# Adaptation to Climate Change to enhance Food Security

# and Environmental Quality:

# Zayandeh Rud Basin, Iran

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## 1. Introduction

The Zayandeh Rud basin is located in the central part of Iran, with geographical coordinates between 50º 24' to 53º 24' north longitudes and 31º 11' to 33º 42' north latitude (Fig.1). The area of the basin is about 42,000 $km^2$. Esfahan province constitutes 87.7% of the Zayandeh Rud basin. In addition, rest of the basin is placed in Bakhtiyary and Yazd provinces. Esfahan is the capital of Esfahan province, which is one of the oldest world cities (Fig. 2).

The river has provided the basis for centuries of important economic activity, including the growth and establishment of Esfahan itself as the former capital city of Persia. The region has been able to support a long tradition of irrigated agriculture, in order to meet the domestic needs for the basin substantial population and industrial demands.

However, the agriculture sector being the main water consumer using more than 80% of the available water resources is heavily under pressure. Numerous factors including continued growth of urban population, development of new agriculture lands and rapid increases in industrial demands have caused water shortage since an half century ago. To overcome this problem, number of trans-basin water projects have been executed and exploited during last decades, but still there is normally insufficient water to irrigate the total irritable area. This has also resulted in reduction of water quality of the Zayandeh Rud, especially downstream the city of Esfahan. Deterioration of water quality causes problem for the ecosystem of the rivers and Gaw Khuny swamp as the final outflow point of the river.

In addition to the internal changes and activities that are presently going on in the basin or can be predicted in future, there is an important external change due to climate change. Climate may change significantly and may, therefore, impact the water resources of the basin. The strategies that can be taken to mitigate its possible negative impacts are scope of this research work, which is part of the Dutch funded project ADAPT (Aerts and Droogers, 2002). This project is aimed to investigate and compare adaptation strategies to cope with climate change impacts in several parts of the world with different climate and economic situations. The selected basins for the ADAPT international project are:

- Mekong, South-East Asia
- Rhine, Western-Europe
- Sacramento, USA
- Syr Darya, Central Asia
- Volta, Ghana
- Walawe, Sri Lanka
- Zayandeh, Iran

This report describes and analyses the present status of the water resources and related socio-economic aspects of Zayandeh Rud basin and possible changes in future due to climate change. Adaptation strategies to diminish possible negative impacts of climate change have been explored and can be grouped into four categories, each of those aiming at alleviating impacts for a different sector. The adaptations strategies are:

- Adaptation strategy 1; Food security adaptation
- Adaptation strategy 2; Environment adaptation
- Adaptation strategy 3; Industrial adaptation

- Adaptation strategy 4; A combination of 1, 2 and 3

The performance of the four strategies will be compared to a business as usual strategy, which can also be just defined as the impact of climate change.

The first sections of this report describe the geographical setting of the Zayandeh Rud basin. Thereafter, the emphasis is on those parts of the basin that directly get water from the river. Next, the focus is on the current status of water supplies and demand and the related socio-economic aspects, finally, possible adaptation strategies are developed and evaluated.

# 2. Current Situation

## *2.1. Natural resources*

The Zayandeh Rud basin includes 7 subbasins, namely Plasjan, Shur Dehghan, Khoshk Rud, Morghab, Zar Cheshmeh, Rahimi and Gaw Khuny swamp (Fig. 3 and Table 1). The upper catchment of the basin is part of the Zagros Mountains. This part of the basin is mountainous, with high altitudes, ample of precipitation. General slope direction of the basin is west to east and the elevation of the basin varies between 1000 to 3600m mean sea level elevation (msle). This part of the basin is of paramount importance in terms of water resources, since almost all water that is used in the basin originates from here.

The natural vegetation cover over the basin is low as precipitation in the lower part of the basin is very low (50-200 mm $y^{-1}$) and erratic. Grass cover can be seen in the basin's plains during spring. The density of the vegetation cover substantially depends on amount of received annual rainfall.

### 2.1.1. Climate

Elevation has a significant effect on climate specification of the basin and its spatial and temporal variation. According to the Dumartan climate classification, most of the basin is identified as Semi-Dry to Ultra-Dry climate and only small portion of the upper catchment areas lay in Cold climate (type B). Precipitation of the basin is mainly affected by the Mediterranean rainfall systems, which enter from North-west of the country. The western mountains of the basin and their direction induce substantial rainfall events. Rainfall reduces rapidly on the Zayandeh Rud basin from west to east. The annual precipitation ranges from 1400 mm on the most upper portion of the catchment (where it is mostly in form of snow) to 700 mm in intermediate part. The amount of rainfall reduces to 300 mm on the region, where the dam is constructed and less than 100 mm on the Gaw Khuny swamp.

In basin, temperatures varies, similar as the rainfall patterns, with elevation. It ranges from 6ºC over the west and North-west mountains to 15ºC on the Gaw Khuny swamp. Every year, a number between 75 to 150 freezing days occur in the basin.

Evaporation is recorded through the Class A pan in the study area. Maximum evaporation occurs in the Gaw Khuny Swamp and the lowest is in the western and northern parts, ranging from 1450 mm to 2800 mm. Likewise, evapo-transpiration, as estimated using Penman-Monteith’s equation, ranges from 1262 mm to 1600 mm. In the Zayandeh Rud maximum and minimum relative humidity occurs during winter and summer, respectively (ranging from 23.6 to 63.3%). Annual cloudiness per Octa scale varies from 2.5 in upper catchments to 1.7 on the Gaw Khuny Swamp.

Prevailing wind direction is western. Maximum wind speed occurs during March and minimum in November, ranging from 6.1 to 9.6 knot.

Climatic variables are recorded in more than 75 stations in the basin. These stations are supervised by the Ministry of Energy and Iranian Meteorological Organization. Among them 3 stations are synoptic, 50 stations are Climatological stations and the rests are simple rain gauges. Record lengths of the stations are different and vary from 11 to 36 years. But, most of them have records more than 20 years. Summery of annual mean of the subbasins meteorological variables are shown in Table (2).

#### 2.1.2. Topography

The topography of the Zayandeh Rud Basin varies from the western part of the basin to the eastern part. Simultaneously, slopes reduce as the river gets closer to the swamp. The western part of the basin is part of Zagros Mountains. High mountains and steep slopes are the specifications of this part. The upstream Zayandeh Rud and Plasjan basins are located in this region. In the Zayandeh Rud River route to the Gaw Khuny Swamp, a number of contributors feed the river, although in recent times most water from these contributors is already used before it reaches the Zayandeh Rud river. These rivers have small watersheds and mountains constitute less part of them. The digital elevation model (DEM) of the study area is also shown in Fig. 4.

#### 2.1.3. Land Use

In general, pastures and uncultivated lands are the dominant land use in the study area. Major land use types of the Zayandeh Rud subbasins are presented in Table 3. The table shows importance of the Morghab subbasin from an agriculture point of view. The main irrigation networks are constructed in this subbasin. Most of the forests and rain fed areas are also located in the Plasjan subbasin. So, it is clear that these two sub-basins are crucial in terms of economic activities of the Zayandeh Rud basin. The major irrigated areas that directly get water from Zayandeh Rud River, are located in Morghab subbasin.

#### 2.1.4. Water Resources

Numerous water projects have been constructed, are under construction or under study for the basin. The Chadegan dam is the main water reservoir with 1450 MCM capacity and has been exploited since 1971. After the construction of the dam, 90,000 hectares were added to the traditional network and the presently irrigated land, surface water and groundwater dependent, is about 297,000 hectares.

The availability of water resources of the basin, even with the construction of the dam, was not sufficient and water scarcity is common in the basin. Therefore, inter-basin transfer has been applied to alleviate this severe water shortage. For example, part of Karoon River water is diverted to the Zayandeh Rud basin by means of two tunnels. These tunnels divert 300 to 400 MCM water per year. In spite of these huge projects, the basin is still under threat and two additional tunnels are under construction. Tunnel No.3, same as Tunnels No.1 and 2, will divert water from Karoon River and No. 2, the Lenjan tunnel, from Dez River upper catchment (Anonymous, 1993a). These two new tunnels with total capacity of 425 MCM are expected to be completed in 2004 and 2008, respectively. Another tunnel, the Behesh Abad, is under study, but has to be 75 km in length which requires a huge investment. The total diversion of water from this tunnel is estimated to be 700 MCM and should join the Zayandeh Rud River downstream of the Chadegan Dam. These projects will play a crucial role in minimizing water deficiency in the basin and the possible negative impacts of climate changes.

Besides these efforts to alleviate water scarcity by transferring water from outside the basin towards the Zayandeh Rud, there are also projects diverting water out of the basin to neighboring cities. First phase of the Yazd project diverts 42 MCM per year to this city and is being exploited since 2002. In the second phase of the project, the diverted water will be increased to 78 MCM/yr. Kashan and Shahr Kurd diversion projects with total capacity of 24 MCM per year are also under construction. Fig. 5 shows the said trans-basins and diversion projects.

#### 2.1.5. Ground Water

Out of 41,347 km$^2$ of the study area, about 25,000 (60%) belongs to alluvial plains. Twenty unconfined aquifers and two confined aquifers have been identified in the Zayandeh Rud basin. In addition to these resources, few karstic aquifers exist in the basin. These resources have a very crucial role in storage and regulation of water resources. Specific investigation is needed to identify this kind of aquifers.

Wells and qanats, the traditional Iranian system to extract groundwater, are the main means to extract groundwater. Presently, about 20,138 deep and semi-deep wells, 1726 Qanats and 1613 springs exploit 3223, 314 and 82 MCM/yr of groundwater, respectively.

Comparing the surface water resources (1245 MCM) with the groundwater ones (3619 MCM) reveals the significance role of groundwater resources for the study area. It can be also concluded that about 90% of the total water resources of the study area are controlled (Anonymous, 1993a).

The basin includes a number of plains. Kohpayeh-Segzy, Esfahan-Borkhar, Nafa Abad, North Mahyar and Lejanat, have been investigated extensively in this study, because of their direct connection with the river. The amounts of exploited water from groundwater from these plains are estimated to be 836, 1011, 553, 74 and 266 MCM/yr, respectively. The selected irrigation systems that are scope of this study lay in part of these plains and they are less dependent to the groundwater.

The Esfahan Water Authority (EWA) studies the basin groundwater budget every year. The 2000 study reveals that all the mentioned plains have negative budget. One of the main reasons is that during 2000 the basin suffered from a sever drought. To estimate long term groundwater budget; recharge from rainfall, seepage from the river and upper catchment runoff infiltration have been modified based on the 30 year average rainfalls and other parameters have been kept constant. Finally, considering the budget equation, variations in total groundwater volume and consequent changes in water table have been estimated and presented in Table 4. From the table it is evident that the agriculture return flows from the irrigation system are the main sources for groundwater recharges. Such that in long term budget this is 576, 44, 280, 22 and 93 MCM/yr for the plains mentioned before, respectively. The results show that only Kohpayeh-Segzy plain is in equilibrium status and the other plains still have negative trend.

#### 2.1.6. Water Demands

The Zayandeh Rud River has for centuries provided the basis for important economic activities. These activities can be categorized in three sectors including agricultural, industrial and domestic consumptions. As it was stated before, agriculture is the dominant water user that consumes more than 80% of the river yield. But, there has normally been insufficient water to irrigate the total irrigable area. It is estimated that water consumption per hectare varies from 10,000 to 14,000 cubic meters.

Huge industrial complexes have been located in the basin. The most important ones are Esfahan Steel Mill, Mobarekeh Steel Complex and number of textile factories that consumes about 100 MCM water per year. Population of Esfahan city is about 2 millions. Domestic water use is estimated to be 80 $m^3$/yr per capita. In addition, 70 MCM is the minimum water requirement to preserve Gaw Khuny Swamp ecosystem.

As it was already stated, not all of the cultivated areas are directly fed by Zayandeh Rud River. The major traditional irrigation systems as well as the modern ones are located along the river (Fig. 6). The total area of these systems is estimated to be about 180,000 ha., where Neku Abad, Abshar, Borkhar and Rudasht are the major irrigation systems in the basin.

The Neku Abad and Abshar irrigation systems were constructed in 1970. The designed command area of these systems is about 90,000 ha. Borkhar and Rudash with a total command area of 83,000 ha are under cultivation since 1997 and part of the systems are still under construction. There are irrigation systems that are expected to be exploited in near future (e.g. Keron irrigation system).

#### 2.1.7. Soil

The basin general soil map is shown in Fig. 7. It is evident that in Plasjan and Morghab subbasins the major soil class is clay and loam is the dominant soil type in other subbasins. The figure also shows the soil texture classes of the major irrigation systems.

### *2.2. Agriculture*

The dominant crop patterns in the basin are: cereals (wheat, barley, rice, maize and sorghum), forage (alfalfa, clover, sainfoin and maize), pulse (bean, lentil and chickpea), and industrial crops (cotton, sugar beat, safflower and potato). Wheat, rice, barley and potato are the main staple crops in the basin. They supply in a substantial portion to caloric demand of the people and livestock (see Table 7). The yields provided in this table of these staple crops are average values and some farms in the basin have higher performances.

The cropping pattern in the major irrigation systems that are located along the river is also shown in Table 8. Some other crops of minor importance can also be found in the basin such as onion, sugarbeet and vegetables.

### *2.3. Environment*

The Zayandeh Rud River and the Gaw Khuny Swamp are two important natural ecosystems in the basin. The Gaw Khuni Swamp as the final outflow point of the river, is one of the international recognized wetlands according to the Convention of Ramsar (1975). Mean area of the swamp is about 43000 ha that varies yearly with respect to the total inflows. During wet years, depth of the swamp reaches to 1.5 m, but normal depth is between 0.3 to 0.6 m. Quantity and quality of the river highly depends on releases of the dam and also numerous water intakes that take place along the 350 km route of the river to the swamp. Furthermore, water quality of the river and swamp is affected by the return flows from the up stream demand sites. From another point of view, the wild life of the swamp depends on the water depth. Lowest possible depth for vital activity is about 15 cm. This depth can be met with 2.2 $m^3/s$ inflows to the swamp (75 MCM/yr). Mainly, benthos can suffer this depth. A more favorable depth is 30 cm, which can be maintained through a discharge of about 4.5 $m^3/s$ (140 MCM/yr). This depth is the optimal one for life of the aquatic organisms (fish, Benthos), birds, plants, and small mammals (Mahboubi Sufiani, 1996; Moeinian, 2000).

***Water Quality Indices***

Biological Oxygen Demand (BOD), Dissolved Oxygen (DO) and Total Suspended Solid (TSS) are the selected indices for evaluation of water quality of the river. BOD is one of the most valuable and commonly used indicators for assessing water quality. BOD is the amount of oxygen, which is used by microorganisms to aerobic decomposition of organic matter. BOD is negatively correlated to streamflow. Standard value of BOD required ensuring a healthy environment and aquatic life is less than 3 mg/l.

The DO of water is another indicator of pollutant levels in an aqua environment, where under DO lower than 5 mg/l aquatic organisms activity will decline. In critical conditions (DO=0), the river lies in anaerobic state and big species will die or migrate to other places. BOD and DO correlate reversibly.

Insoluble solids in water, which appear in suspension state, are called TSS. Turbidity is the direct and physical result of suspended solids in water. Turbidity causes less sun radiation penetration to water. This condition declines the aquatic photosynthesis and result to low DO in the river. Also, settlements of suspended materials on river bed destroy the habitat of aquatic organisms and change the suitable places for fish nursery and spawning. TSS has an inverse correlation with river flow and high levels of TSS causes a decrease in the potential of the river to decay pollutants. Standard levels of TSS are 30 mg/l.

***Sources of Pollution in the River***

Main sources of the river pollution can be categorized into three groups including domestic effluents, industrial, and agricultural return flows (Anonymous, 1993b). Eighteen stations measure the limnological parameters of the Zayandeh Rud River and are maintained by the Esfahan Water Authority and Esfahan Environment Organization. The river water quality can be categorized in four segments. The first segment is from the Chadegan dam up to the upstream of Esfahan (Km 180). For this part, main sources of pollutants are agriculture return flows. In the second part significant changes can be seen on water quality (Km 180 to 220). Return flows from industry, especially textile factories, and Esfahan water treatment plant are the main sources of pollutants that cause these changes. Third segment is from Km 220 to 270. The highest river ability to decay pollutants exists in this segment. After this segment, again agricultural return flows are the main sources of pollutants that deteriorate water quality. The Segzy drain is one of the main drains in this segment.

***Domestic Pollution***

The largest source of domestic pollutant of the Zayandeh Rud River is the effluent of Esfahan city. The wastewater treatment plant of the southern part of Esfahan is in the vicinity of the river. This system consists of three separate units, which was designed for 800,000 people. Total volume of entering effluents is some

126,400 $m^3$/day causing serious environmental problem in the river ecosystem, especially during low flows. Although water treatment purification of the system reduces the organic discharge of the wastewater (Table 9), purification efficiency is only about 85% and needs improvement. Beyond Esfahan city, domestic originated pollutants are less relevant and the river water quality is more affected by the agriculture drainage.

***Industrial Pollution***

Numerous industrial activities are taking place in the Zayandeh Rud basin. Among them, huge factories such as Mobarakeh steel complex, Esfahan steel mill, Sepahan cement factory and a number of textile factories are located close to the river. From these the textile factories are the main cause of pollution.

***Agricultural Pollutants***

Agricultural drainages contain soluble salts, insecticides and herbicides residues, leached chemical fertilizers and heavy metals. The Zyandeh Rud basin has three main agricultural drainage systems referred to as Steel Mill, Rudasht and Segzi drains. They enter to the river at Zarrin shahr city, Shah karam village and Farfan village, respectively. These drains enter the river at distances from the Regulating dam of 111, 254 and 296 km, respectively. Steel Mill drain is an open channel to control level of groundwater of Zarrin shahr region located at the western part of Esfahan city. It receives high amounts of return flows from agricultural lands and conveys them to the river. The approximate flow rate is about 14,400 $m^3$ $d^{-1}$. It also receives part of the outflow from the Esfahan steel Mill water treatment plant. The Rudasht drain collects drainage water of Rudasht region and discharges it to the river with 5808 $m^3$ $d^{-1}$. The Segzi drain is the largest and most important drain of the basin. After collecting the drains of the Segzi region and some border parts of Rudasht plain, the drain reaches to the Zayandeh Rud River. During some periods the discharge of the drain is more than the river flows, particularly in summer and autumn. Mean drain discharge is about 28,700 $m^3$ $d^{-1}$. Salinity levels in the downstream parts of the basin are too high to be suitable for irrigation (Table 10).

## 2.4. Socio-economic characteristics

From 1966 to 1991 population in the basin increased from 1.1 to 3.0 million. According to the 1996 census, population of the entire basin was 3.9 million from which 2.9 million people live in the urban areas (34 cities) and 1.0 million are rural residents (1212 villages). Most of the residential areas and almost 82% of the basin's population (cities as well as villages) are located along the Zayandeh Rud River. About 76% of rural population lives in the Morghab subbasin. Population of Esfahan and its suburbs is about 2 million that their drinking water is directly supplied by the Zayandeh Rud River.

The government has taken positive measures to control population and it has started to decrease since 1991 and growing rate is estimated to be about 2% for 2000. Growing rate is still expected to have decreasing trend.

### *2.5. Institutional arrangements*

The main responsible entity for water resources exploitation and distribution is EWA that is supervised by the Ministry of Energy. This institute is responsible for large size water projects, although small ones to some extent are considered by them. Water distribution up to tertiary irrigation channel level of the irrigation systems are also the responsibility of the Ministry of Energy. Supervision on the exploitation from groundwater resources is included as well in their mandate.

The Esfahan Agriculture Authority that is supervised by the Jehad-Keshavarzy (Agriculture) Ministry coordinates the water distribution in tertiary and lower level channel networks. Watershed management and small scale water projects (e.g. groundwater artificial recharge) are some of the related water duties of the Esfahan Agriculture Authority.

Environmental issues in the basin are controlled by the Esfahan Environment Authority. The Iranian Environment Organization is an independent organization, which is directly under supervision of the Iran President.

Non-Governmental Organizations (NGO) have been recently activated in Esfahan focusing on Zayandeh Rud River and the river ecosystem. In addition to this several NGOs have invested in minor irrigation systems and maintenance the irrigation systems.

Climate change issues are hardly getting any attention from policy makers. At the national level a few activities have been initiated by the National Environmental Organization, but so far no structured policy is in place.

## 3. Future Projections

### *3.1. Climate Scenarios*

It is obvious that meteorological conditions, such as temperatures and rainfall, have a direct impact on water resources in the basin. Looking at trends in the past can be useful as a first indicator of what possible consequences climate change might have on the water resources and, consequently, on agriculture, environment and domestic and industrial water use (Morrison et al., 2000).

As was pointed out earlier, most of the water resources in the basin (or transferred), is derived from upper subbasins (mainly Plasjan subbasin). Record from the Damaneh Freidan station is a good indicator for climatic situation and possible climate changes over these areas because of its high altitude (2340 meter m.s.l.e.). Fig. 8 shows mean annual temperatures with a linear trend line for the stations. For this station and also some other stations in the vicinity, the mean annual temperature increase is estimated to be 0.03 to 0.05 ºC/yr. It should be mentioned that this positive trend is not seen for all the stations in the basin. The Spearman and Kendal tests for trend analysis have been applied for the historical data and results indicate that all of the stations do not indicate significant trends in temperatures (Table 5).

To generate climate change data, two approaches have been identified. The first approach is based on historical data and using statistical methods to extrapolate these trends. The second approach is based on the general circulation models (GCM) (Pao-Shan et al., 2000). For this research work the latter has been used, and from the seven available GCM data at the IPCC (Intergovernmental Panel on Climate Changes; URL: www.ipcc.ch./) the Hadley GCM has been used. Projection based on the most recent IPCC emission scenario, the so-called SRES (Special Report on Emission scenario) has been done. Here results of the A2 and B2 scenarios are selected, which are characterized as: ”a differentiated world” and the time slices 2010-2039 and 2070-2099 were chosen for further analysis. The underlying theme is that of strengthening regional cultural identities, with an emphasis on family values and local traditions, high population growth, and less concern for rapid economic development.

The Hadely GCM projections are based on grid cells of 2.5º x 3.75º. According to the ADAPT methodology, the GCM data have been downscaled to 0.5º x 0.5º grid. Then they were transferred in such a way that the main statistical properties of historical measured data match the GCM outputs. For this, the 1972-1990 observed and modeled temperature and precipitation data were used to derive adjustment factors that were subsequently applied to the future projections (2010-2039 and 2070-2099).

Results of applying the above methodology reveal that according to the Hadley GCM outputs, the Zayandeh Rud basin won’t have significant changes in meteorological variables for the first period 2010-2039. However, for the second period 2070-2099, the basin will face with more drastic changes. According to the A2 scenario, mean annual temperature is expecting to increase about 4.5 ºC and mean annual rainfall depth decreases 234 mm. In case of the B2 scenario, temperature increase is 3.2 ºC and rainfall decrease is 149 mm. Mean monthly precipitation for the two periods and the selected scenarios are shown in Figs. 9 and 10 (see also Table 6).

This should be emphasized that the GCM results are based on the current state of climate change research work and are only a possible scope of the future and are not real realizations. This work is mainly a tool to provide information to policy makers and mangers on possible future outcome and to prepare proper measures that can be taken to adapt to negative impacts of climate change.

### *3.2. Socio-economic projections*

Growing population for the 2010-2039 is estimated to be two percent and for the 2070-2099 period it is expected to decrease to one percent. Water consumption per capita has been reduced to 60 $m^3$/capita. Increase in industrial demands has been assumed to be negligible. This means that the total domestic water demand will increase with 400 MCM up to the end of this century.

## 4. Modeling activities

For this research work three different simulations are identified to be necessary for a proper assessment and exploration of adaptation strategies: rainfall-runoff simulation, water allocation programming and crop production predication. Artificial Neural Networks (ANNs), ZWAM and SWAP (Van Dam et al., 1997) have been selected as the appropriate models to be used. Furthermore, few statistical analyses have been done with SPSS and CFA packages.

### *4.1. Rainfall-runoff Model*

Rainfall-runoff modeling is required to analyze the processes that convert rainfall into runoff that can eventually be used for irrigation purposes. Several approaches exist ranging from more physically based methods using semi-distributed hydrological models towards simplified rainfall-runoff statistical regression models. We have selected here to use an Artificial Neural Network approach, since this was already developed, well-tested and validated for Zayandeh Rud Basin.

An ANN is described as an information processing system that is composed of many nonlinear and densely interconnected processing elements or neurons. It has been reported that an ANN has the ability to extract patterns in phenomena and overcome difficulties due to the selection of a model form such as linear, power, or polynomial. An ANN algorithm is capable of modeling the rainfall-runoff relation due its ability to generalize pattern in noisy and ambiguous input data and to synthesize a complex model without prior knowledge (Dawson and Wilby, 1998; Coulibaly et al., 2000).

For rainfall-runoff simulation, 31 years (1972-2002) records of the Chadegan Dam gauging station that measures total inputs to the dam (upper catchments and transferred water from Tunnel#1 and Tunnel#2) have been used to train and test the model. Applying different inputs, ANNs models and architectures, the recursive Elman Networks with 7-2-1 architecture was found suitable for the study area. The selected input for the ANN model is:

$$Q(t)=f(Rain(t),Tmax(t),Tmin(t), Rain(t-1),Tmax(t-1),Tmin(t-1),Rad(t))$$

where *Q(t)* is monthly discharge($m^3/s$), *Rain(t)* is monthly rainfall (mm), *Tmax(t)* is monthly maximum temperature ($^oC$), *Tmin(t)* is monthly minimum temperature($^oC$), *Rad(t)* is monthly radiation (cal $cm^{-2}$ $d^{-1}$ ) and *(t)* and *(t-1)* refer to time *t* and time *(t-1)* (one lag monthly data).

### 4.2. Water Allocation Model

Water allocation between and within different sectors is of paramount importance in Zayandeh Rud. The basin is highly developed in terms of water resources and any change in water allocation has direct impact on other water users. To deal with these issues the ZWAM (Zayandeh Rud Water Allocation Model) was developed for the study area. The model is able to simulate different water allocation policies, dam operations, environmental issues and examining different scenarios for future changes of the study area. The model is a node oriented and the main water demand sites along the river have been embedded in the model.

The ZWAM model is similar to the WEAP model (2000), which is based on similar concepts, has also demonstrated to be helpful for objectives of this research work.

### 4.3. Field-Scale Model

The agro-hydrological analyses at field scale have been done using the SWAP model (Soil Water Atmosphere Plant). The model is a physically based one for simulating water, heat and solute transfer in the saturated and unsaturated zones. The model is also capable to simulate crop growth using meteorological data, irrigation planning and phonological crop data. More detailed description about the model is available in Van Dam et al. (1997).

# 5. Impacts and Adaptation

## 5.1. Introduction

The ADAPT project follows a generic methodology that allows for quantifying food and environmental related impacts under climate change. Based on these impacts, stakeholders are able to develop and evaluate different adaptation strategies to alleviate negative impacts of climate change (OECD 1994, Aerts et al. 2003).

In the iterative approach, climate change scenarios are used as input to simulation models in order to quantify the impacts of climate change on the water resources system of a river basin, and consequently, the implications on industry, the environment and food production and security that all closely relate to the water resources system.

For this, it is important to define a representative set of *State indicators*, which reflect the value over time of the water resources system for preserving food security and environmental quality. Hence, impacts are here defined as the change in the values of *State indicators.*

Fig. (19) briefly explains the different components of the generic approach.

## 5.2. Indicators

To describe the current state of water resources of the basin as well as its future status, a number of indicators have been selected each valuing the state of the environment (mainly wetlands) and food security.

The indicators that can quantify the state of food security are allocated water to agriculture (MCM/yr), food production (ton/yr) and crops derived energy production (Calories/yr). The last indicator makes it possible to compare food production with different crop types. Furthermore, since environmental quality is mainly function of water availability and amount of water that reaches to the swamp, it has been decided to use three environmental indicators as “years with inflows< 75 MCM’, ‘75< years with inflows < 140 MCM’ and ‘years with inflows> 140 MCM’. To evaluate the whole water system of the basin, number of years that the water resources can not meet the demands (even after implementing adaptation strategies) can be a good indicator. These years will be called *dry years*.

In summary the following indicators are used to express the current state and the expected state in the future with and without adaptation strategies:

- water allocated for food production (MCM $y^{-1}$)
- total food production (ton $y^{-1}$)
- total food energy production (cal $y^{-1}$)
- low-flow-years to wetland

## 5.3. Impact

The impact of climate change on water, food, industry and environment has been assessed by using the modeling framework as described before. These impacts can also be seen in terms of adaptation strategies, where impact means “business as usual”.

In the project methodology, climate change is the driver, which includes also other factors such as increasing population and growth in the domestic water demands, increasing population and more food requirements, and growth in the industrial water demands. Of course there are few other drivers that are for the moment not included. Technological improvement is one of such a driver, where crop breeding is important to develop crop species that are more resistant to water shortage, water salinity or high-yielding varieties.

Overall the analysis shows that the basin is under threat due to the above described drivers. Climate change will have negative impacts on the available water resources. The average basin rainfall may reduce up to 15% and the temperature increases up to 4ºC. These two changes are associated with reduction in water resources quantity and quantity. With respect to the future population growth, the basin domestic water requirement that is presently about 150 MCM, will reach to 344 and 540 MCM in 2039 and 2099, respectively. The growing rate of the industrial water demand has been assumed to be 1% up to 2010 that becomes about 115 MCM at this time and then it is considered to remain constant. This assumption is based on the conservative policies in water demands for the industry.

#### 5.3.1. Stream Flow

Using the trained ANNs model, the streamflows have been simulated for the selected 2010-2039 and 2070-2099 periods for both the A2 and B2 scenarios. The mean monthly flows and their distribution under the A2 scenario shows significant changes in timing and volume comparing with the historical flows (Fig. 11). But, the changes under the B2 scenario are lower and stream flows show almost same temporal pattern (Fig. 12 and also see Table 6). The sequences of successive dry and wet years have been estimated and are shown in Figs 13 and14. As it is evident in the figures while the maximum successive dry years during observed period is 2 years, it is 11 years in A2 and 3 years in B2.

#### 5.3.2. Impacts on Groundwater Resources

Considering the changes in rainfall and river flows due to the climate change scenarios, the groundwater budget for the periods 2010-39 and 2070-99 were estimated (Table 11). Results show that Kohpayeh-Segzy and North Mahyar will be almost in equilibrium state, but for the other plains a negative budget can be expected. For instance, Najaf Abad aquifer may have up to 2.6 m/yr drawdown in water table. The analysis indicate clearly that any increase in exploration of groundwater is not possible, unless new sources (e.g. transfer of water from adjacent basins) for recharge can be defined. In general scenario B2 for the period 2010-2039 show a declining trend, which was even more profound for the A2 scenario for the period 2070-2099.

#### 5.3.3. Impacts on Agriculture and Food Production

Climate change impacts on agriculture production are the result of two processes, increasing air temperature (i.e. increasing transpiration) and $CO_2$ enrichment of the atmosphere. These two have been separately considered in this research work, as follows.

In the first step, the SWAP model has been run for the staple crops and the current climate situation as well as the selected future periods with scenarios A2 and B2. Results are depicted in Figs. 15 to 18 for wheat, barley, rice and potato through relative yield (actual yield /potential yield) contours. The general patterns of the contours reveal that considering solely the variation in temperature and rainfall, there is not much change in relative yield for the period 2010-39 comparing with the current situation. But, for the period 2070-99, 10 to 15% reduction in crop yields can been expected. To make it more clear, comparisons of the crops relative yields for two ordinary irrigation depths (Irr.Dep.) and salinity amounts (EC) are shown in Table 12. For instance, while 1000 mm irrigation water with 4 dS $m^{-1}$ salinity for wheat results in 62% relative yield for the current situation, it is decreases up to 55% for the period 2070-99. Similar patterns for other crops are found.

Contribution of $CO_2$ fortification and its impact on the crop yields is the next step of the study. It is expected that $CO_2$ levels in 2100 reaches to 640 ppm that is an increase of more than 300 ppm compared to the present situation (Parry et al., 1999; IPCC, 2000). Responses of plants to this phenomenon will be different. It is expected that C3 plants will response more positively to rising level of $CO_2$. Wheat, barley, rice and potato that are dominant crops of the Zayandeh Rud basin are categorized as C3 crops. Wange and Connor (1996) studied the impacts of increased CO2 levels on a number of plants. They predicted wheat, barley and rice will have a 31, 30 and 27 percent increase in biomass production under increased $CO_2$ levels. In a case study in Tabriz (North West of Iran) Koochaki and Kamali (1999) also reported an increase in crop yield to expected $CO_2$ enrichment.

With respect to the negative impact of climate change due to variation in climate variables and positive one due to $CO_2$, it can be concluded that crop yields in the basin will increase up to 25 %. But, it should be emphasized that this is only potential yield. In addition to potential yield, the actual yield is a function of irrigation water quality and quantity that are anticipated to decline in the future periods. More investigations are needed for precise conclusion in this regard.

## *5.4. Adaptation strategies*

### 5.4.1. Business as usual

As mentioned before, the impact of climate change and associated other drivers can be considered as the “business as usual” adaptation strategy. Using the aforementioned drivers and indicators, the simulation models were applied to calculate indicator values. The status of the basin will be separately evaluated for the selected periods and climate change scenarios.

According to the present water allocation policies, domestic and industrial demands have first and second priority, respectively. Agriculture and environment sectors are next, such that during the recent prolong drought spells (1997-2001) water was completely cut for the Gaw Khuny Swamp. But with respect to the new regulations, Esfahan Water Authorities has been committed to allocate 75 to 140 MCM/ yr for the river and the swamp ecosystem, depending on wetness situation of years. These policies have been embedded in the ZWAM model to examine possible water deficits and consequent durations during the future periods. So, whatever happens with the climate: the domestic and industrial water demands must be fulfilled and what is left over, can be used for agriculture and environment.

So far, it is clear that the agriculture sector is the main water consumer. While this sector absorbs 80% of the basin water resources, this will be 77, 72, 69 and 66% in 2010, 2039, 2070, and 2099 assuming fixed agriculture demands and no new source of water from trans-basin transfer. From this it is clear adaptation strategies are essential to be taken.

### 5.4.2. Food Focused Adaptation (St_F)

As was stated before, the general impact of climate change on the basin crop production seems to be negative (section 5.3.3). However, there is clear a need to produce more food in the future considering the increase in population. Two types of adaptation measures have been evaluated to explore this:

- Change in the total cropped area in the basin
- Change in the cropping pattern

It should be noted that the available data about crop yields is not irrigation system wise; rather it is according to the regions that have been defined by the Esfahan Agriculture Organization (EAO). From another point of view, there are lots of inherent differences between the irrigation systems that are located along the river (e.g. soil condition, quality of received water, crop patterns). We have selected to concentrate the analysis on the Nekou Abad and Abshar irrigation systems that are located in the Esfahan region according to the EAO divisions. Rice and potato have been analyzed according to Nekou Abad situation and wheat and barley according to the Abshar.

Using previously published reports, the cropped area for rice, potato, wheat and barley are estimated to be 11,260, 3,480, 20,892 and 4,273 ha. Also, optimum water extractions to these crops are estimated to be 17,000, 11,000, 9,000 and 8,000 $m^3$ $ha^{-1}$. It should be mentioned that different figures about the area and water consumptions have been found too.

To perform our analyses on food adaptation strategies the basin level and field level models were linked to indicate water quality and quantity at the irrigation systems and response of crops to the allocated water for the climate change scenarios. Fig. 20a to 20d show results of these extensive runs that have been undertaken. Also, Table 13 shows average and coefficient of variation of the major crops. It is evident that during the 2070-99 period a negative impact on crop production (average as well as variation) can be expected and also, that rice is more sensitive to the climate change than the other crops in the basin.

To compare adaptation strategies we used also water consumptions of the crops as an indicator, in addition to the caloric production indicator, within the periods considered (Table 14). This caloric production was calculated assuming that 3600, 760, 4000 and 4000 are the total produced calories per kilogram of rice, potatoes, wheat and barley, respectively (Table 15).

***Change in the total cropped area in the basin (St_F1)***

Two of the main negative impacts of climate change on the basin are reduction of quality and quantity of water. One of the possible adaptation strategies is to reduce total cropped area. This strategy has been investigated and cropped areas have been reduced such that optimum water requirements can be meet for the major crops. The results of this strategy are shown in Table 16. The table shows that this strategy has only positive impact on rice, but if we consider other crops using the same area is more beneficial. This result has been confirmed by other optimization models too.

***Change in the cropping pattern (St_F2)***

Changing the cropping pattern is one of the possible strategies that can be applied. Table 14 shows that rice and wheat get almost the same amount of water in the irrigation systems. But, the energy produced by wheat is about 2.9 to 5.5 times more than rice for the different periods considered (Table 17). Another important point in this regard is the coefficient of variation of rice during the two periods. While in case of wheat it ranges from 0.14 to 0.29, for rice it is 0.59 to 1.21. So, from a food security point of view rice production is not providing a reliable source of food too.

Presently, the main interest of farmers to plant rice is its high income in comparison to the other crops. Domestic price of rice in the basin is much higher than current world market prices. But, because of the expected serious future water scarcity, the government should take measurers to make crops like wheat more beneficial. Potato and wheat can be substituted instead of rice. Potato may produce more calories, but it may have some marketing problems. So, it is wheat that can be recommended for substitution of rice. Such a strategy can result in an increase of 33 to 48% in the total produced calories in the basin (Table 18). This strategy can reduce agriculture water demands up to 10%.

#### 5.4.3. Environment Focused Adaptation (St_E)

The positive measures that have been taken by the Esfahan Environment Organization to have a minimum flow of 75 MCM $y^{-1}$ to the Gaw Khuny swamp and continuation of such actions can preserve the river and the swamp ecosystem in dry years and also the changes that are expected due to climate change.

The impacts of these measures can be seen in Figs. 21 and 22 showing the BOD and TSS fluctuations of the Zayandeh Rud River during recent years. Although the water quality indices are followed by a similar patterns in different years, pollution rates have been decreased in the 2000, whereas in this year the basin faced with a sever drought too. The recent regulations have committed the industrial sector to increase their wastewater treatment efficiency, installation of new wastewater treatment facilities and even number of factories have been relocated to other places. In case of textile factories the painting units of these factories have been also committed to shift to the places that are far from the river.

In spite of these positive measures, results of ZWAM show that for all of the future periods, BOD beyond the return flow of Esfahan water treatment will deteriorate. Even for months of May when the river is in its highest mode, still the BOD is greater than 10 mg/l. Another point that can be concluded from the results of ZWAM is that even no water allocated for the swamp, at least 75 MCM/yr reaches to the swamp. Actually, this amount is obtained from return flows of the upstream demand sites. This was also checked with records of inflows to the Gaw Khuny swamp. The records show that inflows to the swamp ranges from 30 to 639 MCM over the last years. Of course, in the recent years (1997 to 2000) yearly inflows are usually down to 30 MCM as a result of the severe drought. This difference between this 30 MCM and the minimum flow requirement of 75 MCM should come from future additional inflows of Lenjan Tunnel and Tunnel #3 to the dam that will be exploited after 2010. So, if even no water is allocated for the swamp, it will get a volume close to 75 MCM. Thus allocating 75 MCM/yr exclusively for the swamp can be an adaptation strategy. This will be summarized as adaptation strategy ***St_E***.

#### 5.4.4. Industry and Domestic Focused Adaptation (St_D)

The total amount of the water that has been presently allocated for the industrial sector is about 100 MCM. According to communications that have been done during this research work, there is not much industrial developments through the basin that rely on water.

The only hydro-power unit in the basin is the hydro-power unit of the Chadegan dam. The total electricity consumption in the basin has been estimated to be about 3000 GWH, while the Chadegan dam has produced only 5% of this amount (according to the 2002 information) (Fig. 23). The main source of power generators in the basin is natural gas. With respect to the portion of hydroelectric to the total amount of the generated power in the basin, it is not found vulnerable to climate change.

Reduction in domestic water requirements up to 25% by undertaking extension activities and modification of the drinking water networks to reduce the present losses (i.e. reduction of 80m$^3$/yr/capita to 60m$^3$/yr/capita) is the major measure that can be taken to reduce domestic demand and will be summarized as ***St_D***. It should be added that ***St_D*** is only a strategy for the period 2010-2039. For 2070-2099 it has been assumed that by modification of the drinking water networks the domestic water demand will reduce to 60 m$^3$/capita. In other words, for the period 2070-2099 it is a driver rather than a strategy.

#### 5.4.5. Combined Food and Environment Focused Adaptation (St_TB)

As was stated before the climate change data should be considered as an indication on what might be happen in the future, rather than a real realization. For this section the evaluation of the suggested strategies based on the indicators has been discussed for the two periods considered. Furthermore, effects of the sequences of inflows have been also included in the analyses to assess possible consecutive dry years.

***The Period 2010-39***

Assuming the same agricultural and environmental demands, the total water demands with respect to the drivers have been estimated. Total water requirement in year 2010 is 2376 MCM and it will reach to 2522 MCM in 2039. As was pointed out earlier, two tunnels (Tunel#3 and Lenjan tunnel) are presently under construction and will start to be in operation before 2010. So, their water capacities have been added to the present available water. Total capacities of these tunnels are estimated to be 425 MCM. It is assumed that 425 MCM is the maximum capacity, and with respect to variations in rainfall, the total deliverable water to the basin also changes. Results of running the ANNs model (rainfall-runoff simulation) and ZWAM model (water allocation model) with respect to A2 and B2 climate change scenarios that constitute total supplied water in the basin are shown in Fig. 24. Comparison of A2 and B2 scenarios for this period reveals that in A2, the basin will face more severe and longer water deficits.

To evaluate the strategies, they have been compared with the present water distribution and cropping patterns (business as usual, ***BAU***). It is clear that applying ***St_E*** to save the swamp, causes almost 5% reduction in food production (calories) and higher water shortage. But, applying ***St_F2*** does not only eliminate the previous negative impacts but also increases food production up to 20%, and reduces dry years and water shortage. For the next step and applying ***St_D***, the agricultural production may increase up to 25% compared to ***BAU*** and lower water shortage. It is evident that reduction in agriculture demands has a significant impact to reduce vulnerability of the basin to water deficits. Table 19 shows results of applying the mentioned strategies in detail. The impacts of the above strategies are shown in Fig. 25 and Table 19.

***The Period 2070-99***

In the Period 2070-2099, the competition for domestic and agriculture demands will be more seriously. While the present domestic demands is about 10% of available water resources, it rises to 20% at the beginning of this period and increases up to 25% at the end (Fig. 26).

The present water resources can not meet the basin water requirements (with same agriculture and industrial demands and also increase in domestic demand due to increase in population). For this period the basin will face more water shortage and scarcity. Similar to the previous periods, strategies ***ST_E*** and ***St_F2*** have been examined for this period. The impacts of these strategies are shown in Fig. 27.

As it was already pointed out, the Behesht Abad trans-basin project is one of the projects that are proposed by the Esfahan Water Authority to transfer water from the neighboring basin (Karoon basin). This project requires huge investments and may have also some negative impacts on hydropower infrastructures in the Karoon basin. More investigation is needed to assess this issue. Fig. 27 shows impact of this project on the basin available water. The transfer capacity of the project is between 700 to 1000 MCM, but for the present analyses 700 MCM has been applied. Including this volume of water to the total available water resources of the basin not only rectify the mentioned water shortage but also makes new capacity to improve agriculture lands and produce more crop. Such an improvement is definitely required for this period, when the basin should accommodate and feed about 7 to 9 million people. This strategy is referred as ***ST_TB*** and shown in Fig. 28**.** While present resources of the basin are enough to produce 3460 calories/capita.day, it reduces to almost 810 in year 2099. But, applying ***ST_TB*** increases it up to 1400 calories/capita.day for this time. Therefore, even after applying this strategy, the basin will still need to import a substantial amount of food. The results of the selected strategy for this period are shown in Table 20.

## 6. Conclusion

In this study, impacts and adaptation strategies of climate change on the water resources, food production, and environmental preservation of the Zayandeh Rud Basin were investigated for two time periods, 2010-2039 and 2070-2099 by implementing GCM projections in a modeling framework. The results showed a negative impact on the available water resources and possible decline in water quality.

Rice, potato, wheat and barley as the basin staple food were selected to evaluate responses of crops to the future climate change. In general, crop production will increase because of positive impact of enhanced $CO_2$. But, this increase is not enough to compensate for the negative impacts of the decline in water quantity and quality for some of the crops. Among them rice shows the most negative responses to these changes in terms of average yield as well as variations. But, in case of potato the response is positive, although the yearly variation is estimated to be higher. Presently, domestic and industrial demands get 20% of the total available water, but at the end of this century it will reach to about 35%. This increase is mainly result of population growth. So, the portion of agriculture water is expecting to go down.

To eliminate the aforementioned negative impact a number of adaptation strategies have been assessed and evaluated using a generic approach that can be used by policy makers and water resources managers. However, there are some positive measures that are initiated by the basin's policy makers that have been evaluated during this study. The following result has been concluded from this study:

- Climate change will confront the basin with more water scarcity and salinity problems that makes proper water management at basin level as well field level more crucial.
- The results show that there will be a need to some changes in cropping pattern. Specifically, with respect to the future changes, rice will not be a recommendable plant to be cultivated.
- Pricing policy for the crops should be conducted to make crops with more calories production, more beneficial.
- Competition for domestic and agriculture water requirement is going to be more serious in future of the basin. So, population control is going to be an essential policy for the basin.
- The ecosystem of the Zayandeh Rud River suffers from domestic and industrial return flows. The purification efficiency in these sectors should be improved.
- The present water resources of the basin will not be sufficient for the selected future period of this research work. Transfer of water from the neighboring basins to the Zayandeh Rud basin is an essential adaptation measure.
- Impact of such transfer is also needed to be investigated on the original basins with respect to the climate change.

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## 8. Tables

**Table 1. Areas of the Zayandeh Rud subbasins**

| Subasin | Plasjan | Shour | Khoshk Rud | Mor Ghab | Zar Chesh. | Rahimi | Gaw Khuny | Total |
|---|---|---|---|---|---|---|---|---|
| ***Area ($km^2$)*** | 4246 | 4023 | 5716 | 11948 | 4718 | 7080 | 3616 | 41347 |
| ***Area (%)*** | 10.3 | 9.7 | 13.8 | 28.9 | 11.4 | 17.1 | 8.8 | 100.0 |

**Table 2. Annual average of meteorological variables in the Zayandeh Rud Subbasins**

| Subbasin | Rainfall (mm) | Av.Temp (º C) | Evapor. (mm) | Ev-Trans.(mm) |
|---|---|---|---|---|
| ***Plasjan*** | 500-1600 | 6-11 | 1450-2400 | 1200-1400 |
| ***Shour Dehghan*** | 250-500 | 9-15 | 1600-2550 | 1400-1500 |
| ***Khoshk Rud*** | 250-300 | 9-15 | 1800-2550 | 1400-1500 |
| ***Morghab*** | 140-200 | 5-15 | 1800-2550 | 1300-1500 |
| ***Zar Cheshmh*** | 200-300 | 8-13 | 1600-2550 | 1300-1500 |
| ***Rahimi*** | 140-200 | 9-15 | 1600-2550 | 1300-1500 |
| ***GawKhuny*** | <140- 140 | 13-15 | 2400-2800 | 1400-1600 |

**Table 3. Land use types in the Zayandeh Rud subbasins**

| Subbasin | Area ($Km^2$) | Irrigated Area (%) | Rain fed & Fallow (%) | Forest (%) | Pastures (%) | Resid-Inf Structures (%) | Marsh (%) | Uncult. Lands (%) |
|---|---|---|---|---|---|---|---|---|
| ***Plasjan*** | 4246 | 16.3 | 10.5 | 19.5 | 51.5 | 1.0 | 1.1 | 0.1 |
| ***Shour Deh*** | 4023 | 11.6 | 0.4 | 1.6 | 64.4 | 1.0 | 0.2 | 20.8 |
| ***Khoshk R.*** | 5716 | 2.4 | - | - | 88.3 | - | - | 9.3 |
| ***Morghab*** | 11948 | 14.4 | 0.3 | - | 52.0 | 3.1 | 3.2 | 27.0 |
| ***Zar Ches*** | 4718 | 0.4 | - | - | 89.3 | - | 0.5 | 9.8 |
| ***Rahimi*** | 7080 | 0.5 | - | - | 55.9 | 0.1 | 29.6 | 13.9 |
| ***Gaw Khoni*** | 3616 | 5.7 | - | - | 70.4 | 0.4 | 0.8 | 22.2 |

**Table 4. Long term status of ground water in a number the Zayandeh Rud Basin plains**

| | Kohpayeh-Sagzi | | Isfahan-Borkhar | | Najafabad | | Mahyar North | | Lenjanat | |
|---|---|---|---|---|---|---|---|---|---|---|
| Volume in MCM | 2000 | Long term | 2000 | Long term | 2000 | Long Term | 2000 | Long Term | 2000 | Long Term |
| Area (sq. km) | 4046 | 4046 | 2822 | 2822 | 780 | 780 | 151 | 151 | 719 | 719 |
| Subsurface Inflow | 179.50 | 179.50 | 192.10 | 192.10 | 116.10 | 116.10 | 52.60 | 52.60 | 112.60 | 112.60 |
| Rainfall Infiltration | 36.98 | 97.10 | 24.38 | 73.37 | 10.58 | 24.96 | 1.95 | 3.62 | 6.42 | 25.50 |
| Domestic and Industrial Infiltraton | 0.89 | 0.89 | 130.52 | 130.52 | 26.75 | 26.75 | 2.00 | 2.00 | 10.90 | 10.90 |
| Irrigation System | 370.00 | 370.00 | 50.00 | 50.00 | 320.00 | 320.00 | 24.20 | 22.20 | 150.00 | 150.00 |
| Traditional Irrigation System | 170.00 | 170.00 | 30.00 | 30.00 | 38.00 | 38.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Pumping from River | 50.00 | 50.00 | 13.00 | 13.00 | 14.00 | 14.00 | 0.00 | 0.00 | 49.40 | 49.50 |
| Wells and Qanats | 834.80 | 850.00 | 1007.80 | 1011.00 | 499.80 | 560.00 | 52.50 | 52.50 | 245.60 | 266.00 |
| Infiltration Rate for Irrigation | 0.40 | 0.40 | 0.40 | 0.40 | 0.30 | 0.30 | 0.30 | 0.30 | 0.20 | 0.20 |
| Infiltration from Irrigation | 569.92 | 576.00 | 440.32 | 441.60 | 261.54 | 279.60 | 23.01 | 22.41 | 89.00 | 93.10 |
| Infiltration from Runoff | 1.24 | 3.26 | 0.91 | 2.73 | 1.76 | 4.14 | 1.00 | 1.86 | 1.08 | 3.19 |
| Artificial Recharge | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | | 0.00 | 0.00 | 0.00 |
| Recharge from River | 4.80 | 12.60 | 0.00 | 0.00 | 26.70 | 63.01 | 0.00 | 0.00 | 0.00 | 0.00 |
| Storage Coeficient | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 |
| Drawdown (m) | 0.73 | 0.00 | 1.79 | 1.22 | 4.37 | 2.72 | 0.84 | 0.59 | 1.31 | 0.60 |
| Change in Storage | 147.68 | 0.00 | 252.57 | 172.14 | 170.43 | 106.08 | 6.34 | 4.45 | 47.09 | 21.57 |
| Total Inflow | 942.00 | 869.35 | 1040.80 | 1012.47 | 613.85 | 620.64 | 86.90 | 86.95 | 267.09 | 266.86 |
| Subsurface Outflow | 5.50 | 5.50 | 1.40 | 1.40 | 57.20 | 57.20 | 12.70 | 12.70 | 0.00 | 0.00 |
| Wells, Qanats, Springs | 836.50 | 850.00 | 1011.00 | 1011.00 | 553.30 | 560.00 | 74.20 | 74.20 | 266.00 | 266.00 |
| Draiange Canal | 78.00 | 14.00 | 28.40 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.00 | 1.00 |
| Evaporation | 22.00 | 0.00 | 0.00 | 0.00 | 3.30 | 3.50 | 0.00 | 0.00 | 0.00 | 0.00 |
| River Drainage | | | | | | | | | | |
| Total Outflow | 942.00 | 869.50 | 1040.80 | 1012.40 | 613.80 | 620.70 | 86.90 | 86.90 | 267.00 | 267.00 |

**Table 5. Results of the Spearman test for trend analysis for the selected stations**

| Station | Jun | Feb | Mar | Apr | May | Jun | July | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Ghaleh.* | + | + | + | - | - | + | + | + | - | + | + | - |
| *Zayan.Dam* | - | - | - | - | - | - | - | - | - | - | - | - |
| *Damaneh* | - | - | - | - | + | + | - | - | + | - | - | + |

Note (+, trend exists)

**Table 6. Statistical parameters of rainfalls, mean temperatures and discharges according to climate change scenarios**

| *Period* | *Stat. Par.* | *Rain (mm)* | *Tmean (C)* | *Q (m3/s)* | *Rain (mm)* | *Tmean (C)* | *Q (m3/s)* |
|---|---|---|---|---|---|---|---|
| *1971-2001* | *AV* | 1458.2 | 10.0 | 45.3 | 1458.2 | 10.0 | 45.3 |
| | *SD* | 371.2 | 0.9 | 14.1 | 371.2 | 0.9 | 14.1 |
| | *MAX* | 894.0 | 24.8 | 289.2 | 894.0 | 24.8 | 289.2 |
| | *MIN* | 0.0 | -7.7 | 6.3 | 0.0 | -7.7 | 6.3 |
| *Scenarios* | | *A2* | *A2* | *A2* | *B2* | *B2* | *B2* |
| *2010-2039* | *AV* | 1469.8 | 11.0 | 44.2 | 1427.0 | 11.1 | 44.6 |
| | *SD* | 538.2 | 0.9 | 30.9 | 361.1 | 0.6 | 33.7 |
| | *MAX* | 809.2 | 27.5 | 165.6 | 632.2 | 27.1 | 169.8 |
| | *MIN* | 0.0 | -6.4 | 15.5 | 0.0 | -3.5 | 0.7 |
| *2070-2099* | *AV* | 1224.2 | 14.6 | 42.6 | 1309.3 | 13.2 | 43.4 |
| | *SD* | 377.4 | 1.1 | 31.9 | 441.8 | 0.6 | 40.2 |
| | *MAX* | 776.2 | 31.2 | 220.3 | 521.3 | 30.4 | 252.5 |
| | *MIN* | 0.0 | -5.0 | 10.4 | 0.0 | -2.5 | 5.7 |

**Table 7. Area of the staple foods and their average performances in the Zayandeh Rud basin**

| Crop Type | Area (ha) | Av. Performance (kg/ha) | Max.Performance (kg/ha) |
|---|---|---|---|
| *Wheat* | 78995 | 4547 | 9000 |
| *Barely* | 28763 | 4418 | 7000 |
| *Rice* | 7698 | 4828 | 10000 |
| *Potatoes* | 21807 | 26256 | 50000 |

**Table 8. Cropping pattern in major irrigation systems of Zayandeh Rud Basin**

| Crop | Nekou Abad (ha) | Abshar (ha) | Rudasht (ha) | Borkhar (ha) | Mahyar (ha) |
|---|---|---|---|---|---|
| Winter | | | | | |
| ***Wheat*** | 21832 | 14587 | 18062 | 13000 | 1528 |
| ***Barely*** | 4982 | 1857 | 3539 | 4000 | 719 |
| Summer | | | | | |
| ***Rice*** | 15006 | | | | |
| ***Potatoes*** | 5744 | | | | |

**Table 9. Qualitative characteristics of water, up and down of the Esfahan wastewater treatment plant (1986-1999)**

| | BOD (mg/l) | | COD (mg/l) | | TSS (mg/l) | |
|---|---|---|---|---|---|---|
| | inflow | outflow | inflow | outflow | inflow | outflow |
| ***Mean*** | 241 | 33 | 510 | 86 | 281 | 44 |
| ***Max*** | 330 | 36 | 600 | 110 | 440 | 38 |

**Table 10. Electrical conductivity and flow rates of the three main agricultural drainages that discharge to Zayandeh Rud**

| Drain | EC (Ds.m-1) | Flow ($m^3$/day) |
|---|---|---|
| ***Steel mill*** | 5 | 14400 |
| ***Rudasht*** | 10 | 5808 |
| ***Segzi*** | 30 | 28700 |

**Table 11. Results of the Spearman test for trend analysis for the selected stations**

| | Kohpayeh-Sagzi | | | | Isfahan-Borkhar | | | | Najafabad | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Volume in MCM** | **2010-39A** | **2070-99A** | **2010-39B** | **2070-99B** | **2010-39A** | **2070-99A** | **2010-39B** | **2070-99B** | **2010-39A** | **2070-99A** | **2010-39B** | **2070-99B** |
| **Area (sq. km)** | 4046 | 4046 | 4046 | 4046 | 2822 | 2822 | 2822 | 2822 | 780 | 780 | 780 | 780 |
| **Subsurface Inflow** | 179.50 | 179.50 | 179.50 | 179.50 | 192.10 | 192.10 | 192.10 | 192.10 | 116.10 | 116.10 | 116.10 | 116.10 |
| **Rainfall Infiltration** | 105.03 | 87.31 | 101.72 | 93.56 | 69.20 | 57.63 | 67.16 | 61.63 | 30.05 | 24.96 | 29.09 | 26.75 |
| **Domestic and Industrial Infiltraton** | 0.89 | 0.89 | 0.89 | 0.89 | 184.62 | 186.77 | 184.22 | 184.93 | 26.75 | 26.75 | 26.75 | 26.75 |
| **Irrigation System** | 154.00 | 147.79 | 146.74 | 152.85 | 181.50 | 171.48 | 174.30 | 179.18 | 357.50 | 337.50 | 342.42 | 350.50 |
| **Traditional Irrigation System** | 455.71 | 452.81 | 448.92 | 451.83 | 121.26 | 115.30 | 110.03 | 114.11 | 38.00 | 38.00 | 38.00 | 38.00 |
| **Pumping from River** | 50.60 | 50.60 | 50.60 | 50.60 | 50.00 | 50.00 | 50.00 | 50.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Wells and Qanats** | 912.00 | 872.00 | 896.00 | 886.00 | 1011.00 | 1011.00 | 1011.00 | 1011.00 | 560.00 | 560.00 | 560.00 | 560.00 |
| **Infiltration Rate for Irrigation** | 0.40 | 0.40 | 0.40 | 0.40 | 0.40 | 0.40 | 0.40 | 0.40 | 0.30 | 0.30 | 0.30 | 0.30 |
| **Infiltration from Irrigation** | 628.92 | 609.28 | 616.90 | 616.51 | 545.50 | 539.11 | 538.13 | 541.72 | 286.65 | 280.65 | 282.13 | 284.55 |
| **Infiltration from Runoff** | 3.52 | 2.93 | 3.41 | 3.14 | 2.58 | 2.15 | 2.50 | 2.30 | 4.99 | 4.14 | 4.83 | 4.44 |
| **Artificial Recharge** | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Recharge from River** | 13.63 | 11.33 | 13.20 | 12.14 | 0.00 | 0.00 | 0.00 | 0.00 | 75.85 | 63.01 | 73.43 | 67.54 |
| **Storage Coeficient** | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 |
| **Drawdown (m)** | 0.00 | 0.00 | 0.00 | 0.00 | 0.13 | 0.25 | 0.20 | 0.21 | 1.97 | 2.61 | 2.18 | 2.34 |
| **Change in Storage** | 0.00 | 0.00 | 0.00 | 0.00 | 18.34 | 35.28 | 28.22 | 29.63 | 76.83 | 101.79 | 85.02 | 91.26 |
| **Total Inflow** | 931.50 | 891.24 | 915.62 | 905.74 | 1012.34 | 1013.03 | 1012.34 | 1012.30 | 617.21 | 617.40 | 617.33 | 617.39 |
| **Subsurface Outflow** | 5.50 | 5.50 | 5.50 | 5.50 | 1.40 | 1.40 | 1.40 | 1.40 | 57.20 | 57.20 | 57.20 | 57.20 |
| **Wells, Qanats, Springs** | 912.00 | 872.00 | 896.00 | 886.00 | 1011.00 | 1011.00 | 1011.00 | 1011.00 | 560.00 | 560.00 | 560.00 | 560.00 |
| **Draiange Canal** | 14.00 | 14.00 | 14.00 | 14.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Evaporation** | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **River Drainage** | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Total Outflow** | 931.50 | 891.50 | 915.50 | 905.50 | 1012.40 | 1012.40 | 1012.40 | 1012.40 | 617.20 | 617.20 | 617.20 | 617.20 |

**Table 11 (Continued). The groundwater budget of a number of plains in the basin in the climate change periods**

| | Mahyar North | | | | Lenjanat | | | |
|---|---|---|---|---|---|---|---|---|
| **Volume in MCM** | **2010-39A** | **2070-99A** | **2010-39B** | **2070-99B** | **2010-39A** | **2070-99A** | **2010-39B** | **2070-99B** |
| **Area (sq. km)** | 151.00 | 151.00 | 151.00 | 151.00 | 719.00 | 719.00 | 719.00 | 719.00 |
| **Subsurface Inflow** | 52.60 | 52.60 | 52.60 | 52.60 | 112.60 | 112.60 | 112.60 | 112.60 |
| **Rainfall Infiltration** | 5.53 | 4.60 | 5.36 | 4.93 | 18.23 | 15.14 | 17.64 | 16.23 |
| **Domestic and Industrial Infiltraton** | 2.00 | 2.00 | 2.00 | 2.00 | 10.90 | 10.90 | 10.90 | 10.90 |
| **Irrigation System** | 26.54 | 25.68 | 23.74 | 25.17 | 165.02 | 155.73 | 157.07 | 162.55 |
| **Traditional Irrigation System** | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Pumping from River** | 0.00 | 0.00 | 0.00 | 0.00 | 43.80 | 43.50 | 40.36 | 41.92 |
| **Wells and Qanats** | 83.00 | 80.70 | 81.50 | 81.30 | 266.00 | 266.00 | 266.00 | 266.00 |
| **Infiltration Rate for Irrigation** | 0.30 | 0.30 | 0.30 | 0.30 | 0.20 | 0.20 | 0.20 | 0.20 |
| **Infiltration from Irrigation** | 32.86 | 31.91 | 31.57 | 31.94 | 94.96 | 93.05 | 92.69 | 94.09 |
| **Infiltration from Runoff** | 2.84 | 2.36 | 2.75 | 2.53 | 3.07 | 2.55 | 2.97 | 2.73 |
| **Artificial Recharge** | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Recharge from River** | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Storage Coeficient** | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 |
| **Drawdown (m)** | 0.00 | 0.00 | 0.00 | 0.00 | 0.91 | 1.06 | 0.99 | 1.00 |
| **Change in Storage** | 0.00 | 0.00 | 0.00 | 0.00 | 32.71 | 38.11 | 35.59 | 35.95 |
| **Total Inflow** | 95.83 | 93.47 | 94.28 | 94.00 | 272.47 | 272.34 | 272.39 | 272.51 |
| **Subsurface Outflow** | 12.70 | 12.70 | 12.70 | 12.70 | 5.50 | 5.50 | 5.50 | 5.50 |
| **Wells, Qanats, Springs** | 83.00 | 80.70 | 81.50 | 81.30 | 266.00 | 266.00 | 266.00 | 266.00 |
| **Draiange Canal** | 0.00 | 0.00 | 0.00 | 0.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| **Evaporation** | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **River Drainage** | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Total Outflow** | 95.70 | 93.40 | 94.20 | 94.00 | 272.50 | 272.50 | 272.50 | 272.50 |

**Table 12. Two samples for comparisons of relative yields in the current situation with the climate change periods.**

| Wheat | Irr.Dep. mm | EC Ds/m | Irr.Dep. mm | EC Ds/m | Barley | Irr.Dep. mm | EC Ds/m | Irr.Dep. mm | EC Ds/m |
|---|---|---|---|---|---|---|---|---|---|
| | 1000 | 4 | 900 | 5 | | 1000 | 4 | 900 | 5 |
| *Current Situation* | 62 | | 55 | | *Current Situation* | 74 | | 65 | |
| *2010-30(A2)* | 62 | | 55 | | *2010-30(A2)* | 72 | | 65 | |
| *2010-30 (B2)* | 60 | | 55 | | *2010-30 (B2)* | 72 | | 65 | |
| *2070-99(A2)* | 52 | | 48 | | *2070-99(A2)* | 62 | | 57 | |
| *2070-99 (B2)* | 55 | | 50 | | *2070-99 (B2)* | 66 | | 58 | |
| **Rice** | **Irr.Dep. mm** | **EC Ds/m** | **Irr.Dep. mm** | **EC Ds/m** | **Potatoes** | **Irr.Dep. mm** | **EC Ds/m** | **Irr.Dep. mm** | **EC Ds/m** |
| | 1500 | 2 | 1400 | 3 | | 1000 | 3 | 900 | 3 |
| *Current Situation* | 80 | | 50 | | *Current Situation* | 65 | | 60 | |
| *2010-30(A2)* | 75 | | 50 | | *2010-30(A2)* | 65 | | 60 | |
| *2010-30 (B2)* | 75 | | 45 | | *2010-30 (B2)* | 58 | | 55 | |
| *2070-99(A2)* | 60 | | 40 | | *2070-99(A2)* | 58 | | 55 | |
| *2070-99 (B2)* | 70 | | 40 | | *2070-99 (B2)* | 62 | | 60 | |

**Table 13. Statistical parameters of the major crops for the climate change scenarios**

| Scenario | Base line | | A2 | | | | B2 | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Period** | **1990-2000** | | **2010-39** | | **2070-99** | | **2010-39** | | **2070-99** | |
| **Crop** | ***Av.(ton/yr)*** | ***C.V.*** | ***Av.(ton/yr)*** | ***C.V.*** | ***Av.(ton/yr)*** | ***C.V.*** | ***Av.(ton/yr)*** | ***C.V.*** | ***Av.(ton/yr)*** | ***C.V.*** |
| ***Rice*** | 4828 | 0.17 | 2989 | 0.59 | 1312 | 1.21 | 2778 | 0.85 | 1383 | 1.07 |
| ***Potatoes*** | 26256 | 0.08 | 34562 | 0.2 | 24791 | 0.39 | 29541 | 0.25 | 27979 | 0.39 |
| ***Wheat*** | 4611 | 0.07 | 4870 | 0.14 | 3663 | 0.23 | 4550 | 0.23 | 3850 | 0.29 |
| ***Barley*** | 4418 | 0.11 | 4751 | 0.15 | 3535 | 0.24 | 4462 | 0.26 | 3689 | 0.31 |

**Table 14. Total water consumption by the major crops within the climate change Sceneries in MCM/yr and Percent of consumed water to the total water allocated for the agriculture sector**

| Scenario | A2 | | | | B2 | | | |
|---|---|---|---|---|---|---|---|---|
| **Period** | **2010-39** | | **2070-99** | | **2010-39** | | **2070-99** | |
| **Crop** | ***Cons.Wat*** | ***%*** | ***Cons.Wat*** | ***%*** | ***Cons.Wat*** | ***%*** | ***Cons.Wat*** | ***%*** |
| ***Rice*** | 206.26 | 11.26 | 175.27 | 9.57 | 196.97 | 10.76 | 179.28 | 9.79 |
| ***Potatoes*** | 41.25 | 2.25 | 35.05 | 1.91 | 39.39 | 2.15 | 35.86 | 1.96 |
| ***Wheat*** | 215.4 | 11.76 | 186.74 | 10.20 | 205.8 | 11.24 | 186.68 | 10.19 |
| ***Barley*** | 39.15 | 2.14 | 33.95 | 1.85 | 37.42 | 2.04 | 33.94 | 1.85 |

**Table 15. Produced energy from a cubic meter of water by the major crops within the climate change sceneries (Calories/$m^3$)**

| Scenario | A2 | | B2 | |
|---|---|---|---|---|
| Crop \ Period | 2010-39 | 2070-99 | 2010-39 | 2070-99 |
| ***Rice*** | 587.4 | 303.6 | 577.9 | 312.9 |
| ***Potatoes*** | 2216.3 | 1870.8 | 1814.9 | 2064.1 |
| ***Wheat*** | 1889.7 | 1639.4 | 1673.8 | 1723.4 |
| ***Barley*** | 2074.1 | 1779.7 | 1886 | 1858.1 |

**Table 16. Produced energy by the major crops within the climate change sceneries (Calories*$10^9$ /yr) using fixed cropped areas and fixed irrigation depth (*St_F1*)**

| Scenario | A2 | | | | B2 | | | |
|---|---|---|---|---|---|---|---|---|
| **Period** | **2010-39** | | **2070-99** | | **2010-39** | | **2070-99** | |
| **Crop** | ***Fixed Area*** | ***Fixed Irr.*** | ***Fixed Area*** | ***Fixed Irr.*** | ***Fixed Area*** | ***Fixed Irr.*** | ***Fixed Area*** | ***Fixed Irr.*** |
| ***Rice*** | 121.16 | 132.59 | 53.21 | 56.13 | 112.65 | 113.82 | 56.09 | 78.63 |
| ***Potatoes*** | 91.14 | 84.66 | 65.58 | 61.54 | 78.14 | 71.49 | 74.01 | 67.32 |
| ***Wheat*** | 406.98 | 367.1 | 306.14 | 225.48 | 380.25 | 344.46 | 321.74 | 241.65 |
| ***Barley*** | 81.21 | 73.97 | 60.43 | 53.85 | 76.28 | 70.57 | 63.07 | 57.9 |
| **Total** | **700.49** | **658.32** | **485.36** | **397.0** | **647.32** | **600.34** | **514.91** | **445.5** |

**Table 17. Produced energy by the major crops within the climate change sceneries (Calories * $10^9$ /yr) after discarding rice *(St_F2)***

| Scenario | A2 | | B2 | |
|---|---|---|---|---|
| *Crop* \ Period | 2010-39 | 2070-99 | 2010-39 | 2070-99 |
| ***Wheat (Substituted)*** | 389.77 | 287.34 | 329.69 | 308.97 |
| ***Potatoes*** | 91.14 | 65.58 | 78.14 | 74.01 |
| ***Wheat*** | 406.98 | 306.14 | 380.25 | 321.74 |
| ***Barley*** | 81.21 | 60.43 | 76.28 | 63.07 |
| **Total** | **969.1** | **719.49** | **864.36** | **767.79** |

**Table 18. Average produced energy by a cubic meter of water in the basin with and without rice (Calories/$m^3$)**

| Scenario | A2 | | B2 | |
|---|---|---|---|---|
| **Period** | **2010-39** | **2070-99** | **2010-39** | **2070-99** |
| ***Including Rice*** | 1395.4 | 1126.1 | 1349.8 | 1181.6 |
| ***Discarding Rice*** | 1930.5 | 1669.3 | 1802.3 | 1761.9 |

**Table 19. Responses of the indicators to the adaptation strategies on food and environment for the period 2010-30**

| *Period* | A2 | | | | B2 | | | |
|---|---|---|---|---|---|---|---|---|
| *2010-39* | **BAU** | **St_E** | **St_F2** | **St_D** | **BAU** | **St_E** | **St_F2** | **St_D** |
| ***Food*** | | | | | | | | |
| *Total produced calories [10^9 cal/yr]* | 2488.53 | 2383.88 | 2968.23 | 3122.61 | 2372.8 | 2268.15 | 2824.13 | 2978.51 |
| *Max. shortage [MCM]* | 600.14 | 670.14 | 487.03 | 591.83 | 835.1 | 864.76 | 681.65 | 591.85 |
| *No. dry years [yr]* | 15 | 20 | 10 | 6 | 15 | 15 | 14 | 14 |
| *Max. continuoes dry years [yr]* | 7 | 7 | 3 | 2 | 15 | 15 | 14 | 14 |
| ***Environment*** | | | | | | | | |
| *Infl. < 75MCM [yr]* | 12 | 0 | 0 | 0 | 15 | 0 | 0 | 0 |
| *75< Inf. <140MCM[yr]* | 18 | 12 | 12 | 12 | 15 | 15 | 15 | 15 |
| *Inf. > 40MCM [yr]* | 0 | 18 | 18 | 18 | 0 | 15 | 15 | 15 |

**Table 20. Responses of the indicators to the adaptation strategies on food and environment for the period 2070-99**

| *Period* | A2 | | | | B2 | | | |
|---|---|---|---|---|---|---|---|---|
| *2070-99* | **BAU** | **St_E** | **St_F2** | **St_TB** | **BAU** | **St_E** | **St_F2** | **St_TB** |
| ***Food*** | | | | | | | | |
| *Total produced calories [10^9 cal/yr]* | 2245.02 | 2140.36 | 2665.02 | 4556.91 | 2271.86 | 2167.2 | 2698.44 | 4590.33 |
| *Max. shortage [MCM]* | 778.11 | 848.11 | 664.97 | 0 | 1201.2 | 1271.22 | 1088.08 | 0 |
| *No. dry years [yr]* | 19 | 19 | 18 | 0 | 17 | 20 | 16 | 0 |
| *Max. continuous dry years [yr]* | 11 | 11 | 11 | 0 | 3 | 4 | 3 | 0 |
| ***Environment*** | | | | | | | | |
| *Infl. < 75MCM [yr]* | 14 | 0 | 0 | 0 | 11 | 0 | 0 | 0 |
| *75< Inf. <140MCM yr]* | 16 | 14 | 14 | 14 | 18 | 11 | 11 | 11 |
| *Inf. > 40MCM [yr]* | 0 | 16 | 16 | 16 | 1 | 18 | 18 | 18 |

## 9. Figures

**Figure 1. Location of the Zayandeh Rud basin**


**Figure 2. Zayandeh Rud River at Esfahan city**

**Figure 3. Subbasins of the Zayandeh Rud River**

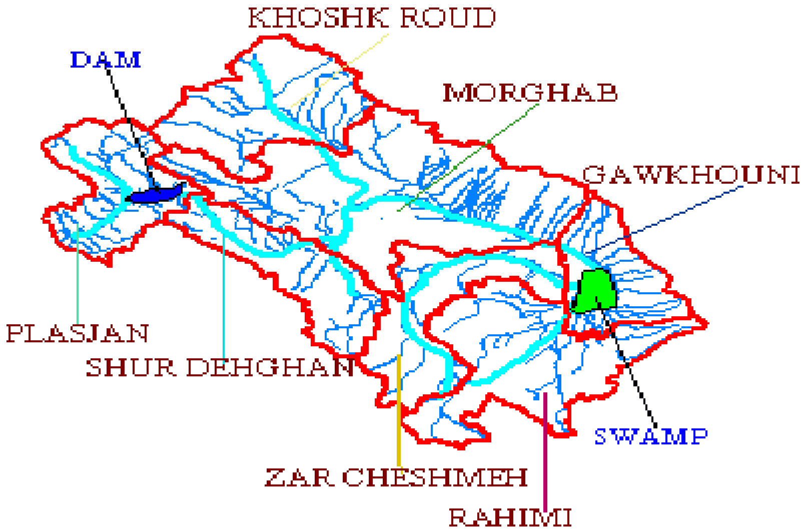



**Figure 4. Topography of the Zayandeh Rud Basin (DEM) (Salemi, et al., 2000)**

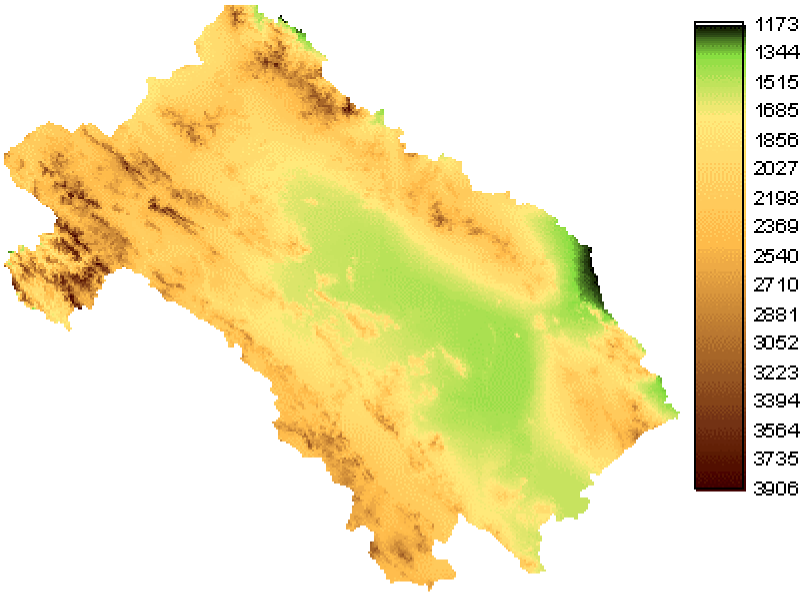


**Figure 5. The main water storage and diversion project in the Zayandeh Rud basin**

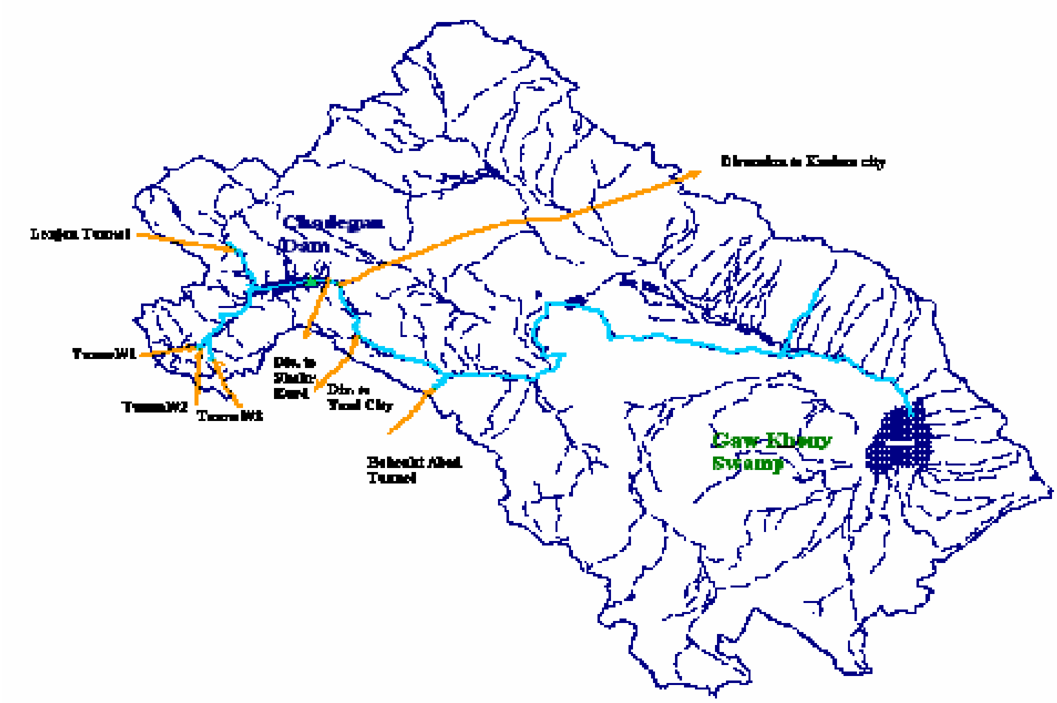



**Figure 6. The major irrigation systems along the Zayandeh Rud River (Murry-Rust et al., 2000)**

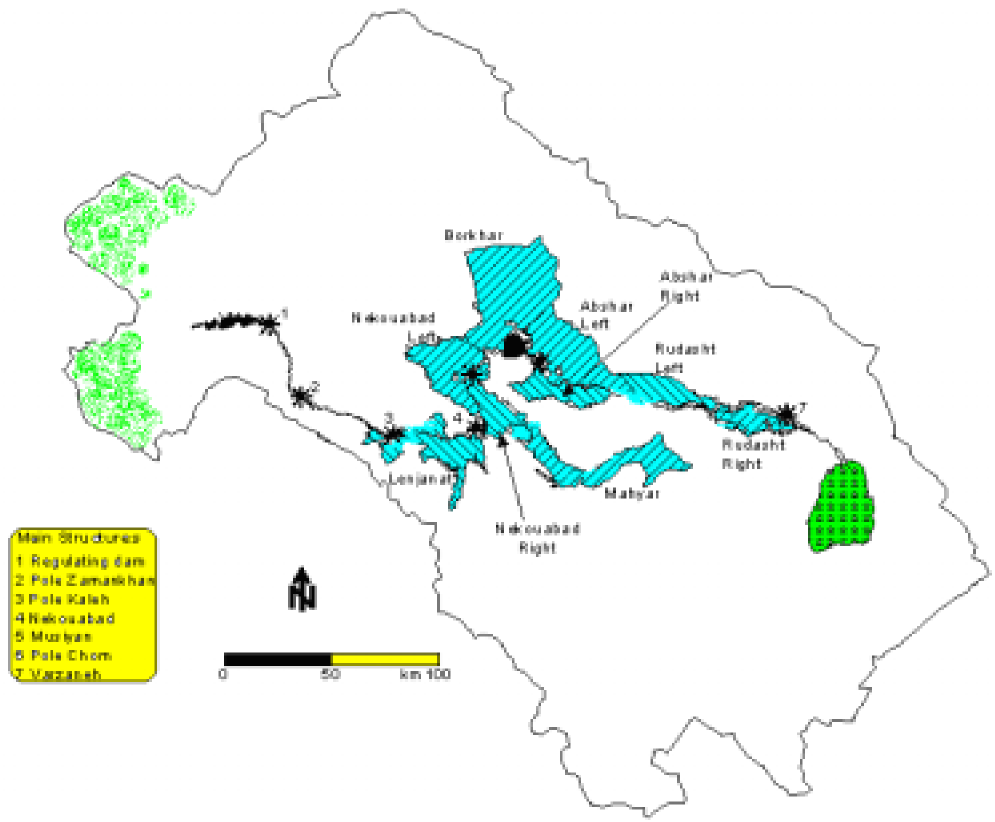


**Figure 7. The general soil map of the Zayandeh Rud basin (a) and the major irrigation systems (b) (Drooger and Torabi, 2002).**

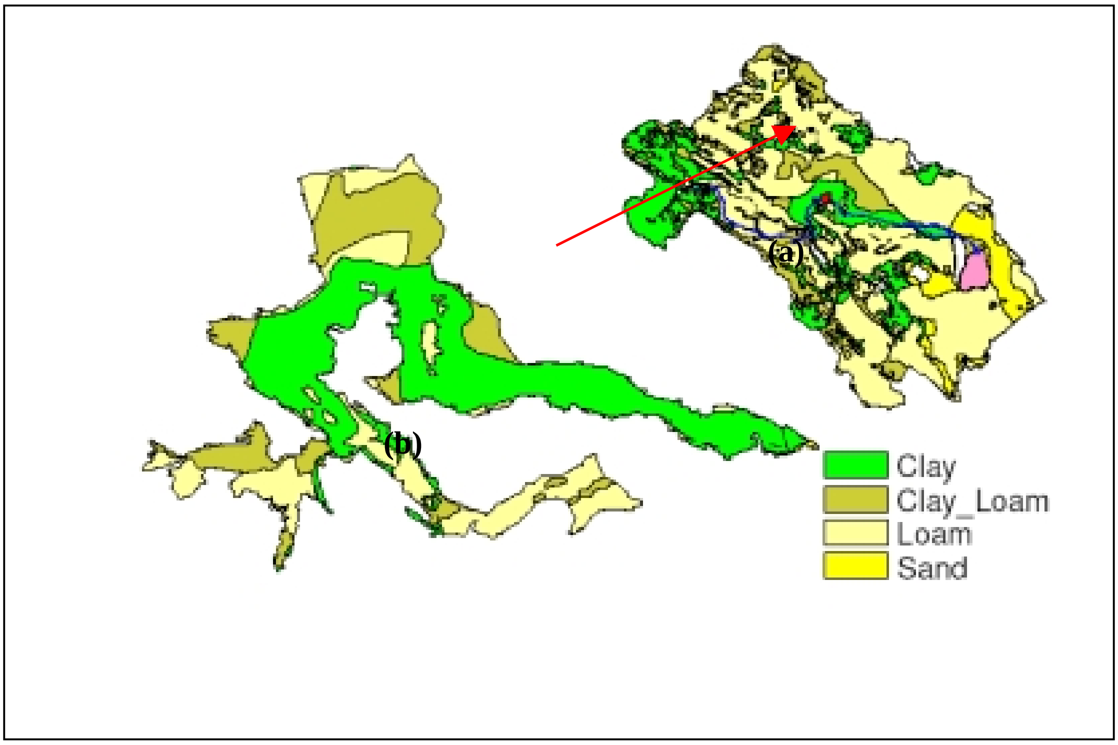



**Figure 8. Mean annual temperature and their trend for the period of 1968-1998 for Damaneh Freydan station**

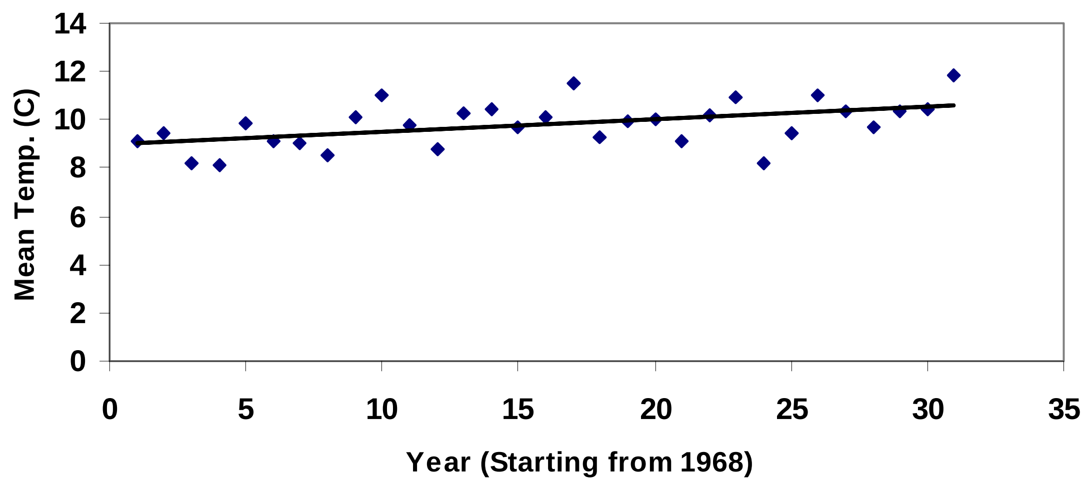



Fig. 8. Mean annual temperature and their trend for the period of 1968-1998 for Damaneh Freydan station.

**Figure 9. Monthly distribution of precipitations according to A2 scenario for Zayandeh Rud basin**

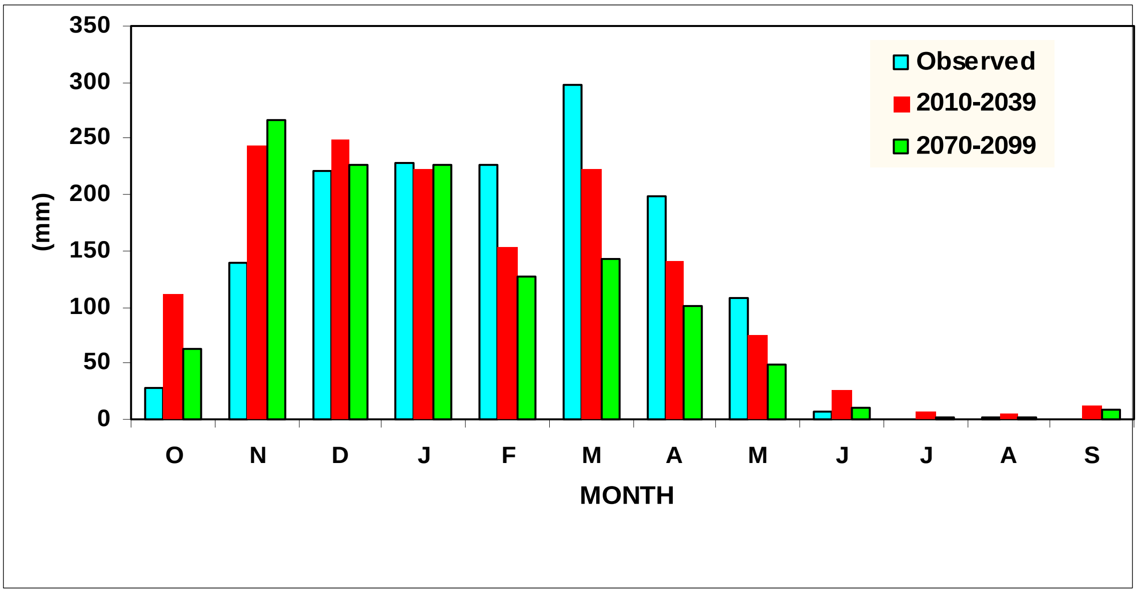



**Figure 10. Monthly distribution of precipitations according to B2 scenario for Zayandeh Rud basin**

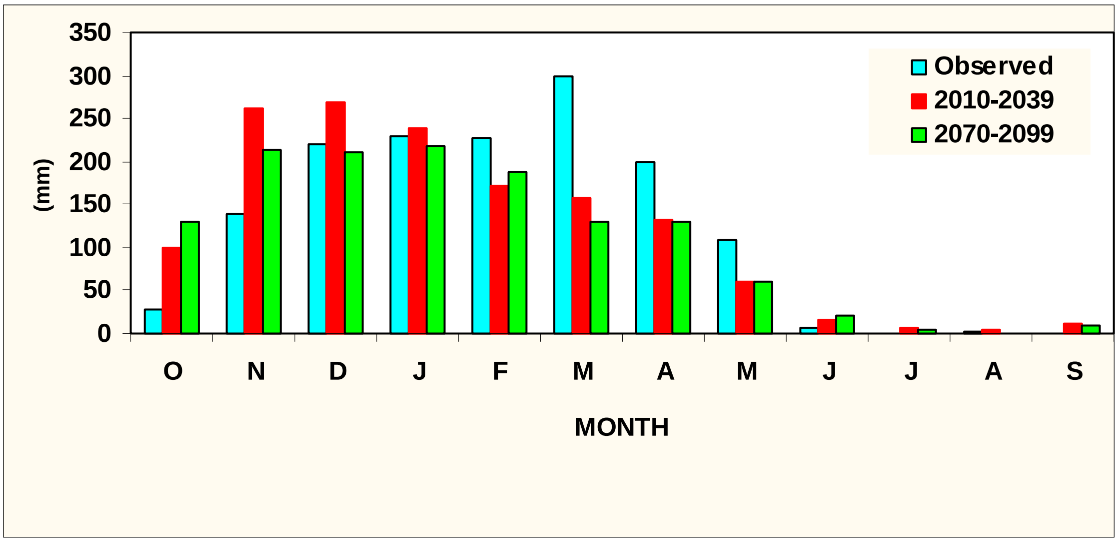


**Figure 11. Monthly distribution of discharges according to A2 scenario for Zayandeh Rud basin**

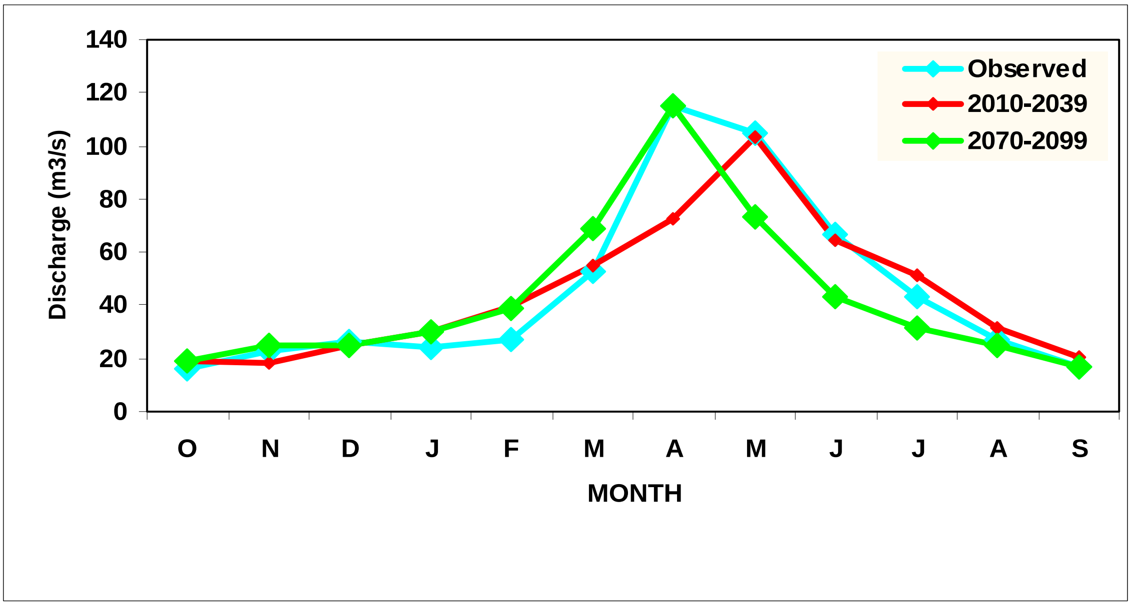



**Figure 12. Monthly distribution of discharges according to B2 scenario for Zayandeh Rud basin**

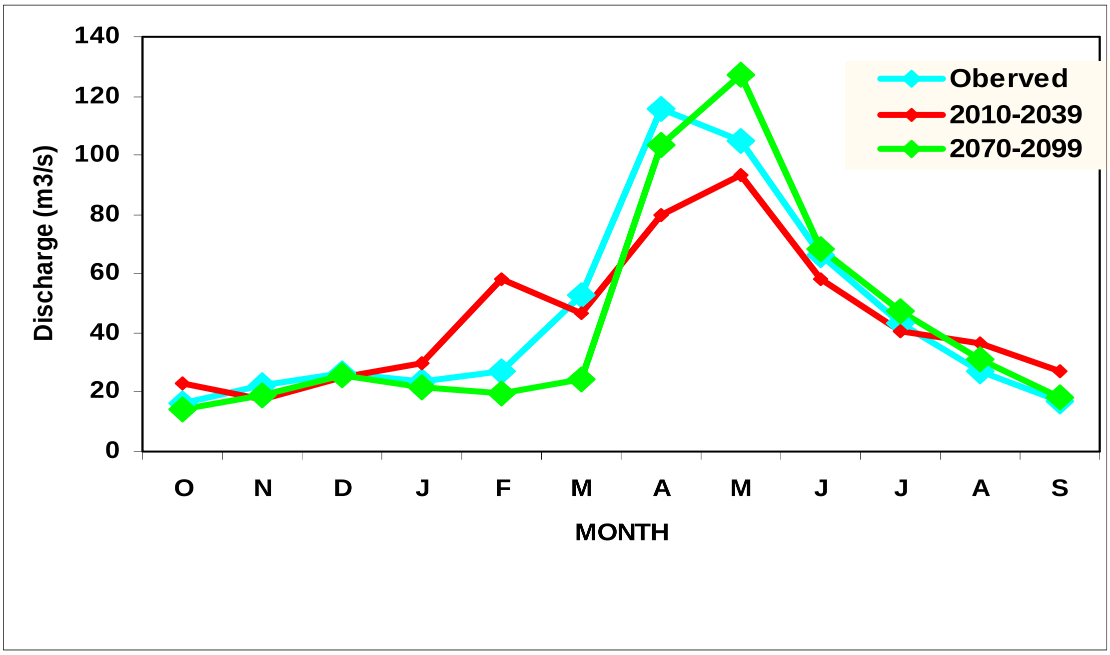


**Figure 13. Frequency of number of successive dry years for historical and climate change periods, scenario A2.**

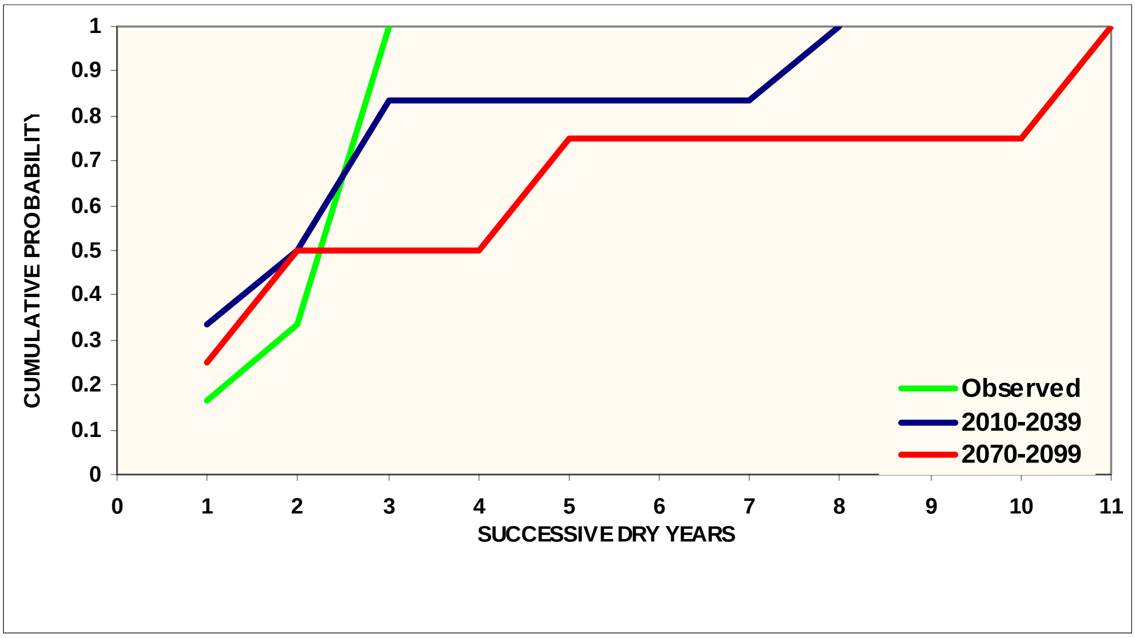
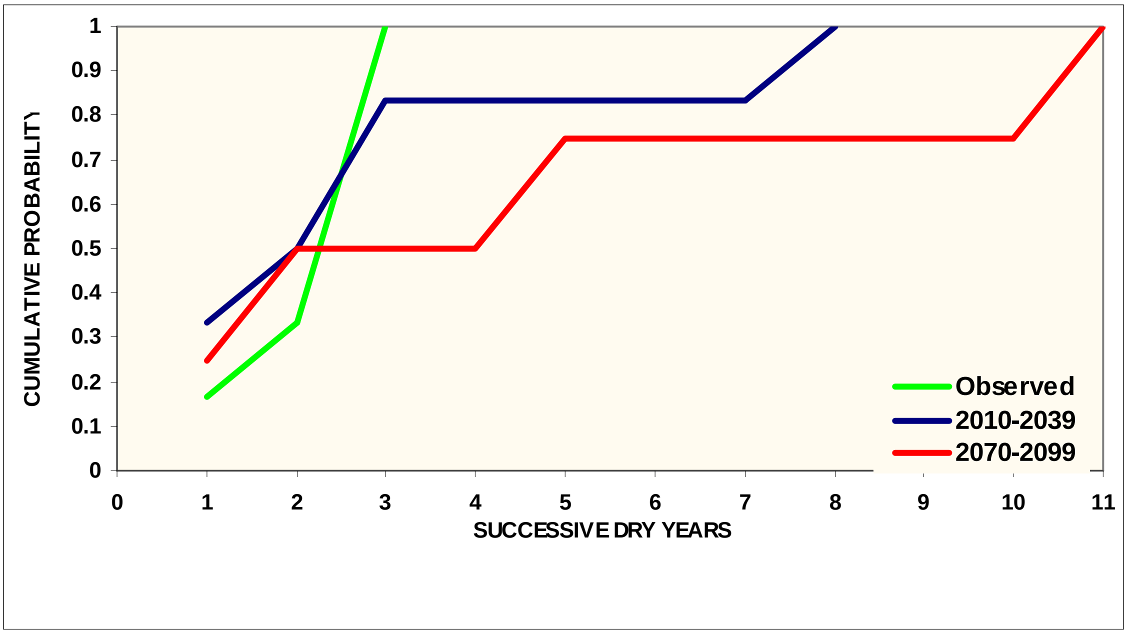



**Figure 14. Frequency of number of successive dry years for historical and climate change periods, scenario B2.**



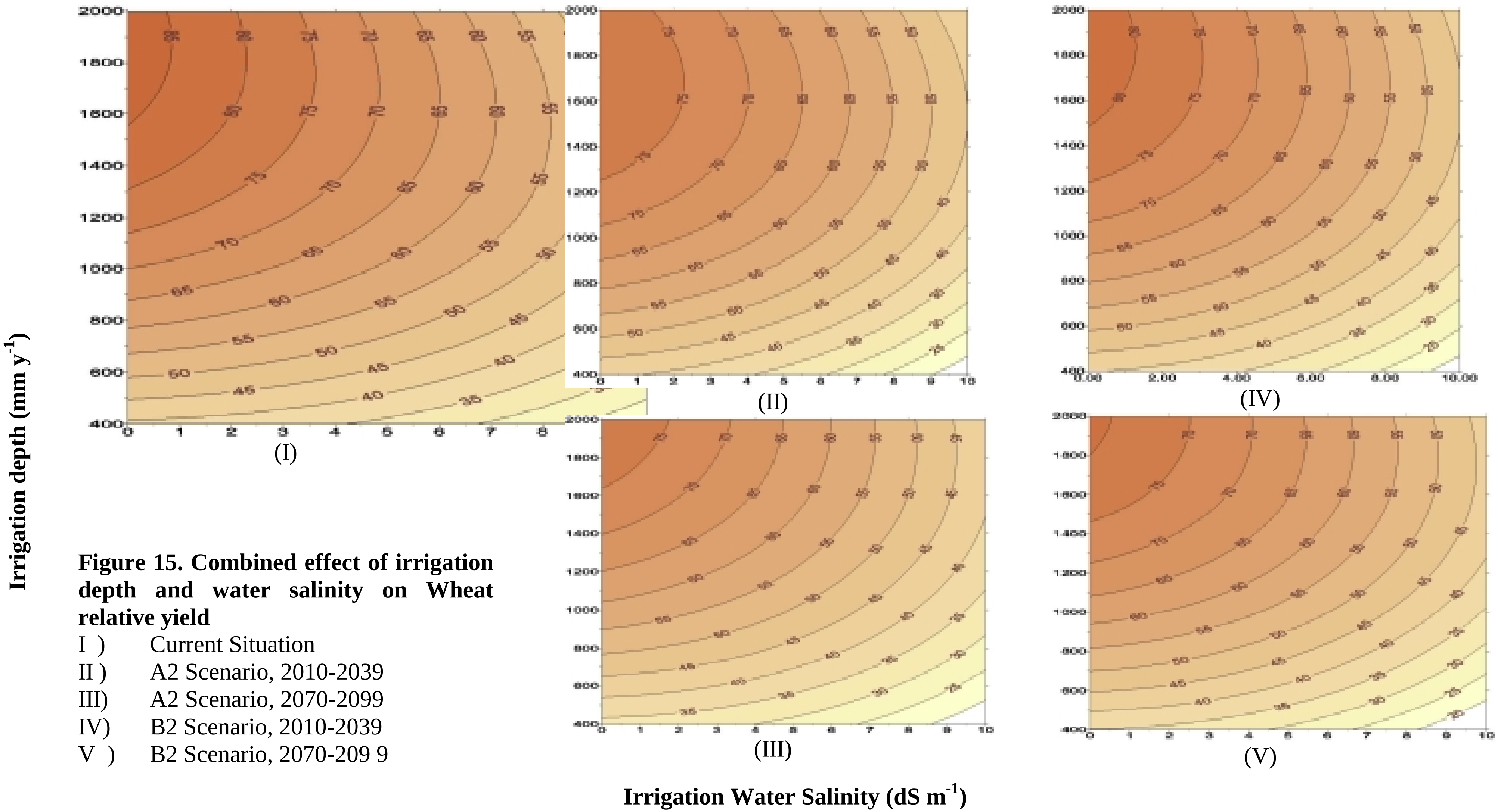



**Figure 15. Combined effect of irrigation depth and water salinity on Wheat relative yield**

I ) Current Situation
II ) A2 Scenario, 2010-2039
III) A2 Scenario, 2070-2099
IV) B2 Scenario, 2010-2039
V ) B2 Scenario, 2070-209 9

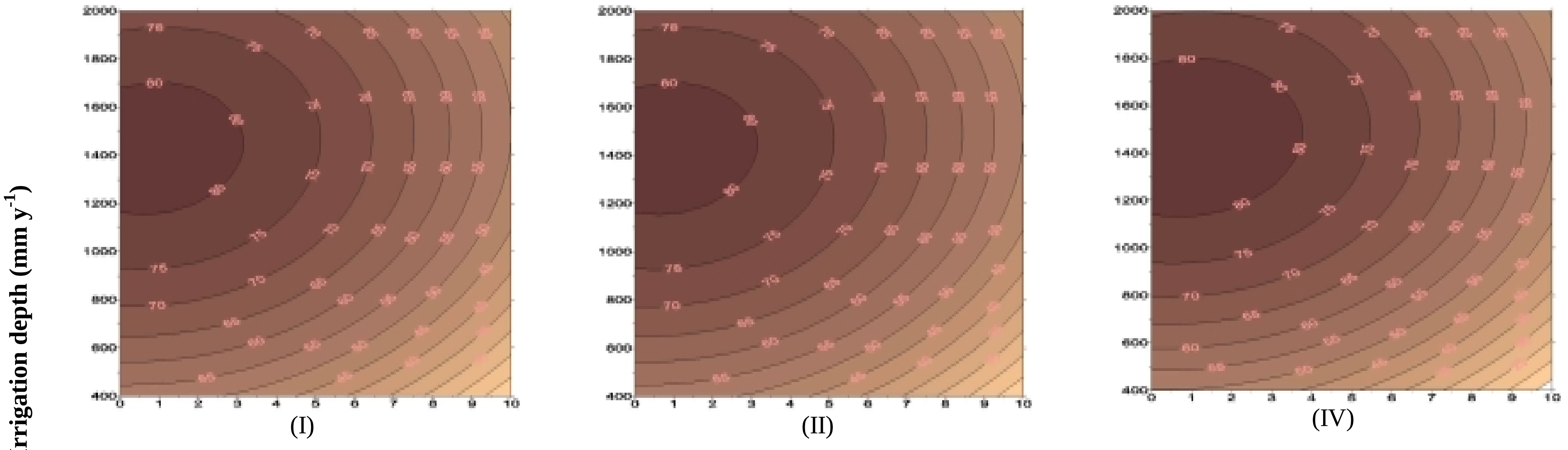
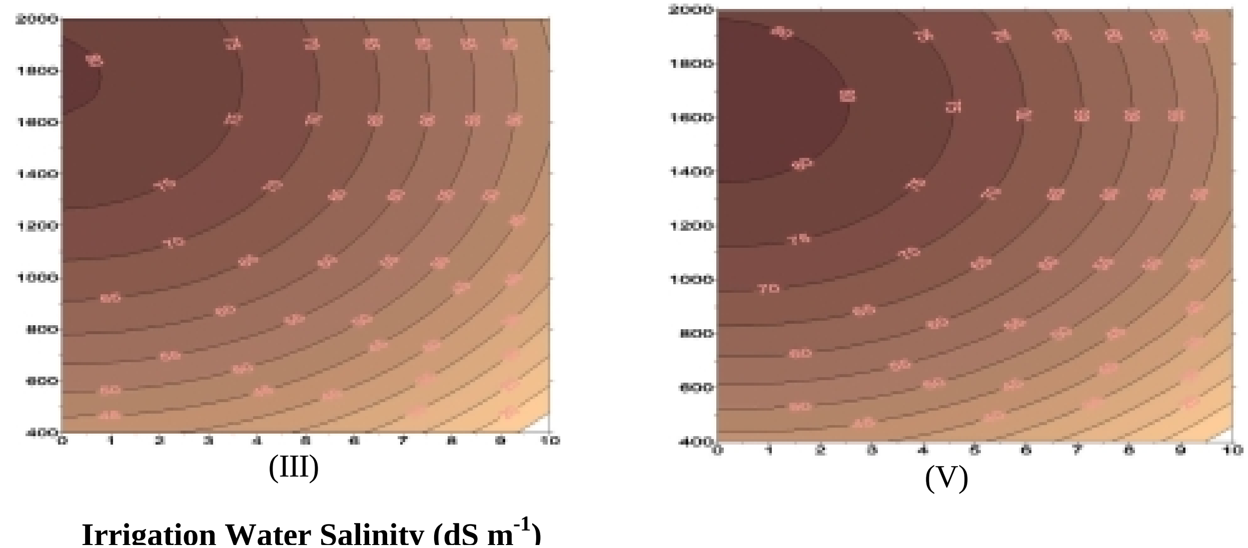



**Figure 16. Combined effect of irrigation depth and water salinity on Barley relative yield**

I ) Current Situation
II ) A2 Scenario, 2010-2039
III) A2 Scenario, 2070-2099
IV) B2 Scenario, 2010-2039
V ) B2 Scenario, 2070-209 9



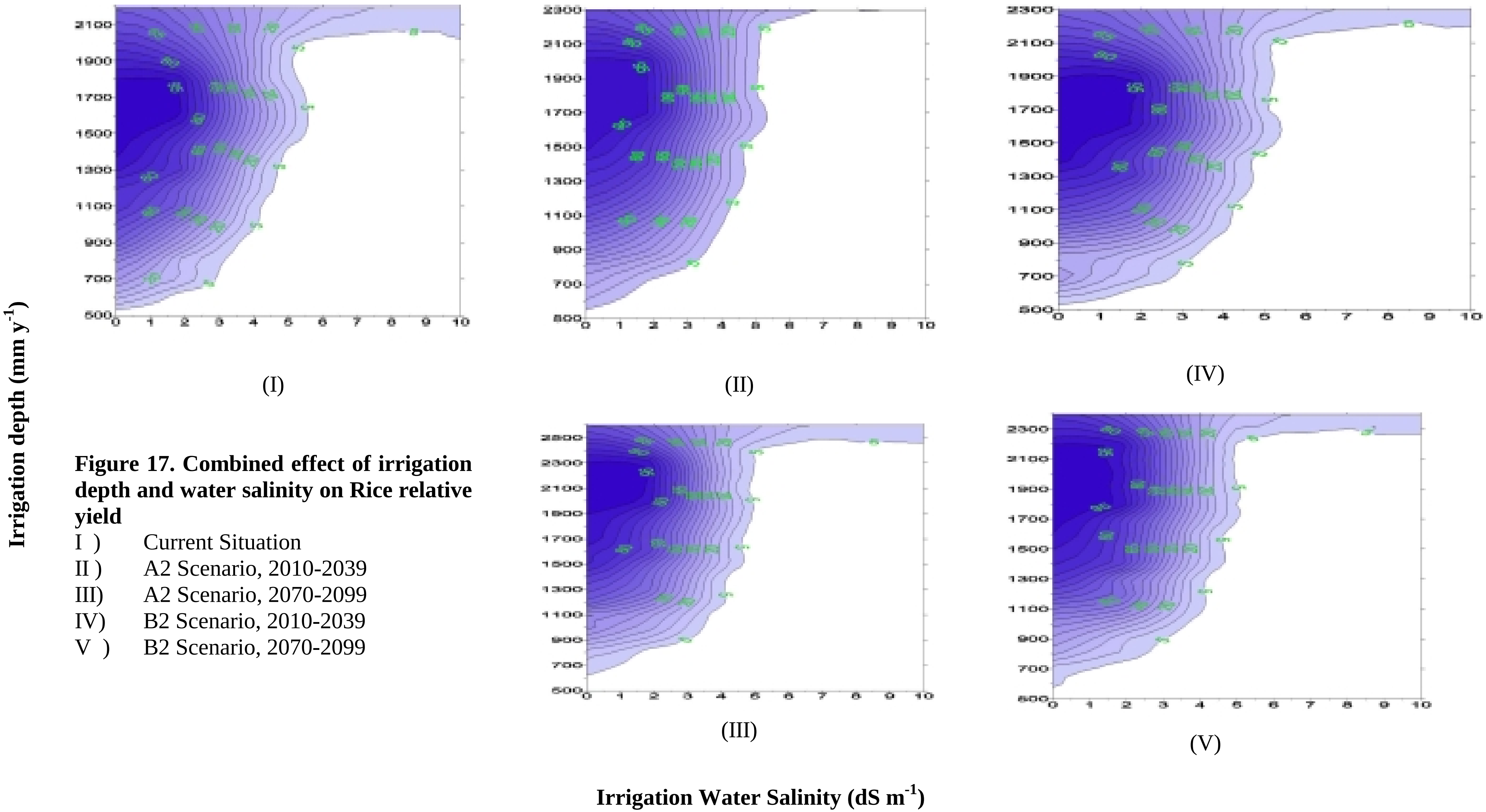



**Figure 17. Combined effect of irrigation depth and water salinity on Rice relative yield**

I ) Current Situation
II ) A2 Scenario, 2010-2039
III) A2 Scenario, 2070-2099
IV) B2 Scenario, 2010-2039
V ) B2 Scenario, 2070-2099

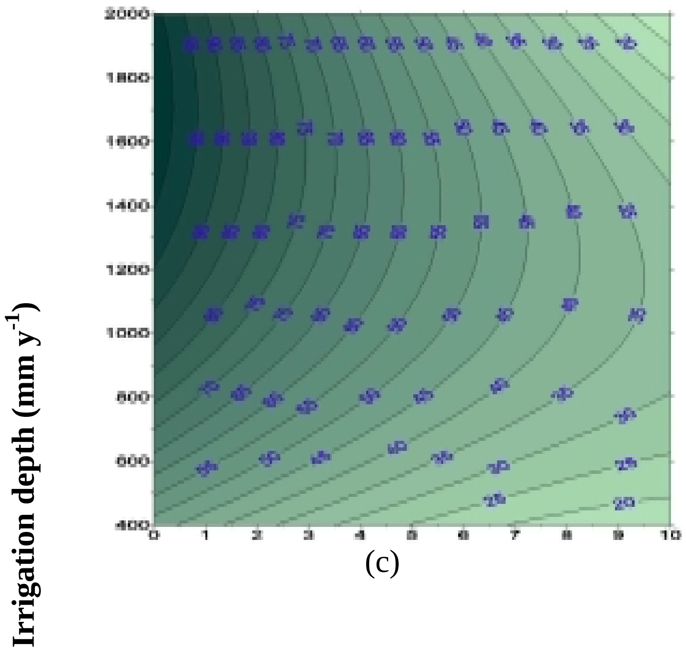



**Figure 18. Combined effect of irrigation water quality and quantity on Potato**
c) Current Situation
a1) A2 Scenario, 2010-2039
a2) A2 Scenario, 2070-2099
b1) B2 Scenario, 2010-2039
b2) B2 Scenario, 2070-209 9

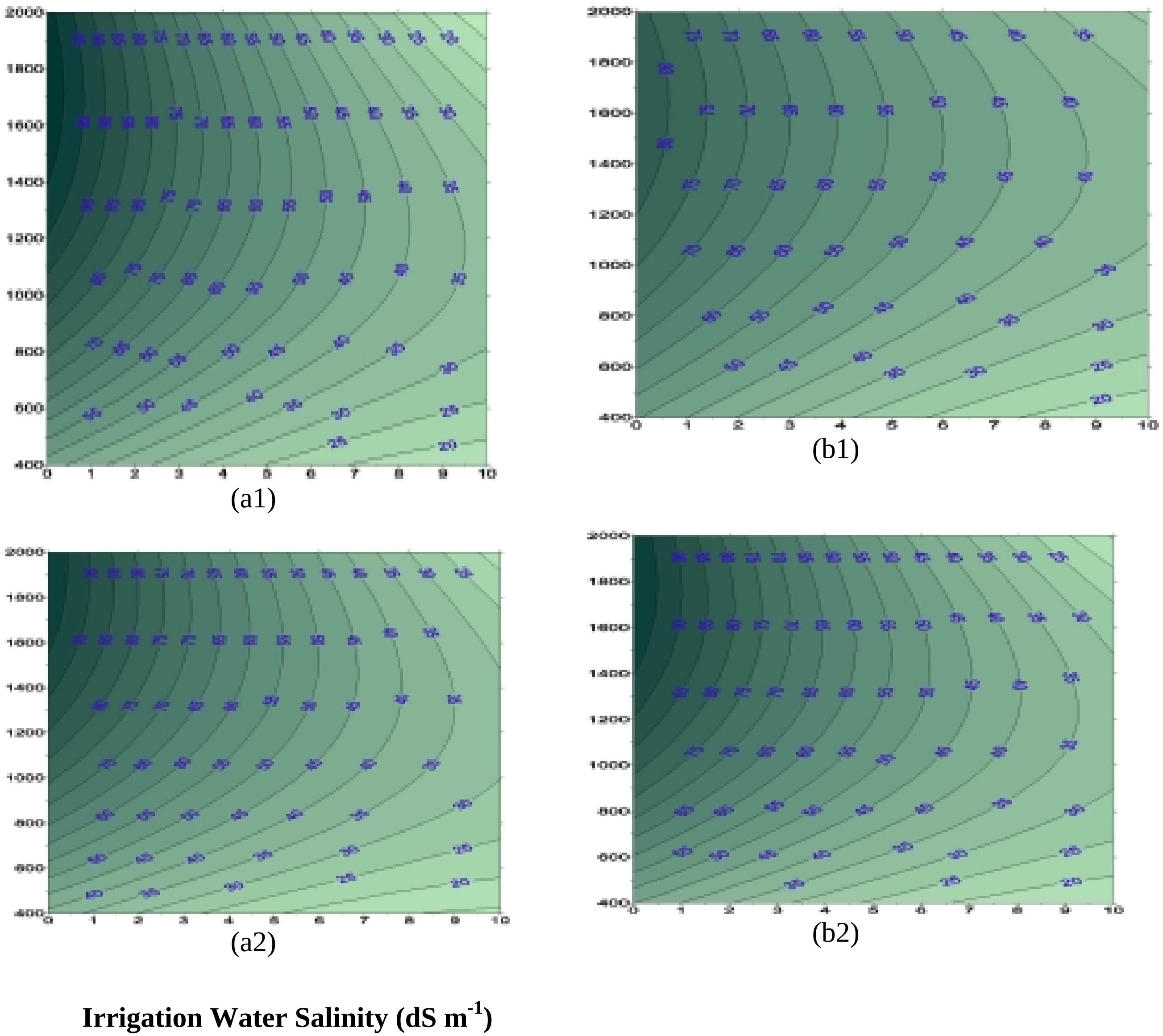


**Figure 19. Components of the generic approach, applied in the adapt project**

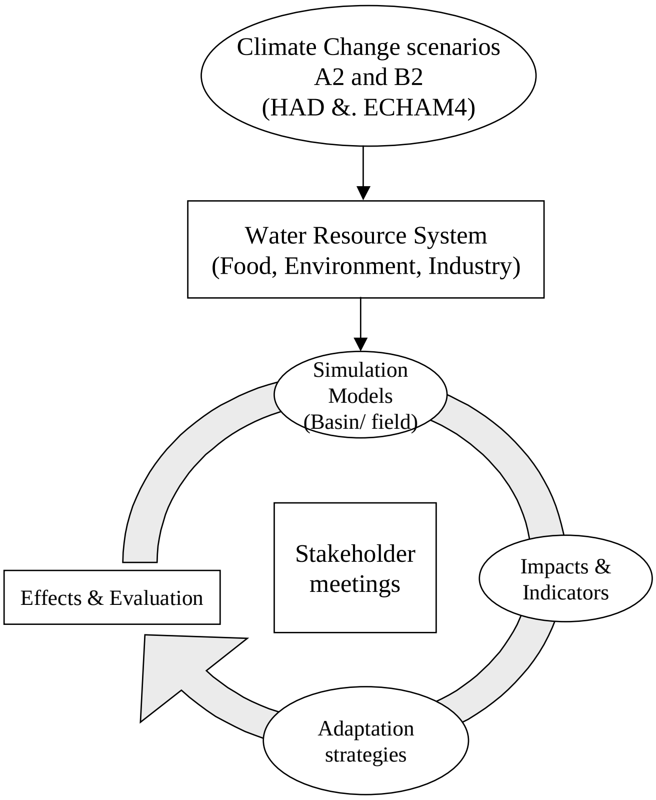
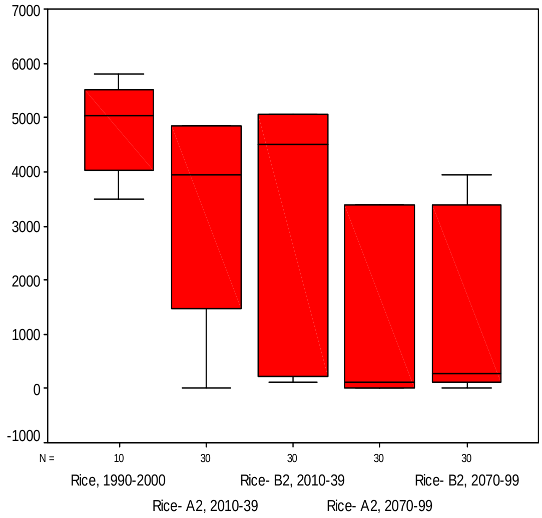
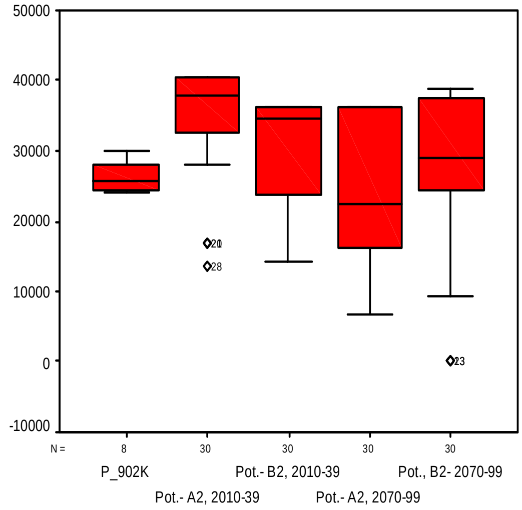


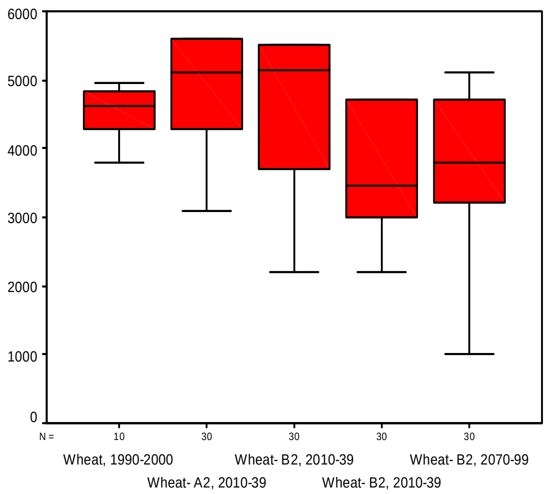
**Figure 20. Box plots of the staple crops yields (Kg/ha) for the climate change periods**



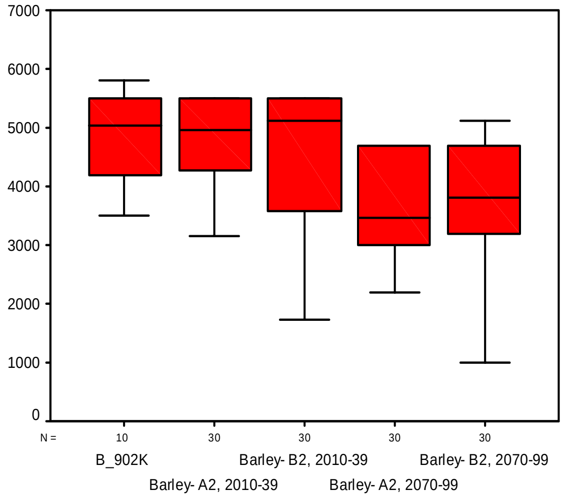

(A)




(B)




(C)




(D)

**Figure 21. BOD variations along Zayandeh Rud River**

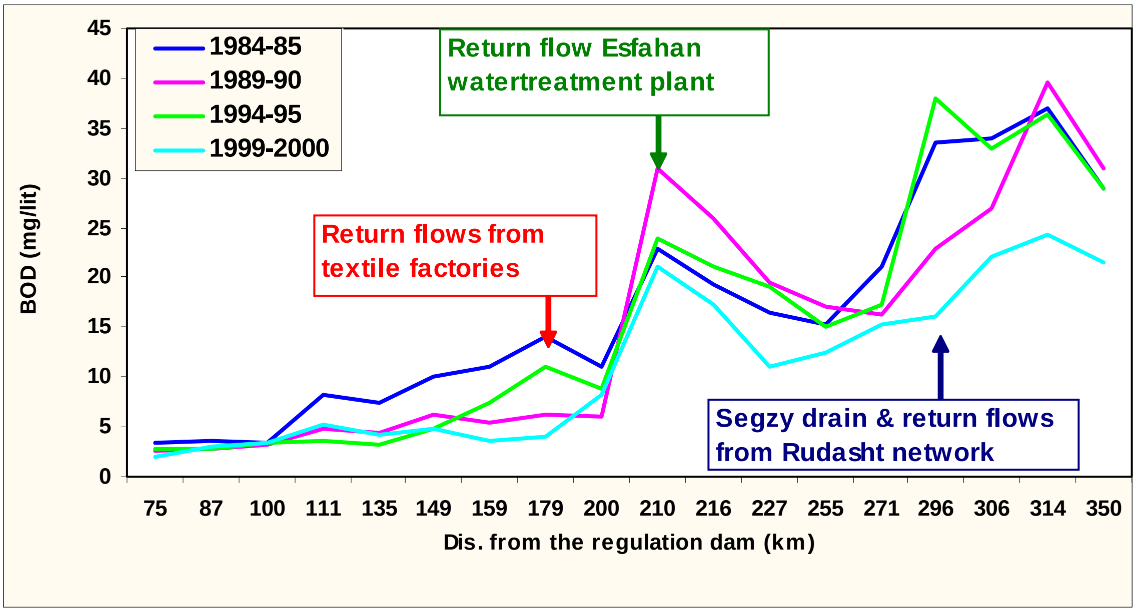



**Figure 22. TSS variations along the Zayandeh Rud River**

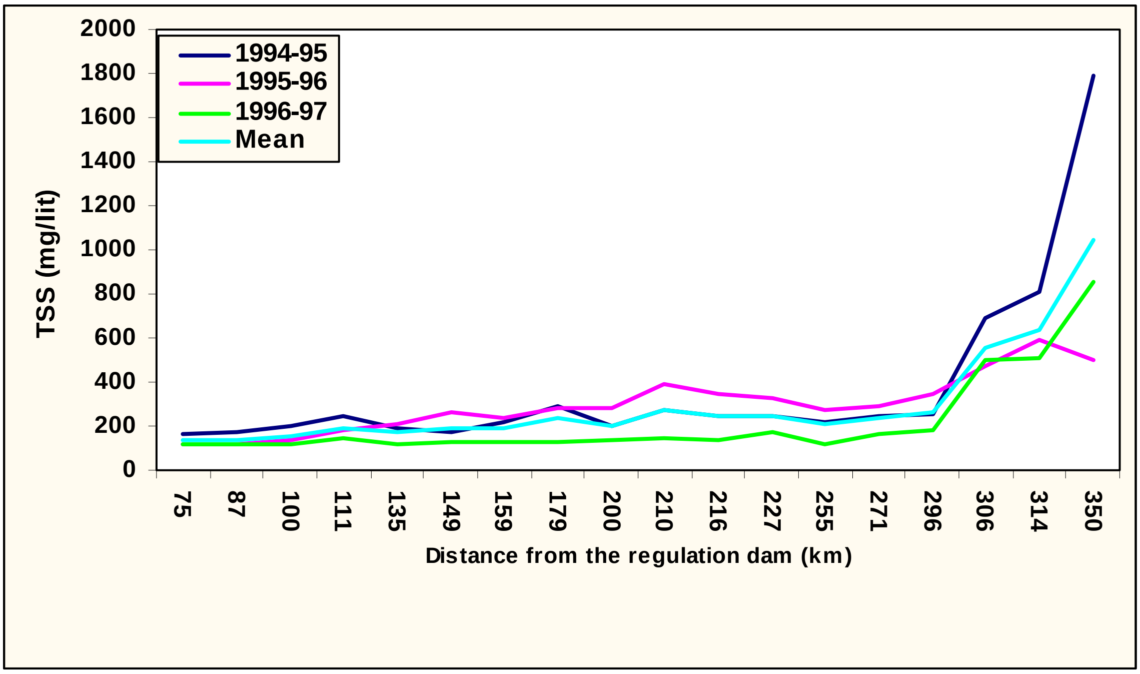


**Figure 23. Comparison of total power consumption in the Zayandeh Rud basin and power generated by the Chadegan Dam.**

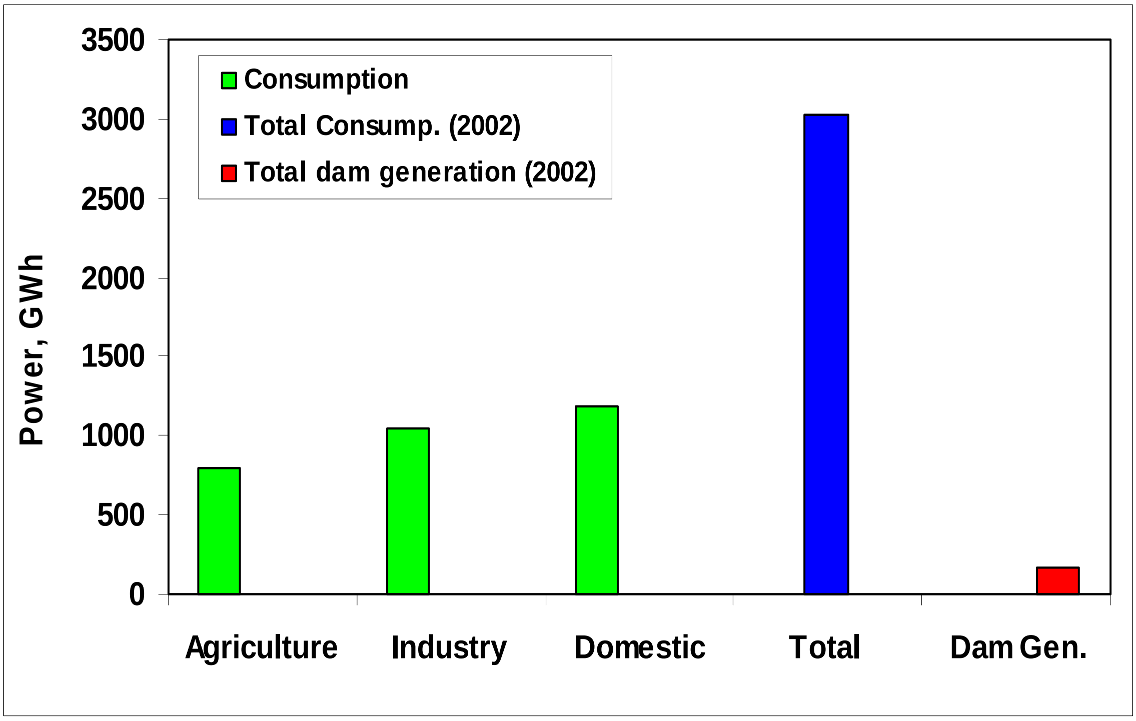



**Figure 24. Water requirements of different sectors and available water according to the scenarios A2 and B2 for the period 2010 to 2039**

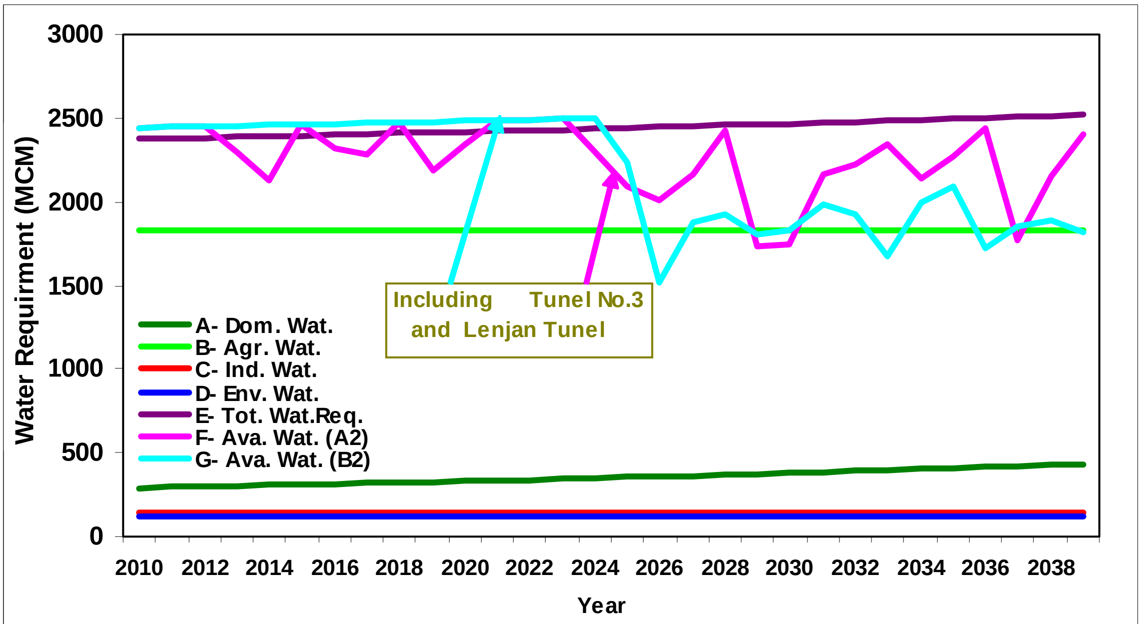



Fig. 24. Water requirements of different sectors and available water according to the scenarios A2 and B2 for the period 2010 to 2039

**Figure 25. Impact of implemented strategies on water resources for scenarios A2 and B2 in the period 2010 to 2039**

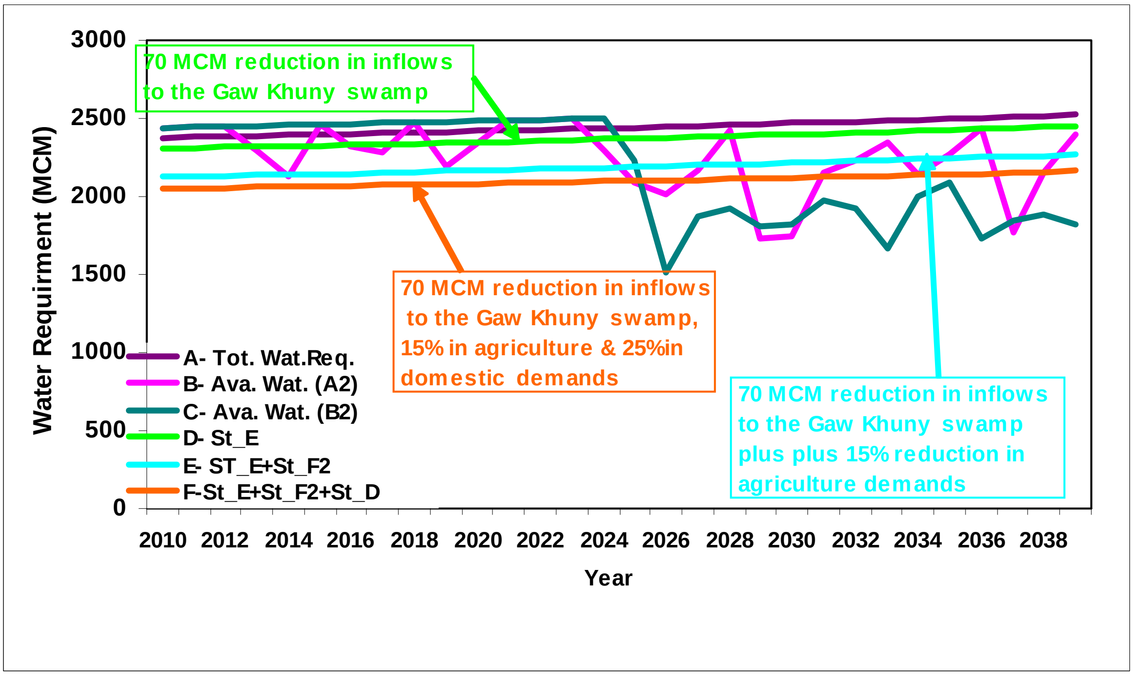



**Figure 26. Water requirement of different sectors and available water according to the scenarios A2 and B2 for the period 2070 to 2099**

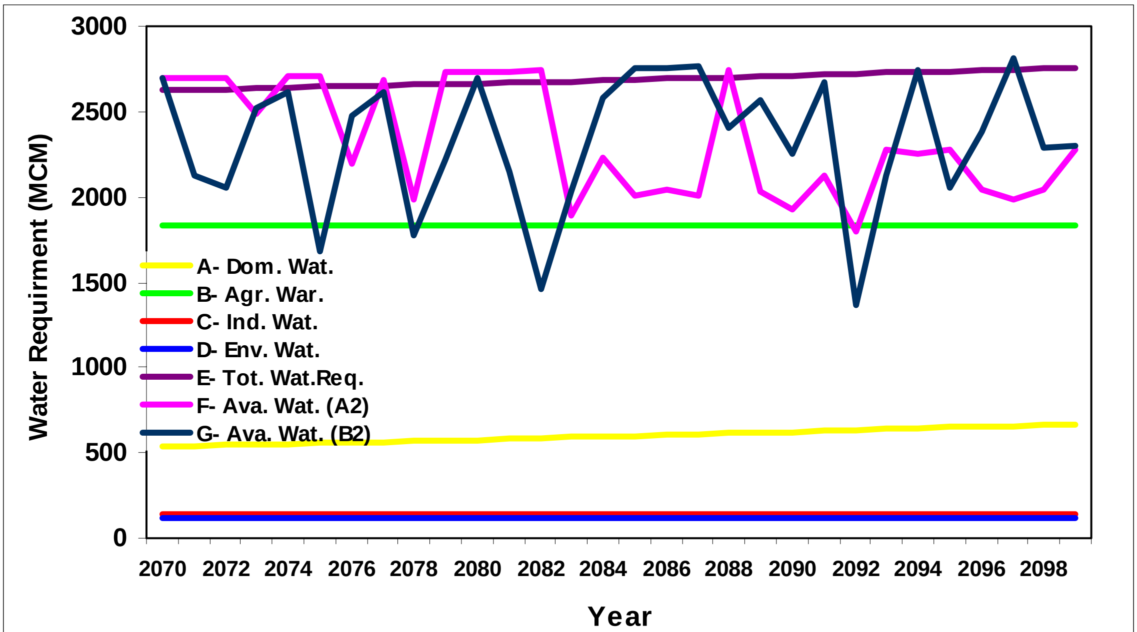



Fig. 26. Water requirement of different sectors and available water according to the scenarios A2 and B2 for the period 2070 to 2099

**Figure 27. Impact of implemented strategies on water resources for scenarios A2 and B2 in the period 2070 to 2099**

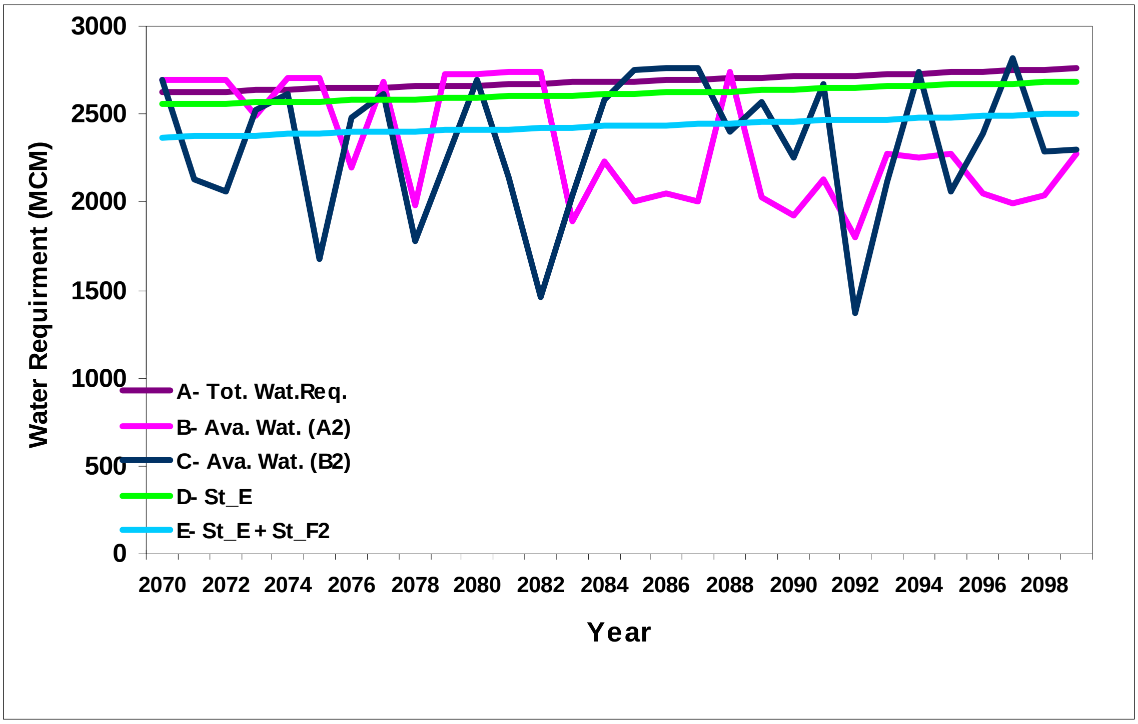



**Figure 28. Total water requirement and available water according to the scenarios A2 and B2, associated with Behesht Abad Tunnel for the period 2070 to 2099 (St_TB)**