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Water consumption management using WEAP and conceptual models (Case study: Golestan province – Iran)

Naser Moharam Nejad [1], Amir Hosein Javid [1], Abdol-Reza Karbasi [2], Seyed Masoud Monavari [1] and Sahar Rezaian [1]*

*[1] Faculty of Environment and Energy, Science and Research Branch, Islamic Azad University, Tehran, Iran. [2] Graduate Faculty of the Environment, University of Tehran, P. O. Box 14155-6135, Tehran, Iran. *e-mail: s_rezaian@yahoo.com*

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Abstract

Iran is located among the world's arid and semi-arid lands climatically, so its water consumption management is of vital importance. Golestan province as one of the important poles of Iran's farming and agricultural products is not excluded and in terms of water supply has not a desirable situation. Due to over pumping and reduction in precipitations, groundwater reserves have not been satisfactory condition. Exploitation of surface water do not conform any management principles as well. On the other hand due to population growth, development of agricultural and industrial activities, as well as decreasing trend of water resources, setting up principled approach for water consumption is an undeniable fact. In this study, water supply sources were identified in various parts of the region. Subsequentially, the role of major water consumption sections in quantitative changes of water resources was determined. Finally the obtained results were used to project of conceptual model for quantitative changes of water resources in order to achieve sustainable development in different parts of water development in this province. The result of conceptual model shows that about 371.51 million cubic metres of water in Golestan province is lost due to lack of adequate reserves. On the other hand, reviews different management scenarios indicated that the problem of water shortages in this province is not resolved alone with construction of new dams. Meanwhile modified consumption pattern is considered as effective and complementary step in sustainable water consumption management.

Key words: Sustainable development, conceptual model, water consumption, water management, agriculture, industry, drinking water sector, WEAP software, water demand, water supply, water shortage.

Introduction

One of the problems with the countries located in arid and semi arid regions is water shortage. Irregular rainfalls, low annual precipitation, lack of enough water supplies are only a small fraction of the problems that people living in these areas are dealing with it.

In addition to the above, excessive exploitation of water resources along with various industrial pollutions makes the situation tense for future generations. It is essential that necessary measures be thought in the form of management plans, to provide optimal solutions for sustainable water use. Nowadays natural waters are heavily polluted in many cases, and protection is inevitable from the standpoint of natural resources, as well as human life circumstances [1]. Despite uneven distribution of water resources and worldwide population densities, water demands exceed supplies in nearly 80 countries with more than 40% population of the world [2]. Nowadays densely populated arid areas, Central and West Asia, and North Africa, with projected availabilities of less than 1000 m^3/capita/year are strongly suffered of water scarcity [3]. Regarding current demographic trends and future growth projections, as much as 60% of the global population may suffer water scarcity by the year 2025 [4]. The use of water in dried regions requires innovative and sustainable research, as well as an appropriate transfer of technologies [5]. Because of the importance of water management, much research has been done in this field using various methods and tools that in continue some of them are referred. Lanzarone and Zanzi [6], prepared a monitoring system allowing consumers to be better informed about their consumption behavior and challenging them to improve efficiency in utilization along with saving costs. In their study the benefits of the developed system is described and consequences of its performing is explained in details. Johansson *et al.* [7] carried out a research on allocating irrigation water with a focus on efficiency, equity, water institutions, and the political economy of water allocation. Hurst *et al.* [8] examined implications for improving efficiency of irrigation water use from shallow water tables. Their results showed that no irrigation would be required for static water tables within 1 m of the soil surface. Hsu *et al.* [9] proposed a methodology to analyze an existing water distribution system and identify the potential bottlenecks in the system. The results represented the alternatives for improving the water supply efficiency. Tetzlaff *et al.* [10] proposed management options for European water resources sustainable management using cost-efficient programmes. Al-Omari *et al.* [11] proposed a Water Management Support System using WEAP model. In their study the water resources and demands of Amman Zarqa Basin in Jordan were modeled as a network of supply and demand nodes connected by links. The results showed that domestic and industrial demands can be satisfied by proper management of the available resources. Alber [12] reviewed literatures related to affect of freshwater inflow changes on estuaries. He already represented a conceptual model that explores scientists, citizens, politicians and managers' role in the management of freshwater inflow to estuaries. This model was used for estuaries management located in Texas, Florida and California.

The main objective of this project indicate development of conceptual model that will allow utility strategic planners to effectively evaluate options for managing and developing reliable, adequate, and sustainable water supplies and consumptions for agricultural, industrial and drinking water sectors. This tool will allow the evaluation of multiple future water management scenarios including integrated social, financial and economic analyses that are pre-requisite to sustainable and long-term water supply planning.

Materials and Methods

Introduction of the study area: Golestan is one of the 30 provinces of Iran, located in the northeastern part of the country, south of the Caspian Sea. Golestan is situated between 36°44' and 38°05' north latitude and 53°51' and 56° east longitude. It has a population of 1.7 million and an area of 20,380 km². It contain moderate and humid climate known as "the moderate Caspian climate". The effective factors behind such a climate are: Alborz mountain chain, direction of the mountains, height of the area, and neighborhood to the sea, vegetation surface, local winds, and altitude and weather fronts. As a result of the above factors, three different climates exist in the region: plain moderate, mountainous, and semi-arid. Southern section valley has a semi-arid climate. The average annual temperature is 18.2°C and the annual rainfall is 556 mm. Geographically it is divided into two sections, the plains and the mountains of the Alborz chain. In the eastern Alborz section, the direction of mountains faces northeast and gradually decreases in height. The highest point of the province is Shavar, at 3,945 m in elevation. Location of Golestan province in Iran is illustrated in Fig.1.

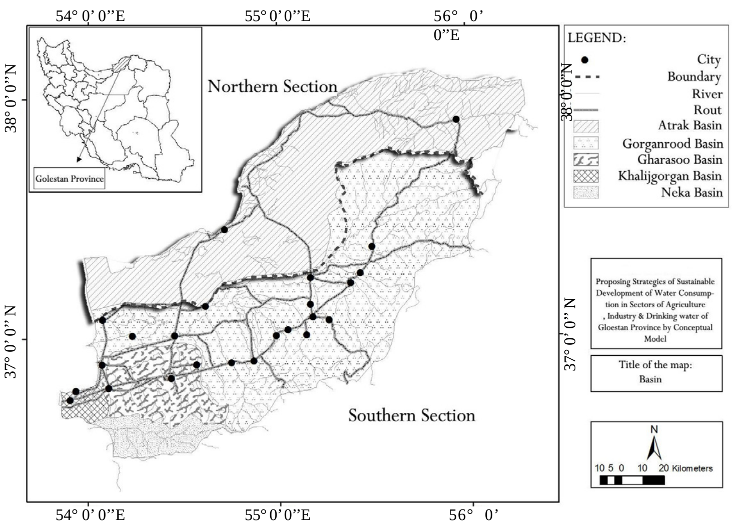

Figure 1. The location of Golestan Basin in Iran.

Data preparing: Golestan Province water resources management requires considering wide ranges of data in different instances as follows:
- Water resources statistics (wells, springs, aqueduct).
- Hydrodynamic characteristics of aquifer.
- Location of dams, irrigational networks, artificial nutrition, considering the location of aquifer.
- Safe yield potentials and development of groundwater resources with regard to the concepts of sustainable water resources.
- Hydraulic profile information of all water resources in watershed areas.
- Statistic information about consumption of drinking water in the entire watershed.
- Information about under construction projects, water transfer and water supply.
- General information about existing facilities.
- Comprehensive plan of area.
- Number of factories, types of industries for predicting water and waste water production rate in purpose and design courses.
- Population statistics from cities and villages in the watershed areas.
- Reservoir evaporation.
- Data on area dams (type, capacity, geometry).
- Demand sites including all industries, residential areas, farm lands
- Characterization of water resources development projects in watershed areas.
- Minimum environmental water right of different sections regarding water resources and natural ecosystems protection.

All required data were collected from meteorological organization, Ministry of Industries and Mines, regional water company located in study area.

Water consumption conceptual model: The conceptual water consumption model used for Golestan province is based on mass balance principle (Eq.1). A mass balance (or a material balance) is an application of mass conservation which can be identified by accounting for material entering and leaving a system. Mass balances are widely used in engineering and environmental studies [13-17].

$$Accumulation = Input - Output \pm Si \qquad (1)$$

Input: Volume of water that naturally and without human interference is entered to the basin of Golestan province.
Output: Volume of water that is naturally removed from basin of Golestan province.
Sink: Volume of water that is harvested and consumed by humans, including agriculture, residential and industrial sectors.
Source: Volume of water that enters the Golestan basin by human intervention.

Running of WEAP model: Water management support system was carried out using WEAP (Water Evaluation and Planning). WEAP is a software tool for integrated water resources planning, provides a comprehensive, flexible and user-friendly framework for planning and policy analysis. It takes in several steps as follows [18]:

- *Study definition:* The time frame, spatial boundaries, system components, and configuration of the problem are established.
- *Current accounts:* A snapshot of actual water demand, pollution loads, resources and supplies for the system are developed. This can be viewed as a calibration step in the development of an application.
- *Scenarios:* A set of alternative assumptions about future impacts of policies, costs, and climate, for example, on water demand, supply, hydrology, and pollution can be explored (Possible scenario opportunities are presented in the next section).
- *Evaluation:* The scenarios are evaluated with regard to water sufficiency, costs and benefits, compatibility with environmental targets, and sensitivity to uncertainty in key variables.

In this study total annual demand was calculate using Equation 2.

$$A_{DS} = \left(\sum T_{BR} \times W_{BR}\right) \quad (2)$$

where
A_{DS}= Amount of annual demand for every consumption place.
T_{BR}= Active level for every consumption place.
W_{BR}= Amount of annual water consumption per unit of total active level.

While the supply requirement is the actual amount needed from the supply sources. The supply requirement takes the demand and adjusts it to account for internal reuse, demand side management strategies for reducing demand, and internal losses (Equation 3).

Monthly Supply Requirement = (Monthly Demand x (1 – Reuse Rate) x (1 - Demand Side Management Savings)) / (1 – Loss Rate) (3)

Various performance steps of this study are illustrated in Fig. 2.

Results and Discussion

Definition of the study area: At first step in WEAP software, all demand and water supplies sites of river systems should be defined to get the schematic of study area. It contains a distinct set of information and assumptions about a system of linked demands and supplies.

Current accounts: In the next step the current situation of Golestan province including its actual water demand, pollution loads, resources and supplies were developed for the first year of the study on a monthly basis.

Scenarios: Scenarios were defined based on all water resources including dams, precipitations underground and surface waters to find out the water shortage, demand and supply of different sections (industrial, agriculture and potable water) in two cases: current status and planned situation (for the next decade). The result is showed in the Tables 1-4.

Conclusions

Generally, it can be said that, the problem of water shortage in Southern section basin is far more acute than Northern section region. On the other hand regarding irregular rainfalls and lack of enough reservoirs for supplying waters there are 25.40, 74.77 and 78.9% water shortage in August, September and October, respectively.

Also due to performance of planned programs such as establishment of new dams and reservoirs in the study area as well as urban development, population increase and land use changes the water demand and supply situation will definitely changes in the next decade. These changes were predicted using WEAP model. Fig. 3 shows that due to irregular rainfall, inappropriate pattern of water consumption, lack of enough dams and reservoirs to supply water during the peak rainfall, there always exists a major gap in the supply and demand spatially in dry seasons.

In order to solve this problem different solutions are proposed in the form of various scenarios.

Solution 1: Modified consumption pattern.
One of the best ways to combat water shortage is the rational consumption. Currently water consumption in sections of industry, agriculture and drinking does not have a desirable situation.
In this study modification effect of water consumption pattern in water supply situation was evaluated in the form of following assumption.
- 20% savings in water consumption.

At this stage, assuming ten percent reduction in water consumption in different sectors, requirements, shortages, and water supply were examined, which results are presented in Fig. 4.

Solution 2: Construction of new reservoirs.
Running of WEAP model indicate that 371.51 MCM of Golestan Province waters is lost due to lack of sufficient reserves for water supply. So another way to combat water shortages is to construct new reservoirs in the region. In order to assess impact of new reservoir construction other new scenarios were evaluated as follow:
- Construction of the reservoirs with a capacity of 100 MCM (Fig. 5).

Examination of different scenarios showed that the water supply problem of Golestan Province requires long-term planning. It could not be solved only by establishment of new dams. Meanwhile consumption patterns change is more effective solution. Best management solutions are provided based on planning for training consumers to save water consumption along with the presentation and implementation of new reservoirs and dams in the study area. In general based on global experience, five primary proposed actions which are necessary to achieve sustainable management of water consumption in Golestan province, are as follows:
- Involving stakeholders in interconnected management: unfortunately stakeholders (Men and women, whose life and livelihoods depend on wise water management), have not any participatory roles in decision-making.
- Moving toward the actual pricing of water in all consumption sectors of Golestan Province: In Golestan, water is scarce but not treated as an economic good. It is recommended that consumers pay the full costs of water collection, treatment and transport of their waste. Appropriate pricing of water is considered as an essential step towards a framework that finally reveals full economic value of water. Meanwhile water pricing should be accompanied with payment targeted and transparent subsidies to low-income groups and individuals.
- Increasing public investment for research and innovation in

Golestan public works.

- Give recognition to cooperation in the water resources interconnected management at boundary basin.
- Increase the volume of investments in water sector of Golestan province: Respond and solve problems related to water resources requires heavy investment. Such investments need to provide infrastructure development and especially investment by the private sector, should be accelerated.

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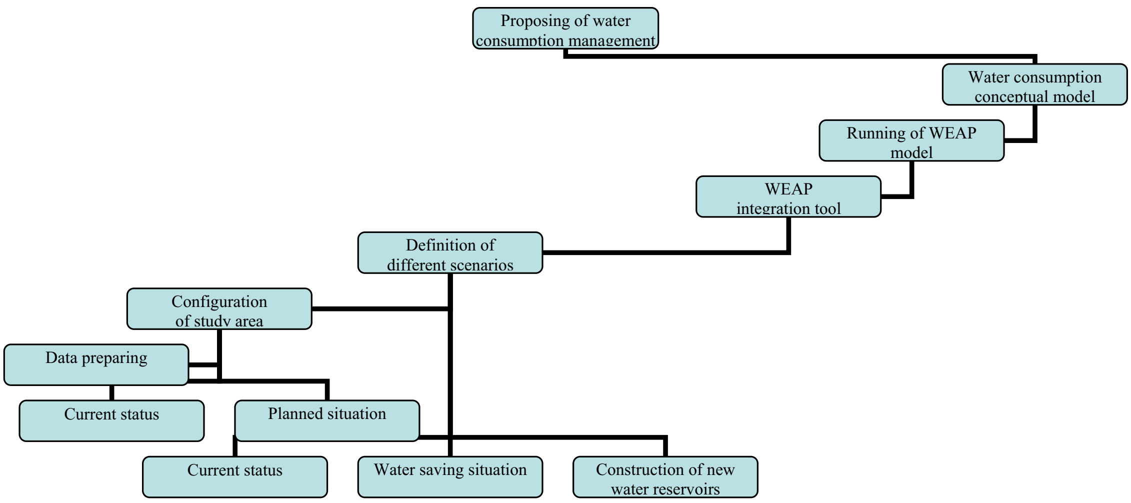

Figure 2. Different stages of Golestan province water management study.

Table 1. Water volume that is naturally entered to the basin of Golestan province.

Golestan province	River flux volume (mcm)*	Underground water (wells) volume (mcm)
Northern section	419.46	13.6
Southern section	964.46	794.8
Total	1383.92	808.4

*mcm= million cubic meter.
Input water volume to the province: 808.4 + 1383.92 = 2192.32 MCM.

Table 2. Water volume that is removed from basin of Golestan province, naturally.

Golestan province	Evapotranspiration (mcm)	Underground water volume (mcm)
Northern section	41.54	141.87
Southern section	46.82	288.87
Total	88.36	430.74

Total Volume of water output from the province: 430.74 + 88.36=519.1 MCM.

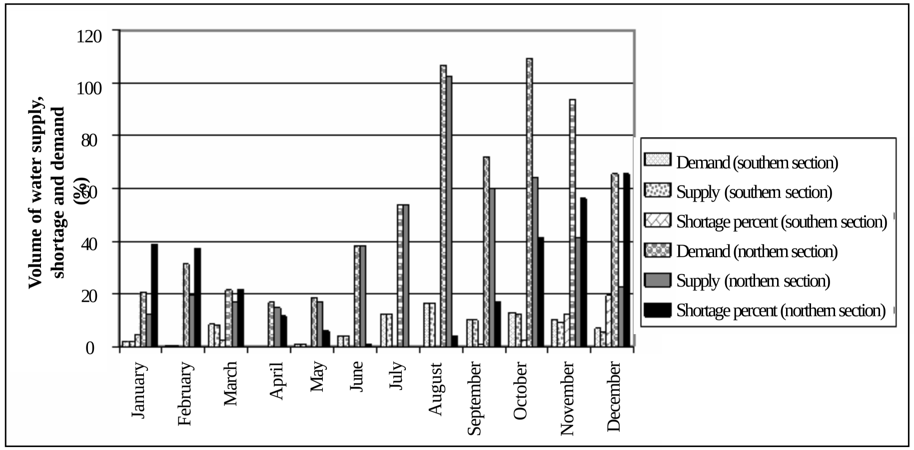

Figure 3. Water demand, supply and shortage of Golestan province in planned situation.

Table 3. Volume of water that is harvested and consumed by humans from Golestan Province.

Golestan province	Agricultural consumption	Potable consumption	Industrial consumption
Northern section	34.32	2.59	1.11
Southern section	1316.94	74.55	31.95
Total	1351.26	77.14	33.06

Sink: 33.06 + 77.14 + 1351.26=1461.46 MCM.

Table 4. Volume of water that enters the Golestan basin with human intervention.

Golestan province	Agricultural wastewater	Potable wastewater	Industrial wastewater
Northern section	2.24	2.2	0.55
Southern section	75.43	63.36	15.97
Total	77.67	65.56	16.52

Wastewater volume of the province: 16.52 + 77.67 + 65.56=159.75 MCM.
Excess Water Volume: 808.4 + 1383.92=2192.32 MCM.

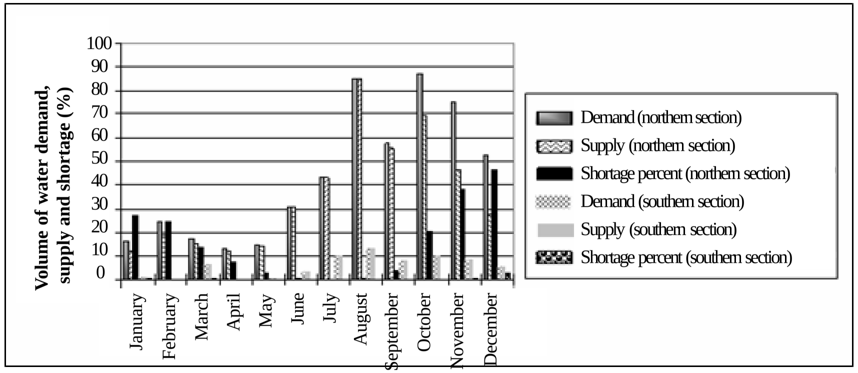

Figure 4. Water demand, supply and shortage considering -20 % savings in water consumption.

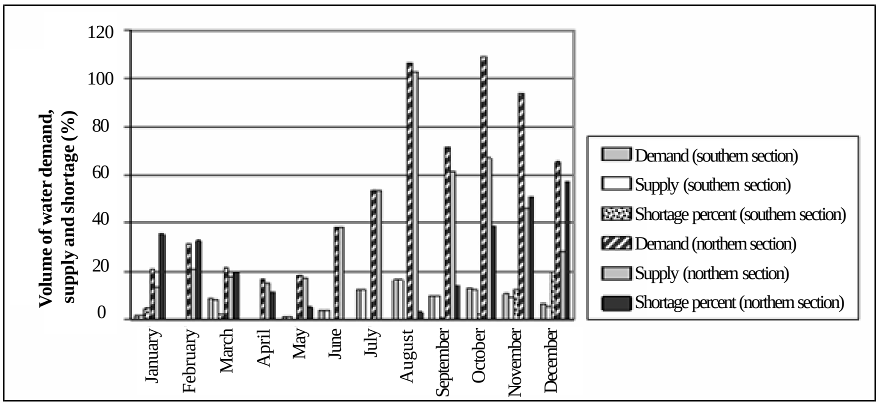

Figure 5. Water demand, supply and shortage considering reservoir establishment with capacity of 100 MCM.