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# Water Productivity Enhancement in a Semi-Arid Persian Garden[1]

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## Abstract

**Introduction:** Persian garden is an architectural combination of solids and plants, a living component that reflects the culture of Persian nation and regional climate situations. The main structure of all of the world's historical gardens are based on the nature and architecture or the method of combining plants, water and buildings that organize the body to create a suitable space for human life. What distinguishes the gardens as a cultural and natural heritage from other places is the conceptual layers of the meanings as well as physical and functional characteristics.

**Materials and Methods:** The purpose of this study is the optimal use of water in Persian gardens and according to the previous and present works with a combination of the modern innovations such as constructed wetlands and hydroponic greenhouses that attempt to use an optimal amount of water by reusing it in these gardens.

**Results:** There are two direct and indirect ways to improve water efficiency. There are three direct ways to improve productivity: I. Increasing the deduction form without changing the amount of water consumed. In this way, the fractional face increases without reducing the amount of water used. Improving the fertilizer program (feeding), changing the cultivar, improving crop management are solutions that reduce water consumption, will

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increase the face of the fraction and thus improve the efficiency of water. II. Reducing the denominator of the fraction means implementing a program to reduce applied water by recognizing the physiological behavior of plants, recognizing useless uses and making arrangements to control them, modifying agricultural operations to reduce water consumption such as modifying the planting date, changing cultivation methods such as transplanting, modification cultivation arrangement, modification of irrigation method. III. Integrated method, in the sense that at the same time as decreasing the denominator of the fraction, the form of the fraction also increases. In this strategy, recognizing the useless uses, recognizing the physiological behavior of the plant, modifying the irrigation method along with modifying the management of fertilizer consumption and agricultural operations are cases that will lead to reduce the denominator and increasing the fraction. The indirect method basically deals with processes that, although very important and for which different inputs are used, but are not considered. Crop losses from harvest to consumer consumption, energy losses of agricultural and irrigation machines, leaching of fertilizers and damage caused by agricultural hazards are among the cases of loss of agricultural products. Obviously, the use of potash fertilizers can increase the crop resistance to frost or the use of blowers, irrigation, windbreaks, and other methods of dealing with agricultural hazards, will be effective in reducing damage and thus production productivity will increase. Constructed wetland and hydroponic system have been used in this research and have increased the water productivity.

**Conclusions:** This research has been accomplished by a descriptive-analytical method and field observation to improve the water productivity in Persian gardens and proposing a suitable plan for theses gardens in the semi-arid city of Esfahan. The first prerequisite for achieving water saving is the correct knowledge and understanding of the definitions and interpretations in the field of sustainable use of water, that is, to use correct and meaningful concepts. In the first step, a distinction must be made between "water use" and "water consumption". In order to identify and select technical and effective economic solutions on water demand and consumption management in each catchment, a regular system and framework of "water accounting" should be established. Instead of paying much attention to the development of pressurized irrigation in the country, more attention should be paid to other farming methods that reduce water consumption in agriculture. A Hybrid use of constructed wetland and hydroponic system in urban botanic garden could certainly overcome the water scarcity in semi-arid and arid regions such as Esfahan.

**Keywords:** Persian Garden, Irrigation, Esfahan, Water Efficiency, Water Productivity.

## 1. Introduction

Persian garden refers to gardens based on architecture and its constituent elements, such as geometric structure, water, trees, middle pavilions, etc., which have been prevalent mainly in the plateau of Iran and surrounding areas influenced by its culture. In Persian literature, the Persian garden is called "Bagh Sara", Pardis or Firdos, Bostan or Boustan. The word "bagh" is a new Persian word and its translation is "Persian Garden".

The Persian Garden has three unique structures and designs: First, it is located on the path of the water atmosphere. Second: it is enclosed with high walls. Third, it is located inside the garden of the summer mansion and the water pool. These three characteristics distinguish Persian gardens. In fact, the European tourists who saw this garden of Persian greenhouse described it with the name "Question Garden". Persian garden or "Serai Garden" refers to its unique structure and design. The Persian Garden is related to the history of the aqueduct. The first Persian gardens were formed on the exit route of the aqueduct. Examples of such gardens can be seen in Tabas, Yazd, Gonabad, Birjand and most arid and semi-arid areas. One of the characteristics of the Persian garden is the passage of water inside the garden, which usually has a pool and a mansion or a summer building in the middle of the garden. Some gardens are in the form of four gardens and they pass the water in 4 ways.

Pasargad Persian garden is considered the origin of these gardens' architecture. Cyrus the Great had personally ordered how to create the garden of Pasargad and how to plant the trees, and in fact, the geometry of the garden and its shape and icon were taken from Cyrus's point of view to the Persian garden. In the Sassanid era, gardens were formed in front of palaces and temples, and this issue continued in the Islamic era as well.

The oldest graphical document depicting the order of the Persian garden dates back to the Sassanid period. In the bas-relief of Taq-e Bostan, the hunting scene of Khosrow Parviz shows his garden-hunting design in Taq-e Bostan. This relief largely shows the geometry of the garden and its function.

As a complete structure, these gardens express the close relationship between the cultural and natural environment and are a sign of adapting and harmonizing the needs of man and nature. In the past, the Persian garden was the manifestation of the hidden power of the environment and the perception of its complexities. By relying on his experimental knowledge, the creator of the garden created a space that caused the survival and dynamism of the natural bed.

## 2. Persian Gardens and Water Scarcity in Iran

Water scarcity is the first and most challenging crisis worldwide. With the growing world population, it is imperative to find alternative water resources to meet water demand (Maleki & et al., 2021). Adaptation to water scarcity is a topic that has recently received a lot of attention from water experts. Providing appropriate solutions in this field and long-term and efficient planning for it requires dialogue and consensus on the issue (Maleki & et al., 2022). The world's growing population puts severe demands on freshwater production and supply, and in many areas, existing water resources are already overstressed (Kummu & et al., 2010). Specifically, existing potable water resources are being depleted in many areas due to climate change (in terms of both precipitation and evapotranspiration), rapid urbanization, exponential population growth, and lack of (or inadequate) treatment of wastewater.

By 2025 two-thirds of the worldwide population is expected to live in regions with water scarcity (Macedonio, et al., 2012). In view of high population growth and water resources deficit in arid and semi-arid areas and water resources shortage in mountainous areas, there is an urgent need to identify the alternative sources of water (Zamani & et al., 2021). Intense water shortages are currently experienced by 470 million people and it is projected that by 2025, the number of people living in water-stressed countries will increase to 3 billion (Obispo, 2009). Regarding the estimations, 2.4 billion people in the world lack access to safe drinking water and there are about 1.7 million deaths per year worldwide because of diseases found in poor water quality (Obispo, 2009).

Drought and water scarcity in Iran is a climatic reality due to the fact of growing needs in different sectors for water consumption including drinking, agriculture and industry. This problem will become even more acute in the coming years. The average long-term rainfall of the country is about 243 mm (about one third of the global average) and the potential evapotranspiration in the country is about 2000 mm per year (three times of the global average). The total volume of water resources produced from the rainfall in the country is about 403 billion cubic meters, which more than 70 percentage becomes unavailable through evaporation. Renewable water resource volumes are about 100 billion cubic meters, which about its 70% is used in agriculture sector (Naseri & et al., 2017).

In such conditions, one of the effective and practical solutions is to consume the water, optimally and economically. In the meantime, management of water consumption in the Persian gardens can be very effective. Obviously, to achieve this, identifying the main indicators of water consumption management is necessary (Abbasi & et al., 2017). It is clear that the most effective and practical way to adapt with this climatic condition, is the planning for the optimal use and saving the water. Water consumption productivity is one of the indicators for the evaluation of optimal water consumption.

Ever since man began farming and invented the plow to prepare the soil, he has experimented with the geometric rule that the easiest way to work the land is to move in a straight, parallel direction. The land became square and rectangular. The same geometric rule was considered as an easy way to irrigate the fields by traveling shorter distances and preventing water wastage (Diba, 1997). Therefore, in some studies, the main reason for the square shape of garden plots is the ease of irrigation, which has been common in Persian agriculture for thousands of years (Pirnia, 2007)

But some other research is the decisive alignment, explicit dimensions, precise lines, definite angles, right ear surfaces, parallel walls, clear and rhythmic arrangement of independent spaces, flat coverings, stone structure, geometric and synchronous composition, plan attributes the stable and smooth to the time of the settlement of the Aryans in the land of Iran (Abolghasemi, 2005)

## 3. Principles of water productivity

Water efficiency is one of the indicators of optimal irrigation water consumption. According to the general definition, water productivity is the ratio that in the analytical note of the denominator of its deduction is applied water (irrigation water, rainfall (and in that case various cases of quantitative concepts. These include product performance, income and profit. The amount of energy produced the number of calories produced, the amount of benefit, etc. Generally, the two concepts of physical and economic water efficiency are more used in analyzes and decisions. The amount of product produced is per unit volume of water consumed, expressed in kilograms per cubic meter. In this paper, the physical productivity of water, here in after referred to as productivity, is estimated for agricultural and horticultural products.

Production is usually simpler and can be estimated based on official statistics. However, in terms of water consumption, the statistics are very different. As a result, the quantity of productivity is highly dependent on statistics related to the volume of water consumed, and the determination of productivity is always accompanied by doubts. This index at the beginning of the fourth development plan is between 0.8 to 0.9 kg cubic meters have been reported. In the 20-year vision plan, this index is targeted at 1.6 kg / m3. Water productivity is a need and an initial step and can never be considered the end of monitoring, which is the beginning of a large activity.

Obviously, the index of 5 kg of forage corn per cubic meter of water consumption will never be equal to the index of 0.4 kg of pistachios per cubic meter of water; even the index of water productivity in wheat production will be different in different places with different water qualities or different cultivars. In addition, each should be checked in its place. One way to evaluate extensively is to use the same dimensional analysis and take into account the net income that the concepts of economic productivity will become objective.

In Spain, for example, since 1990, a significant portion of investment in modernization to replace open-channel networks used for surface irrigation by pressurized irrigation mass distribution networks has been made mainly by drip and sprinkler irrigation (Playán & et al., 2006; Fernández García & et al., 2014). The renovation projects are a private initiative with a common European and national budget, and they are responsible for changing the infrastructure from about 2 million hectares to 3.7 million hectares of irrigation in Spain. Today, 50% of the irrigation area is drip irrigation, 25% is surface irrigation, 16% is sprinkler irrigation and 9% is self-irrigation systems (Esyrce, 2017). The transition from one system to another depends on local conditions and in particular on the product of interest.

Mexico covers an area of approximately 2 million square kilometers and is classified as an arid and semi-arid country. The agricultural sector plays an important role in the country's economic development, accounting for 3.5% of GDP and employing 13% of the population in 2019 (World Bank, 2020). By 2017, irrigated agriculture accounted for 21% (Siap, 2020) of total irrigated land. About 43% of Mexico's agricultural products were exported to more than 40 countries by 2017, so Mexico is in the top 10 largest export economies of agricultural products (Siap, 2020). The country has 6.5 million hectares of irrigated land, of which 3.3 million in 86 integrated irrigation areas and another 3.2 million more than 40, 000 irrigation units (Conagua, 2020). About 69% of the total water level is in Asia, 17% in the United States, 9% in Europe, 4% in Africa and 1% in Oceania. Mexico is the sixth country in the world with irrigation infrastructure after India, China, USA, Pakistan and Iran (Aquasat, 2020; FAO, 2020).

In the Mexican state of Zacatecas, about 1, 350, 047 hectares are dedicated to agriculture. About 14% and 86% are irrigated and rain fed lands, respectively. Rain was not enough to cover the water required for the crop

(250 to 500 mm), especially in mid-summer, with temperatures between 15°C and 29°C. About 95% of crops are planted in spring and summer alone. 5% in autumn and winter. The main crops that are not irrigated only in seasonal rainfall are: beans, corn, wheat, oats, barley and oat bran. While aquatic products are: beans, corn, wheat, chili, vines, guava and peaches, etc. (Galindo & et al., 2006). In other words, the climatic conditions in the region are not conducive to dam storage to meet the crop water needs for the next season (a seasonal planting plan is usually done on October 1 of the previous season).

## 4. Research method

This research has been done in a descriptive-analytical manner. The methods of data collection are library, documentary and having direct field observation. In this regard, by referring to the gardens of Esfahan parks, they have been studied

## 5. Research background

Many studies have been done on the water productivity issues. The followings are only some samples:

Bustani & Mohammadi (2008) in a study examined the water productivity and water demand function in beet production in Eghlid region and stated that increasing productivity, which is considered as increasing available water, can have a significant effect on the level of production.

Khazaei (1999) emphasized the need to increase the agricultural water productivity due to its scarcity and states that agricultural water productivity is currently not in a favorable condition and is at a lower level compared to the other sectors. He considered a low irrigation as a factor to keep productivity low and said that it is necessary to increase the efficiency of agricultural water productivity.

Kijne & et al. (2003) in a study examined the food security by improving water productivity of the agricultural products that they have payed. The results of this study showed that by productivity of agricultural water and its saving in agricultural water can be planted the crops that have a high economic efficiency and can produce more than the consumption of the product.

## 6. Necessity and importance of increasing water productivity.

The reduction of water resources, the gradual change of the share of water consumption in the agricultural sector to the other sectors of consumption and the replacement of crop cultivation with higher economic value than strategic plants, lead the situation to food insecurity. Lack of proper water productivity and an increase per capita consumption per person over time has led to the drying up of the rivers, lakes and also a drop in groundwater levels. At present, many countries in the world face a great challenge to produce food from limited water resources (Kiani & Sedaghat Doust, 2016). The issue of climate change and management has doubled the problem.

## 7. Artificial Wetlands

In two hundred years, almost 50% of natural wetlands have been destroyed by human activities, while wetlands are important in many valuable activities and are effective for the hydrological balance of the area. The use of treated water in wetlands can create good benefits that require:

- Creation, repair and increase of the wetlands

- Creating an alternative humid climate waste with a water recycling system for wetlands that underwent the hydrological changes.

In less than 50 years, due to the development of urbanization and industries, the collection systems and the wastewater treatment facilities have been developed and more attention has been paid to decentralized wastewater treatment at the production site. When applied to the effluents and wastewater, this approach is in line with the concept of sustainable development and the goal of sustainability is to minimize the long-term and short-term impacts.

The environment is the result of development activities through the resource conservation, recycling and energy utilization. Bioremediation or phytoremediation is one of the most important reasons for creating the artificial wetlands to improve the water and develop the principles of sustainability. The efforts have prepared a wide range of bacteria and fungi to be used and combined with the wetland treatment systems. For example, the corrosive bacterium methane has been identified and cultured to produce enzymes that convert 95% of pollutants such as vinyl, chloride and other toxins into salt. The researchers at the US Maritime Center and the US Environmental Protection Agency have used the phytoremediation in artificial wetlands to clean up TNT and cyclonite contaminants in groundwater. Of course, the creation of wetland treatment systems is associated with land restrictions and its use in urban settings and the disturbance of vegetation and algae and the isolation of the environment. A number of cities have developed their own wetland enhancement and treatment systems to create wildlife ecosystems. (Eslamian & Turkesh-Esfahani, 2011).

The benefits of wetland treatment system are improving water quality; creating a canvas for wildlife and protecting green vegetation. In the present study, the first and third advantages have been used by considering the artificial wetland in the design of the botanic garden park.

## 8. Water consumption efficiency and improving methods

Water use efficiency is one of the indicators of optimum irrigation water consumption. According to the general definition, water efficiency is a ratio that in the analytical note is the denominator of its application water (irrigation water, rainfall) and in that case a variety of quantitative concepts placed. These include the product performance, revenue (profit), net energy production, calorie production, value added. Generally, the two concepts of physical and economic water efficiency are more widely used in analysis and decision making. By definition, physical productivity of water consumption is the amount of product produced per unit volume of water consumed, expressed in kilograms per cubic meter. How much income does the vector make in terms of the amount of water it consumes? In this research, the physical productivity of water, hereinafter referred to simply as productivity, is estimated for agricultural and horticultural products.

There are two direct and indirect ways to improve water efficiency:

### 8-1. Direct method

There are three direct ways to improve productivity:

I. Increasing the deduction form without changing the amount of water consumed. In this way, the fractional face increases without reducing the amount of water used. Improving the fertilizer program (feeding), changing the cultivar, improving crop management (planting time, how to prepare the land, planting machine, weed control, pest and disease control) are solutions that reduce water consumption, will increase the face of the fraction and thus improve the efficiency of water. Also, reducing costs and taking additional measures to improve the product quality will increase the deduction.

II. Reducing the denominator of the fraction means implementing a program to reduce applied water by recognizing the physiological behavior of plants, recognizing useless uses and making arrangements to control them, modifying agricultural operations to reduce water consumption such as modifying the planting date, changing cultivation methods such as transplanting, modification cultivation arrangement, modification of irrigation method (from traditional methods to modern irrigation systems).

III. Integrated method, in the sense that at the same time as decreasing the denominator of the fraction, the form of the fraction also increases. In this strategy, recognizing the useless uses, recognizing the physiological behavior of the plant, modifying the irrigation method along with modifying the management of fertilizer consumption and agricultural operations are cases that will lead to reduce the denominator and increasing the fraction (Tavakoli, 2016).

### 8-2. Indirect method

This method basically deals with processes that, although very important and for which different inputs are used, but are not considered. Crop losses from harvest to consumer consumption, energy losses of agricultural and irrigation machines, leaching of fertilizers and damage caused by agricultural hazards are among the cases of loss of agricultural products. Obviously, the use of potash fertilizers can increase the crop resistance to frost, or the use of blowers, irrigation and windbreaks and other methods of dealing with agricultural hazards, will be effective in reducing damage and thus production productivity will increase (Baghani & et al., 2015).

## 9. Case study-design of the Persian museum garden

The design of the Persian museum garden adapted to the hot and dry climate in Esfahan that is the study plan, which is shown in Figures 1 to 6.

This project is located in an area of approximately 13, 000 square meters of design, which has 47 non-productive gardens. In designing this complex, the goal was to create an entertaining educational complex. In this complex, due to water saving, it has treated and reused the produced effluent in the complex, and in the east of the complex, two primary treatment plants have been located. A wetland with horizontal and subsurface and medium depth is located in the west of the museum garden to be used as a third treatment plant and has two inputs and two outlets that divert the treated water to the other side of the design. In this wetland, the Reed and Louie plants have been cultivated. The effluent in the wetland and in the predetermined paths move horizontally and with the calculated retention time, the effluent pollution, including heavy metals, is absorbed by the wetland plants. These plants can later be used in the wood industry. Modified effluent could be used in the greenhouse. Another practice for water efficiency in the project is the use of hydroponic greenhouses. The area of each greenhouse is about 5 thousand square meters.

## 10. Practical recommendations

Considering the issues mentioned in order to improve water use efficiency, it is necessary to pay sufficient attention to improve the current situation of the two main components of productivity, namely the amount of water consumed and the amount of production of Persian gardens per unit volume of water consumed. In this regard, some technical and practical points are suggested as follows:

I. Improving the pattern of water consumption in the garden and park

II. Special attention to mechanization of surface irrigation methods or the use of pressurized irrigation methods

III. Paying attention to the environmental issues and the principle of sustainability of water and soil resources in the development of various irrigation methods

IV. Attention to the racial issues; To agriculture and biotechnology with the approach of reducing water consumption

V. Development of tillage in soil of the crops

VI. Develop and implement of a monitoring program to reduce evapotranspiration

VII. Use of greenhouse capacities in the production of plant products, especially hydroponics

VIII. Determining and analyzing the water efficiency index of water supply, conveyance, distribution, consumption and post-consumption

## 11. Conclusions

Due to the global climate change, the design process for Persian gardens should be compatible with the lack of rainfall and increased evapotranspiration. This is doubly important in arid and semi-arid regions. In this regard, the issue of increasing water efficiency is necessary. In the present study, which is based on the city of Esfahan, two innovations have been developed in the garden design, one is the design of natural wastewater treatment, i.e. constructed wetland, and the other is the design of hydroponic greenhouse (without soil). In selecting the wetland plants, the native plants of the region, namely Reeds and Louei, have been used. Due to the existence of the wetland, low-cost initial pre-treatment has been used. Transferring this experience to other semi-arid regions of the world can increase the productivity on a large scale.

The first prerequisite for achieving water saving is the correct knowledge and understanding of the definitions and interpretations in the field of sustainable use of water, that is, to use correct and meaningful (non-ambiguous) concepts. In the first step, a distinction must be made between "water use" and "water consumption". In order to identify and select technical and effective economic solutions on water demand and consumption management in each catchment, a regular system and framework of "water accounting" should be established. Instead of paying much attention to the development of pressurized irrigation in the country, more attention should be paid to other farming methods that reduce water consumption in agriculture (such as the use of mulches and conservation agriculture, observing proper crop rotation, etc.).

In case of water crisis and in order to achieve real water savings, water efficiency criteria based on production performance per field water used in the field should be based on water efficiency criteria. If the water efficiency index is calculated with this method, it can be used to determine the effectiveness of water sequestration solutions. Judged irrigation systems (such as pressurized irrigation, etc.) and compared different technical and managerial solutions and measures.


**Fig. 1.** Entrance to the museum garden

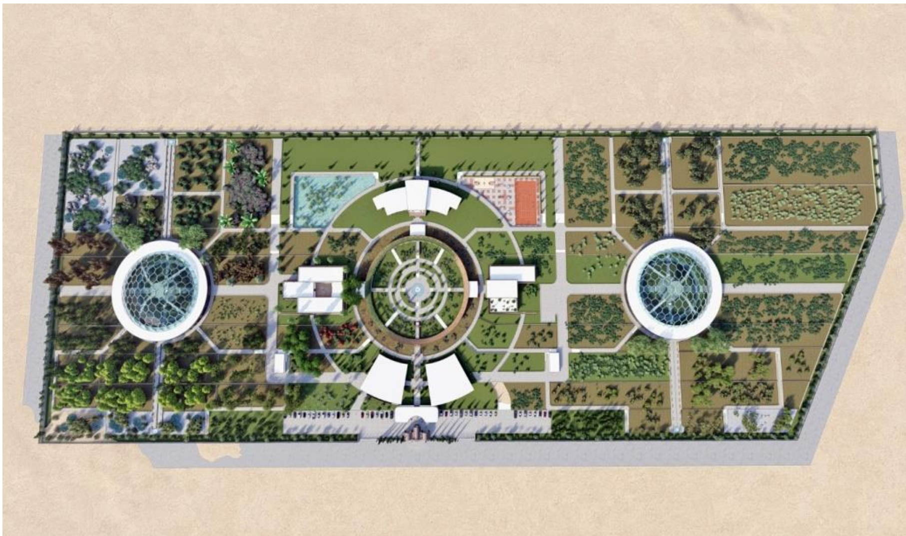

**Fig. 2.** Overview of the museum garden

**Fig. 3.** Garden pit in the museum garden design

**Fig. 4.** Wetlands in the museum garden

**Fig. 5.** Hydroponic greenhouse in the museum garden

**Fig. 6.** Hydroponic greenhouse and bridge in the museum garden

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