Exploratory Scenarios for Socio-Technical Analysis of

Agricultural Water Demand Management in Arid and Semi-Arid Regions:

A case study of Zayandeh Rud basin, Iran

A Thesis Defense

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Abstract

Today, there is an urgent necessity to consider alternative ways that society can manage scarce water resources in response the ever-growing demand for freshwater around the world. Yet, this need is even more acute in arid and semi-arid regions, like the Middle East and North Africa (MENA) countries that water resources are extremely limited, and are projected to decline due to climate change and population growth. In the MENA region, the agriculture sector is responsible for more than 90% of water usage, and that is not enough to secure the food demands of the region. Current mitigation strategies are short-term, ineffective and to some extent, they just make the problem worse.

In this research, I used the Zayandeh Rud watershed in Iran as a case study to explore adaptive agricultural water demand management strategies. I utilized the results to develop a small set of coherent, plausible and systematically different water governance scenarios for Zayandeh Rud 2030, through a participatory formative scenario construction approach.

While the first scenario resembles an extension of the status quo, the other scenarios represent four different mitigation approaches to manage agriculture water demand. These exploratory scenarios will set the stage for future quantitative research into the key civil and environmental engineering strategies and the dynamic responses in the agricultural sector. However, the different mitigation strategies might offer different levels of effectuality and sustainability. Each scenario might represent and serve a group of stakeholders' values and interests better than others. Further, these scenarios may provide stakeholders with insights about the potential decisions and impacts on water and food security, local communities' resilience and ecological sustainability of watershed. The result of this study can facilitate communication between stakeholders and induce collective and informed decision-making.

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Table of Contents

List of Figures

List of Tables

Chapter 1: Introduction

Looking at this shiny blue planet from outer space, it may sound unbelievable that access to fresh water has been always one of the greatest challenges for humankind. All renewable, non-frozen available fresh water is less than 0.005% of the total water on Earth, which still would be enough for current world population if it was shared equally across the Earth. Yet, 62% of fresh water flows in 45% of the land area and can be readily accessed by only 24% of the Earth's human population. The Middle East and North Africa (MENA) region's share of fresh water is only about one percent, however, it is home to 6% of the world's population. Even across the MENA region, the availability of water resources varies considerably. Adding climate change implications and rapid population growth into this makes water management, one of the most vital challenges of this arid and semi-arid area.

In most MENA countries, the agriculture sector is responsible for more than 90% of total water demand, even though its economic, crop and labor productivity rates are much lower than global averages. For example, in Iran, the agriculture sector employs 20% of manpower and it is responsible for 92% of available water consumption, while its contribution to GDP is only about 10%. There are numerous factors that need to be considered as drivers of inefficiency in the agriculture sector, such as, inefficient irrigation methods, outdated agricultural practices, high evapotranspiration in this region, uncompetitive markets, and a lack of effective policies (Roudi-Fahimi, Creel, & De Souza, 2002).

These complex factors constitute water governance, which is defined as a set of political, social, economic and administrative systems to regulate development and management of water resources (Pahl-Wostl, Holtz, Kastens, & Knieper, 2010). Understandably, water governance, especially in arid and semi-arid regions, is not a straightforward problem with a single concrete solution, and thus can be described as a "wicked problem"(Rittel & Webber, 1973). In Iran limited water resources, climate change, conflicting stakeholders' interests, in conjunction with many interconnected socio-economic and socio-politic considerations make water management a sophisticated- multi faceted challenge for decision-makers (Stewart et al., 2007). The problem is even more challenging, due to high data uncertainty for many variables like climate and demographic change, economic growth and political instability in the region. Lack of accuracy and/or insufficient data in developing regions should not be overlooked as another source of uncertainty (Safavi, Golmohammadi, & Sandoval-Solis, 2016).

In such situation, that decision making processes involve trade-offs under conditions of high uncertainty, complexity and knowledge constraints, an adaptive governance system is an urgent necessity (Norton, 2005). Dietz and Ostrom (2003) claim that top-down, large scale governance (i.e. decisions made at the national level) are usually oversimplified and fail to address the complexities at local levels. They argue that "science is necessary for commons governance, but not sufficient. Too many strategies for governance of local commons are designed in capital cities or by donor agencies in ignorance of the state of the science and local conditions" ,Page1910 (Dietz, Ostrom, & Stern, 2003).

Water governance in the MENA region is generally centralized and decisions are made mostly at the national level, which is a clear mismatch with the theories put forward by Nobel Prize winning work by Ostrom (Ostrom et al., 2003?). Countries in the MENA region are over-focused on technical and large-scale infrastructure solutions. Donor organizations, like the World Bank, contribute to the preference for technical and infrastructural solutions. These organization are used to providing monetary aid to infrastructure projects, which rely on a western development paradigm that does not adequately consider the socio-economic, cultural and ecological differences of host region (Yazdanpanah, Thompson, Hayati, & Zamani, 2013). Facing high data uncertainty and an external, dominant planning paradigm, there is a pressing need to explore alternative water governance options that are more adaptive and responsive in guiding sustainable development (Foley & Wiek, 2014; Keeler, Wiek, White, & Sampson, 2015). Scenario planning provides a powerful tool to study these alternatives. It helps to study all plausible pathways that the future can unfold. It also provides a framework in which decision-makers can evaluate the sustainability of their decisions, which can lead to more proactive, protective and collective decision-making, or what it called "anticipatory governance" (Quay, 2010; White, Keeler, Wiek, & Larson, 2015).

The first objective of this research is to perform a study of the a) looming water crisis in MENA and more specifically in Iran, its implications and possible causes b) water consumption patterns and the challenges regarding water supply and demand c) water governance system and its limitations and capacities. Furthermore, this thesis secondarily offers an exploratory scenario approach to construct a small set of alternatives, which provide plausible water governance regimes that address agricultural water demand.

The goal is to address the question: "What alternative policies and water infrastructure investments in agriculture can alleviate future water scarcity of this region?" To start to answer this question, I chose the Zayandeh Rud watershed as an exemplary case study. This watershed is located in an arid and semi-arid part of Iran that is a considered the most complicated watershed in Iran in terms of agricultural water demand and socio-political concerns (Ebrahimnia & Bibalan, 2017).

To fulfill this purpose the thesis: i) identifies key variables that can affect the agricultural water demand in this watershed, ii) analyzes alternative policies and infrastructures that demonstrate potential or are currently in use elsewhere, iii) develops a small set of signature governance-oriented scenarios that can inform current planning efforts, and iv) assesses the impacts of each scenario socio- economic and ecological sustainability of the watershed. Before returning to these methods and the findings, I will briefly introduce and describe the complexities that embody the case study.

It should be mentioned that this is a preliminary application of the scenario analysis method at a highly conceptual level. It offers a systematic approach to understanding the system of agricultural water governance in the Zayandeh Rud watershed as an illustration of potential approaches to the broader issues sof water governance in MENA and other arid and semi-arid regions. More data and refined models are required to confirm the impacts of each scenario on the future of the Zayandeh Rud watershed, and to make policy inferences for broader issues of agricultural water governance.

Chapter 2: Study Context

2.1 Water scarcity definitions and indices

There are numerous definition for water security and water scarcity. The United Nations (UN) defines water security as “the capacity of a population to safeguard sustainable access to adequate quantities of acceptable quality water for sustaining livelihoods, human well-being, and socio-economic development” (UNWater, 2013). Yet, Rijsberman’s (2006) definition of water scarcity is widely used by scholars and defines a specific area water scarce when a large number of its population are water insecure for a significant period of time. Since those two definitions are too general, more specific definitions have been developed to elaborate this concept. One specific definition categorizes water scarcity based on *physical* and *economic* characteristics. *Physical water scarcity* occurs in a region with limited water resources and/or high density population. In contrast, *economic water scarcity* is mainly caused by a lack of investment in water infrastructure or insufficient human and institutional capacity in a way that the population cannot afford to use an adequate source of water, such that water resources are abundant in comparison to demand. Figure 2-1 shows the areas on Earth with either physical or economic water scarcity. It also shows that physical water scarcity is concentrated in MENA region, while economic water scarcity mainly affects countries located in central Africa and East Asia.

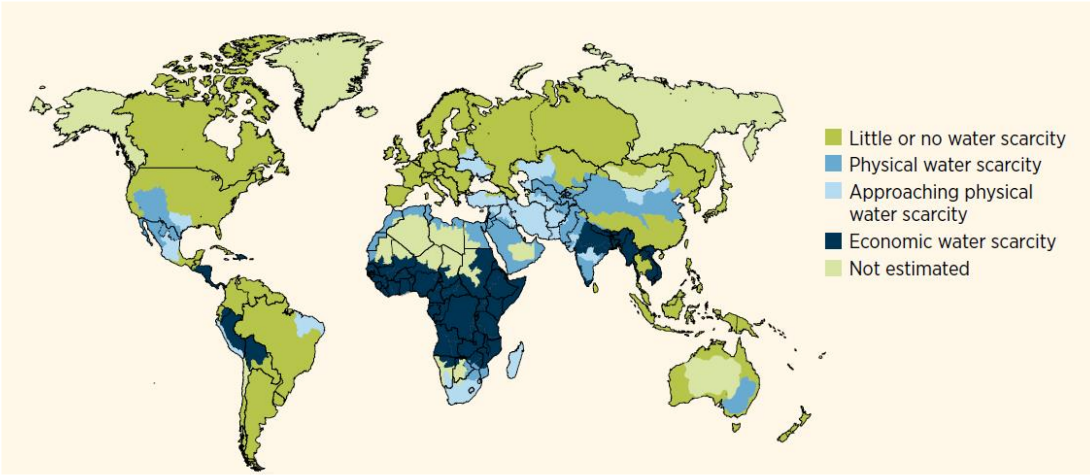

Figure 2-1. Physical and Economic Water Scarcity (UNWater, 2014)

Several different indices are being used to classify water availability. They are mostly based on human water requirements and sometimes based on ecological vulnerability requirement. The most common water scarcity index is *Falkenmark Stress Indicator*, which represent fresh water availability as the "per capita per year", usually on a national scale, see table 2-1 for this simple classification (Brown & Matlock, 2011). It should be noted that this index represents physical water scarcity as it does not reflect infrastructure's impact on water availability. It also does not demonstrate spatial variability of available freshwater throughout a region, as well as water requirement variability in different regions. Last but not the least, the Falkenmark index does not include virtual water input and outputs, such as imported food.

Table 2-1- Falkenmark water scarcity index.

Index (m^3 per capita)	Category/ Condition
>1700	No stress
1000-1700	Stress
500-1000	Scarcity
<500	Absolute Scarcity

2.2 Water scarcity in Middle East and North Africa (MENA)

Water scarcity in the MENA countries is a constant condition as this region is located on the arid and semi-arid belt of the earth (Peel et al. 2007). Fresh renewable water resources are limited so that it enjoys only 1% of earth's total fresh water storage while it includes 4% of the earth's total land area and 6.4% of world's population. This makes it the most water scarce region in the world. Available water resources are approximately 1100 m^3, which is predicted to decline to 500 m^3 by 2050, which is not distributed evenly among these countries. Figure 2.1 shows the available water per capita of each MENA country and their change between 2002 and 2014. Rapid population growth in this region is the key reason for the significant decline in per capita water resources. The MENA population has increased by about 500% over the last 65 years, from 82 million in 1950 to 421 million in 2015.

On the other hand, MENA countries are dealing with a complicated situation of low precipitation and high variability, which is a big challenge for water management in this area. This variability includes both spatial and temporal dimensions. Figure 2.2 shows this reality, as most of MENA countries fall into the low precipitation, high variability quarter (World Bank 2007). For some of these countries, the big challenge is uneven distribution of precipitation, both spatially and temporally, like Iran, Lebanon, Morocco, Djibouti, Algeria, Tunisia and West Bank.

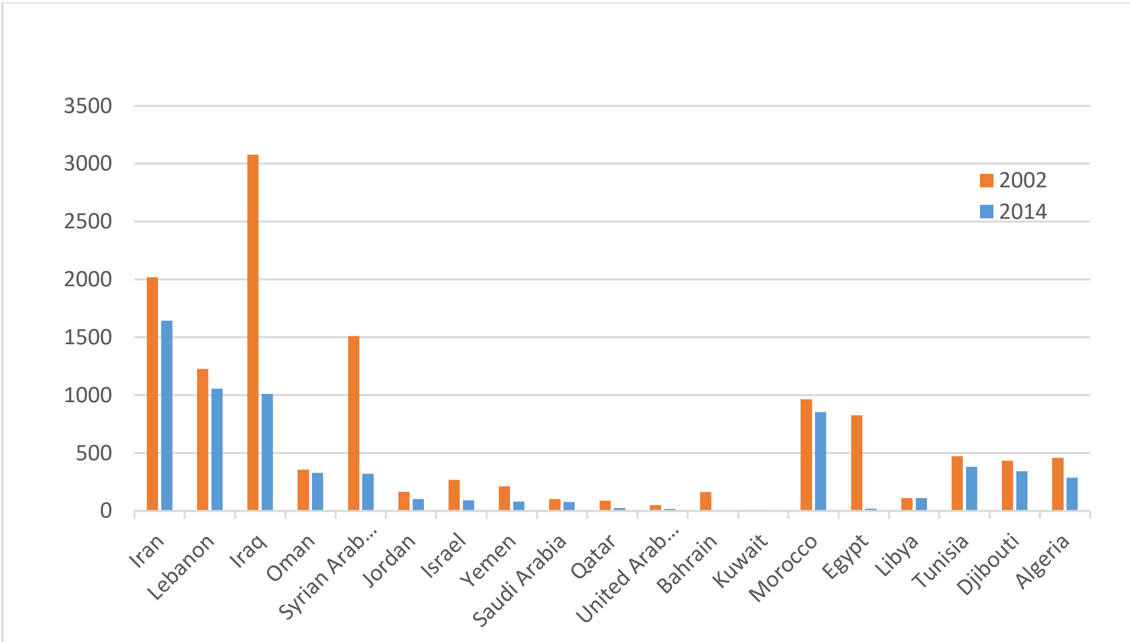

Figure 2-2Total Renewable Water Resource per capita per year in 2002 VS 2014 (Data retrived from http://www.indexmundi.com)

Another category embraces Bahrain, Gaza, Jordan, Kuwait, Libya, Oman, Qatar, Saudi Arabia, the United Arab Emirates, and Yemen, which are consistently arid. Very limited water resource forces them to rely mostly on unconventional supply augmentation methods like water desalination. These kinds of expensive technologies are not affordable for low income countries like Gaza, Yemen, and Jordan.

The last category belongs to countries which are highly dependent on transboundary water resources, such as Egypt, Iraq, and Syria. Increasing water demand and political instability across the region implies that international water agreements are not as reliable as before. Figure 3-3 depicts the interdependency level among these countries. Given this high interdependency, water conflicts are increasing dangerously, and it is predicted that "Water Wars" will be inevitable in the following decades (Ameri, 2002). However, such warnings have not slowed down governments’ efforts to harness crucial boundary waters through building giant dams and executing water transfer projects.

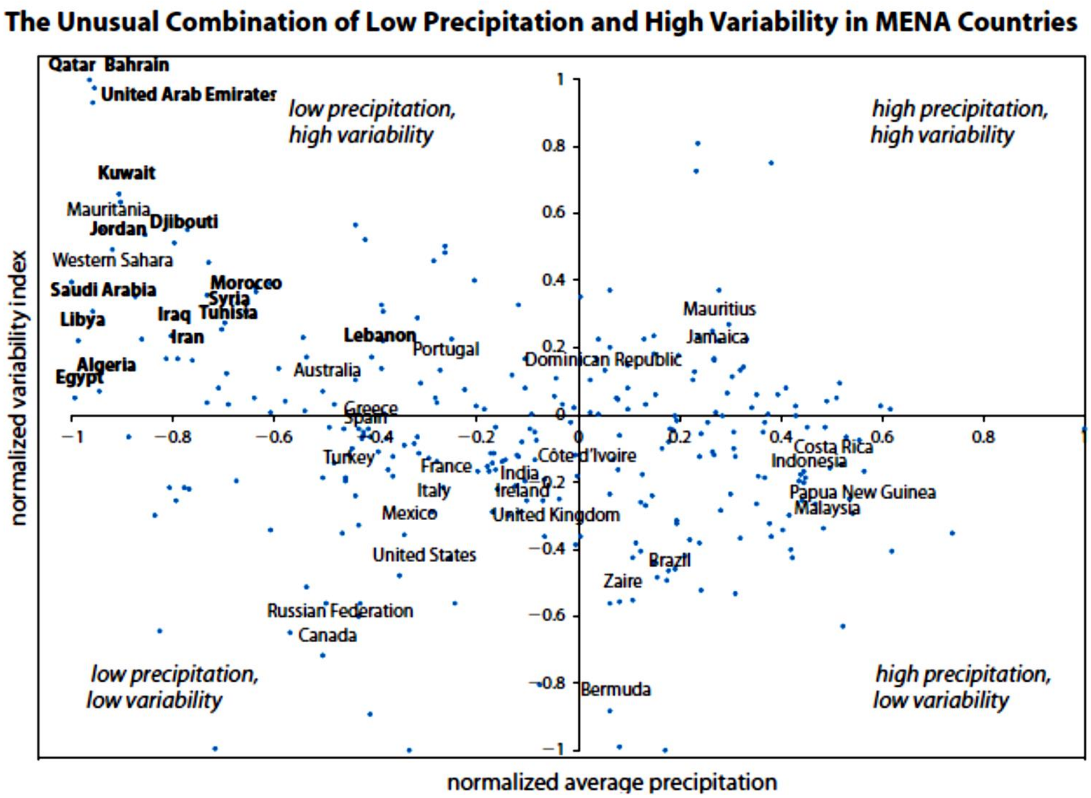

Figure 2-3- The unusual combination of low precipitation and high variability in MENA countries variability (Bucknall, 2007)

2.3 Water scarcity in Iran

2.3.1Water availability

Iran is located on the western part of the Iran plateau in the southwestern part of Asia, and is host to a population of 77 million persons (2012 census), which makes it the eighteenth most populated country among the 266 countries in the world.

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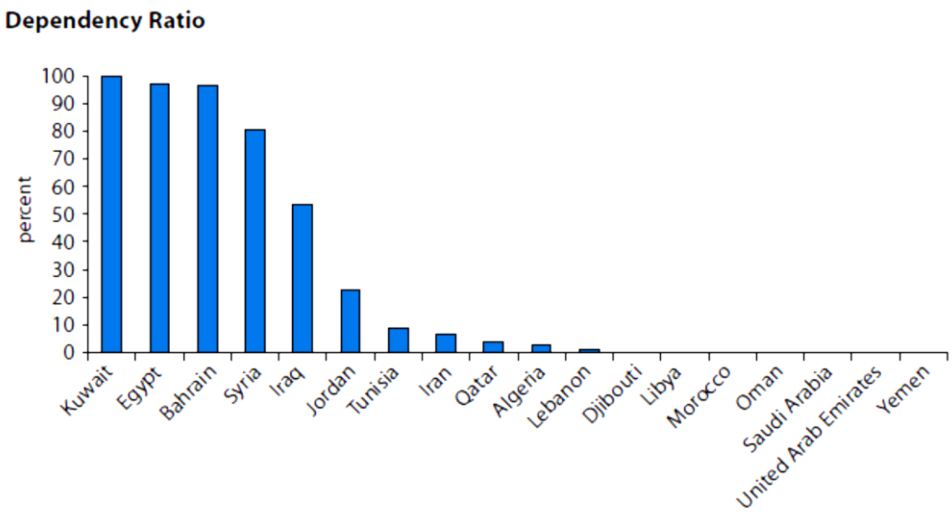

Figure 2-4- The degree of dependency on international water resources (Bucknall, 2007)

Most of the central and eastern parts of Iran are categorized as arid and semi-arid regions with average rainfall of 62.1 to 344.8 mm annually. The average precipitation in Iran is less than 240 mm/year, which is approximately one third of the world average and half of the Asian average. Most of this precipitation falls in the north and northwest parts while average precipitation in east and southeast of the country is less than 100 mm/year. In fact, 75% of total precipitation happens in about 25% of the country, see Figure 2.4.

While Iran receives 400 billion cubic meters of precipitation, just about 130 billion is available for consumption and 270 billion cubic meters evaporate. In the past two decades, the available water has been declining as a result of less precipitation and more evaporation, due to subtle temperature increases. The annual renewable water per capita in Iran is estimated to be less than 1,700 m^3, well below the global level (7,000 m^3) and slightly above the MENA level (1,300 m^3).

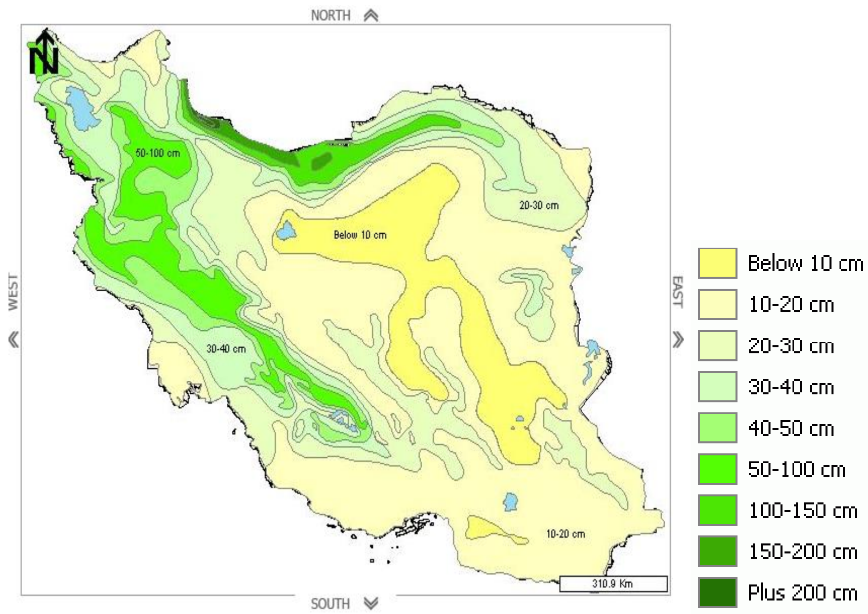

Figure 2-4- Annual rainfall Average (Adopted from National Geoscience database of Iran)

2.3.2 Drinking water and sanitation access in Iran

Like most of the Gulf countries, Iranians enjoy an acceptable level of access to water services. Based on 2015, MDG database, 96% of Iranians use improved drinking water source, which includes 98% of the urban population and 92% of the rural population. Moreover, 89% of the total population have access to improved sanitation facilities, including 93% and 82% of urban and rural population, respectively (*WorldBabk DataBank* 2016).

Despite traditionally high access to water and wastewater infrastructures, recent decades have seen deteriorating water scarcity condition, causing many residents of Central, Eastern and Southern Iran to lose their continuous access to piped water, especially during the summer. This population are mostly rural, and during blackout times the government provides truck-borne water, which puts this population at risk of waterborne disease. Besides, the provided water is so limited, it can't satisfy all sanitation and household water needs. Currently, about 7,500 villages are in this situation and their numbers are growing fast. Figure 3.5 shows one of these mobile water trucks.

Figure 2-5- Water trucks distributes water in rural area (Photographer: Abdolreza Valaei)

2.3.3 Water consumption data

Although the available renewable water is decreasing, most likely due to climate change impacts, the overall water consumption is increasing in Iran. Based on a five-year development plan, water consumption has increased from 88 billion cubic meters (BCM) in 1999 to 100 BCM in 2007. Groundwater resources comprise 60% of this water and the rest is supplied through surface resources.

Agricultural use accounts for 92% of this water, while the share of industries and residential water is about 1.5% and 6.5% respectively. By comparison, the global average for agriculture water consumption is 70%, with 20% for industry and 10% for domestic purposes, respectively.

2.3.4 Water Crisis implications

Because of increasing demand as well as frequent droughts during last twenty years, many of Iran's major surface water resources; including lakes, wetlands and streams, have been shrinking severely. Lakes Urumia, Hamoon and Parishan, as well as the Zayandeh Rud river are some catastrophic cases of this condition. Moreover, to meet the ever-increasing demand for fresh water, groundwater resources have been overexploited. During the last 40 years, annual groundwater consumption has quadrupled, so that more than 70% of groundwater reservoirs are being extracted well beyond the maximum recommended renewable rate of 40%. Consequently, across Iran, water tables are declining repidly. Figure 2.6 shows the reduction in groundwater resources over the last half century.

Land subsidence is another effect of rapid groundwater depletion. This has caused permanent damage to the land morphology of many plains in Iran (Madani, 2014; Mohajeri et al., 2016). On the other hand, rural communities are the most affected group by water shortage among Iranian citizens. They keep losing their water resources even though farming is generally their sole source of income. Furthermore, the lack of appropriate wastewater treatment facilities causes contaminant penetration into aquifers. So, as groundwater levels decline, water contaminants get concentrated and increasingly affect the quality of remain resources. This is a serious threat to human health, especially in rural communities with less access to public drinking water treatment facilities.

Keshavarz et al. 2013 describes many socio-economic difficulties that these communities are experiencing because of the ongoing water crisis. Some of these problems includes reduced income and lack of alternative income sources, increases conflict over water access, food insecurity, health impacts and reduced access to health services, reduced access to education, forced displacement, impoverishment and reduced quality of life, psychological and emotional distresses including depression and frustration, changed family plans such as delaying marriage, and family and community disharmony and disintegration. (Keshavarz, Karami, & Vanclay, 2013).

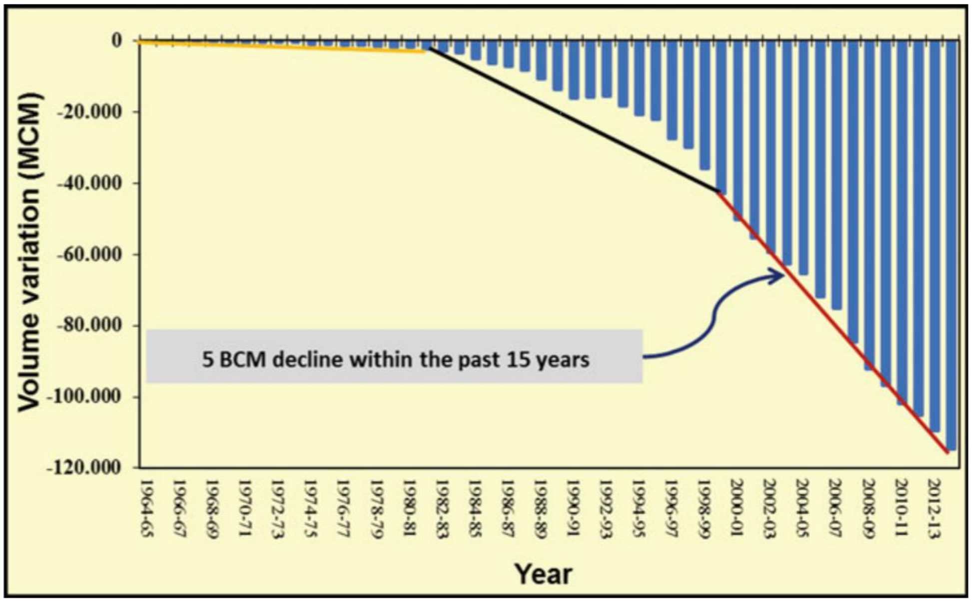

Figure 2-6- Groundwater depletion during the last half century (Mohajeri et al., 2016).

2.4 Water governance in Iran

Currently, the Ministry of Energy and the Department of Water and Wastewater affairs are the main water policy-makers in Iran. They mandate the administrative tasks of the two main government-owned holding companies, the Iranian Water Resource Management Company (IWRMCo) and the National Water and Wastewater Engineering Company (NWWEC). Each of these two holding companies has a subsidiary in each province.

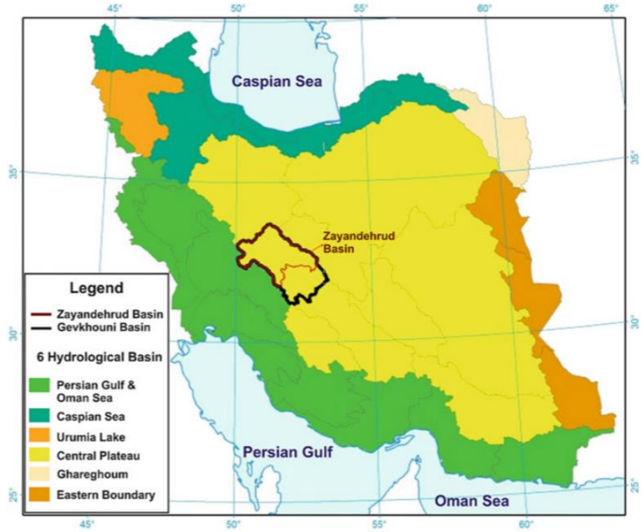

Figure 2-7-Zayandeh Rud Basin

Many of these agricultural water demand policies overlap with decisions made by departments like the Agriculture Ministry, Industry and Mining Ministry, Commerce Ministry and Department of Environment. So, a Supreme Council of Water was founded, which is supposed to coordinate the cross-cutting issues. However, the dominant approach of this council is to support the agricultural sector's development projects aimed at achieving food self-sufficiency and augmenting the water supply through heavy water infrastructure. Water demand management is a less important concern of this council. Besides, provincial IWRMCo. and NWWEC subsidiaries exacerbate the competition over available water in shared watersheds (Ebrahimnia & Bibalan, 2017).

2.5 Zayandeh Rud Watershed

The Zayandeh Rud river originates from the Zagros ranges in Chahar Mahal and Bakhtiari Province and flows 250 miles in arid and semi-arid central plains and finally ends up in the Gavkhooni swamp (Fig 2.7). This river passes through the city of Isfahan with more than four million residents, the second most populous metropolitan area in Iran after Tehran.

The total basin area of 10,392 mi^2 extends into two provinces of Isfahan and Chahar Mahal and Bakhtiari, respectively. The Chahar Mahal and Bakhtiari provinces are located upstream of the river, but its share of the river basin is just 7% of the land and 1.8% of the population.

The name of this river, in Persian means the “life-giving river” and implies the historical importance of this river for the region. Currently, more than one million of the basins’ residents survive on farming income and subsistence over an area of nearly 200,000 hectares. The majority of heavy industries like oil, steel and cement in Iran are concentrated along this river and those industries employ more than 300,000 people (Mohajeri et al., 2016). This river is also responsible for providing residential water for five million residents of three provinces of Isfahan, Chahar Mahal and Yazd). This river has been experiencing severe and frequent droughts in the last six decades. In 26 of the last 59 years, it has been in a drought condition, and the average runoff of the river has decreased by 30%, while the demand for water keeps increasing. In these circumstances, meeting this demand without compromising the sustainability of the basin seems impossible.

The Gavkhooni wetland, which Iran has committed to preserve with the Ramsar Convention, has not been receiving its minimum water allocation during the last two decades. Moreover, this river is a key feature of Isfahan City, a hub of tourism in Iran. Many outstanding features of this ancient city, such as bridges and palaces, rely on the glory of this “life-giving” river.

Figure 2-8 shows one of these ancient bridges before and after drought. These ecological and socio-political challenges make this the most sensitive and strategic watershed in Iran.

Figure 2-8- One of the historic Bridges on Zayandeh Rud river, before and after drought

Chapter 3: Literature Review

Scenario analysis is the process of studying the possible future states of a system by exploring alternative, yet plausible and consistent pathways that could evolve out of present conditions (Funke, Claassen, & Nienaber, 2013; Mahmoud et al., 2009; Stewart et al., 2007). These trajectories are called scenarios, which are a useful foresight tool to help understand and analyze the key embedded uncertainties of a specific system (Fig 4.1). Scenario planning can be used by policy makers and companies as a decision tool in strategic planning and can help them to take more informed and coordinated decisions in an highly uncertain environment (Henriques et al., 2015). It should be noted that scenarios are not forecasts, prediction or projections of the future; rather, each might be understood as a “cone of plausibility” (Fig 4.1) and presents each scenario is one plausible image of how the future can unfold (Henriques et al., 2015).

3.1 Scenario Planning Background

During World War II, the concept of scenario planning was used by the United States (US) Air Force, to explore their enemies’ plausible actions and reactions. Afterwards, RAND Corporation started to develop scientific framework to apply this methodology in other highly uncertain and complex problems like energy markets. One of the earliest promising cases of scenario planning in business was by the Royal Dutch Shell and used during the oil price shock of 1973. Shell responded quickly and secured their long-term profitability and led to great growth (Funke et al., 2013).

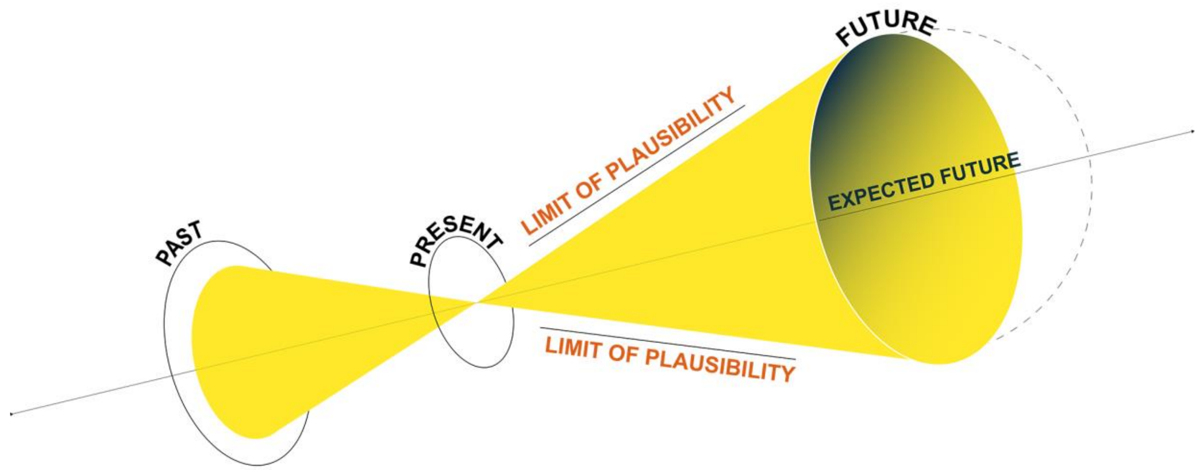

Figure 3-1- Cone of Plausibility adapted from: http://www.horizons.gc.ca/eng/content/module-3-scanning-presentation

In recent years, the application of scenario planning in environmental issues has increased significantly specially to evaluate the implications of climate change. Climate scenarios developed by the Inter-Governmental Panel on Climate Change (IPCC) are a foundation for many environmental scenarios planning studies, including water resource management studies (K. C. Abbaspour, Faramarzi, Ghasemi, & Yang, 2009; Moss et al., 2010; Stewart et al., 2007).

Scenarios also can be a valuable tool to address the uncertainties associated with demographic, economic, social, technical and political conditions that affect the performance of water resource systems, including their influence on future water availability, water demand and water management strategies (Dong, Schoups, & van de Giesen, 2013; March, Therond, & Leenhardt, 2012). Further, they can support managers and decision-makers to shift their perspective from predicting to exploring the future, and from predictive to anticipatory management (Liu et al., 2008).

3.2 Water Governance scenario planning

Governing common resources might be one of the biggest challenges facing humankind. It is only getting more difficult, as resources are limited, demand is growing, stakeholders express diverse values and interests, and the system dynamics are highly uncertain. This is where adaptive governance is vital to balance demand-supply equilibrium through administrative controls and management strategies, without compromising the system's integrity and sustainability (Dietz et al., 2003).

Currently, water is one of the most complex shared natural resource systems, since its indigenous complexity and uncertainty are exacerbated by uncertain climate change impacts, the demand is ever-increasing by population growth, and stakeholders are diverse with conflicting needs and expectations (Wiek & Larson, 2012). Especially in arid and semi-arid regions, demand surpasses the supply, and available water resources are not able to meet the total water demand. In this situation, an adaptive and responsive water governance regime becomes useful to coordinate stakeholders and facilitate sustainable and collective decision-making. Here, scenario planning can offer alternative governance options as a tool to explore the future in a systematic and comprehensive way (Kuzdas, Wiek, Warner, Vignola, & Morataya, 2015; Quay, 2010).

However, the role of climate change, population growth and economy growth on the future state of water resources is unspecified. Therefore, narrowing down the water scenario planning to these drivers without considering other socio-economic, technical and ecological aspects of the system cannot support comprehensive sustainable governance approaches (Keeler et al., 2015; Wiek, Binder, & Scholz, 2006). In fact, the water governance scenarios should be able to link the aforementioned variables systematically and reflect the impact of actors' decisions and actions on the whole system (Wiek & Larson, 2012).

3.3 Research Gap

In the MENA region, the application of scenario planning is still limited to a few studies that evaluate the impact of climate change, population growth, and supply augmentation plans on economic growth. For instance, Abbaspour et al. 2009 applied scenario planning to assess the impact of climate change on water resources in Iran (K. C. Abbaspour et al., 2009). Madani 2009 and Gohari et al. 2013 used this concept partially to develop a system dynamics model to evaluate the impact of new water augmentation projects on supply-demand balance in Zayandeh Rud watershed (Madani, 2007, Gohari et al. 2013). Safari, et al. 2015 also developed an Adaptive Network-based Fussy Inference System (ANFIS) model to evaluate the impact of climate change and supply augmentation projects on the near future condition (2015-2019) of this watershed (Safavi, Golmohammadi, & Sandoval-Solis, 2015; Safavi et al., 2016). These water scenario planning studies are the extent of previous work in this area. However these studies have several limitations, namely;

1) they do not apply a systematic approach to develop all plausible and distinct future alternatives;
2) they do not study the impact of the water governance attributes, water policies and decisions on the future of the watershed, and finally,
3) they do not address agricultural water demand management as the most important concern of water resource management of the region.

At the global level, there are few studies which develop and analyze governance-focused scenarios to evaluate the impact of water policies and water governance institutional frameworks on the ecological and socioeconomic sustainability of watersheds. For example, Kuzdas 2014, used a participatory approach to develop governance scenarios in Costa Rica to address water conflicts, and Keeler et al. 2015, use multiple methods, including stakeholder survey, qualitative scenario analysis and system dynamics modeling, to study different urban water governance regimes in metropolitan Phoenix 2030 (Keeler et al. 2015).

However, there has been no previous work to develop alternative governance scenarios to manage agricultural water demand in arid and semi-arid regions like California, in the US, and the MENA region.

3.4 Research Contribution

To fill this research gap, this study aims to apply a systematic scenario development approach (Scholz & Tietje, 2002) to construct a few consistent and distinctive signature governance-oriented scenarios which consist of of a set of selected migratory water policies and actions as well as adaptive organizational reforms to manage agricultural water demand in arid and semi-arid regions. The Zayandeh Rud watershed is chosen as the illustrative case study due to its critical and challenging nature of its agricultural water demand management and its implications for socioeconomic and ecological sustainability.

Chapter 4: Methodology

4.1 Data Gathering procedure

A mixed, semi-structured approach was used to gather the study input data from different stakeholders including water experts, farmers, policy-makers, cross- level water managers and environmental activists. The reason for choosing this approach was the high diversity of stakeholders, their different level of literacy and some other socio-political concerns. So, this semi-structured approach provided enough flexibility in our data gathering procedure which let us have a diverse range of participants and answers.

Accordingly, data collected through 15 individual semi-structured interviews, eight online think tanks and forums, media interviews, government reports and documents, previous studies and global best practices. The individual interviews were recorded in person, during January 2015. The interviewees were selected from a diverse range of stakeholders and decision-makers. The think tank discussions occurred through the "Telegram" application, which is the most popular phone-based communication application among Iranian citizens. It provides a flexible, affordable, free and secure medium for stakeholders to express their ideas. Some of these forums represent the official think tanks and some others are unofficial discussion groups each of which are supported by a group of stakeholders and their interests and values. Some of these groups that engaged in the research are listed in Appendix A.

4.2 Scenario development

In this study, I adapted the "formative scenario analysis" methodology (Scholz & Tietje, 2002; Tietje, 2005) to construct a discrete set of consistent, diverse and governance-oriented scenarios for the Zayandeh Rud basin 2030. This research places emphasis on agricultural water demand management, alternative options and the impact on sustainability of the watershed. I linked the "formative" scenarios with expert knowledge to come up with "normative" signature scenarios which are comprehensible and informative enough for decision-makers (Foley & Wiek, 2014; Keeler et al., 2015). The stepwise procedure of our study is illustrated in Fig. 4.1.

4.2.1 Step 1- Defining system variables and future projections

Table 4.1 demonstrates an initial set of variables (50 variables) that was identified based on participant knowledge within three different interfaces of socio-economic environment (formal and informal), built environment (technological), natural environment (ecological). The variables are categorized based on the five domains of supply, delivery, use, outflow and cross-cutting activities (Larson, Wiek, & Keeler, 2013; White et al., 2015). This set of variables comprises all proposed actions, policy interventions and governance reforms which may help to manage agricultural water demand (AGW). It also includes some important exogenous variables which can potentially affect the AGW such as, climate change, population growth, political stability and economy growth. Furthermore, an accurate definition plus a few (2 or 3) future projection statements were assigned to each variable, so that they clearly cover all range of plausibility of a particular variable.

Scholz and Tietje (2002) suggest narrowing down the number of variables to end up with less than 20 final variables. To do so, the variables were ranked based on the following procedure:

1- Sustainability importance- the potential independent impact of each variable on AGW, was examined by means of a qualitative review of the literature. Thus, this assessment is subject to the values of the researchers.
2- Systemic importance- the potential uncertainty and complexity that any single variable adds to the whole system was evaluated by means of a qualitative review of the literature. Again, this assessment is subject to the values of the researchers.
3- Minimum redundancy- the redundant variables and those could be merged together were identified through inspection by the researchers.
4- Maximum diversity across interfaces and domains was evaluated iteratively by the researchers.

It should be noted that the order of above criteria is not based on their priorities; rather, the final set of variables was selected in a long back and forth iterative process by the researchers and stakeholder representatives selected to participate in this study.

4.2.2 Step 2- System Analysis

The final set of variables to analyze the system was scored for their cross-impact of each variable on all other variables on a scale from 0 (no impact), 1 (indirect impact) to 2 (Direct impact). The result is an impact matrix which includes impact relationships among all pairs of variables, see appendix B. This matrix is not symmetric as impact of Variable A on B can be different from impact of variable B on A. We used *Systaim* software to analyze this matrix. This analysis helps to understand the interconnections of the system, the activity or passivity of each variable. It also supports the further steps of analysis like scenario selection and interpretation processes (Kuzdas et al., 2015).

Table 4-1-Initial set of variables

Interfaces		Activity Domains: Supply	Delivery	Uses	Outflows	Cross-Cutting
Interfaces	Socio-economic Environment (Formal/ informal)	-Virtual water trading -Water export regulation -Water market/bank	-Water Pricing System -Water Allocation System -Fair outcome distribution	-Irrigated area regulation -Land use planning -Green water utilization -Agricultural waste/ loss control -Crop rotation plan -Irrigation scheduling -Farm consolidation -Agricultural practices	-Runoff and drainage recycling	-Direct and indirect subsidies -Dispute resolution system -Education and Training -Rural Development Plan -Social Engagement -Social Democracy -Economic Growth -Institutional integrity -Political Stability -Governance hierarchical system -Population Growth (Pro-natalist Family planning) -Demographic shift (Urbanization) -Food security -Governance Legitimacy
	Built Environment (Technological)	-New inter-watershed transfer project -New dam project -Unconventional supply augmentation -Flood harvesting	-Storage & distribution efficiency -New distribution networks -Evaporation control technologies -Qanat Recovery	Efficient Irrigation Technologies -Land improvement	-Aquifer recharge wells -In-situ groundwater remediation -Wastewater treatment packages -Animal waste management (storage impoundments)	
	Natural Environment (Ecological)	-Climate change (Precipitation, Temperature) -Groundwater Safe yield	-Gavkhooni Wetland water right -Stream minimum flow	-Unauthorized extraction -Soil erosion control -Groundwater quality protection (Optimized fertilizer and pesticide)	-Effluent disposal regulations	

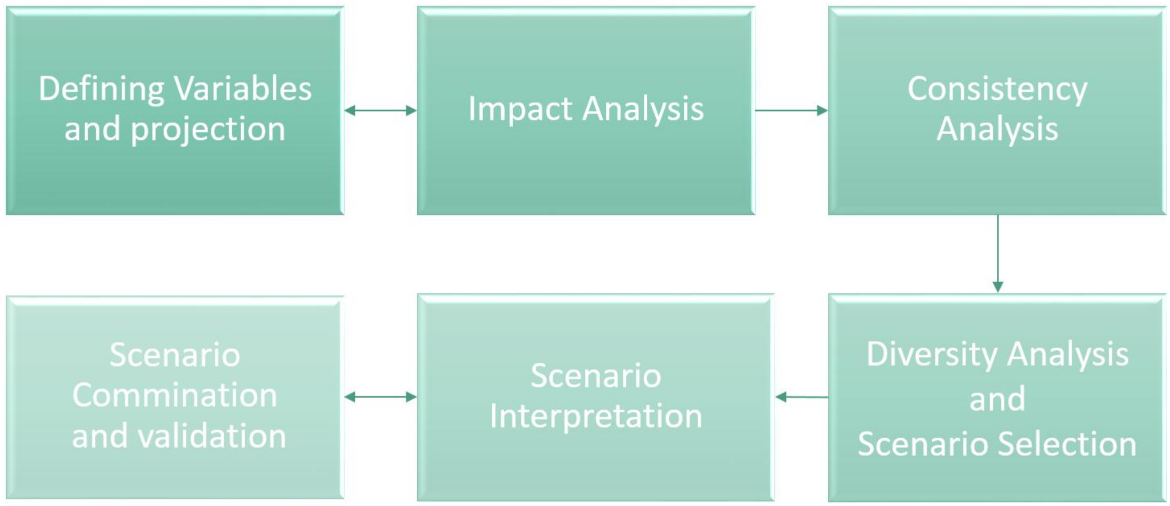

Figure 4-1- Study methodological steps

4.2.3 Step 3- Consistency Analysis

In this step, we checked the logical consistency of each scenario through a set of calculations. To do so, another matrix was prepared which includes the consistency level of each pair of future projections. Unlike the impact matrix (See appendix B), the consistency matrix is triangular and consistency values are scored between -2 to 2 (Table 4.2)

Table 4-2-Consistency scoring system

Additive indicator	Explanation	Multiplicative indicator
-2	Prevents the occurrence	0
-1	presents a barrier, but occurrence is possible	0.5
0	No Impact between projections	1
1	Weak Support	2
2	Required for Projection to Occur	3

There are several different options to calculate each scenario consistency value, each of which has its own pros and cons. The first method is Additive consistency, which simply sums up all consistency values for pairs of a scenario.

$$c^*_{\text{add}}(S_k) = \sum_{i=2}^{n} \sum_{j=1}^{i-1} c_{\text{add}}(y_i^{m_i}, y_j^{m_j}) \quad \text{Eq. 4.1}$$

For Scenario S_k additive consistency is (Tietje, 2005) where y_i^{mi} denotes the m_ith level of the ith impact variable and n_i is the number of levels of the ith impact variable. The main disadvantage of additive consistency is that it is compensating, as it does not reflect the key obstructions or inconsistencies from pairs of future projections which cannot occur in a single scenario. To overcome this problem, two other indices can be used.

First is multiplicative consistency, which is defined as product of all combinations scores:

$$c^*_{\text{mult}}(S_k) = \prod_{i=2}^{n} \prod_{j=1}^{i-1} c_{\text{mult}}(y_i^{m_i}, y_j^{m_j}) \quad \text{Eq. 4.2}$$

It should be noted that the previous matrix should get adjusted for this consistency. We transformed the previous matrix to a new matrix using a multiplicative scoring system (Table 4.2). Unlike additive consistency, multiplicative consistency is an excluding measure, because any scenario with one and more obstructive relationships (c_{add}=0) the total C^*_{mult} would be zero. To solve this problem, the "number of inconsistencies" can be used, which is simply the sum of all obstructive relations in a single scenario.

In order to do a comprehensive study, we used a combination of additive and number of inconsistencies indices. Since with 20 variables and 48 projections, the number of scenarios would be as high as 30 million, we wrote a computational model using Python programming language to expedite the process of calculation (See the code in appendix D). We used a filtering criterion, which is a combination of additive consistency, multiplicative consistency and number of consistencies to come up with a smaller set of consistent scenarios.

4.2.4 Step 4- Scenario Selection and Diversity Analysis

Although most of the scenarios got filtered through consistency analysis, the remaining consistent scenarios have to be narrowed to a small set of plausible, distinctive and sustainable scenarios. For this purpose, we used one of the standard formative procedures, "The distance-to-selected (dts)" and combined it with a set of exclusive criteria to select the final scenarios (Tietje, 2005).

1. We select the most consistent scenario which is close to the status quo scenario as the initial scenario. We used this scenario as an anchor to find the next scenario.
2. To do so, the distance between all other filtered scenarios to the first scenario were calculated using this function:
    a. $$d(S_k, S_\ell) = \sum_{i=1}^{n} \begin{cases} 1 & \text{if } y_i(S_k) \neq y_i(S_\ell), \\ 0 & \text{otherwise.} \end{cases}$$ Eq. 4.3
3. A wise tradeoff is required to choose the second scenario from a small set of distinct and consistent scenarios. To overcome this problem, we used normative techniques including surveys and interviews, sustainability analysis and best practices to find the most meaningful and coherent scenario among those scenarios that are most distant and consistent to the first scenario (Foley & Wiek, 2014; White et al., 2015).

4. At this point, we have to find the most distant scenarios to both selected ones. To do so, the harmonic mean (eq. 4.4) was implied because it is the less compensating average in comparison to arithmetic and quadratic averaging functions.

$$I_j^s(S_i, S_k) = \begin{cases} 1 & \text{if } c_j^*(S_i) < c_j^*(S_k), \\ 0 & \text{otherwise,} \end{cases} \qquad \text{Eq. 4.4}$$

5. Step 4 was iterated until the dts values were too small. We set 50% distance as the threshold for stopping the scenario selection procedure.

4.2.5 Step 5- Scenario Interpretation and Validation

As Tietje 2002 claims, the most natural way of interpreting the scenarios is simply through deep discussions about future state of the system under each governance scenario. This method is consistent with our methodology's mission, which is transforming our decision-making process from "operations on numbers to operation on concepts" (Scholz & Tietje, 2002). This method of evaluation also helps to communicate and validate our scenarios with targeted audiences more effectively.

Accordingly, we shared the key systemic features of our scenarios with participants and asked them to discuss them and explain their imagination of Zayandeh Rud basin in 2030, under each governance regime. We used these discussions to evaluate each scenario through the following sustainability concerns:

1- Agricultural water demand

2- Ecological sustainability

3- Agriculture sector development

4- Rural communities' welfare

5- Food security

6- Conflict level

These discussions led us to assign a storyline to each scenario. These narratives, along with some visualizations, were used to keep communicating and validating our scenarios.

Chapter 5: Results and Discussion

5.1 Selected Variables and future projections

The final set of variables along with their definitions and future projections are illustrated in Table 5.1. It also includes the current state of each variable during 2015-2017.

Table 5-1-Final set of variables

	Item	Variable	Future Projection	Description	Current state	Sources
Socio-economic System and Supply	1	Trade regulation	1-Agricultural products in/out trading is regulation-free and based on economic profitability (free market). 2--Agricultural products in/out trading is regulated based on their water footprint (Virtual water trading). 3--Agricultural products in/out trading is regulated based on food security concern (Self-sufficiency supporting).	The trading tariffs and other official regulations on agricultural products' import and export.	Agriculture ministry is exclusively in charge for regulating the international and domestic food trading. The trading regulations are in support of agriculture sector development and domestic production, so that, importing tariffs on strategic goods are very high while the tariffs on exporting are almost insignificant.	(Felmeden, 2014) (Gohari et al., 2013) (Arabi, Alizadeh, Rajaee, Jam, & Niknia, 2012) (Antonelli & Tamea, 2015) (Faramarzi, 2010)
	2	Water market	1-Established water markets/banks facilitate water and effluent trading between customers and water right holders. 2-There are only informal, small scale and direct bartering of water rights among farmers.	Water banks are a marketing instrument which allows irrigators or industries within a region to exchange water in order to mitigate the short-term effects of drought.	Traditionally, water right holders, trade/lend their water rights. This is more common among Qanat water right holders. This system is absolutely informal, unorganized and non-competitive.	[1] [Gosh et. Al 2014] (Rosegrant, Ringler, & Zhu, 2009) (Chong & Sunding, 2006) (Bakker, 2014; Ghosh, Cobourn, & Elbakidze, 2014)
Socio-economic System and Delivery	3	Water Pricing System	1-Volumetric irrigation water consumption is measured and priced based on the cost of supply, delivery and maintenance 2-Water pricing system is unchanged.	The methodology to calculate the irrigation water price.	Currently, surface water is charged as 1 to 3% of total value of cultivated crops. There is also no pricing system for groundwater. Farmers only have to pay the capital cost of well drilling and pumping system in addition to maintenance charges. Qanat users are only responsible for maintenance costs and they are not charged officially for consumed water.	(DonyayeEghtesad, 2014) (Nikouei & Ward, 2013) (Mohayidin, Attari, Sadeghi, & Hussein, 2009)
	4	Water Allocation System	1-Water is distributed based on government discretion and priorities, in an unfair way. 2-Traditional water rights are followed as the central criteria for water allocation 3-Traditional water allocation is modified and followed	The allocation scheme to distribute limited water among all stakeholders including (Farmers, industries, urban areas and ecosystem).	The current water allocation system is based on government discretion and priorities. Urban and industries water demands are the highest priorities. Thee remained irrigation water does not distributed equally among water right holders. Consequently, some areas are receiving their full water rights while other areas (mostly located on eastern part of river) are not getting equal share of irrigation water.	(François Molle & Mamanpoush, 2012) (Francois Molle, 2008) (Degefu & He, 2016)

	Item	Variable	Future Projection	Description	Current state	Sources
Socio-economic System and Uses Activities	5	Irrigated land area regulation	1- A restrictive upper limit on total irrigated land is set and enforced 2- There is no regulation to control irrigated area	An official regulation to restrict total cultivated (irrigated) land area	During the last three decades, Increasing the cultivated area has been always a fixed part of the watershed and national development plans. Based on figures of 2012, the Agriculture Organization of Isfahan assumes that an increase of the cultivated area of about 68% for farmlands and 23% of orchards can be possible until 1404.	(Felmeden, 2014) (Sarhadi & Soltani, 2013)
Socio-economic System and Uses Activities	6	Land Use Planning (Crop choice)	1- Crop choice is made based on a national/watershed comprehensive cultivation plan 2- Farmers decide about their cultivation plan collectively considering their available water and socio-economic concerns 3-Farmers individually decide about their cultivation plan based on their experience and discretion.	Cultivation plan means the annual or seasonal choice of crop for each land parcel.	There is no comprehensive land use plan to suggest crop choice. Farmers usually choose their cultivation plan individually based on their available resources, their experiments and market situation.	(Mohajeri et al., 2016) (Gohari, Mirchi, & Madani, 2017)
Socio-economic System and Uses Activities	7	Farming practices	1- The large-scale Industrialized farms are dominant type of practice in the watershed 2-Improved traditional practice is dominant 3-Traditional small-scale or subsistence farming is dominant	Industrialized farming refers to fully mechanized, large-scale practice which has the highest productivity. Improved farming refers to those small traditional farms that are improved by applying soft adaptation strategies like land consolidation, scheduling, crop rotation, drainage and so on. Traditional farming refers to small scale and mostly subsistence farming practices.	However, the industrialized farms are growing, traditional small-scale or subsistence farming is dominant among rural communities.	(NationalResearchCouncil, 2005) (Hamdy, Ragab, & Scarascia-Mugnozza, 2003) (Qadir, Boers, Schubert, Ghafoor, & Murtaza, 2003)
Socio-economic System and	8	Runoff and drainage recycling	1-Most of marginal quality water is recycled and reused 2- Most of marginal water is disposed without recycling	Marginal water refers to agricultural drainage water, saline groundwater, reclaimed municipal and industrial wastewater	There is no infrastructure to gather, basic treatment and redistribute marginal quality water in farms.	(NationalResearchCouncil, 2005) (Hamdy et al., 2003) (Qadir et al., 2003)

	Item	Variable	Future Projection	Description	Current state	Sources
Built Environment and Supply Activities	9	New Water Transfer Projects	1-New water transfer projects are pursued 2-No new water transfer projects pursued	Water supply augmentation through new water diversion tunnels from Karoon river	Besides three working tunnels, several other projects are under construction like Kohrang 3, Beheshtabad and Golab 2	(Safavi et al., 2016) (Gohari et al., 2013)
Built Environment and Delivery Activities	10	Storage & distribution system	1- Distribution system is lined and covered to minimize percolation and evaporation 2- The distribution system is unchanged	The modification of water distribution networks including channels, qanats, ponds and reservoirs in order to avoid deep percolation and extra evaporation, such as covering and lining them	The irrigation water storage and distribution networks are mostly open and uncover.	(NationalResearchCouncil, 2005) (Mohajeri et al., 2016) (Qadir et al., 2003)
Built Environment and Uses Activities	11	Efficient Irrigation Technologies	1- Efficient irrigation technologies are used in most farms 2- Traditional irrigation system is still dominant among farmers	Irrigation water use efficiency can be defined as the ratio of beneficial water use to applied water. Efficient irrigation technologies refer to pressurized systems like sprinkler heads and drip emitters which improve this ratio through increasing the irrigation uniformity and reducing the percolation and evaporation.	Flood irrigation is still dominant in this watershed	(NationalResearchCouncil, 2005) (Nikouei, Zibaei, & Ward, 2012) (Akbari, Toomanian, Droogers, Bastiaanssen, & Gieske, 2007)

	Item	Variable	Future Projection	Description	Current state	Sources
Natural System and Supply Activities	12	Groundwater Safe yield	1- Groundwater safe yield is pursued as the central governance policy 2- Groundwater safe yield is not pursued properly.	The priority level of safe yield in water governance system. Safe yield refers to the amount of water which is renewable and can be extracted without compromising the sustainability of aquifers.	Safe yield is not a controlling policy, so that, aquifers are over drafted and groundwater level is declining very fast in this region.	(Keeler et al., 2015) (Mohajeri et al., 2016)
Natural System and Delivery Activities	13	Gavkhouni Wetland Water Right	1-Gavkhouni receives its water right continuously. 2-Gavkhouni does not receive its water right.	The amount of water that is allocated and received by the Gavkhooni Wetland. Minimum flow requirement is about 176 (MCM/year) or inflow of 5.5 m3/s during normal periods and 60 (MCM/year) during drought periods.	Current inflow is about 0.3-0.5 m3/s (Intermittently) and 99% of wetland area is totally dried out.	(Safavi, Golmohammadi, & Sandoval-Solis, 2015) (Sarhadi & Soltani, 2013)
Natural System and Uses Activities	14	Unauthorized extraction	1-Unauthrized extraction is regulated effectively and administered fairly. 2-Unauthorized extraction is not regulated properly or it is regulated but the enforcement system is unfair and/or ineffective.	The regulations and policies to prevent unauthorized water extraction and the administration fairness and effectiveness.	They are some regulations but they are not prohibitive enough. The enforcement is also very weak and ineffective and at some extend corrupted.	(Francois Molle, 2008) (Felmeden, 2014)
Cross-Cutting Activities	15	Subsidies	1- Both direct and indirect subsidies are used to support domestic production 2- Directed/purposive Subsidies are used to motivate the sustainable farming and conservative water consumption 3- All kind of subsidies are totally removed	All kind of discounts that government pay to support domestic production. Direct subsidies are those discounts that are paid directly to farmers, while the indirect ones are paid to customers but the purpose is still supporting agriculture sector.	In addition to inexpensive water, other type of direct subsidies are used to support agriculture sector including subsidized energy, farming equipment and devices, seed, fertilizer, pesticides and insurance. Indirect subsidies are also used to compensate high production cost like subsidies that are paid to end-users on essential foods retail prices including subsidized milk, bread, meat, poultry etc.	(Schramm & Sattary, 2014)
	16	Self- Sufficiency	1- Self-sufficiency is the central governance approach 2- Self-sufficiency is not the governance system central principal	Self-sufficiency refers to independency of a nation or area of importing food -especially strategic foods.	For last 4 decades, self-sufficiency has been one of the most important national security concerns in Iran. In this watershed also, self-sufficiency is the central approach.	(Gohari et al., 2017) (Madani, 2014)

	Item	Variable	Future Projection	Description	Current state	Sources
Cross-Cutting activities (Continued)	17	Agricultural education	1- Collaborative Knowledge System 2-Knowledge Push education 3- Traditional Knowledge transfer system	Collaborative Knowledge means regular educational workshops and programs that designed and held while farmers are incentivized to attend these programs where information is shared between government agencies and farmers. (To be continued in "current state")	There are some forms of scattered knowledge push but the agricultural education/training system is dominated by traditional training. Continue from "description": Knowledge push refers to informational packets that government distributes to all farmers via mail/email on an annual basis. Traditional Knowledge means farmers are trained by their elders (parents) and knowledge is passed down in the family/clan (Traditional Knowledge).	(Foley, Archambault, & Warren, 2015; Warren, Archambault, & Foley, 2010)
	18	Rural Development Plan	1- Local non-farming entrepreneurships are highly encouraged and incentivized 2- Access to basic services are provided and subsidized 3-There is no supportive plan for rural development	Rural development refers to approach of governing system toward rural area development including support plan for local entrepreneurships or providing proper access to healthcare, education, and other basic needs such as water, energy and improved sanitation.	Most of rural area have access to affordable basic needs including preliminary heath care and education in addition to drinking water, proper sanitation, electricity, etc. However, due to frequent droughts and lack of alternative businesses, more 500 villages around the watershed have been evacuated and it is rapidly growing. In average 10,000 people have to migrate to urban areas annually.	(M. Abbaspour & Sabetraftar, 2005; Mahdi, Mahdi, & Shafiei, 2014; Selby & Hoffmann, 2012)
	19	Governance Integrity	1- There is a high institutional integrity among all parties over objectives, approach and decisions. 2- The system is fragmented in which actors follow different and sometimes conflicting objectives, approach and decisions.	The level of consonance between different actors at all governing levels over objectives, approach as well as decisions-making process. This institutional parties includes water and energy ministry, agriculture ministry, politicians, state and so forth.	Different sectors poorly cooperate. There is not a clear objective and approach to manage agricultural water demand .conflicting decisions are made by different actors.	(François Molle & Mamanpoush, 2012) (Madani, 2014) (Yazdanpanah et al., 2013)
	20	Governance hierarchical system	1-Top-Down (Centralized) 2-Local water governance (Decentralized) 3-Collaborative governance	The water governance hierarchical order in term of decision-making process, execution and responsibilities.	The governance system is dominantly top-down. The government is in charge of supplying water, and guaranteeing the farmers' profit by pre-purchasing agricultural products while farmers' participation in decision-making process is limited to community councils which are more symbolic than effective.	(François Molle & Mamanpoush, 2012) (Yazdanpanah et al., 2013)

5.2 System Analysis

The system analysis categorized the system variables into four level of activity and passivity (Figure 5-1). Active variables can be defined as those variables which have the most impact on other variables while they receive the least influence from other variables. In this watershed, organizational features like integrity, hierarchical order and knowledge sharing variables are key active variables. Moreover, the water pricing system and new water resource are key decisions for any type of governance.

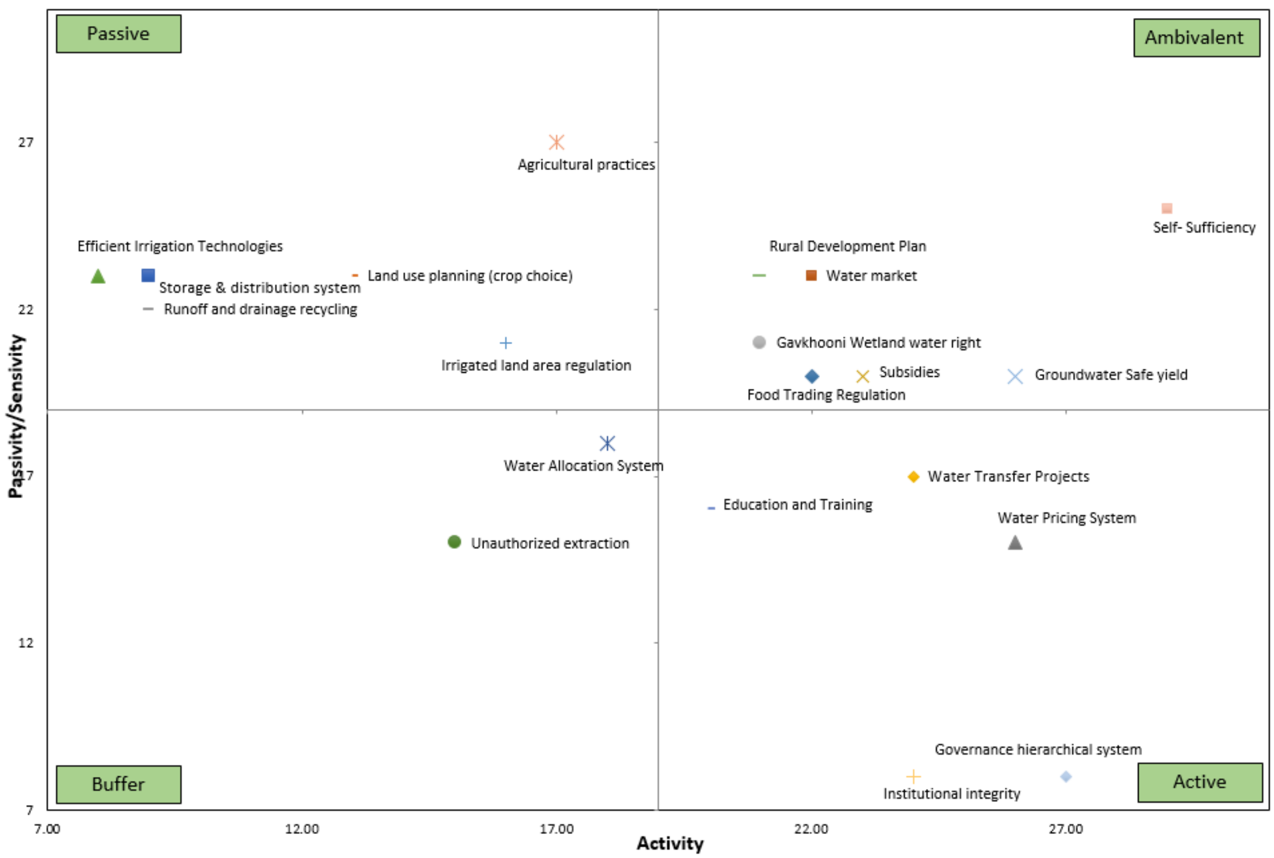

Figure 5-1 A system grid of the Activity and Passivity scores

The second category, called ambivalent variables, refers to variables which can highly influence and get influenced at same time. These kinds of variables can play a mediatory role in the system. In the Zayandeh Rud watershed, market variables and governance approaches to water and food security are included in this category. The third category belongs to passive variables, which are not system drivers but absorb a lot of impact from other variables. In this study, the adaptation strategies related to agricultural efficiency and productivity have this impact level. The last category includes buffer variables, which are neither drivers nor influence absorbers, but exert an indirect impact on system outcome variables.

5.3 Selected Scenarios

Five consistent, systematically different scenarios were selected out of about 26 million scenarios, through the five-step filtering procedure that was explained in chapter 4. The summary of selected scenarios' settings is illustrated in Table 5-3. The consistency and diversity indices for each scenario are presented in Table 5-2. No obstructive relation (zero inconsistencies) plus acceptable additive and multiplicative consistencies provide enough confidence about plausibility of scenarios.

Table 5-2- Scenario selection statistical results

	Scenario #1 Status Quo	*Scenario #2 Free market*	*Scenario #3 Reformed Top- Down*	*Scenario #4 Local water governance*	*Scenario #5 Collaborative governance*
Additive consistency	76	53	66	48	67
Multiplicative Consistency	3.2E+21	9.0E+16	1.7E+18	1.6E+13	8.3E+18
Number of inconsistencies	0	0	0	0	0
Distance-to-Selected (%)	61	66	67	60	75

On the other hand, high Distance-to-Selected (dts) values and their low deviation support the satisfactory diversity level of our scenarios. Since the dts value implies the harmonic mean distance of each scenario from all other selected scenarios, it guarantees that any similarity between any pair of scenarios was not compensated (Tietje, 2005).

Table 5-3-Selected scenarios and summary of their future projections

Variable	Summarized Future Projection	Scen#1 Status Quo	Scen#2 Free market	Scen#3 Reformed Top- Down	Scen#4 Local	Scen#5 Collaborative
Food Trading Regulation	1- No regulation 2- Virtual water 3- Domestic production	3	1	3	1	2
Water market	1-Effective market 2-Ineffective market	2	1	2	2	1
Water Pricing System	1-Modified 2-Unmodified	2	1	2	2	1
Subsidies	1- Subsidized 2- directed/purposive subsided 3-Unsubsidized	1	3	2	3	2
Water Allocation System	1- Government discretion 2-Traditional water rights 3-Modified water rights	1	2	1	2	3
Unauthorized extraction	1- Regulated and enforced 2-Unchanged	2	2	1	2	1
Irrigated land area regulation	1-Restricted 2-Unrestricted	2	2	1	2	1
Land use planning (crop choice)	1- Comprehensive 2- Locally collective 3- Individual choice	3	3	1	2	1
Runoff and drainage recycling	1-Reused 2- Not reused	2	1	1	2	2
Water Transfer Projects	1-Pursued 2- unpursued	1	2	1	2	2
Storage & distribution system	1- Modified 2-Unchanged	2	1	1	2	2
Efficient Irrigation Technologies	1- Efficient 2- Inefficient	2	1	1	2	2
Groundwater Safe yield	1- Pursued 2-Unpursued	2	2	1	1	1
Agricultural practices	1- Industrialized 2- Improved traditional practice 3-Unchanged	3	1	1	3	2
Gavkhooni Wetland water right	1- Allocated 2- Unallocated	2	1	2	2	1
Education and Training	1- Collaborative 2- Knowledge Push 3- Traditional Knowledge transfer	2	3	2	3	1
Rural Development Plan	1- Local alternative income 2- Access to basic needs 3-No supportive plan	2	3	2	3	1
Institutional integrity	1-Integrated 2-Unintegrated	2	2	1	2	1
Governance hierarchical system	1-Top-Down (Centralized) 2-Collaborative 3-Local (Decentralized)	1	1	1	3	2
Self- Sufficiency	1-Pursued 2- unpursued	1	2	1	2	2

5.4 Scenario Interpretation- Key features of scenarios

The key systemic features of each scenario are demonstrated in Figure 5-2 to 5-6. These diagrams along with their following interpretations are aimed to offer insights about each scenario framework and their main approach toward solving the ongoing water crisis.

5.4.1Scenario #1- Technical, food self-sufficiency based management (Status quo)

This scenario is almost the continuance of the dominant governance system since the 1970s. The central objective for Iranian agricultural water management, is to safeguard food security by achieving self-sufficiency and decreasing the nation's dependence on imported foods, specifically strategic goods[1]. Food security concerns arose during 1980's when Iraq initiated war with Iran, which lasted for eight years. During this unexpected war of attrition, food security was recognized as a key vulnerability on the Iranian side. Thus, Iran created national priorities around strategic food production to increase the resilience of the country against subsequent potential threats (Madani, 2014). Since that time, not only has the political stability of Iran not improved significantly, but the entire MENA region is now less stable than ever. Despite regional instability, the central government insists on food self-sufficiency regardless of a severe water crisis in most parts of the country. This includes the Zayandeh Rud watershed, which is a closed basin[2] as a result of the last decades' overdevelopment in this watershed (François Molle & Mamanpoush, 2012).

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[1] No accurate definition has given by Agricultural ministry about strategic foods, however, wheat is considered as the most strategic crop and this spectrum usually encompasses other crops like barley, Oily seeds, sugar cane and also meat and poultry and dairy.

[2] Closed basin is a term in hydrology to describe overdeveloped basins in which water demand is always more than supply which means these basins usually have no outflow.

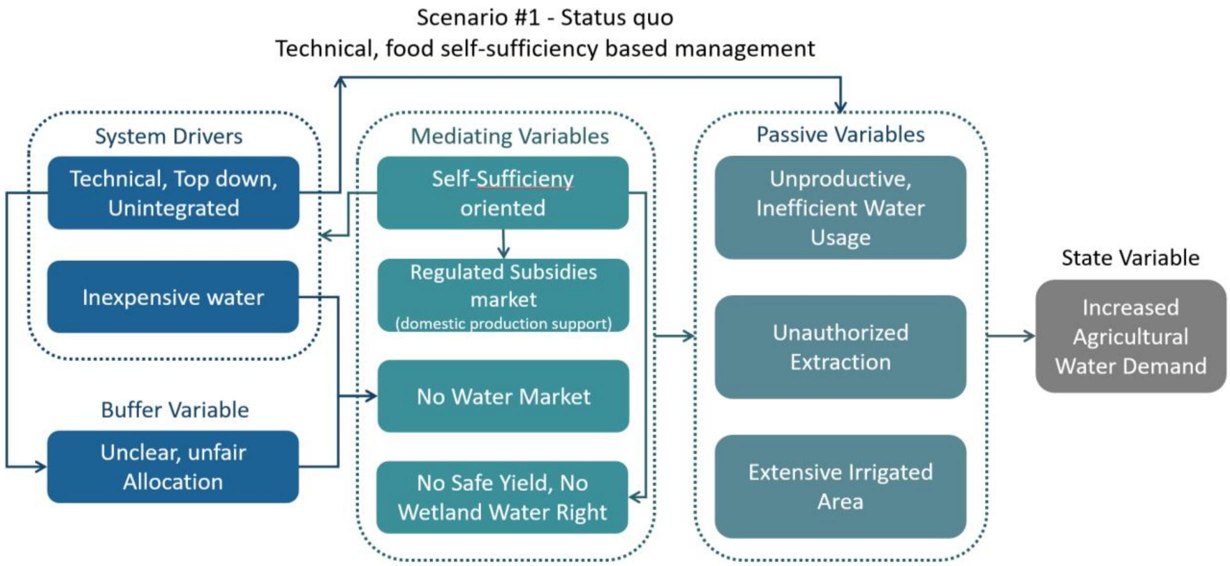

Figure 5-2-Scenario#1 Systemic key features

The key approach of this scenario to overcome water shortage is *supply augmentation* through large-scale technical developments with a focus on building new heavy infrastructures like dams and huge water transfer tunnels. Moreover, this scenario is characterized by a top-down governance system. Agricultural water policies are made at the national level, while regional and local water managers (that mediate interactions between the farmers and policy-makers) have limited decision-making authority. Similarly, farmers and other residents have minimum participation in national policy decisions, which makes them highly dependent on government decisions and affords them little recourse.

Although the water governing system is top-down, there is not enough integrity, or coordinated decision-making across different levels of governance, to support comprehensive mitigation strategies. For instant, the water management authority is still fragmented based on political borders (provincial) rather than watershed borders, which exacerbates the competition over limited resources. Similar segregation exists over objectives and problem-solving approaches among different sectors like parliament representatives, agriculture, water, energy ministries and academia.

However, there is a legally documented water rights system, which has been followed for several centuries to distribute water in this watershed. Currently, water storage is allocated in an unclear and unfair process in which residential and industry water have the highest priority and the remaining water is allocated to the agricultural sector based on government discretion, so that many downstream users who have water rights receive almost no water. It is totally in conflict with the traditional water allocation system in which a fair distribution was guaranteed. Moreover, the Gavkhooni wetland water rights that Iran has committed to meet based on the Ramser Convention of 1971, has no priority in this water allocation system. The rest of water shortage is usually made up through overexploitation of nonrenewable groundwater resources, as sustainable yield is not a prohibitive strict guideline in this scenario.

Besides, to achieve self-sufficiency, market manipulation tools are extensively used to facilitate domestic production and secure rural social security. For instance, trading of food products, especially strategic grains, is highly regulated and strictly controlled by government. Therefore, only the deficiency (gap between demand and domestic production) can be imported, which is done directly by government or semi-public companies. The water pricing system is unchanged, which calculates the surface water price as 1-3% of total production value, while groundwater is totally free of charge and farmers only should pay the capital for the excavation and pumping system. Besides, regulation for unauthorized water extraction is not prohibitive enough, and the administration process is ineffective and by some means corrupted, which has let farmers dig numerous illegal wells all around the watershed.

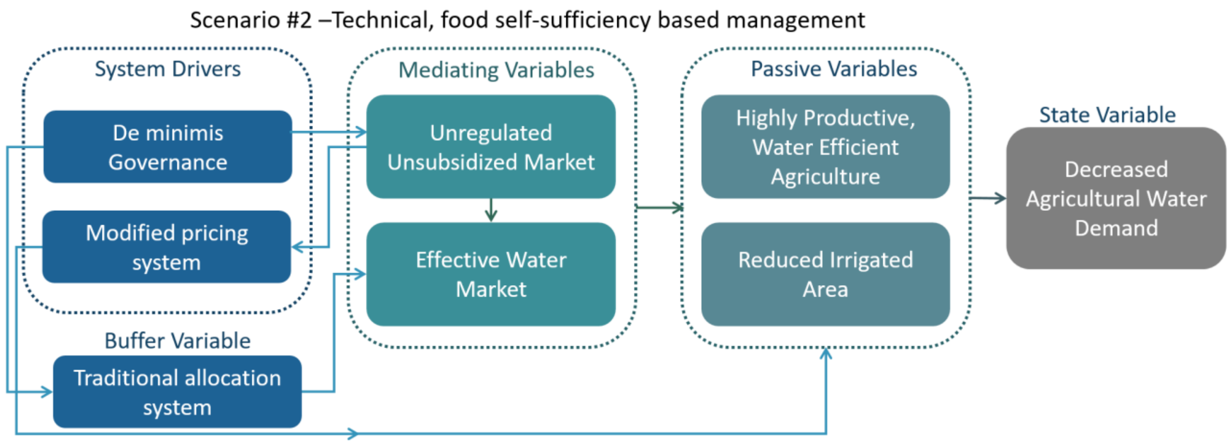

Figure 5-3-Scenario#2 systemic key features

By the way, after these market interventions, the final sale price of domestic products is not competitive with global prices. So, to support domestic production and control food price inflation, the government compensates part of the production costs in the form of direct and indirect subsidies to farmers and customers.

5.4.2Scenario #2- Free market-oriented governance with de minimis regulation

This scenario carries forward economists' notions of free-market governance. The extensive market manipulation during the last decades is dissolved to unleash the power of the free market and correct for the value of limited resources like water. (Chong & Sunding, 2006; Madani, 2014; Rosegrant et al., 2009). Then, the main idea of scenario#2 is to expose both the water and agricultural sector to near free market conditions in which market equilibrium will redefine the water governance system. In other words, the primary objective is providing a *de minimis* regulatory framework in which water creates the greatest economic value while the self-sufficiency paradigm from the 1990s is not the central guideline anymore. This scenario is not feasible without an effective national foreign diplomacy that ensures stable and constructive economic relationships between Iran and a majority of other nations.

However, the water governance system is still top-down, the central government’s role and responsibilities are down-sized and restricted to mediating jobs like administrative, monitoring and facilitating processes. Subsequently, the central government works to remove regulations so that both international and inter-watershed food trading is open and individuals and firms seek maximum economic profits.

Besides, all available water is also allocated to traditional water rights holders, so they can trade them effectively with other farmers, industries and even government entities all across the watershed. However, this water allocation system does not guarantee the water rights of critical ecosystems like the Gavkhooni wetland. The volumetric value of allocated water is calculated and priced by water markets with high accuracy. The water price covers all human-related costs such as supply, distribution and maintenance. On the other hand, all forms of direct subsidies, including energy, agricultural equipment and other supplies like seed and fertilizer as well as indirect subsidies like specific food subsidies are totally removed.

As it was mentioned before, the role of governing system is limited to supply, delivery and monitoring, so it has minimum impact on farm level decisions like crop choice, irrigation methods, total cultivated area and education.

5.4.3Scenario #3- Reformed, integrated national planning effort

Many participants claim that increasing the water efficiency and agricultural/ economical productivity through an integrated plan and proper and directed/purposive policies, not only will solve the ongoing water crisis, but also guarantee the food self-sufficiency and economic growth in this sector.

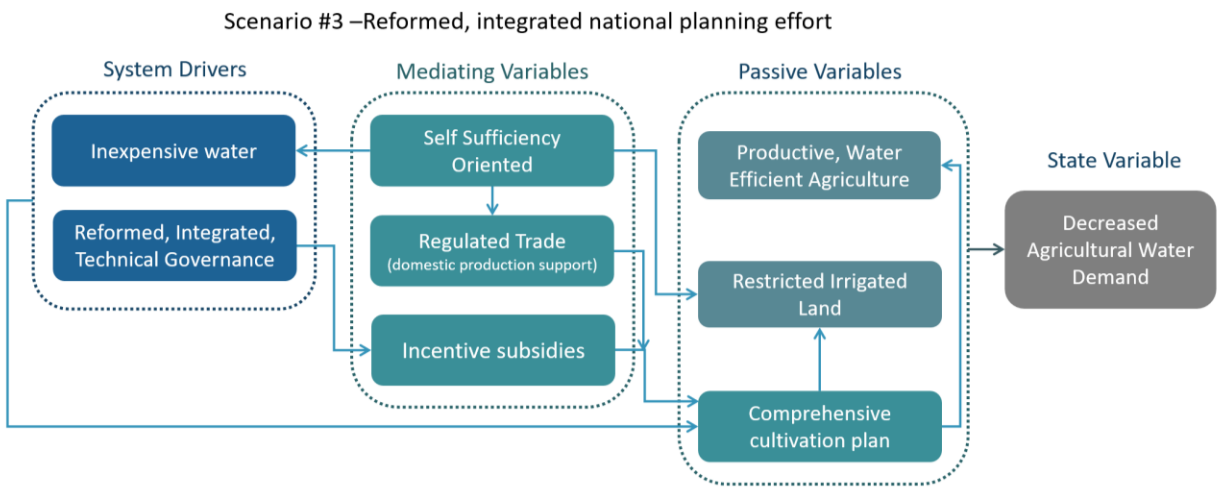

Figure 5-4-Scenario#3 key systemic features

In fact, this scenario responds to the current governance system's lack of integrity in approaches and objectives and for the unconditional support plans which do not encourage adaptive agricultural water management strategies.

So, the main objective of this water governance scenario is to achieve food self-sufficiency and safeguard the water security of the watershed through an integrated approach and comprehensive plan (at national level) to develop a productive and water efficient agricultural sector.

To fulfill this goal, a comprehensive cultivation plan is prepared dynamically, based on soil properties, available water, and food requirements. To execute this plan, incentive policies like directed/purposive subsidies are used like subsidies for energy, equipment, seeds and fertilizer. Water is allocated based on this comprehensive plan rather than traditional water rights.

Similar incentive policies are used to encourage the use of efficient irrigation technologies and improved practices. In addition to a traditional education system, the governing system uses a knowledge push approach to inform farmers about adaptive strategies.

Technical development is still followed intensively, including new tunnel projects, lining and covering channels and reservoirs to prevent extra evaporation, recycling the marginal quality effluent to be used as irrigation water.

On the other hand, the extent of cultivated land is controlled by the governing system, which is defined based on water resources' safe yield. However, the wetland water right is not a priority in this allocation system.

5.4.4 Local Water Governance

Periodic cycles of drought in Iran is not a recent issue. Darius the Great (500 BC), in his famous prayer, wished for the Persian Empire to be preserved from enemies, drought and lies. Studies show the important role of water governance on the flourishing of great civilizations in this region. They elaborate how this water governance system includes every citizen from kings to kids and employs all sociocultural tools to establish a highly fair, legitimate, productive and, most importantly, sustainable governance system. Then they show how this unique water governance system, which has developed and survived during thousands of years, was abandoned by technocrats during the last century in the belief that technological advances are able to bypass natural resource limitations and expedite human development. They blame the new governance paradigm, which is grounded on hasty economic growth and top-down management, for the ongoing water crisis (François Molle & Mamanpoush, 2012; Yazdanpanah et al., 2013; Zafarnejad, 2009; zafarnezhad, 2014).

Accordingly, this scenario represents the idea of how a decentralized, pluralized governance system with minimum top-down intervention might affect agricultural water management. It

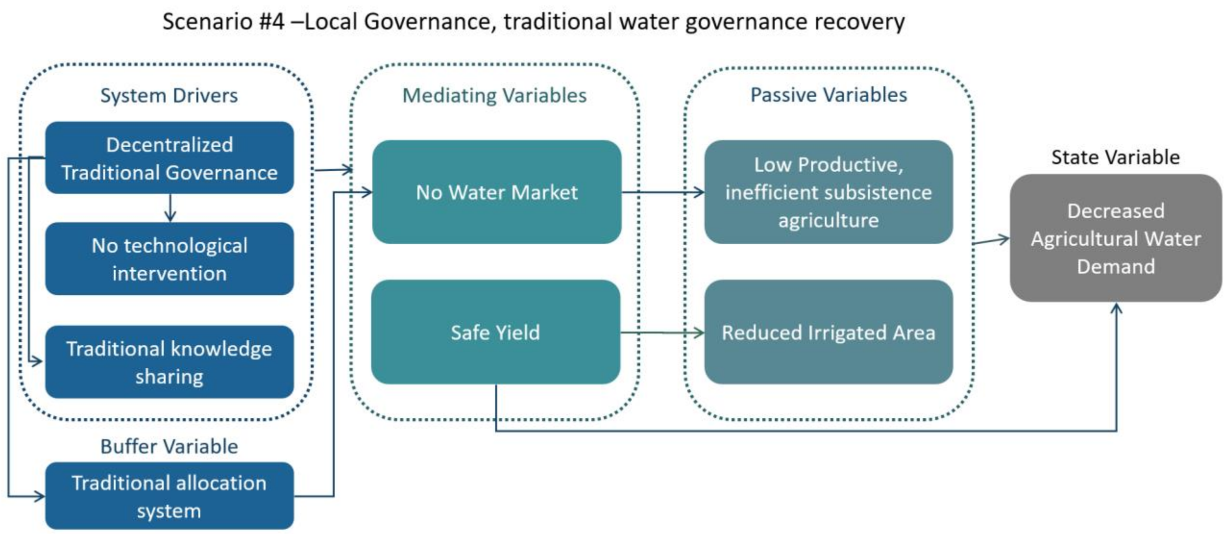

Figure 5-5- Scenario #4 Local governance

aims to revive the traditional water governance framework again through acknowledging the water resource ownerships and allowing the owners to govern the water in the way it preserves their long-term profits best.

Subsequently, as with the free market scenario, all kinds of subsidies are lifted, trading restrictions are removed, and water is allocated as per traditional water rights, while the water pricing system remains intact. The new water transfer tunnel projects are canceled, while the qanats are revived as the dominant groundwater distribution system.

The governing structure is totally run by local people and there is no official mediating or watershed governing system. Accordingly, the education system is limited to intra- family/clan knowledge transfer.

5.4.5Scenario #5- Collaborative governance, rural development

Finally, the last scenario supports some interviewees' idea that the most effective and least harmful strategy to manage agricultural water demand in this area, is to downsize this sector through supporting the alternative, less water-intensive businesses in rural communities. They contend, given the aggravating climate change and water crisis condition in this area, development of the agricultural sector is neither economically nor environmentally defensible, they believe downsizing this sector, while it employs 20% of the labor force and makes 11% of GDP is not possible without a support plan to smooth this transition. Otherwise, it will just lead to higher unemployment rate, (while the unemployment has been already more than 12%) and more enforced displacement. So, the key goal in this scenario is to have flourishing and resilient rural communities with less reliance on agriculture income.

This goal cannot be fulfilled without a close collaboration between all parties, including the local population, policy and lawmakers as well as academia and NGOs. In fact, under this integrated scenario, state, policy-makers, academia and NGOs are all backing the robust local governing system to achieve its goal which is the sustainable development without compromising the water and food security, however, national food self-sufficiency is not the central guideline anymore.

In this scenario, traditional water allocation is modified and updated so that it is clear and practicable and more supportive of ecological water demand. So the wetland water right is secured by an allocation system. Allocated irrigation water is measured and priced properly to cover all supply and maintenance fees. Water markets are effective and trading regulation supports more positive virtual water import. The subsidy option is also available to incentivize

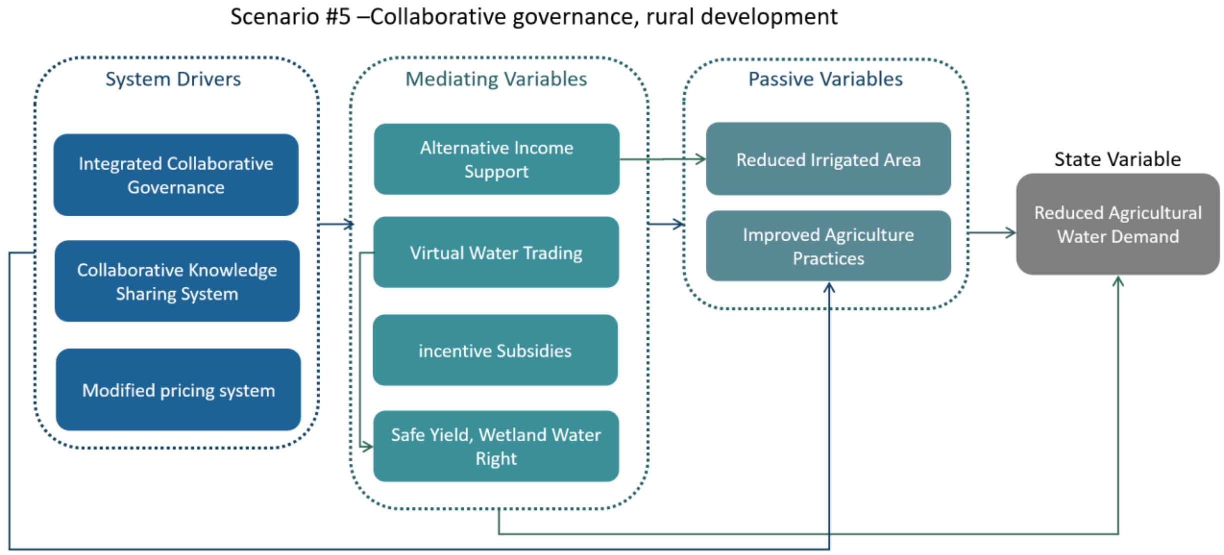

Figure 5-6- Collaborative governance, Rural development

sustainable businesses and farms. It is also used to keep the total irrigated area within pre-set limits.

Despite these overall regulations and policies at the local level, there is a democratic, inclusive and legitimate water governing system, which is run by farmers' representatives. It facilitates a collective decision-making process and dispute resolution as well as administers the rules and regulations. Besides, it is in close collaboration with the state and high-level policy makers.

5.5 Scenario communication and validation

The result of discussion sessions and assessment surveys led to a set of narratives. These narratives attempt to offer a glimpse of the Zayandeh Rud watershed in 2030 under each scenario regime in order to communicate these scenarios to a broader audience. The narratives do not present either the dynamic changes between 2017 and 2030 or the quantified results.

5.5.1 Scenario Narratives

Zayandeh Rud in 2030 under scenario #1

Due to non-competitive water prices, unfair allocation and extensive unauthorized extraction, water markets are practically infeasible. Inexpensive irrigation water plus no regulation on cultivated land area has led to a constant increase of irrigated area. Thus, water efficiency is not a big concern for farmers. Floating irrigation is still being used as the dominant irrigation method while distribution network water loss is high and storm water runoff is not recycled for agricultural irrigation.

There is a lack of proper education, comprehensive land planning, and competitive market (due to restricted trading). These conditions drive lower agricultural and economic productivity in comparison to global averages. So, the central government usually has to compensate famers with different kinds of subsidies. Short-term subsidies and supply augmentation help farmers to survive, yet over the long-run, these types of interventions just deter the agricultural sector from becoming more productive.

Almost all qanats are totally dried out, groundwater levels keep declining all across the watershed, so digging deeper wells reaches nothing but severely polluted briny water. Irrigating marginal fields with briny water leads to salty soil and land productivity is in decline.

The Gavkhooni wetland is totally dried out and is now the source of frequent sandy storms (called haboobs), which causes severe air pollution and damage crops.

On the other hand, new water transfer projects keep farmers hopeful that the new tunnels will eventually revive the river and their farms. Yet, the new tunnels are a disincentive to farmers that consider making investments in agricultural efficiency technologies.

In every local or national election, candidates promise that if they get elected, they will expedite the Beheshtabad projects while the frustrated farmers, environmental activists and other civilians in donor watershed keep protesting in front of construction sites every day. The protests get more violent and construction laborers refuse to resume their work as they don't feel safe anymore. The protesters believe these new tunnels, and another three completed tunnels which divert water from Karun River to Zayandeh Rud River, are the death sentence for this fading river which used to be Iran' most influential. In opposition, in response to the lack of integrity and legitimacy of the water governance system, farmers, with support of local authorities in donor watersheds, develop extensive irrigated farms to cultivate water intense products, which has led to the highest and most devastating form of competition over limited water resources.

Additionally, due to overdevelopment in watersheds upstream and injustice in irrigation water allocation, downstream farmers keep losing their lands. Many farmers (mostly younger population) are finally forced to immigrate and settle in urban margin areas. The remaining residents in the area have serious food and drinking water security issues. They have very limited income and most rely upon small cash transfers from family members in the city and subsidies provided by the government or other charities. Occasionally, these angry farmers break the drinking water pipelines that support neighboring cities to irrigate their fields. Intermittently cities experience acute water shortages that chronically affects the farmers.

In summary, all of the above mentioned heavy investments and market interventions to support the agricultural sector in this watershed, only postpones the start of the adaptation process. Productivity and irrigation efficiency are not improved meaningfully while the cultivated area is slightly increasing. Therefore, it can be concluded that the agricultural water demand increases under this scenario with no significant change in productivity. Given the fact that population also grows constantly, self-sufficiency is still not achieved and importing food is higher than ever. The water security and ecological sustainability in the region are totally compromised without any significant improvement in food security and farmers' well-being.

Finally, although only in the feasibility study phase, the Beheshtabad tunnel was predicted to compensate for all water deficiency of Zayandeh Rud basin for at least 20 years, due to destructive intra and inter watershed competition, it seems very unlikely that the tunnel could support the watershed for that long.

Zayandehroud in 2030-Scenario #2

Before introducing a new governance framework, many agricultural products were barely able to compete with imported food due to a lack of agricultural productivity even with inexpensive water and subsidized energy. So, the government worked to enter into the world water markets to stabilize the region and support the notion of free market principles in the agricultural sector. Removing all supportive instruments including subsidies, trade restrictions and inexpensive water, caused a severe shock to the agriculture sector. Farmers could no longer keep their lands economically viable without making improvement in water efficiency to realize greater productivity (yield) and quality. However, most of the technology-based adaptation strategies like using irrigation technologies, runoff recycling, advanced equipment and devices demand substantial capital cost, which small farmers usually are not able to afford without government' supportive plans. On the other hand, soft strategies like land planning and consolidation, crop choice, soil improvement, farm scheduling and so forth require a robust and supportive governance system which facilitates collective decision-making, collaboration and knowledge sharing process.

That is why an adaptation process to new market settings is not as fast as expected in among small farmers. Besides, as there is no actual plan for rural development to support local industries and entrepreneurships, many farmers are forced to trade their water rights and lands and immigrate to urban area to seek new income sources.

In contrast, industrial agriculture adapts faster than traditional small farms. They conglomerate to invest in water efficient technologies, runoff recycling and improved practices like better crop and seed choice. This results in a gradual shift from small subsistence farming to industrialized agriculture.

In summary, the agriculture sector, especially traditional small farming practices go by the wayside in the food market. The new growing farms are more water efficient and productive, which can make higher economical value. As a result, agricultural water demand, which has dropped extensively right after the new emerging market settings, is growing back. The aquifers are slowly getting restored and the wetland is receiving enough water after several years.

On the other hand, due to the costly water and lack of a legitimate governing system, unauthorized water extraction is increasing, which causes serious water conflicts among farmers while there is no effective dispute resolution system. The rural communities are greatly damaged due to very high rate of urbanization, many of these communities are getting totally evacuated while the remaining residents have many serious challenges to access basic needs.

Zayandeh Rud in 2030 under scenario #3

As a result of comprehensive land use planning and directed/purposive subsidies, water and agricultural productivity has increased significantly and most farms are equipped with efficient irrigation technologies.

In contrast, from an economic point of view, productivity and profitability of agricultural practices (average cost per unit of production) have not changed meaningfully. The reason is the very high costs of water efficiency technologies needed to subsidize water usage in this plan. Farmers that receive subsidies, as well as those farms which use efficient irrigation system must follow the integrated cultivation plan. The integrated planning efforts and subsidies guarantee the farmers' profit by pre-purchasing their products and underwriting costs to improve water efficient technologies. Besides, it pays the cost of not cultivating in regions where the irrigated area surpasses the specified upper limit. The result is a highly expensive governing system which lowers the competitiveness and profitability of the agricultural sector. Since, the water productivity is increasing and the safe yield and restricted cultivated area help prevent agriculture overdevelopment, aquifers are reviving slightly. Selective resource allocation and insisting on water diversion projects increases both intra-watershed and inter-watershed disputes while the conflict resolution system is not as effective as expected.

In summary, new governance settings help to increase water productivity (production per water unit) to some extent. However, the total irrigation water demand has not changed significantly. It also enhances the agricultural productivity (Production per hectare), however, the high cost of governing, makes this sector economically unsustainable.

So, in some areas (mostly upstream farms), farmers have better job and financial security, in other areas, farmers lose their job and social security. In general, this costly extended governance system reduces the reliance on imported food, but does not improve water security.

Zayandeh Rud in 2030 under scenario #4

There is a highly inclusive local governing system which is comprised of all residents, including land and water owners, peasants, well diggers as well as religious leaders (priests), the clan's leader, teachers, doctors and so forth. A main board or council is formed and the members are elected from trustworthy and capable candidates through a voting system on a regular basis. The hierarchical positions are defined precisely to cover all needs of a formal organization. All water rights holders must pay some dues, based on their water share, to contribute to water infrastructure development and maintenance as well as administrative costs and fees.

This framework provides farmers and peasants with an opportunity to collaborate closely. For example, in the beginning of each cultivation period, they get together to brainstorm about crop choice based on their domestic needs, market condition, soil moisture and precipitation. However, they don't use scientific and technological advancement to predict their yield. Elder farmers have a pretty acceptable intuition which is based on very long practice. They also teach new farmers how to enhance productivity, quality, and resilience of plants through choosing the right seed, crossbreeding, rotational cultivation, natural fertilizing and so forth. Although they seem to be reluctant to use irrigation technologies to increase productivity (even if they want to, they may not be able to afford it), they know how to use soft strategies to improve water efficiency such as land leveling, irrigation scheduling, sequential irrigation and covering the channels.

Besides, deep well digging and water resource contaminating is seriously prohibited. Although these kinds of regulations have no legal obligation, they are very effective. The reason is that this local governance system has been highly legitimatized and supported by religious and cultural beliefs and customs for thousands of years. Water polluting and illegal water extraction are considered as two of the most inexcusable sins in Persian-Islamic culture. Violators get severely punished by getting deprived of social benefits. As a result, aquifers are less under pressure and safe yield is an unwritten principle in water governing. Although, since the available water is limited, the water return is not enough to meet the wetland minimum inflow. The other advantage of this legitimate socio-cultural arrangement is that most disputes also get resolved easily by the intervention of priests and elders.

They use most of their products domestically or barter them with nearby farmers. The family's diet is totally based on locally accessible foods like diary, wheat, potatoes, meat and poultry. The dominant fruits are still apple, grapes and figs, which are local products, so, fruits like berries and tropical fruits are not common on their table. They (usually women) process their cultivated products to make many different by-products many of which are kept for winter season consumption. Consequently, agricultural loss is at a minimum. Even small wastes are used to feed livestock. Although many imported foods are available in cities at cheaper prices, many urban residents prefer to drive to the nearest rural area for their grocery shopping due to the high quality and high nutrition of this local food. Consequently, there are active weekly farmers' markets in each village to barter and trade their products.

Seasonal agricultural festivals or religious events also provide a great opportunity for rural communities to fortify their social bonds, resolve outstanding disputes, plan for new collaborations, and increase their society's resilience. These kinds of events also make them the exciting Agritourism destinations which are good chances to advertise their agricultural products, handcrafts and arts.

Despite very effective internal dispute resolution systems at the watershed level and inter-watershed level, some problems are not easy to resolve and cause violent contentions between different clans.

Due to water limitation, they can cultivate all of their arable lands; productivity is also not as good as industrial farming and final retail prices are not competitive enough. Therefore, traditional farming has a small economic return. They do not have any job security and they are vulnerable to natural hazards like droughts and flood incidents. So, they usually do not have any saving or capital to invest in alternative profitable businesses. For the same reason access to basic infrastructure like electricity, gas, drinking water and improved sanitation is still limited. The formal education and health care are very basic, which means they have to travel to urban areas for any major health issue or advanced education. This contributes to relatively low life expectancy and high illiteracy rates, especially among women.

Zayandeh Rud in 2030 under scenario #5

Under a collaborative governance regime, farming, in the form that it used to be, is no longer feasible because the water and energy cost increases the cost of production to the level that it is not competitive with imported goods. The adaptation process starts right away and traditional farmers are supported by the central government during the transition period. Local communities run frequent information and knowledge sharing sessions for relationship building between farmers and national policy makers. These forums are held at local council hall and the goal is to derive the adaptive strategies based on local potentials, available resources, cultural attributes and central government resources and subsidies. It also transfers these proposals along with required supports to the regional and watershed governing system through regular workshops, which includes representatives of all stakeholders. Viable proposals are supported and funded through the government's entrepreneurship budget, regional banks, industries, NGOs and microfinance organizations.

As a result, compatible local businesses are growing steadily so that in one village saffron farms are developed, while in another village a small factory is starting to process medical herbs that widely grow there. Carpet weaving, which is one of the oldest industries in the whole area, makes one of the finest and most valuable types of carpet, and is well-known globally as Isfahan carpet[3], has been dwindling for decades as a result of an unsupportive industry sector and inappropriate trade regulation. Now, this industry is going to shine again as new carpet weaving studios are emerging again, which are mostly run by rural women.

Although the agriculture sector is not the sole rural industry anymore, it is not totally removed.

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[3] The carpets woven in Isfahan during the sixteenth century are famous for their elaborate colors and artistic design, and are treasured in museums and private collections all over the world today. Their unique patterns and designs have set an artistic tradition which was kept alive centuries until the half century ago.

The old practices are replaced by adaptive, productive and water efficient farms, thanks to the collaborative workshops, cultivation plan suggestions, and incentive policies and subsidies. Small farmers consolidate their farms and share their water rights to get the most benefit of their resources.

Permanent and occasional local markets and festivals provide a wonderful chance to exhibit and advertise their products directly which cuts off the middlemen and increases local producers' profit. It also absorbs a lot of visitors from all around countries and the world. Visitors could stay with rural families and experience the uniqueness of their culture. This event also is a good chance for community to fortify their bonds, resolve disputes, start new cooperation and preserve the old customs and traditions.

Last but not the least advantage of these kinds of events is decreasing agricultural loss by facilitating the trade of products directly to end users, which saves a lot of resources, especially water.

Local governance also closely monitors safe water yield. Aquifers are filling again and some qanats are revived. Thanks to the high legitimacy of this system, unauthorized water extraction has decreased significantly.

Moreover, large-scale water transfer projects are all abandoned and the budget is reallocated to support local businesses and infrastructures like progressive carpet studies and water and wastewater treatment and recycling units.

5.6 Discussion

Even though each selected scenario represents a systematically different governance manifesto, all of them are supposed to contribute positively to manage agriculture water demand, except for the first scenario which resembles the ongoing governance system, as all study participants are unanimous that the status quo governance regime is not able to manage AWD. So, we can anticipate that, in 2030, under all these four scenarios, AWD is decreased. However, the watershed experiences different transitional conditions under each governance scenario. Figure 4.8, is a hypothetical model that illustrates the potential transitional and long-term trend of AWD under each scenario. Besides, the selected scenarios are very different regarding their long-term socio-economic and ecological impacts on the whole watershed and its residents.

Scenario#2 which is grounded on free market principle causes the most intensive transition. Lack of effective governance, supportive plasn and incentive policies cause a long lagging phase before efficient and productive farms can emerge. Scenario #4 shares similar trade regulations with scenario#2; the difference is that inexpensive water, in addition to robust local governance facilitates the adaptation process and dampens the shock of market change. As a result, in comparison to the *Free market* scenario, scenario #4 *local governance*, causes a smoother transition and ends in more resilient rural communities. Scenario#3 *reformed, integrated governance*, causes the least shock to the agricultural sector. It is anticipated that AWD reduction is less noticeable than the other three scenarios while the domestic food production is higher than the others. From the economic point of view, this scenario is not a self- sufficient governance system as it is greatly dependent on monetary supportive policies.

Like scenario#4 *local governance*, scenario#5 *collaborative governance and rural development*, leads to a

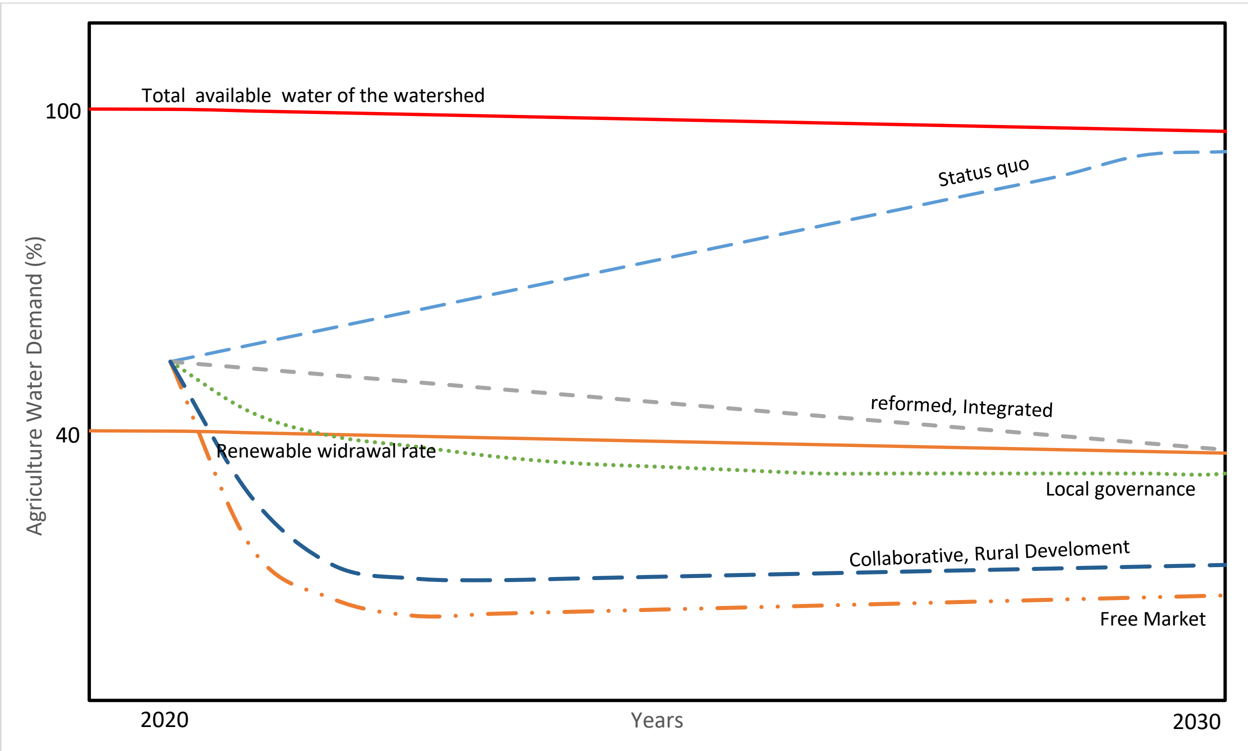

Figure 5-7- Agriculture water demand projections derived from each scenario

very small agriculture sector and significant reduction in AWD. The rural communities are developed and resilient with minimum dependence on irrigation water.

Regarding ecological sustainability, Scenario#5 is the only scenario which considers the Gavkhooni wetland water right in the allocation system. Scenario#2, *free market*, meets the wetland water rights because of substantial shrinking of the agricultural sector, and the fact that it does not guarantee that industries keep growing along the river.

Safe yield is also considered as a central governance principle in all three scenarios 3,4,5 which relieves stress from the aquifers.

Besides the status quo scenario, the only scenario which still considers the water transfer projects, is scenario#3 to supply enough water to develop the agricultural sector and achieve food self-sufficiency in the watershed.

5.7 Research Limitation and Future Research Directions

In this study, due to the diversity of stakeholders and their different accessibility in addition to our resource limitation, we were not able to conduct structured workshops. To overcome this problem, we developed semi-structured, mixed framework to involve participants. It was a combination of individual interviews and informal online discussion sessions. This framework offered us a broad range of participation and unrestricted discussions, however, the participants were not selected and committed to the study and their distribution was different each session. Therefore, a level of subjectivity was required to relate the gathered information and fit them to our formative, structured methodology.

The study aimed to present a set of comprehensive and coherent water governance scenarios for this critical watershed. Another challenge relates to the required trade-off between the comprehensivity of governance scenarios to include all important variables and their interconnections,- and the coherence of scenarios- by avoiding too much complexity. We tried to balance these two aspects through narrowing our study to irrigation water demand and rural communities. So, we did not involve the impacts of our scenarios on industry or residential water security.

Further studies can focus on the urban water demand and/or industrial water demand governance scenarios and a holistic study to develop holistic signature scenarios which support the overall watershed sustainability.

We also kept our study model as qualitative and conceptual as possible, which helped us to include many governance features that cannot be integrated to computational models.

Future research can acquire relevant data on water resource avaability, distribution and use by sector, and develop a computational model to reassess the findings of this study in a quantitative framework.

Chapter 6: Conclusion

Implementation of the scenario development framework towards critical management concerns in the Zayandeh Rud Watershed was a successful endeavor with respect to establishing stakeholder engagement. The methodical approach of the scenario development provided a systematic process to evaluate ongoing water governance regimes and propose a set of distinct, consistent and normative governance alternatives.

These scenarios offer the decision-makers adaptive governance alternatives which are consistent at three different interfaces of socio-economic, technical and ecological environments. Each scenario also reflects a combination of mitigation policies and actions from all activity domains of supply, delivery, uses, outflow and cross-cutting.

The flexible participatory approach of this study also helped to develop scenarios that are able to represent the watershed's diverse stakeholders and their different and somehow conflicting interests and values. It also provided these stakeholders with a great opportunity to communicate their concerns with each other, which can induce and facilitate collective informed decision-making in the Zayandeh Rud watershed.

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Appendix A: The list of discussion forums and participants

Group	Status	Members[a]	Audiences
Iran Water Think tank (Andishkadeh Aab)	Official think tank	220	Water researchers, managers, Engineers and etc.
Water rescuers (Najian Aab)	Official NGO	954	Activists, researchers, farmers and etc.
Rural Development	Official NGO	1139	Agricultural scientists and other rural development researchers including anthropologists, sociologist and etc.
Iran agricultural development	Unofficial Discussion group	3591	Farmers, agricultural experts
Iranian committee of irrigation and drainage	Official media of ICID in Iran	660	Water experts and decision makers
Isfahan Water Resources	Unofficial Discussion group	650	Zayandeh Rud watershed population
Water Diplomacy	Unofficial Discussion group	688	Water policy-makers and researchers
Environmental law	Unofficial discussion group	218	Environmental law makers and researchers

a - As of June 2017

Appendix B: Impact Analysis Matrix

	Food Trading Regulation	Water market	Water Pricing System	Subsidies	Water Allocation System	Unauthorized extraction	Irrigated land area regulation	Land use planning (crop choice)	Runoff and drainage recycling	Water Transfer Projects	Storage & distribution system	Efficient Irrigation Technologies	Groundwater Safe yield	Agricultural practices	Gavkhooni Wetland water right	Education and Training	Rural Development Plan	Institutional integrity	Governance hierarchical system	Self- Sufficiency	**Activity**
Food Trading Regulation	0	1	1	2	1	0	1	2	1	2	1	1	1	2	1	0	1	1	1	2	22
Water market	2	0	2	1	2	1	0	0	2	2	2	1	0	1	1	0	2	1	1	1	22
Water Pricing System	1	2	0	1	0	2	2	2	2	1	2	2	1	2	1	1	1	0	1	2	26
Subsidies	1	1	1	0	0	1	2	2	1	1	1	1	2	2	1	2	2	1	0	1	23
Water Allocation System	1	2	1	2	0	2	2	0	0	1	1	1	1	0	2	0	1	0	0	1	18
Unauthorized extraction	0	1	0	0	1	0	2	0	2	0	1	2	2	1	2	1	0	0	0	0	15
Irrigated land area regulation	2	0	0	1	2	0	0	1	0	1	0	0	2	1	2	1	1	0	0	2	16
Land use planning (crop choice)	2	0	0	1	2	0	1	0	0	0	0	0	1	2	1	1	0	0	0	2	13
Runoff and drainage recycling	0	1	0	0	0	1	0	0	0	1	2	1	0	2	0	0	0	0	0	1	9
Water Transfer Projects	2	1	1	1	1	1	2	2	2	0	1	1	1	1	2	1	1	2	0	1	24
Storage & distribution system	0	2	0	0	0	0	0	0	2	0	0	1	1	1	0	0	1	0	0	1	9
Efficient Irrigation Technologies	0	0	0	0	0	0	0	0	1	0	1	0	0	2	1	0	1	0	0	2	8
Groundwater Safe yield	2	2	1	2	1	1	2	2	1	0	2	2	0	2	1	1	2	0	0	2	26
Agricultural practices	0	2	1	1	0	0	0	1	2	1	2	2	1	0	0	1	1	0	0	2	17
Gavkhooni Wetland water right	1	1	1	0	2	0	2	2	1	1	2	2	1	2	0	0	1	0	0	2	21
Education and Training	0	2	0	1	0	2	0	2	2	0	2	2	1	2	0	0	2	0	0	1	19
Rural Development Plan	1	1	1	2	1	2	0	1	1	1	1	1	1	1	1	2	0	0	0	1	19
Institutional integrity	1	2	2	1	1	2	2	2	1	1	0	1	1	0	1	2	2	0	1	0	23
Governance hierarchical system	2	1	1	2	2	1	1	2	0	2	1	1	1	2	2	2	1	2	0	1	27
Self- Sufficiency	2	1	2	2	2	1	2	2	1	2	1	1	2	1	2	1	1	1	1	0	28
Passivity	20	23	15	20	18	17	21	23	22	17	23	23	20	27	21	16	21	8	5	25	**19**

Appendix C: Consistency Matrix

			1			2		3		4			5			6		7		8			9		10	
			Trading regulation			Water market		Water Pricing System		Subsidies			Water Allocation System			Unauthorized extraction		Irrigated land area regulation		Land use planning (crop choice)			Runoff and drainage recycling		Water Transfer projects	
			No regulation	Virtual water	Domestic production	Effective	Not effective	Modified	Unmodified	Subsidized	Purposeful	Not subsidized	Government discretion	Traditional water rights	Modified water rights	Regulated and enforced	Unregulated	Restricted	Not restricted	comprehensive	collective	Individual	Pursued	Unpursued	Pursued	Unpursued
2	Water market	Effective	1	1	0																					
		Not effective	0	0	1																					
3	Water Pricing System	Modified	0	2	0	2	-2																			
		Unmodified	0	0	1	-2	2																			
4	Subsidies	Subsidized	0	-2	2	-1	1	-1	1																	
		Purposeful	1	1	1	1	0	1	-1																	
		Not subsidized	2	2	-2	1	0	1	-1																	
5	Water Allocation System	Government discretion	0	0	1	-2	2	-2	0	0	0	0														
		Traditional water rights	0	0	0	1	-1	2	0	0	0	0														
		Modified water rights	0	0	0	1	-1	2	0	0	0	0														
6	Unauthorized extraction	Regulated and enforced	0	1	0	0	0	0	0	0	0	0	0	0	0											
		Unregulated	0	-1	0	-1	1	0	0	0	0	0	0	0	0											
7	Irrigated land area regulation	Restricted	1	0	0	1	0	0	0	0	1	0	1	0	0	2	-1									
		Not restricted	0	0	1	0	1	0	0	0	0	0	0	1	0	0	0									
8	Land use planning (crop choice)	comprehensive	-2	1	2	0	0	0	0	0	1	0	1	0	0	0	0	1	-1							
		collective	1	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0							
		Individual	0	-1	-1	0	0	0	0	0	0	0	0	1	1	0	0	0	0							
9	Runoff and drainage recycling	Pursued	1	0	0	1	0	1	0	-2	1	2	0	0	0	1	-1	0	0	0	0	0				
		Unpursued	-1	0	0	0	1	0	1	1	0	-1	0	0	0	0	0	0	0	0	0	0				
10	Water Transfer projects	Pursued	-1	-2	1	0	1	0	0	0	0	0	0	0	0	0	0	-1	1	0	0	0	-1	1		
		Unpursued	1	2	-1	0	0	0	0	0	0	0	0	0	0	0	0	-1	1	0	0	0	-1	-1		
11	Storage & distribution system	Modified	0	0	0	1	0	1	-1	0	1	1	0	0	0	1	-1	0	0	0	0	0	-1	-1	0	1
		Unchanged	0	0	0	0	1	-1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	1	1	0

11		12		13		14			15		16			17			18		19			20	
Storage & distribution system		Efficient Irrigation Technologies		Groundwater Safe yield		Agricultural practices			Gavkhooni Wetland water right		Education and Training			Rural Development Plan			Institutional integrity		Governance hierarchical system			Food security	
Modified	Unchanged	Efficient	inefficient	Principle	not a principle	Industrialized	Modified traditional	Traditional	Allocated	Unallocated	Collaborative	Knowledge push	Traditional	Alternative income	only basic need	No support	Integrated	Unintegrated	Top-down	Collaborative	Local	Self-sufficiency	No concern

12	Efficient Irrigation Technologies	Efficient	0	1	0	1	0	1	-1	-1	2	1	0	0	0	1	-1	1	-1	0	0	0	0	0	-1	1	1	0																				
		inefficient	0	-1	0	0	1	-1	1	2	0	-1	0	0	0	0	0	-1	1	0	0	0	0	0	1	-1	0	1																				
13	Groundwater Safe yield	Principle	1	1	-1	0	0	1	0	0	0	0	0	0	0	1	-1	0	0	1	1	0	1	0	-1	1	0	0	0	0																		
		not a principle	-1	-1	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	-1	0	0	0	0																		
14	Agricultural practices	Industrialized	0	1	0	1	0	1	0	0	0	0	0	0	0	1	-1	1	0	1	0	0	1	0	-1	1	1	-1	1	-1	1	0																
		Modified traditional	0	1	0	0	0	0	0	0	0	0	0	0	0	1	-1	0	0	0	1	0	1	0	-1	1	1	-1	1	0	1	-1																
		Traditional	0	-1	0	0	1	0	1	0	0	0	0	0	0	0	0	0	1	0	0	1	0	1	1	-1	-1	1	-1	1	0	1																
15	Gavkhooni Wetland water right	Allocated	1	1	-1	0	0	0	0	0	0	0	0	-1	1	1	-1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0													
		Unallocated	-1	-1	1	0	0	0	0	0	0	0	0	1	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0													
16	Education and Training	Collaborative	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1	0	0	0	1	0	1	0	1	0	1	1	0	0	0											
		Knowledge push	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	1	0	1	0	1	0	1	0	0	0	0											
		Traditional	0	-1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	-1	-1	1	0	0											
17	Rural Development Plan	Alternative income	1	1	-2	0	0	1	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0								
		only basic need	-1	0	1	0	1	-1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0								
		No support	1	0	0	0	1	1	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0								
18	Institutional integrity	Integrated	0	1	0	0	0	0	0	0	1	0	1	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0					
		Unintegrated	0	-1	0	0	1	0	0	0	-1	0	0	0	0	0	0	0	1	-1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	-1	0	0					
19	Governance hierarchical system	Top-down	0	1	1	1	0	0	0	2	0	0	1	-1	1	-1	1	2	0	2	-1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	1	-1			
		Collaborative	0	0	0	1	0	1	-1	-1	2	-1	-1	1	1	1	-1	1	-1	1	1	-1	0	0	0	0	0	0	0	0	1	-1	1	1	-1	1	-1	2	1	-2	1	0	-1	1	-1			
		Local	2	-1	-2	-1	1	-1	1	-2	-2	2	-2	2	1	0	1	-1	1	-2	2	1	-1	1	-1	1	-1	1	-1	1	1	-1	-1	1	2	-1	1	-1	-1	1	-2	-2	2	-1	1			
20	Food security	Self-sufficiency	-2	-2	2	0	0	-1	1	2	1	-1	2	-2	-1	-1	1	-1	1	1	1	0	0	0	2	-2	0	0	0	0	-1	1	2	1	-1	-2	2	0	0	0	-2	1	-2	0	0	2	-1	-2
		No concern	2	2	-2	0	0	1	-1	-2	-1	1	0	1	1	1	-1	1	-1	-1	-1	1	0	0	-2	2	0	0	0	0	0	0	-1	0	1	2	-1	0	0	0	1	-1	1	0	0	0	1	2

Appendix D: Python Code

```
"""
Created on Sun Mar 26 14:54:30 2017
@author: Neda Nazemi
"""
import numpy as np
import pandas as pd
from random import randint
from numpy import genfromtxt
import itertools
import csv
import math
from datetime import datetime
import time
np.set_printoptions(precision=2)
import scipy
import os
import json
"""
Function to save output data in JSON format
"""
def save_to (listORdict,name,path):
workingdatapath=os.path.join(path, name)
data = open(workingdatapath, 'w')
json.dump(listORdict, data)
"""
Function to read back the saved data in Json format as required
"""
def load_from(name,path):
with open (os.path.join(path, name)) as f:
return json.load(f)
"""
Function to calculate cityblock distances in a 2-dim space#
"""
def Distance(consistant_senarios):
n=len(consistant_senarios)
d=np.zeros((n,n))
for i in range(n):
for j in range(n):
d[i][j]=scipy.spatial.distance.cityblock(consistant_senarios[i],\
consistant_senarios[j])
Distance_matrix=pd.DataFrame(data=d, index=labels, columns=labels)
return Distance_matrix
"""
Loging time
"""
print "It starts at: ", time.strftime('%X %x %Z')
Starttime=time.time()
"""
Reading the consistancy matrix-additive format
```

```
"""
D_in_array_format = genfromtxt('Consistancy matrix.csv', delimiter=',')
M=D_in_array_format
"""
constructing the multipicative consistancy matrix from the additive consistancy one
"""
M2=np.empty(M.shape) #multipicative consistency metric based matrix
for i in range(M.shape[0]):
for j in range(M.shape[1]):
if not math.isnan(M[i,j]):
m=M[i,j]
if m==-2:
M2[i,j]=int(0)
elif m==-1:
M2[i,j]=0.5
elif m==0:
M2[i,j]=int(1)
elif m==1:
M2[i,j]=int(2)
else m==2:
M2[i,j]=int(3)
"""
Data structure design for reading data through consistency matrix and additive and multiplicative consistency measures calculations
"""
levels=(3,2,2,3,3,2,2,3,2,2,2,2,2,3,2,3,3,2,3,2)
sen_rows=[]
for a in range(len(levels)):
s=0
for i in range(a):
s=levels[i]+s
sen_rows.append(s)
sen_cols=[a-sen_rows[1] for a in sen_rows[1:]]
a=[]
for level in levels:
a.append(range(1,level+1))
sen_con=[]
n=0
l=0
gap=100000
"""
additive and multiplicative consistency measures calculations
"""
for senario in itertools.product(*a):
additive_consistency=0
additive_incon=[]
multipicative_consistency=1
multipicative_incon=0
for factor_j in range(len(sen_rows)):
for factor_i in range(factor_j+1,len(sen_rows)):
#additive consistency calculations
m=M[senario[factor_i]+sen_cols[factor_i-1]-1,senario[factor_j]+ \
sen_rows[factor_j]-1]
```

```
if math.isnan(m):
print "Its nan"
additive_consistency=m+additive_consistency
additive_incon.append(m)
#multipicative consistency calculations
m2=M2[senario[factor_i]+sen_cols[factor_i-1]-1,senario[factor_j]+ \
sen_rows[factor_j]-1]
multipicative_consistency=m2*multipicative_consistency
if m2==0:
multipicative_incon=multipicative_incon+1
additive_inconsistency=min(additive_incon)
sen_con.append((senario,additive_consistency,additive_inconsistency, \
multipicative_consistency,multipicative_incon))
n=n+1
#To Log the run
if n>l:
l=l+gap
print "\nsenario n= ", n ," is: ", senario,\
" and its additive-concistancy is: " , \
additive_consistency, " and its additive inconsistency is:" , \
additive_inconsistency
print "it's multipicative-concistancy is: ",\
multipicative_consistency, " and multipicative_incon is: ", \
multipicative_incon
print "It is: ", time.strftime('%X %x %Z')
print "passed time: ", \
time.strftime("%H:%M:%S", time.gmtime(time.time()-Starttime))
"""
Saving the results
"""
w = csv.writer(open("Consistency Anal-output_additive+multipicative.csv", "w"))
for s,a,ma,mu,muin in sen_con:
w.writerow([s,a,ma,mu,muin])
save_to(sen_con,"Consistency Anal-output_additive+multipicative",os.getcwd())
print "It is Done!!!"
```