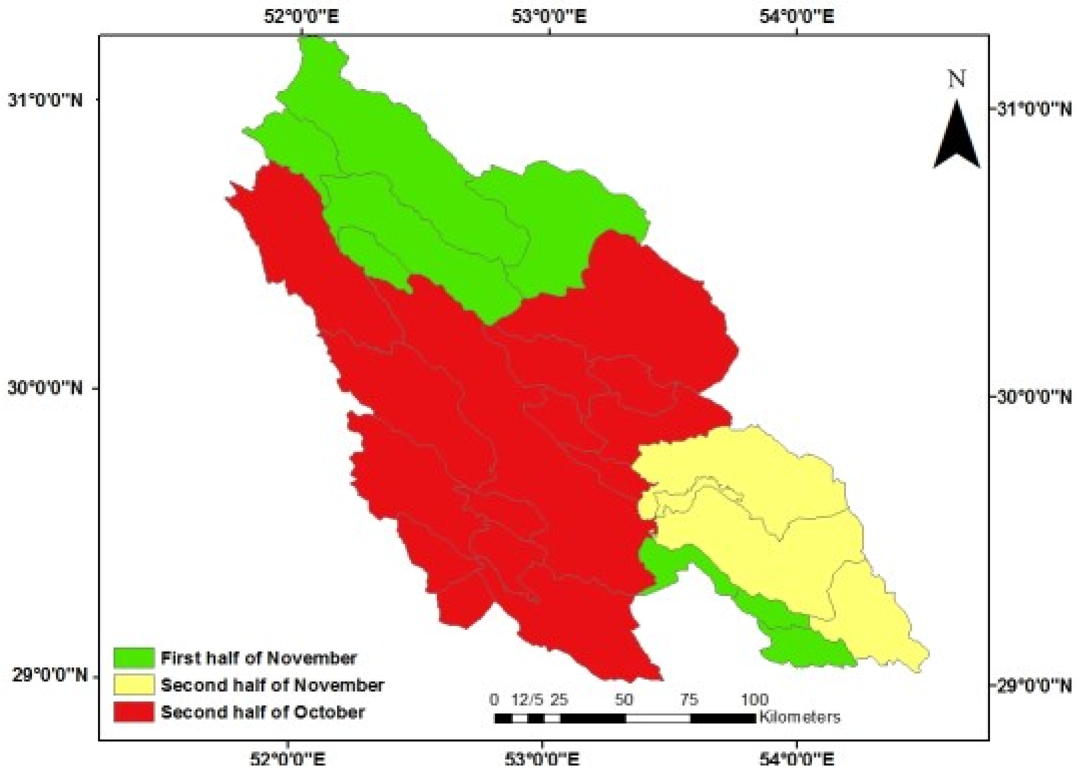

Figure 7-15: Planting date of rain-fed wheat

7.10.3 Elevation of region

The height of the land is an effective in yield production. As a general rule, the higher the altitude is, the more the rainfall is (Eyni et al., 2012). A lot of research has been conducted on suitable altitude for dry land wheat. They concluded that elevation less than 1500 m can have the best potential for rain-fed wheat (Rasooli et al., 2005, Farajzadeh and Takloo-Bighash, 2013). It seems that the south, southeast, southwest and midland are more desirable because of they have appropriate altitude for the cultivation of rain-fed wheat. These regions are situated under the 1500 m above sea level. It seems that lowlands are more suitable for rain-fed cultivation (figure.7-16).

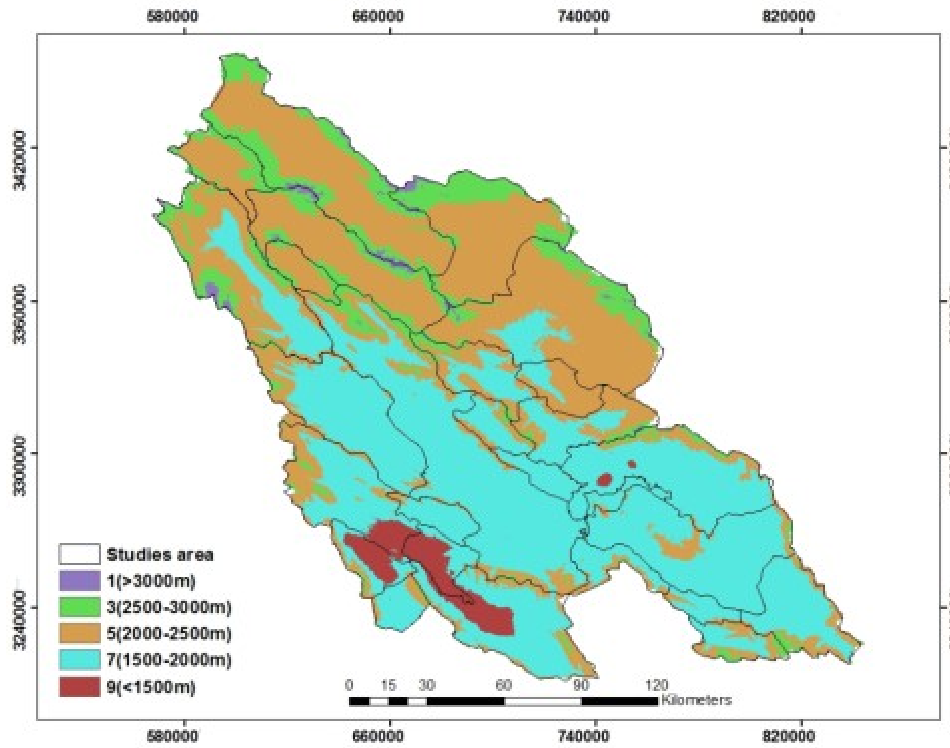

Figure 7-16: Elevation classification of basin

7.10.4 Slope of region

Slope of land is the most physical factors that have a strong influence on the cultivation type of agricultural products. Commonly, high slope lands are not suitable for dry land production. Slopes cause the rapid flow of water on the ground that provides less water absorbed by the soil. Mild slopes allow for more rainwater to be absorbed into the soil and can consequently increase the moisture content of the soil. On the other hand, steep slopes have negative effects on the development of plants and cause excessive leaching of nutritional elements that occur naturally in the soil. Furthermore, temperature fluctuations on gentle slopes are less observed, compared to steep slopes. Lower temperature fluctuations can better assist plant growth. Usually rain-fed lands are on moorland, with slopes of 2 to 8 % (Lotfi et al., 2008). It is visible from the map (figure 7-17) that most of the area in the basin (80%) has land with slopes and over less than 15% of the area is suitable for rain-fed cultivation of wheat. Gentle slopes cause the rainwater to be absorbed more into the soil and thus the moisture is better maintained in the soil. Less leaching of nutritional elements occurs in the soil.

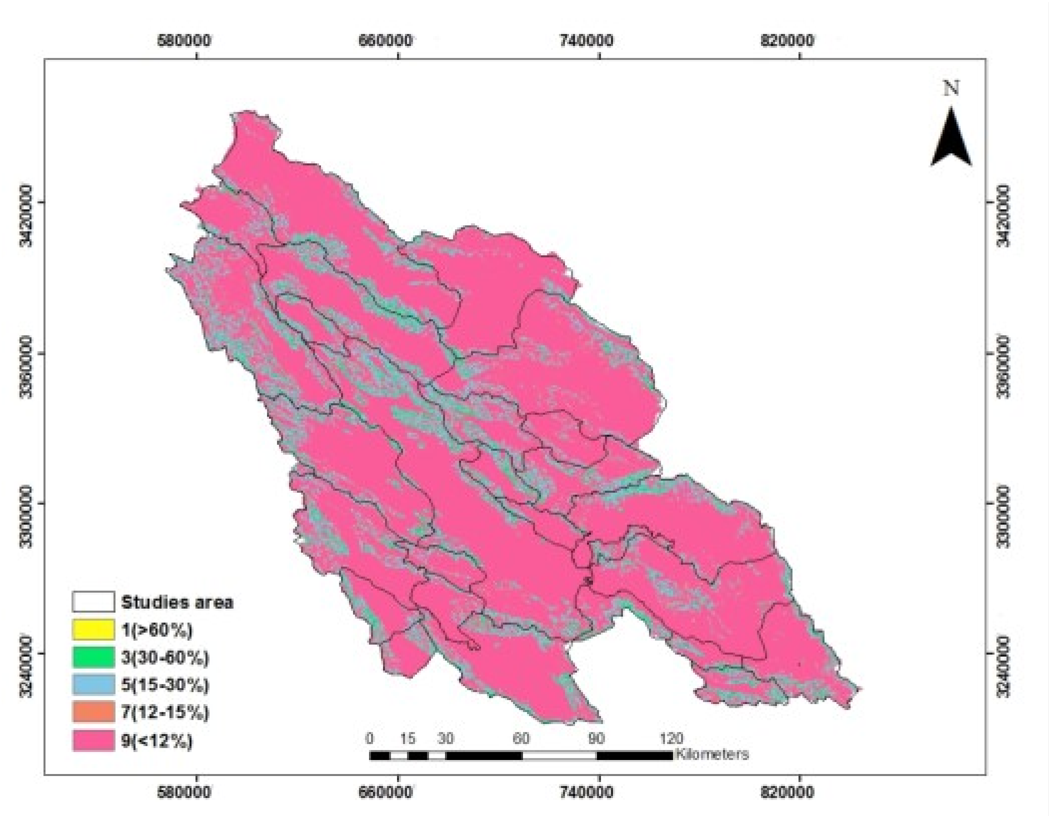

Figure 7-17: Slope classification of basin

7.10.5 Soil of region

Soil structure and the size of particles are effective factors that should be considered in plant growth. Wheat can grow in a wide range of soils, but soils had better be well-drained, with silt-clay-loam or loam and humus textures. Clay-limestone can also give a better product (Behnia, 1997). Map of the soil (USDA soil classification) were obtained from the State Institute of Agriculture in the province of Fars. But unfortunately most parts of the province don't have data. Figure (7-18) shows soil map of the basin.

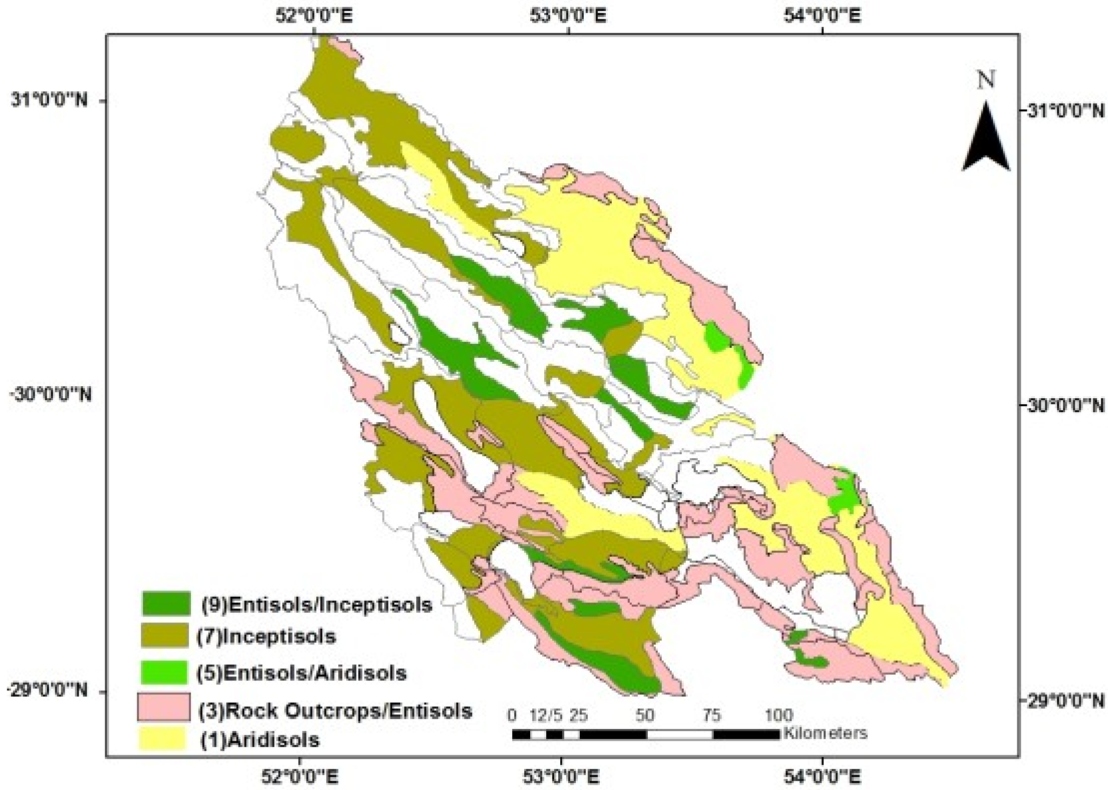

Figure 7-18:Soil classification of basin (State Institute of Agriculture in the province of Fars)

7.10.6 Land use

According to figures, most of the area in the basin (80%) are agricultural land and range land and almost 20% of the basin is salt land, cities, lakes and woodland where cannot be cultivated by agronomy. Therefore, only 19% of the map is qualified to fertile soil for the cultivation of wheat. These are mostly situated in the districts of Marvdasht, Shiraz, Dozkork-Kamphiroz, Zarghan (Figure 7-19).

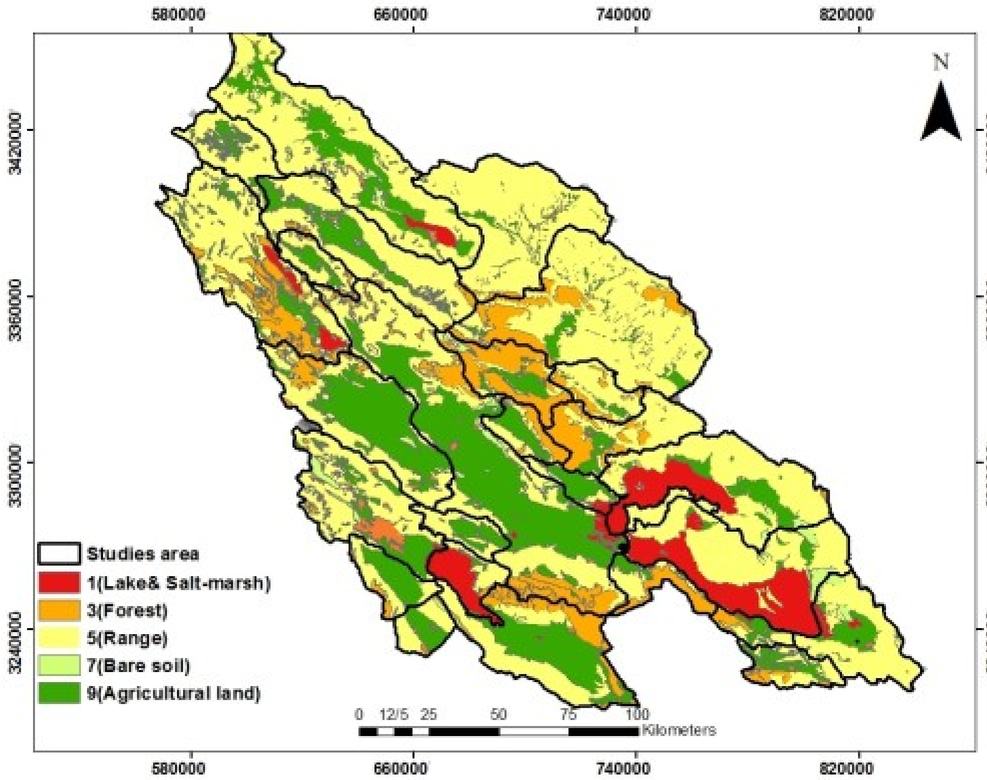

Figure 7-19: Land use classification of basin

7.10.7 Suitable land to cultivate rain-fed wheat

The final map of rain-fed wheat is presented in figure (7-20). This map isprepared by considering the given weighted maps that overlap. According to this map Marvdasht-Kherameh, part of Shiraz, Arsanjan, Seidan-Farough, Beiza-Zarghan, Dozkord-Kamphiroz study areas are suitable regions to cultivate rain-fed wheat.

Based on the limited water resources in the basin, it is a vital to identify suitable areas for dry land cultivation and thereby to maximize the usage of precipitation that can substantially reduce the use of ground water for irrigation.

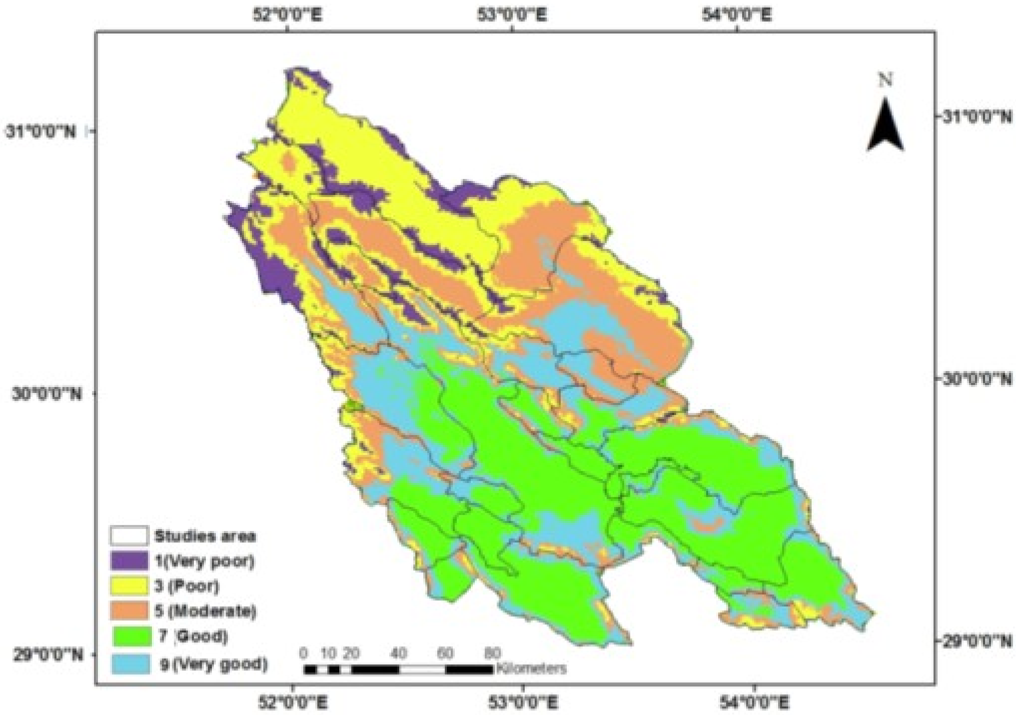

Figure 7-20: Suitable land to cultivate rain-fed wheat

8. Dynamic model of Drodzan dam

8.1 Introduction

Water resource management requires making futuristic decision with a comprehensive approach. Dynamic system science is a management tool based on this approach that is able to simulate complex water resources supporting and decision making systems. The main goal of this method is to simulate current and future behavior condition of system. Today, in dealing with water resources issues, there is need for tools that can define structure and components of water resources system in accordance with their actual characteristics and relationship and next to it, it is easy and fast (Kadkhoda Hosseini et al, 2017).

System dynamics modeling and simulation is specifically designed for modeling and analysis of large-scale socio-economic systems and has been applied in many environmental and water resource studies, including water resource planning and management in different scenarios which scenarios includes climate changing, changing in crop pattern, area under cultivation, energy price and … (Ford 1996; Simonovic 2002; Zu et al. 2002; Stave 2003; Simonovic and Li 2004; Tidewell et al. 2004; Ahmad and Simonovic 2006; Bagheri 2006; Croke et al. 2007; Feng and Huang 2008). System dynamics which provides a unique framework for integrating the disparate physical and social systems important to water resource management is formulated on the premise that the structure of a system, the network of cause and effect relations between system elements, governs the overall system's behavior (Sterman 2000), this systems is strong tool to managing water and make a decision in local or large scales depends on available water resources, government policies and climate changes (Hosseni &Bageri, 2012).

The typical purpose of system dynamic study is to provide an experimental simulation platform for analysis of problems, the objective this model is to help

Provide policies that address the issues of water distribution management (Saysel et al. 2002). Dynamic simulation allows us to observe the behavior of a modeled system and its response to interventions over time. Dynamic simulation models consist of equations describing dynamic change. If system state conditions are known at one point in time, the system state at the next point in time can be computed. Repeating this process one can move through time step-by-step over any desired time interval. Simulation aids our capacity to make predictions of future states. As long as the model describes reality with certain accuracy, the modeling process and its outcomes can be used to improve our understanding of the problem as a necessary step towards affecting sustainable and effective change (Winz et al., 2008).

8.2 Study area

Drodzan dam lake basin lies between longitudes 51º 40´and 48º 17´E and latitudes 25º 05´and 30º 07´, the total area of basin is 4565 km². Drodzan dam is located on 100 km from southwest of Shiraz city and established on Kor river. This dam is a reservoir dam with capacity reservoir of 993 (MCM). Kor river is one of important rivers in Fars province which originated from northwest mountains and flows toward southeast and finally currents to Bkhtegan lake. Kor is a permanent river, melting snow; rainfall and spring are resources of supply water in this river (Figure 8-1 Drodzan dam position).

The study area has a cold semi-arid climate with an average annual precipitation of 443 mm and mean annual temperature of 14 °C. The main reason to establish this dam is supplying agricultural, industrial and also part of drinking water in Shiraz and Marvdasht cities. In up stream of Drodzan dam is suited three plain Dozkord-Kamphiroz, Khosroshirin and Asopas (Figure8-2), Molasadra dam is located beween Asopas and Khosroshirin , this dam is a Regulatory dam and collects surface water of these to plain and transfer them to Dozkord-Kamphiroz plain.

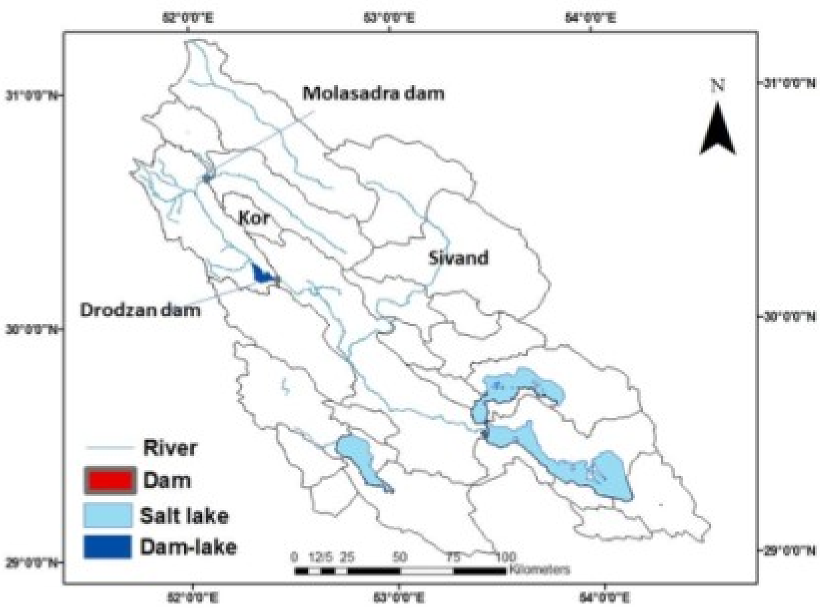

Figure 8 -1: Drodzan dam position in the basin

8.3 Modeling

In this study Anylogic program used to simulate Drodazan dam basin. Modeling has four main stages. The first stage is development of a conceptual model or a Casual Loop Diagram (CLD) of the problem in which the elements of the model and the causal relationships among them were identified, this stage includes:

- Define the purpose of the model.
- Define the model boundary and identify key variables.
- Describe the behavior or draw the reference modes of the key variables.
- Diagram the basic mechanisms, the feedback loops, of the system.

The second stage is formulation that includes:

- Convert feedback diagrams to level and rate equations.
- Estimate and select parameter values.

The third stage is testing includes:

- Simulate the model and test the dynamic hypothesis.
- Test the model's assumptions.
- Test model behavior and sensitivity to perturbations.

The fourth stage is an implementation

- Test the model's response to different policies.
- Translate study insights to an accessible form (Albin, 1997).

Based on the Casual Loop Diagram (CLD) guess or estimate behavior of different variable and decide about variable which participate in model based on purpose of model. The second stage selects the equation and defines parameters of values. At third step development of simulation model and test model assumption, at this stage, it is possible to observe patterns of different parameters in term of graphic and numbers to validate the model. At final stage different policies test on model and observe effect of different changes on model behavior (Streman, 2000).

8.4 Conceptual Model

As mentioned before in upstream of Drodzan dam is located three study areas Asopas, Khosroshirin and Dozkord-Kamphiroz. To make Dam model at first dynamic model of these study area were prepared. The model was made based on groundwater balance, therefore, was applied the general equation of water balance as below:

(8-1) $$Q_{UI} + Q_P + Q_R + Q_I + Q_{SW} - Q_{UO} - Q_{EX} - Q_D - Q_{ET} = \Delta V$$

(Q_{UI}): Input groundwater flow

(Q_P): Penetration of precipitation to aquifer

(Q_R): Feeding of surface flow

(Q_I): Penetration of agricultural uses

(Q_{SW}): Penetration of industrial and drinking water uses

(Q_{UO}): Output groundwater flow

(Q_{EX}): Evaporation of groundwater

(Q_D): Drinage of aquifer by river

(Q_{ET}): Extraction of water from well, spring and Qanat

Input variables includes; the volume of penetrated precipitation, volume of surface flow, volume of groundwater flow and return water from agricultural, industrial and drinking uses.

An output variable includes; evaporation, extraction of water from different sources, surface and groundwater output flow. To construct the model was used five years data from water year 2008-2013.

System dynamic deal with a system using combined approach, individual system in each study areas is essential for integrated dam model. Here, a CLD is developed for each study area.

8.5 Hydrogeological subsystem of Study area in upstream of Dam

Asopas plain is situated in the north of Tashk-Bakhtegan and Maharlu lakes basin, Gavgodar river is the main river in this area that collected surface water and also water from springs then currents to Dozkord-Kamphiroz (figure8-2: schematic graph of river in Asopas) .Hydrologic system of Asopas study area shows in figure (8-3). On the diagram each arrow represents a cause and effect

Relationship. Rainfall, return water from usage are input component and evaporation, withdrawal from groundwater, evaporation and surface flow are the output component in this area. In construction this model was applied five years data from October 2008 to October 2013.

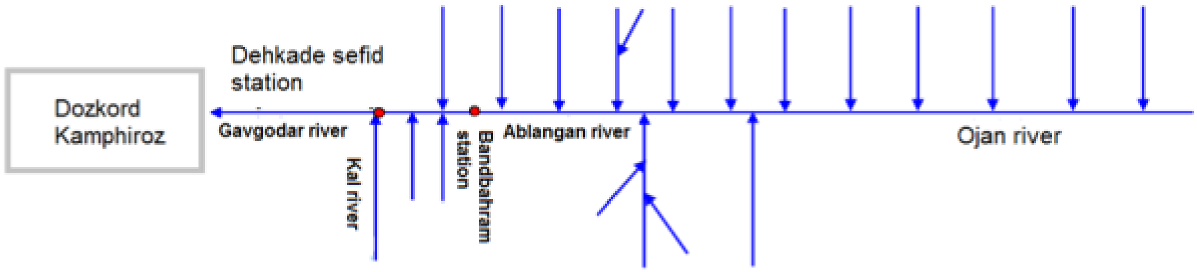

Figure 8-2: Schematic graph of river in Asopas study area (Farsab Sanat consulting office, Iran)

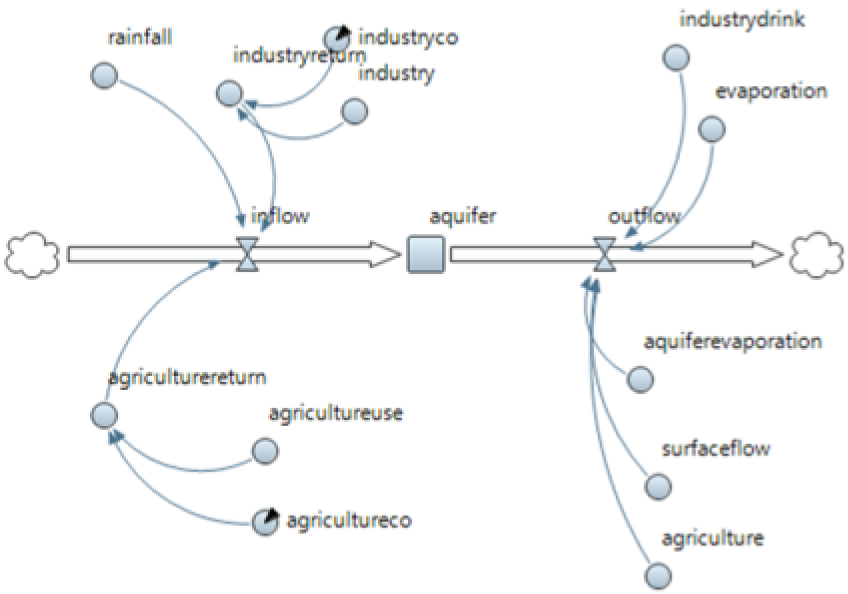

Figure 8-3: Hydrological system of Asopas study area

Khosroshirin study area is situated in northwest of basin. The main river of this area is Sefid river that collected surface and springs water, then currents to Dozkord-Kamphiroz study area (figure 8-4: schematic graph of river current).

Hydrologic system of Khosroshirin study area shows in figure (8-5). On the diagram each arrow represents a cause and effect relationship. Rainfall, return water from usage, ground water and surface water flow are input component and evaporation, withdrawal from groundwater, aquifer evaporation, evaporation and surface flow are the output component in this area.

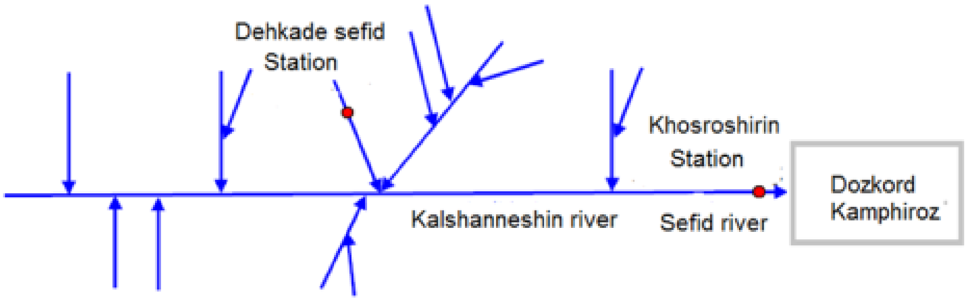

Figure 8-4: Schematic graph of river in Khosroshirin study area(Farsab Sanat consulting office, Iran)

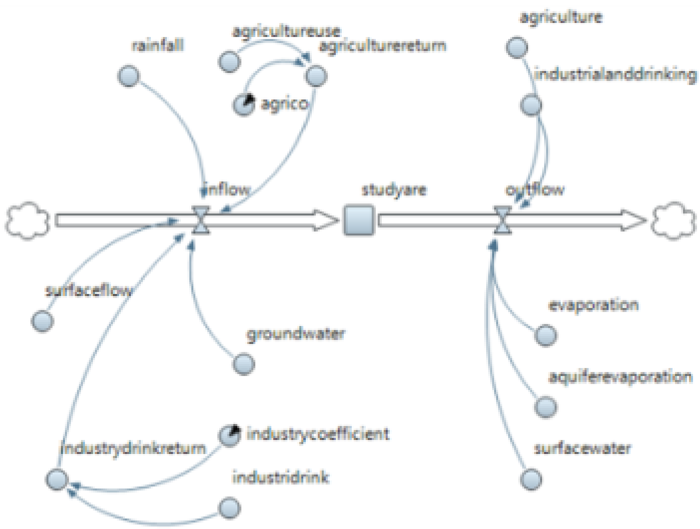

Figure 8-5: Hydrological system of Khosroshirin study area

Dozkord-Kamphiroz study area is suited in northwest of basin, Kor river as main permanent river of basin current is this area which flows to Drodzan dam lake in the end of this area. Kal, Margan, Shol and Dozkord river are joining to Kor river in this area (figure 8-6: schematic graph of river current). Hydrologic system of Khosroshirin study area shows in figure (8-7). On the diagram each arrow represents a cause and effect relationship. Rainfall, return water from usage, surface water flow are input component and evaporation, withdrawal from groundwater, Drodzan dam lake evaporation, evaporation and surface flow and transmitted water (water from this area transmit to Shiraz city as a supplier drinking water) are the output component in this area.

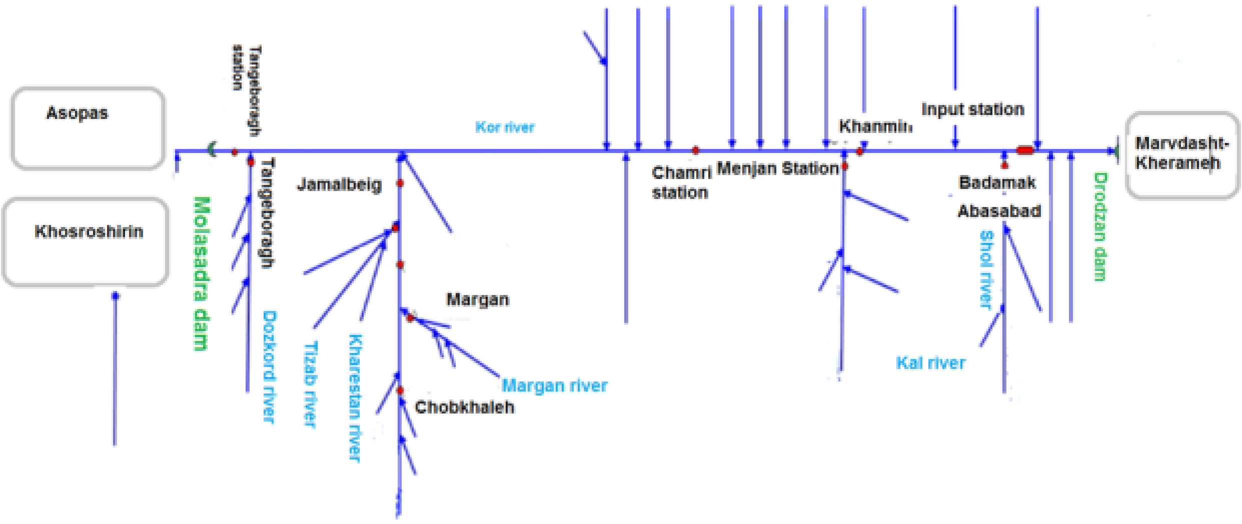

Figure 8-6: Schematic graph of river in Dozkord-Kamphiroz study area(Farsab Sanat consulting office, Iran)

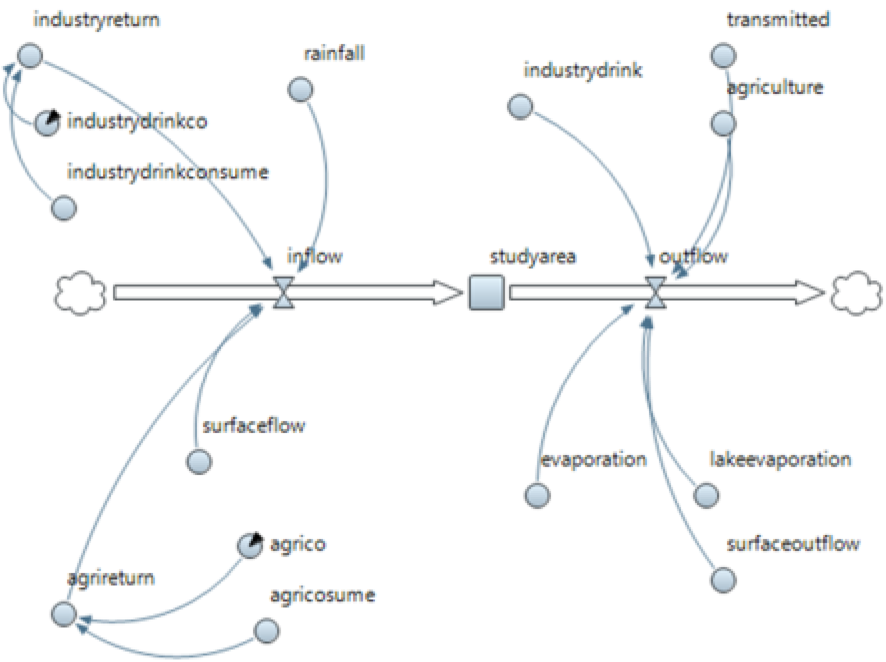

Figure 8-7: Hydrological system of Dozkord-Kamphiroz study area

8.6 Model calibration

Model calibration in its most limited meaning is the modification of model input data for the purpose of making the model more closely match observed heads and flows. In this step model result is compared with a reference, this step helps model producer about accurate and transparent results of model. In this study unit hydrograph of plains used to calibrate model. It should be noted to compare, storage volume of water in simulated area should be change to water fluctuation for that reason specific storage and area of field study was used. The model was calibrated after correction and accurate of parameters and relationship, then calibrated model used as a sample of nature condition.

To calibrate the model in Asopas study area unit hydrograph was used (specific storage (0.050 and area (716.1km²), figure (8-8) shows the comparison of simulated and observed result in Asopas plain.

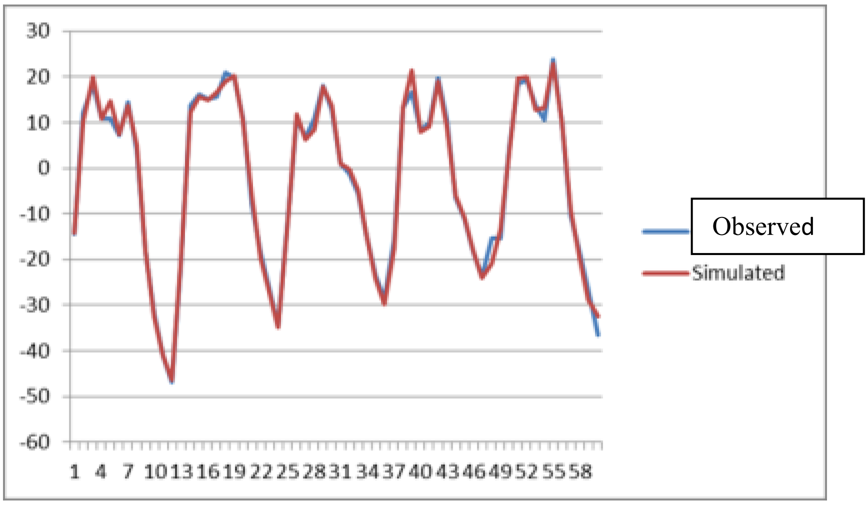

Figure 8-8: Comparison of observed data and simulated result Asopas plain

In Dozkord-Kamphiroz study area, water level data wasn't available during these five years, then the result of water level which measured in previous study (Hajiketabi, 2013) was used and model calibrated just for one year and the results…. to another years (figure 8-9).

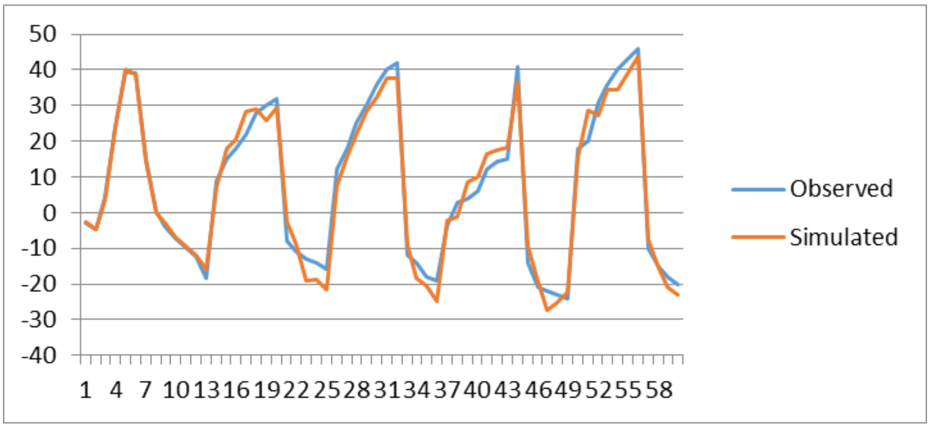

Figure 8-9: Comparison of observed data and simulated result Dozkord-Kamphiroz plain.

In Khosro Shirin .study area there wasn't any water level data then the calibrated parameter in Dozkord-Kamphiroz and Asopas were used in this area.

8.7 Drodzan dam dynamic model

Drodzan dam is suited in the outlet of Dozkrd Kamphirouz plain (figure 8-1), to prepare the dynamic model of this dam the dynamic model of study areas in upstream of dam was prepared and then based on input and output component the dam model was designed. Hydrologic system of Drodzan dam shows in figure (8-10). Rainfall and surface water flow are input component and evaporation, different usage includes agricultural, industrial, drinking and environmental are the output component of dam.

Storage of dam reservoir depends on input parameters, evaporation, release water and dam overflow. In recent years due to water shortage dam overflow of Drodzan dam is zero. Dam storage is determined Based on the maximum damping height, input and output flows and storage of dam reservoir. The total reservoir loss and released water subtracted of input flow and storage volume, the remain volume is compared with maximum damping height and the surplus is going out as a dam overflow. Used code for dam overflow is as a follow:

```
if ((Volume-Evap)/(0.0864*N)+Qin-Demand Total > VNWL/(0.0864*N)){ return Spillway Start; }

else if ((Volume-Evap)/(0.0864*N)+Qin-Demand Total > VMOL/(0.0864*N)){ return  Demand Provided; }
else{ return  Discharge total ; }
```

The release of water from dam reservoir is in order of priority to supplies the needs of drinking, agriculture and industry and environment.

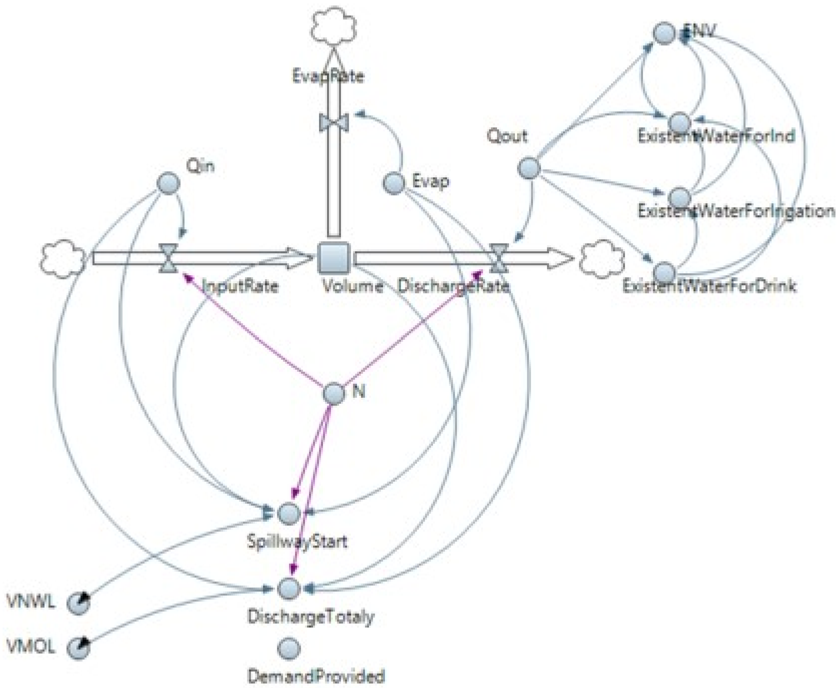

Figure 8-10: Drodzan dam model

8.8 Simulation scenarios

The model is run to observe the consequences of five Different water resources plans and strategies for the Drodzan dam. The run scenarios are as a follow:

- Changing in dam storage until 2020 if the current condition continues.
- A climate change in this scenario was assumed that natural flow decreases up to 20% as a result of declining precipitation.
- Population increase with growth rate of 1.08% per year, therefore, increasing in drinking water demand because of population growth.

8.8.1 Changing in dam storage until 2020

The model was run until 2020 and was predicted dam storage if all condition remains constant, result was shown dam storage decreased dramatically and this area would be in challenge with water deficit. Figure (8-11) shows changing in dam reservoir storage.

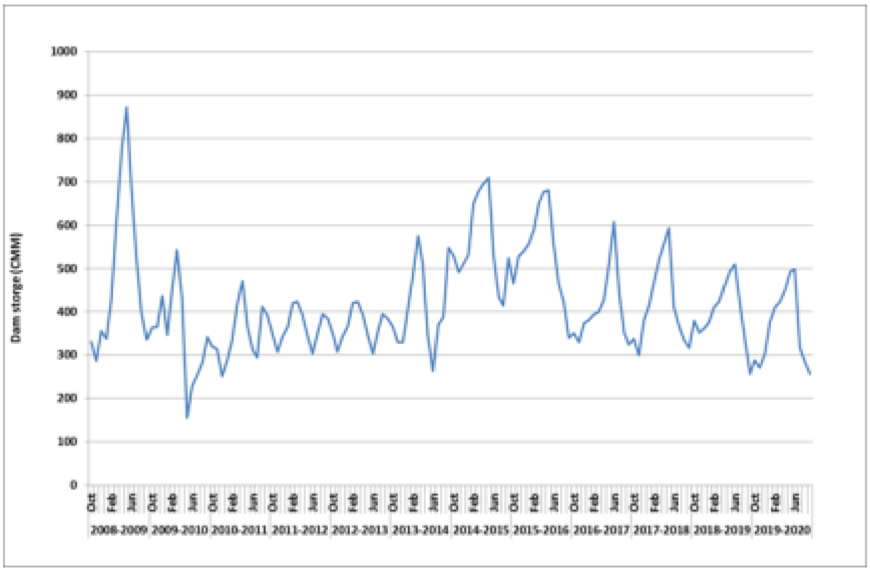

Figure 8-11: Dam storage changes up to 2020.

8.8.2 Input flow decrease by 20 %

According to climate condition in the basin in the second scenario was assumed input flow to dam declining by 20 %. The result shows dam storage will be decreased dramatically and in some months especially in summer the dam storage could be near to lower amount of dam storage stability (figure 8-12).

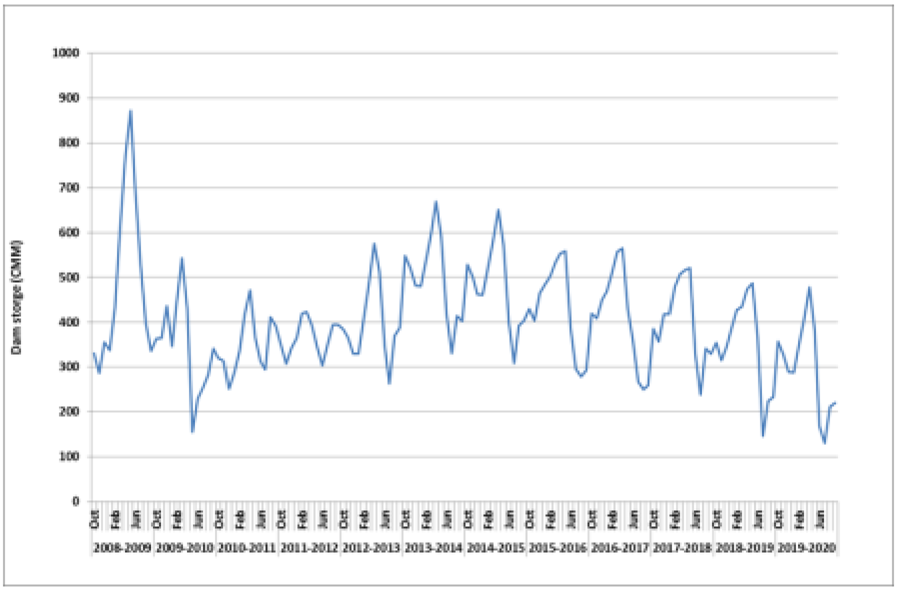

Figure 8-12: Dam storage changes up to 2020 if input flow decrease by 20 %.

8.8.3 Population growth rate changes

Drodzan dam supplies drinking water of Shiraz and Marvdasht cities as two important and also center of population cities of the basin. In average this dam supplies around 50 CCM/Y drinking water demands of these cities. Based on population growth 1.08% (Jamab, 2011), to supply drinking water until 2020 around 60 CCM/Y water is needed for drinking. Drodzan dam water supply policies based on that provide water respectively for drinking, agriculture, industry and environment purposes; therefore this police was used to peredict existent water for different purposes (figure 8-12). If current condition continue dam will be faced with a harsh problem to supply water (Table 8-1).

Table 8-1: Existence water for drinking up to 2020.

Year	Existence water for drinking (CCM)
2008-2009	38/959
2009-2010	38/948
2010-2011	43/385
2011-2012	49/504
2012-2013	50/566
2013-2014	35/834
2014-2015	31/543
2015-2016	29/275
2016-2017	29/065
2017-2018	28/083
2018-2019	27/083
2019-2020	25/504

9. Conclusion and recommendation

This thesis investigates and analysis water and shortage water in Tashk-Bakhtegan and Maharlu lakes basin, Fars province, South of Iran. This study deals with this basin in terms of meteorology, surface water, groundwater, water quality, water balance, evaluate agriculture section as the most water consumer, dynamic models of Drodzan dam as the main water reservoirs and supplier water for drinking and agriculture in the vast part of basin. This study purposefully targeted water resources and water management, evaluating the parameters that affect water deficit. The finding conclusions reached by this study are presented in the following.

9.1 Findings of the study

This section presents findings and conclusions of the study, starting with focus on issues in different chapters and ending with water management solutions and recommendation.

9.1.1 Meteorology of basin

Chapter 2 has evaluated the basin meteorology and components that affected water balance. Precipitation, temperature and evapotranspiration parameters are analyzed in a 42-year period (1970-2013). According to obtained results, temperature increased from north and north east to the south and south west. The reason behind this changes is difference between elevation in the north and south of basin. The average temperature in the north and south of basin is 10.7ºc and 18.9ºc respectively. Average temperature compared to long term average in 5 years ending to 2013 increase by 0.5 ºc.

Precipitation in this basin is almost as rainfall, thus just rainfall has been investigated as a precipitation. Precipitation in this basin decreases from Northwest to Southeast and from West to East. Study area can be divided into three parts base on rainfall:

- The eastern part of the basin with average rainfall of 200-400 mm/year.
- The second part includes northwest of the basin which has high height (2,000 to 3,500 m) showing high average rainfall (mostly 400 to 800 mm).
- The third part includes part of the southwest with height range between 1500-2500 m; this part has mostly 400-600 mm.

The amount of precipitation during the five years leading to 2013 has decreased by 20 % compared to the base period precipitation. In Mahrlu-Bakhtegan basin, average precipitation of heights and plains are respectively 330, 280 mm per year.

Basin’s evaporation also decreases from north to the south of basin, the average evaporation in the plains and heights are 2354.14, 2168.29 mm/year respectively.

9.1.2 Surface water

Kor and Sivand rivers are important permanent rivers. Some of the studies areas are under influence of these rivers.

There isn’t any surface flow into and out of the basin, surface flow currents only between basin’s plains. Average annual -discharge of rivers in the basin during the last five years up to 2013 has decreased by 20 % compared to average annual discharge in the base period.

9.1.3 Groundwater

Groundwater resources are the main water supplier in the basin. In all study areas, there are alluvial aquifer for which unit hydrograph was provided based on observation well statistics (South Tashk lake, Abade Tashk-Jahanabd, Khanekat, Tangehan, Sarpaniran, Dozkord-Kamphirouz, Khosro shirin and Goshnegan are study areas without observing wells network). All of the unit hydrographs show decline in groundwater level especially in recent years.

9.1.4 Water quality

Evaluation of the chemical quality of surface water in the basin shows that in general surface water has a suitable quality and doesn’t have any limitation for different uses such as agriculture, drinking and industrial.

Chemical quality of groundwater indicated that the alluvial aquifer in the north and northwest of basin have more suitable quality than the south and south of basin. In general, water quality decrease from north to the south and south east.
The main reasons for increasing the salinity of water in the basin is presence of Tashk-Bakhtegan and Maharlu lakes, therefore the highest salinity belongs to the studies area that are located around the salt lakes. In the south of basin, outcrop of geological formation such as Hormoz and Sachon reduce water quality.

9.1.5 Water balance

Water years (October through September) of 2012 and 2013 are used for analysis of water balance. Water balance calculation in basins shows that reduction of groundwater storage in the base period in the basin is -834 MCM/Y. Negative water balance shows an impressive decline in groundwater reservoirs. The main reasons behind the decrease in storage changes includes; decrease in rainfall, over-extraction of groundwater resources, using traditional irrigation methods and low irrigation efficiency resulting in huge amounts of water being wasted, incorporate crop pattern that does not match climate condition and water resources.

9.1.6 Agriculture

Agriculture sector plays a key role in the basin's economy and also consumes more than 90 % of water. Due to the unavailability of sufficient surface water in the basin, the agricultural part consumes a lot of groundwater. Marvdasht-Kherameh study area was selected as objective to evaluate agriculture. In this area, 1237 MCM/Y water has been consumed for agricultural purpose. Changing crop patterns and replacing rice by oil seeds, potato and onion could be a good solution to save water in this area. Moreover, wheat is the most water consumer, but food security and the country's policies does not conform to reduce its production. Thus, the solution is to replace irrigation methods by new methods to increase wheat yield instead of expanding the area under cultivation.

As the predominant climate of this basin is dry and semi-dry and water resources are limited, identifying suitable areas for the purpose of cultivating in dry land and maximizing the utilization of rainfall can significantly optimize the water usage foe irrigation. In agriculture section, the zoning of basin has been performed with regard to rain-fed wheat cultivation. According to obtained results, Biza-Zarghan, Marvdasht and Shiraz Studies areas are suitable for growing rain-fed wheat.

9.2 Negative effects of drought in the basin

Negative effects of basin drought can be investigated in three scopes including social, economically and environmental:

Social effect: The basin's opulation growth rate of 1.8 % per year (Iran Statistics Center, 2012) will lead to increase in agricultural, industrial and drinking demands. Therefore, it causes higher amount of withdrawal from water resources. On the other hand, water shortage and lack of adequate water cause decrease in agriculture efficiency. Moreover, it brings about shutdown of agricultural activity in some regions. Many more farmers keep migrating to the urban area for better socioeconomic conditions.

Economically effect: food scarcity, Devaluation of farmlands, lack of energy especial in water, disordering in tourism industry.

Environmental effect: drying maharlu, Tashk and Bakhtegan lakes in the basin is one of important environmental effect of drought in this area. The negative effects are listed as a below:

- Tashk and Bkhtegan lakes with 1150 km² area have important role in climate and plant cover of surrounding area. Thus, dryness of these lakes has long and short term adverse consequent.
- Drying lakes left vast salt region that can be really harmful for health inhabitants close to lake especially for Neyriz city.
- Bakhtegan lake is located at wildlife Sanctuary and National Parks of Bakhtegan and is one of the most important places of breeding birds (Rafii et al., 2011). This is why, dryness of lakes during recent years have exposed their life to real danger.

9.3 Plan for water management

In this study multiple parameters have been taken to analyses. In order to manage water resources and to save more water in this basin, the below plans are presented:

- **Reduction of water extraction for agriculture purpose**: Considering to climate condition and the necessity of developing agricultural sector as a supplier society food reveal the importance of using modern irrigation methods and the need to pay attention to improve the efficiency of water use in agriculture. Approximately more than 90 % of water in this basin is consumed by agriculture sector but the low efficiency of irrigation network in this region leads to loss of million cubic meters of water each year. Continuation of the current trend will evidently cause serious problems to the supply of water and agricultural future of this region.

In the basin with 31492km² area, 4770 km² belongs to agricultural lands of which 4200 km² is irrigated land and the remain is the rain fed land. Low efficiency can be considered as one of the most important factors for increasing water demand in the basin. Therefore, technological development related to irrigation is considered as a management solution. Irrigation efficiency in this basin is below 50 % (in range between 33-45%. The rise of irrigation efficiency even up to 10% can save 400 cubic million meters' water that is a solution to saving more water in the condition of water shortage.

- **Changing crop pattern and growing crops and plants matching to climate condition and available water resources:** one of the important and effective steps to be taken for dealing with this crisis is selecting suitable crop pattern. Proper crops pattern must be identified based on water/ land/ energy availability and also economic efficiency conditions.

As mentioned earlier in water quality chapter, in the south of basin water has a high salinity because existence of Mahrlu, Tashk and Bakhtegan lakes and also geological formation setting. In this region, developing gardening and growing pomegranate and pistachio as two plants that has low water demands and also tolerate high salinity is recommended. Pistachio water requirement is 4000 m^3/ha that compared to crop such as wheat, barley and cotton has lower water requirement. It also can tolerate water salinity up to 8mμ/cm. Accordingly, this is a suitable plant for south and southeast of basin such as Neyriz, Abadeh Tashk, Arsanjan and Tavabee Arsanjan study areas. Pomegranate can be cultivated in regions with warm and dry summer where have cold weather at the end of harvest season.

Finding the suitable lands to cultivate rain-fed products such as wheat (as the most water consumer crop in the basin) corresponding to ecological condition could be helpful to increase productivity. Based on the result of studies, Marvdasht-Kherameh, Shiraz, Beiza-Zarghan and Dozkord- Kamphiroz are suitable places to cultivate this product.

- **Training farmers and government support for use new agricultural methods:**

Agriculture education plays a very important role in food security and sustainable agriculture and rural development. In order to assess the role of agriculture, the research has conducted a survey among 100 farmers of the area. Based on the survey result, most of farmers aren't educated in agriculture. Moreover, government doesn't train them to use new agriculture methods and how they have to confront to drought aspects. There is also no plan for financial government support. Therefore, most of farmers don't know how to manage water and this is an essential reason for wasting high volume of water.

- **Monitoring water resources**

In respect to shortage of available water in the basin, monitoring of water resources has a major role to save more water and avoiding waste water.

Fars province's regional water authority should control amount of water withdraw from water resources. Unfortunately, massive amount of water extracted from illegal wells in this basin and there isn't any control on that. Installing water meters on wells to monitor the amount of delivered water to each farm corresponding to type of planet, area of land and irrigation method might be an efficient way.

- **Raising price of water and energy:** cost of energy and water in Iran isn’t true price matching with available water resources. Government subsidize in energy sector that has a negative effect on right use of energy. Water and energy prices should be raised meaningfully based on available water resources, types of crop and farm area. Instead of subsidizing in energy price, government should finance modernization of agriculture and training farmers to manage water and energy.

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