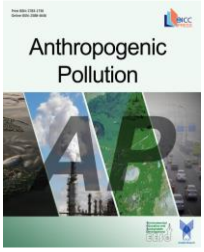

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Research Article

Scenario-Based Conjunctive Management of Surface Water, Groundwater and Reclaimed Wastewater to Improve Groundwater Conditions in the Hashtgerd Aquifer, Iran

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Abstract

This study aimed to optimize the integrated exploitation of water resources to reduce the drop in the level of the Hashtgerd aquifer, Iran, based on an integrated management. Firstly, hydroclimatology and groundwater balances were estimated, revealing that the 25-year drop in the aquifer level is 20.32 m. By modeling scenarios of population increase with a five-year growth rate of 3.4% and the construction of two wastewater treatment plants, along with optimizing the supply of demand through integrating the use of resources in the WEAP model, it was determined that in a five-year perspective, discharge from the aquifer to supply the water needs of drinking and industry will increase by 5.70 and 6.58 million cubic meters (MCM), respectively. By treating 11.32 MCM of industrial wastewater for industrial use along with treating 40% of urban wastewater and 57.37 MCM of agricultural wastewater for agricultural use, discharge from the aquifer showed a reduction. The model determined that agricultural needs exhibited the greatest effect on the aquifer level drop. The results showed that implementing the optimized scenario not only prevents the aquifer level drop in the five-year perspective, but also the aquifer balance will increase up to +2.1 MCM.

Keywords: Consumption optimization; Integrated water resources management; Non-conventional resources; Water resources exploitation

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1. Introduction

Drought and aridity, while both are related to water scarcity, differ significantly (Keyantash and Dracup, 2002; Davoodi Memar Otagvar et al.,2025). Karamouz et al. (2005) investigated the integrated optimal exploitation model of surface water and groundwater resources, emphasizing the characteristics of groundwater quality, using the artificial neural network (ANN) as the base model and genetic algorithm (GA) as the optimization tool. Using this model, with the goal of extracting optimal allocation values from surface water and groundwater resources to agricultural lands in the south of Tehran, the results showed quantitative and qualitative improvements of water resources. In another study, Karamouz et al. (2007) assessed an integrated exploitation model to control changes in the groundwater level, reduction in pumping costs, and providing agricultural water. They again used the ANN-GA approach and their results indicated the advantage of conjunctive model in the allocation of surface water and groundwater resources, where the changes in the groundwater level was reduced to less than 4 m compared to the existing conditions (more than 20 m).

Following the increase in water consumption, the amount of wastewater produced is also increasing (Seyed Mousavi & Saeb,2024). The limitation of renewable water resources has resulted in the use of non-conventional water sources to be considered as one of the most important water sources for consumption (Zamani, 2026; Zare Aghbolagh & Fataei,2016). Zibaee et al.(2013) investigated the integrated use of surface water and groundwater resources in Firuzabad plain of Fars, Iran, by means of a mathematical model with hydrological and management constraints to achieve optimal cultivation patterns in order to optimally use water resources and maximize economic efficiency. The results showed that the conjunctive water use improves the reliability of water resources, which can reduce the loss caused by water uncertainty and thus acts as a risk management system against water uncertainty (Nakhjavni & Fataei, 2015).

Rivers, as the main surface flows, are the first options for exploitation in arid and semi-arid regions such as Iran. However, frequently the existing flow conflicts with the of existing needs, or sometimes the flows occur only seasonally and in floods. In contrast, groundwater resources are one of the best water reserves, which usually provide water with good quality for use in various purposes, especially in dry seasons. However, their management and exploitation is challenging due to water scarcity (Babazadeh and Sarai Tabrizi, 2013; Farhadi et al.,2020). Droughts are natural disasters that can have severe socioeconomic consequences, as seen in the cases of subSaharan and eastern Africa in the 1980s, which resulted in famine, starvation, mass migration, and millions of deaths. These events have become more frequent, especially in arid and semi-arid regions of the world, largely due to the impacts of climate change. The situation gets further worsened by water scarcity issues commonly associated with arid regions.

Valizadegan and Yazdan Panah (2017) simulated the changes in the groundwater level of Mahabad plain using the GMS software. Then, based on the obtained results, they used the ANN method to optimize the use of surface water and groundwater resources. The results showed that the approximate share of water supply was 13.5% for surface water and 86.5% for groundwater. Therefore, the water needs of the region should be provided based on these results to maintain the water resources balanced.

Estimating the balance of water resources with proper accuracy and with the aim of evaluating the current state of these resources and planning for the sustainable development of these resources is of great importance. This issue is more critical in aquifers that are facing excessive exploitation. One of the challenges in the estimation of the balance of water resources is the existence of uncertainties in the input and output factors due to the diversity of soil properties and the complex nature of water movement in the soil (Crosbie et al., 2018; Ketabchi et al., 2018). Also, inaccurate calculations related to the water balance, due to the lack of necessary information and also the impossibility of measuring some components of the water balance, the estimation of the balance has faced many problems in terms of accuracy and application time (Han et al., 2020). For example, Mahmoodzadeh and Ketabchi (2021) showed the impossibility of measuring evaporation, transpiration and infiltration in the Rafsanjan aquifer, Iran. Due to the importance of this issue, several studies have been conducted to estimate the balance of water resources. These investigations have used various methodologies in estimating the important components of the water balance according to the scope of the study and time and place limitations. Among these studies, we can refer to Garcia et al. (2022), who analyzed the groundwater system of southeastern Oregon, USA. Their study, which was prepared by the Geological Survey of the country, presented separate groundwater balances in high and low areas to avoid recalculation of water discharged to upstream springs and recharge of the downstream groundwater system. They utilized various methods to estimate the components of groundwater balance such as soil-water balance model, hydrograph separation, spring discharge measurement, groundwater pumping data, and evapotranspiration modeling. Also, for each component, they considered a method for uncertainty analysis such as the Monte Carlo method.

Drought is a temporary and abnormal condition marked by an unusual lack of water (primarily precipitation), whereas aridity is a fundamental and permanent climatic feature with low precipitation and high evaporation as the norm (Khalequzzaman et al., 2023). Taking into account the climate changes in recent years globally, and the decrease in precipitation and increase in temperature, it is essential to prevent the drop in the level of groundwater resources. The drop in the static level, the interference of salt and fresh water in coastal areas, the costs of drilling and pumping, subsidence, emptying of underground resources, and the reduction of the quality and quantity of water resources are among the problems in the excessive

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use of groundwater resources. Rajaeian et al. (2024) showed that changes in the components of the groundwater balance of the Hashtgerd aquifer in a period of 20 years were in accordance with the programs of the restoration and balancing plan. The results of this study, which was conducted with a modeling approach, indicate an annual deficit of more than 4 million cubic meters (MCM) of aquifer storage during the period of 2012-2016 and a remarkable decrease in its quality. They also showed that preventing unauthorized agricultural wells can increase the aquifer storage on average to more than 7 MCM per year. Moreover, Hanifehlou et al. (2023) estimated the Hashtgerd groundwater supply based on groundwater balance components (runoff, evapotranspiration and transpiration) using WetSpass-M model and satellite images under the influences of climate change. The results of this study indicate a decrease in the amount of recharge and an increase in the share of evaporation and transpiration. Considering the drought conditions, Nishikawa (1998) presented a model for the optimal use of surface water and groundwater resources. The goal was to minimize the cost of water supply using linear programming (LP), taking into account the limitations related to water demand, the groundwater level, and controlling the advance of sea water to the aquifer. In this research, the values of surface water and groundwater withdrawals were considered as decision variables while the values of groundwater level were considered as state variables due to their effectiveness.

Although numerous studies have investigated conjunctive use of surface water and groundwater resources, and several studies have addressed wastewater reuse separately, limited attention has been paid to the integrated use of surface water, groundwater, and reclaimed municipal, agricultural, and industrial wastewater within a unified scenario-based framework. Therefore, the present study aims to evaluate different management scenarios using the WEAP model to improve groundwater conditions in the Hashtgerd aquifer. The novelty of this study lies in incorporating multiple unconventional water resources into conjunctive water resources management and assessing their impacts on groundwater balance.

The literature review shows that the conjunctive exploitation of surface water and groundwater resources has been considered in order to optimize consumption. Previous studies have investigated wastewater reuse in different regions. However, few studies have simultaneously considered surface water, groundwater, and reclaimed wastewater resources within a scenario-based framework for improving groundwater conditions. the aim of this research is the systematic management of integrated exploitation of surface water, groundwater, and non-conventional water resources in the study area of Hashtgerd plain, in order to reduce the drop in the level of groundwater in the region.

2. Material and methods

2.1. Study area

The Hashtgerd region, with an area of 1170.5 km^2 in Alborz province, is connected to Tehran-Karaj region from the east and to Qazvin region from the west. Surface flows from this area enter the Qazvin salt marsh. The most essential river in this area is the Kordan River. The alluvial aquifer of Hashtgerd Plain is of open type, which is multi-layered towards the south of the aquifer. The quality of groundwater in the lower confined layers is better than that in the free layer. In the southern lands of the plain, due to the outcrop of Miocene evaporate sediments, the quality of water in the surface layer has severely degraded and is unusable for agriculture and drinking purposes. Fig. 1 shows the location of the Hashtgerd Plain.

In this study, the meteorological, hydrological, and groundwater level of the Hashtgerd aquifer in the water year 2021-2022 was considered. The area of the highlands, plain, and the aquifer is 579.0, 591.6 and 410.7 km^2, respectively. Using the average values of monthly temperature, precipitation, and evaporation data in the Hashtgerd area using the ArcGIS software, the iso-thermal, iso-precipitation, and iso-evaporation was prepared. The minimum and maximum values of the iso-thermal curve in this study are ranged between 10 and 16 °C. The iso-evaporation curves are from 1600 to 2200 mm, which increases the amount of evaporation from north to south and southwest due to the high elevation of the northern part of the region compared to its central part. The discharge of the Kordan river was measured at the station of Dehsouma as an input station and at the site of Najmabad station as an output station.

We calculated the hydroclimatological balance using the Torrent-White method. This method provides favorable results in arid and semi-arid climates. The Thornthwaite method was selected because of the limited availability of meteorological variables required by the FAO Penman–Monteith method. Since monthly temperature data were available for the entire study period, the Thornthwaite approach was considered appropriate for estimating evapotranspiration under the available data conditions.

Many studies indicate that the calculated values may be lower than the actual value in some areas, but in any case, it has gained global acceptance since it only requires temperature statistics. The aquifer balance was calculated based on FAO standards. By measuring the behavior of 21 study piezometers on the aquifer level during 12 months of the water year 2021-2022 and modeling them in GIS, we calculate the level of the aquifer. Groundwater level observations from 21 piezometers distributed across the aquifer were used to evaluate model performance. Monthly groundwater level measurements from 1997 to 2022 were subjected to quality control procedures. The WEAP model was calibrated using data from 1997–2015 and validated for the period 2016–2022. The model showed satisfactory performance with R^2 = 0.88, NSE = 0.84, and RMSE = 1.37. We then performed modeling in WEAP with three indicators of uses or needs according to Table 1, resources, and scenarios. By identifying the most sensitive variable, we analyzed it through combining the use of resources in the model and estimating the water balance. In this study area, the Najmabad hydrometric and quality measurement station was located on the Kordan river. In terms of drinking water quality, it is generally in good conditions and in terms of agriculture, it is in C2-S1 conditions. Tables 1 and 2 show the uses and needs of groundwater and surface water resources at the level of the study area. Maximum water exploitation was performed from groundwater resources, especially wells. Agricultural uses contained the highest discharge of water resources. Table 3 shows the inflow and outflow of surface flows at the locations of Fashand, Dehsouma and Nahrkordan stations as input stations and Najmabad as output station.

Table 1. Groundwater consumption (MCM) (Iran Water Resources Management Company)

Region	Wells			Aqueduct			Springs			Sum of water consumption
	Industry	Drink	Agriculture	Industry	Drink	Agriculture	Industry	Drink	Agriculture	
Hard formation (heights)	0.66	0.23	2.46	0	0.57	0.38	0.36	2.74	2.86	4.30
Plain	10.24	19.02	277.45	0.07	0	2.43	0	0	0.10	309.21
Aquifer	9.76	17.21	273.31	0	0	0	0	0	0	300.28
Sum (heights + plain)	10.90	19.25	279.91	0.07	0.57	2.81	0.36	2.74	2.96	313.51

Table 2. Surface water consumption (MCM) (Iran Water Resources Management Company)

Region	Arroyo			Dyke			Pump station			Pump motor			Sum of water consumption
	Industry	Drink	Agriculture	Industry	Drink	Agriculture	Industry	Drink	Agriculture	Industry	Drink	Agriculture	
Hard formation (heights)	0	0	35.68	0	0	0	0	0	0	0.04	0	0.03	35.75
Plain	0	0	6.64	0	0	0	0	0	0	0	0	0	6.64
Aquifer	0	0	6.64	0	0	0	0	0	0	0	0	0	6.64
Sum (heights + plain)	0	0	42.32	0	0	0	0	0	0	0.04	0	0.03	42.39

Table 3. The stations and their surface inflow and outflow (MCM) (Iranian Water Resources Management Company)

River	Station	October	November	December	January	February	March	April	May	June	July	August	September	yearly
Kordan	Dehsouma	0.31	0.54	1.01	3.02	1.29	3.02	9.87	11.10	5.29	1.77	0.19	0.36	37.77
Nahr Kordan	Dehsouma	0.03	0.03	0.03	0.04	0.01	0.01	0.03	0.60	0.49	0.26	0.12	0.07	1.71
Kordan	Najmabad	0	0	0	0	0	0	1.65	1.44	0	0	0	0	3.18
Fashand	Fashand	0.11	0.09	0.10	0.09	0.04	0.71	0.44	0.56	0.45	0.26	0.11	0.07	0.253

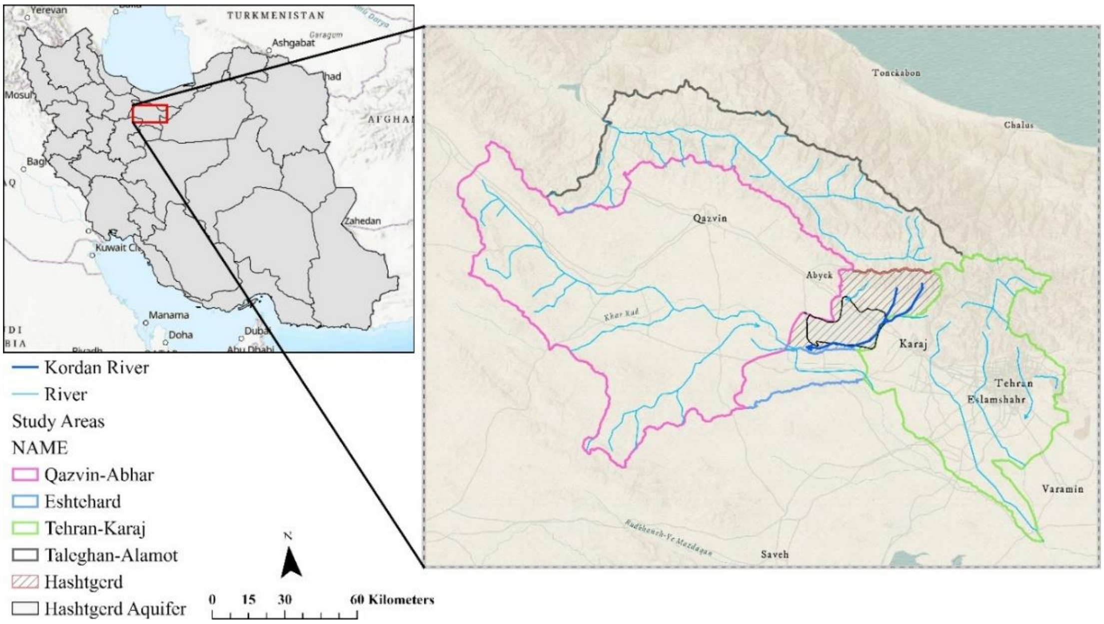

Figure 1. Location of the Hashtgerd aquifer in Alborz province, Iran

3. Results and Discussion

Table 4 shows the monthly data of precipitation in the plain areas and heights of the Hashtgerd aquifer. The potential evapotranspiration values shown in the table were calculated using the Torrent-White method. In this table, the precipitation value in each month was compared with the potential evapotranspiration in the same month, and the lower value was considered as real evapotranspiration. Moreover, if the precipitation was higher than the the potential evapotranspiration, their diference was determined as useful precipitation which is divided into surface runoff and soil infiltration. In Table 5, the general hydroclimatological balance equation for surface water resources was considered in the form of $(I+R)+RET=P$ where P is average annual precipitation, RTE is real evapotranspiration, I is soil infiltration, and R is surface runoff. Although in the southern parts of the plain, the bedrock has Miocene sediments, which contain gypsum and have negative effects on the quality of groundwater, the existence of large and small rivers in this area has caused improvements in the groundwater table. In Table 6, the groundwater balance of the aquifer was calculated based on the difference between aquifer recharge ($Q_{in} + Q_p + Q_r + Q_i + Q_{sw}$) and discharge ($Q_w + Q_d + Q_{eg} + Q_{out}$) where Q_{in}, Q_p, Q_r, Q_i, and Q_{sw} were groundwater inflow, infiltration from precipitation, infiltration from surface runoff, infiltration from agricultural consumption, and infiltration from drinking and industry, respectively, while Q_w, Q_d, Q_{eg}, and Q_{out} were discharge from wells, springs and aqueducts, drainage, evaporation from the aquifer, and groundwater outflow. The total discharge of the Hashtgerd plain was 324.27 MCM per year, while the total inflow was equal to 305.36 MCM, 18.9 MCM lower than the total outflow.

The groundwater inflow mainly enters the aquifer from the nearby highlands and plains, while the outflows are transferred to the downstream lake, desert, and plain. We recorded the inflows and outflows based on the statistics of the Iranian Water Resources Management Company. By comparing the hydroclimatological balance of the plain and the discharge of the hydrometric stations, the infiltration from precipitation was calculated. The percentage of infiltration from agricultural consumption was obtained 37 %, which was calculated according to FAO publication No. 38, which is based on the irrigation efficiency, the irrigation method of the area, and the soil texture. The percentage of infiltrated water from drinking and industrial uses, whose waste disposal is mainly done through absorption wells, was obtained as a value between 60 and 75% of the consumed water. The evapotranspiration from groundwater was calculated according to the Torrent-White's curves method throughout the aquifer. Fig. 2 depicts the parallel curves of the aquifer drawn in the GIS model. According to the figure, the highest level of groundwater (1300 m) is located in Kordan lands in the northeast region, while the lowest (1135 m) is in Najmabad lands located at the southwest of the plain. Therefore, the direction of groundwater flow in the plain is from northeast to southwest.

In Fig. 3, the depth contours of the aquifer are drawn in the GIS model. The contours show the groundwater depth in a range between 10 and 100 m. In the alluvial cone of the Kordan river, the depth of the groundwater level is more than 100 m. The depth of the wells decreases up to 50 m towards the south in Saeed Abad lands. In Namak-

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Alan and Qasim-Abad-Agha lands, due to the bedrocks, the depth is less than 10 m. Exploratory drilling and geoelectrical studies conducted before reveal the thickness of the aquifer between 111 and 311 m. The minimum thickness occurs near the northern and southern heights of the range and increases towards the center. This thickness is more in the course of the Kordan river due to the sedimentation. Also, the subsidence of bedrock in the center of the plain has caused the thickness of alluvium to reach more than 311 m in the north of Mohammadabad and Lashkarabad villages. Towards the east, between Karaj plain and Hashtgerd, the rock rises and reaches about 111 m. In the vicinity of the salt marsh, the thickness of the aquifer decreases, which seems natural due to the topographical situation and the decrease of the slope and the rise of the groundwater level.

Through measuring the data of 21 piezometers located in the Hashtgerd aquifer based on the Thyssen network modeling in the GIS software, the groundwater level maps of the aquifer for the water years from 1997-1998 to 2021-2022 were prepared. Over this period, the groundwater level drop throughout the plain was 20.32 m with an annual average of 78 cm. The maximum annual groundwater level drop (3.64 m) occurred in the water year of 2004-2005, while in the water year of 1997-1998, the average level of the groundwater increased by 177 cm. Over this period, the maximum level of groundwater (1204.42 m) was observed in June of the water year 2001-2002, while the minimum value (1179.96 m) in November of the water year 2021-2022.

Table 4. Potential evapotranspiration and useful precipitation using the Torrent-White method in 2021-2022

Region	Variable	October	November	December	January	February	March	April	May	June	July	August	September	Yearly data
Plain	Average temperature (°C)	18.3	13.4	3.6	2.1	1.2	9.2	12.2	17.6	22.5	28.2	28.6	24.7	15.1
	The evaporation from the surface water (mm)	176.1	102.3	64.3	65.0	57.7	96.5	125.3	147.2	295.0	335.2	350.1	266.2	2080.8
	Potential evapotranspiration (mm)	69.5	35.8	3.8	1.6	0.6	23.4	40.4	84.2	127.7	189.2	180.4	124.2	880.8
	Precipitation (mm)	0.0	13.0	7.4	45.0	60.2	28.7	46.6	53.7	0.0	0.8	0.1	0.0	255.3
	Real evapotranspiration (mm)	0.0	13.0	3.8	1.6	0.6	23.4	40.4	53.7	0.0	0.8	0.1	0.0	137.3
	Useful precipitation (runoff + infiltration) (mm)	0.0	0.0	3.6	43.4	59.6	5.3	6.2	0.0	0.0	0.0	0.0	0.0	118.0
Hard formation (heights)	Average temperature (°C)	15.2	10.4	1.4	1.4	0.7	7.3	9.6	15.6	20.1	24.5	24.9	23.1	12.8
	The evaporation from the surface water (mm)	155.6	82.3	59.8	58.2	40.2	81.5	95.6	120.1	232.7	309.5	312.6	228.5	1776.5
	Potential evapotranspiration (mm)	58.2	29.5	1.6	1.6	0.6	22.1	35.1	78.4	113.8	152.7	145.2	114.8	753.6
	Precipitation (mm)	0.0	21.7	30.3	69.4	88.5	50.3	82.2	70.0	0.0	10.6	0.3	0.0	423.4
	Real evapotranspiration (mm)	0.0	21.7	1.6	1.6	0.6	22.1	35.1	70.0	0.0	10.6	0.3	0.0	163.6
	Useful precipitation (runoff + infiltration) (mm)	0.0	0.0	28.7	67.8	87.9	28.2	47.1	0.0	0.0	0.0	0.0	0.0	259.7

Table 5. Hydroclimatological balance estimate in 2021-2022

Region	Area (km^2)	Precipitation (MCM)	Real evapotranspiration (MCM)	Useful precipitation (MCM)	
				Infiltration	Surface runoff
Hard formation (heights)	579.0	245.10	109.20	33.97	101.93
Plain	591.6	149.29	110.8	28.87	9.62

Table 6. Groundwater balance of the Hashtgerd aquifer (MCM)

	Variable	Value
Aquifer recharge	Groundwater inflow (Q_{in})	102.29
	Infiltration from precipitation (Q_p)	28.87
	Infiltration from surface runoff (Q_r)	48.87
	Infiltration from agricultural consumption (Q_i)	106.64
	Infiltration from drinking and industry (Q_{sw})	18.69
	Total recharge	305.36
Aquifer discharge	Discharge from wells, springs and aqueducts (Q_w)	300.3
	Drainage (Q_d)	0.00
	Evaporation from the aquifer (Q_{eg})	0.00
	Groundwater outflow (Q_{out})	23.97
	Total discharge	324.27
	Change in groundwater volume (ΔV)	-18.9

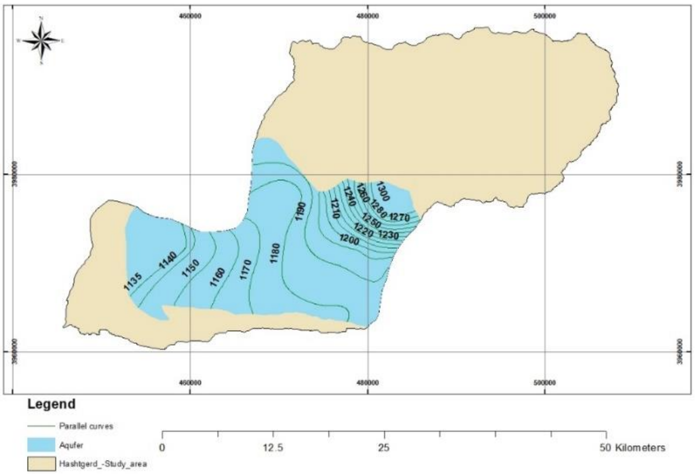

Figure 2. The parallel curves of the Hashtgerd aquifer

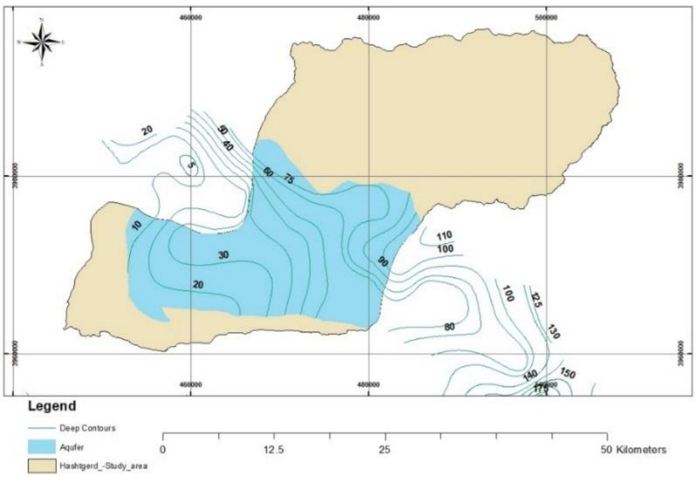

Figure 3. The depth contours of the Hashtgerd aquifer

Based on the data of annual fluctuations, the hydrograph shows an increasing state for wet months (where a precipitation occurred). In the long term, regardless of dry and wet years, the hydrograph shows the balanced state of the groundwater level in case of a partial change in the groundwater level of the aquifer between the first and the last study year. In case of gradual decrease in the groundwater level, the hydrograph shows the water level drop in the aquifer. Using the WEAP model, Fig. 4 shows the aquifer simulation by considering drinking, agriculture, and industrial uses as demands and surface water, groundwater, and unconventional water (a new potential with an upward trend) as water resources. The base year is the 2021-2022 water year and the goal is to reduce the aquifer drop in the 2026-2027 water year. The supply of drinking water from the Taleghan Dam and groundwater is 9.79 and 22.50 MCM per year, respectively.

Table 7 shows the yearly data of drinking water consumption until 2027 according to population increase scenario (Scenario S1). Taking into account an annual 3.4 % growth in population according to the statistics of the Iranian Statistics Center, the increase in population causes an increase in drinking water consumption and an increase in the resulting wastewater. In the five-year period, the population of the study area, including the cities and villages of the region will increase from 112,800 in 2021 to 142,400 in 2026. During this increase in population, drinking water needs also increase from 22.56 MCM in 2021 to 28.48 MCM in 2027. Table 8 shows the amount of drinking water supply by the months from the water year 2021-2022 to 2026-2027 in the model.

The results of applying the monthly discharge from the aquifer for agricultural purposes in the model showed that agricultural uses with an amount of 330.97 MCM per year account for the highest discharge from the aquifer in the Hashtgerd region. In summer, most of the wells are emptied for agricultural purposes. Table 9 shows the results of another scenario (Scenario S2) considered in this study in the months of 2021. Scenario S2 considers the construction of treatment plant T1 to treat drinking and agricultural wastewater for agricultural consumption. This scenario can, to a large extent, provide agricultural consumption and reduce the amount of discharge from the aquifer for agriculture. Si is the amount of water wasted in the transfer of drinking water to treatment plant T1 in the model. The amount of benefit of agricultural needs from the treatment plant T1 is modeled by year. Consumption is equal to the amount of water that is out of reach and does not charge the aquifer and treatment plant as effluent. The amount of agricultural consumption was assumed to be constant in the modeling process in a 5-year perspective.

In Table 10, the amount of industrial effluents according to the report of the Iranian Statistics Center in 2021 was adjusted according to the months of the year. Due to the fact that the disposal of industrial wastewater is through absorption wells, with the construction of another treatment plant (T3) to treat industrial effluents, according to the necessary standards as Scenario S3, it can meet the needs of industries. In the model, the increase of industrial activities in the landscape according to the National Development Documents was considered 4%. Table 11 shows the final output of the WEAP model regarding the aquifer recharge and discharge by applying the relevant scenarios. The surplus amount of agricultural needs is provided from the treatment plant T1 and industrial needs from the treatment plant T3. The amount of aquifer recharge through the drainage of drinking and industrial effluents, due to the return water entering the T1 and T3 treatment plants, has also reached zero. Due to the fact that all agricultural wastewater does not enter the treatment plant T1, the amount of aquifer recharge from agricultural wastewater is 93.60. Fig. 5 shows the simulation of scenarios and their ability in the reduction of consumption from the aquifer. Scenario S1 has the most effects on preserving the aquifer water resources. Table 12 shows the optimized balance of the aquifer by applying the scenarios. In 2027, in case of construction of a treatment plant for agricultural consumption with the input of drinking and agricultural wastewater (S2) as well as the construction of a treatment plant for industrial use (S3), the balance will reach 2.10 MCM. The results indicate that agricultural water demand is the dominant factor affecting groundwater depletion in the Hashtgerd aquifer. Similar conclusions have been reported by Rajaeian et al. (2024) and Hanifehlou et al. (2023), who highlighted the impacts of excessive groundwater abstraction and climate variability on groundwater resources. The present study demonstrates that incorporating reclaimed wastewater into conjunctive water resources management can substantially reduce groundwater withdrawals and improve aquifer conditions.

Table 7. Drinking water requirements according to the population increase scenario (Scenario S1)

Year	2021	2022	2023	2024	2025	2026	2027
Population	112800	116635	120600	124700	128940	133320	137850
Water requirement (MCM)	22.56	23.55	24.53	25.52	26.51	27.49	28.48

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Table 8. Water requirements (MCM) according to the population increase scenario (Scenario S1)

Water year	Fall		winter			Spring			Summer				Total
	October	November	December	January	February	March	April	May	June	July	August	September	
2021-2022	2.05	1.82	1.70	1.68	1.67	1.79	1.65	1.84	2.11	2.11	2.12	1.97	22.50
2026-2027	2.58	2.29	2.14	2.12	2.10	2.25	2.08	2.32	2.65	2.66	2.67	2.48	28.35

Table 9. The amount of treated drinking wastewater in the study area and the ability to transfer it to the T1 treatment plant (Scenario S2)

Wastewater	Fall			Winter			Spring			Summer			Total
	October	November	December	January	February	March	April	May	June	July	August	September	
Total treated drinking wastewater (MCM)	2.20	1.96	1.84	1.80	1.80	1.91	1.78	1.97	2.25	2.27	2.27	2.10	24.23
Si ($0.05 \times vi^{0.08}$)	0.09	0.09	0.08	0.08	0.08	0.08	0.08	0.09	0.10	0.10	0.10	0.09	1.05
The percentage of water returned to the T1 treatment plant by applying Si	95.73	95.63	95.57	95.55	95.55	95.61	95.54	95.63	95.75	95.76	95.76	95.69	95.65

Table 10. The amount of consumption and wastewater produced from industry in the region and the ability to transfer to the treatment plant T3

Industrial water consumption	Fall			Winter			Spring			Summer			Total
	October	November	December	January	February	March	April	May	June	July	August	September	
Total wastewater in 2021 (MCM)	0.948	0.948	0.948	0.9475	0.948	0.948	0.948	0.9475	0.948	0.948	0.95	0.948	11.37
Return water from the industry to the aquifer	0.711	0.711	0.711	0.711	0.711	0.711	0.711	0.711	0.711	0.711	0.711	0.711	8.528
Total wastewater treated in 2027 (MCM)	1.49	1.49	1.49	1.49	1.49	1.49	1.49	1.49	1.49	1.49	1.49	1.49	17.9
Aquifer consumption according to Scenario S3	0.544	0.544	0.544	0.544	0.544	0.544	0.544	0.544	0.544	0.544	0.544	0.544	6.53
Consumption from T3 according to Scenario S3 (MCM)	0.366	0.366	0.366	0.366	0.366	0.366	0.354	0.354	0.354	0.354	0.354	0.354	4.3158

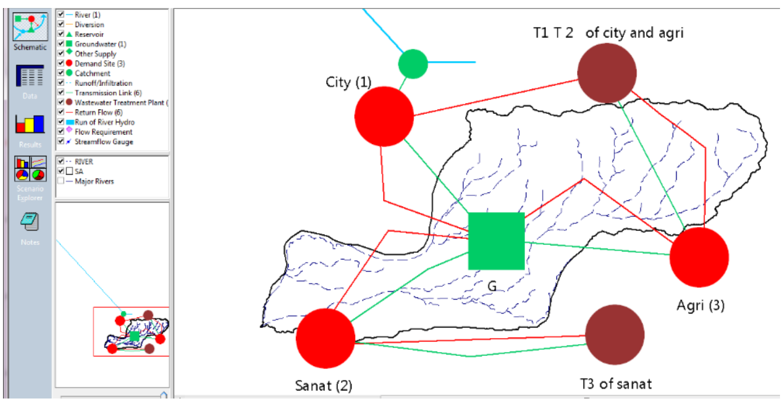

Figure 4. The WEAP model of the Hashtgerd aquifer

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Table 11. Aquifer consumption and aquifer recharge through it by applying scenarios

Consumption types	Consumption from the aquifer in 2021	Consumption from the aquifer in 2027	Aquifer recharge through consumption
Drinking	22.65	28.35	0
Industry	11.32	17.9	0
Agriculture	285.68	228.31	93.6
Total	319.56	274.56	93.6

Table 12. The optimized aquifer balance due to applying the scenarios (MCM)

	Variable	Value
Aquifer recharge	Groundwater inflow (Q_{in})	102.29
	Infiltration from precipitation (Q_p)	28.87
	Infiltration from surface flow (Q_r)	48.87
	Infiltration from agricultural consumption (Q_i)	93.6
	Infiltration from drinking and industry (Q_{sw})	0.00
	Total recharge	273.63
Aquifer discharge	Discharging wells, springs and aqueducts (Q_w)	247.56
	Drainage (Q_d)	0.00
	Evaporation from the aquifer (Q_{eg})	0.00
	Groundwater outflow (Q_{out})	23.97
	Total discharge	271.53
	Change in groundwater volume (ΔV)	2.10

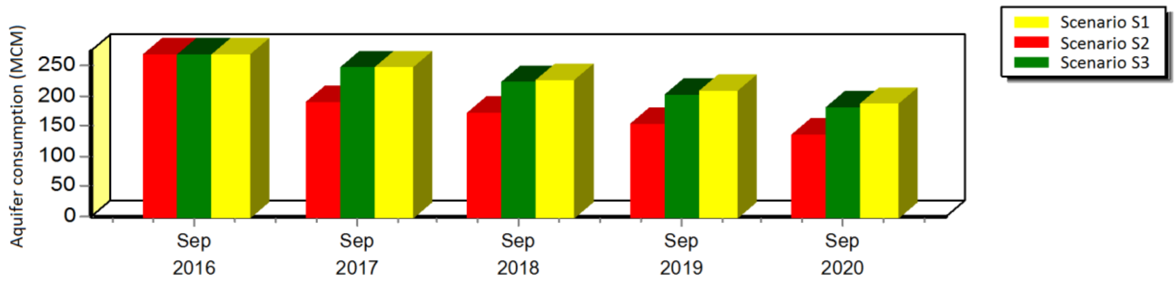

Figure 5. Simulating the ability of scenarios in reducing the aquifer consumption

4. Limitations and Future Research

The present study focused mainly on the quantitative aspects of conjunctive water resources management. Wastewater quality parameters such as BOD, COD, TDS, heavy metals, and pathogens were not investigated because of data limitations. Furthermore, no formal uncertainty analysis was conducted. Future studies are recommended to assess reclaimed wastewater quality according to irrigation standards and incorporate uncertainty analysis using sensitivity analysis and Monte Carlo approaches.

5. Conclusion

The Hashtgerd aquifer is considered to be a relatively suitable alluvial aquifer. However, its limited recharge from the surface water resources of the plain, the reduced recharge from precipitation, over-exploitation, and the climatic change have severely affected the groundwater table in the region. According to the hydrograph of the plain, we are facing an average annual groundwater level drop of about 20.32 m. Considering the importance of the groundwater resources of the Hashtgerd aquifer in the drinking water supply of the region, the possibility of replacing it with other sources in order to preserve the groundwater resources of the region and to balance the groundwater table, it is necessary to use unconventional water sources as a new potential water resources to meet various water needs. and use agriculture. This is possible by constructing water treatment plants for the supply of agricultural and industrial water, so that we can use the agricultural and drinking wastewater for agriculture, while the industrial wastewater for industrial needs by purifying the effluents according to the relevant standards. To

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improve the aquifer conditions, the optimized aquifer balance was calculated in 2027 by applying scenarios of construction of a water treatment plant for agricultural use with the input of drinking and agricultural effluents, as well as the construction of a wastewater treatment plant for industrial use. In addition, a scenario for the population growth with a rate of 3.4% was considered according to the reports of the Iranian Statistics Center. Based on these optimized scenarios, the drop in the groundwater level of the Hashtgard aquifer will not only reach zero, but the balance will reach to +2.10 MCM. In addition to these cases, it is necessary to continue banning and reducing the development of exploitation of the plain, and to prevent unauthorized exploitation by applying monitoring systems.

This study demonstrated the potential of scenario-based conjunctive management of surface water, groundwater, and reclaimed wastewater for improving groundwater conditions in the Hashtgerd aquifer. The results showed that agricultural water demand plays a dominant role in groundwater depletion, whereas the reuse of treated wastewater can considerably reduce pressure on groundwater resources. The proposed management scenarios indicated that groundwater balance can be improved under future conditions. These findings provide useful information for sustainable water resources management in arid and semi-arid regions. Future studies should focus on wastewater quality assessment, economic evaluation, and uncertainty analysis.

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Authors' Contribution
All authors had equal contribution in writing, review, and final approval of the paper.

Availability of data and materials
Data used in this research were obtained from Iran Water Resources Management Company and Iran Meteorological Organisation. The data are not available to share.

Conflict of interests
The authors declare that there is no conflict of interest.

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