The Artificial Recharge of Hashtgerd Plain (NW of Iran)

HOMAYOUN MOGHIMI
Geology
University of Payam-e Noor
No. 8, 5th Alley, Baluchestan St., Gisha St., Tehran
IRAN

Abstract: The climate of Iran is arid and semi-arid. One of the regions affected by excessive exploitation of ground water resources is Hashtgerd plain in the north west of Iran. To prevent the ground water level fall_ 2 to 4 m during the past ten years_ the Artificial Recharge Plan is suggested. The water required is provided from the Kordan River which has an average recharge volume of $3.5 m^3/s$ from February to May. Hydrogeologically, experiment results show that the alluvium has transmissibility of about $3500 m^2/day$, vertical and horizontal hydraulic conductivity of 2 and 14 m/day, and the storage coefficient of 7% to 9%. To calculate the basin dimensions Houisman, and for the ground water level rise after artificial recharge, Hantush and Todd methods are applied.

Key-word: Artificial recharge, infiltration basin, rise, Houisman method, Hantush method, Todd method.

1 Introduction

In recent years, the growing flow of population and consequently excessive use of water resources in Iran, which is considered as an arid and semiarid area has led to perilous results. One of the solutions is the optimized use of surface water resources and transmitting them to ground water. In this respect, concerning the geological, climactic, water resource potentiality, industrial, etc conditions, and different methods of artificial resources can be used. The primary researches and artificial recharge has been done in Ghazvin plain in 1969, Varamin (SE of Tehran) and Naz (NE of Iran in Caspian Sea basin) plains in Sari [2, 9]. Due to excessive use of water resources in Hashtgerd plain and in order to enrich it, artificial recharge has been suggested. Present study is an attempt to analyze the optimal method and location of artificial recharge and its effect on the aquifer.

2 Procedure and Methodology

Hashtgerd plain is about $583.4\ Km^2$. The area is located between latitude of $36^{\circ}, 45' - 36^{\circ}, 05'$ and longitude of $50^{\circ}, 30' - 50^{\circ}, 55'$ (fig.1), and suggested for artificial recharge (fig. 2) is situated in the south of Kordan Village. The area is formed by plioquaternary alluvia and is of great significance from the hydrogeological point of view. Rieben [3] has analyzed these alluvia and divided them into four series of A (Hezardereh series), B (Kahrizak series), C (Tehran series), and D (fig. 2) [3] as follows in table1:

Table 1 Geological specifications of Hashtgerd plain and artificial recharge area

Series	Geological Specifications	Age
D	Cobble and gravel, sand	Recent Era
C	Gravel, sand, silt and clay, forms the main aquifer; significant thickness, high permeability; more tiny-grain materials as you go towards the south (Rieben, 1955)	Quaternary
B	weak cement, gravel and sand, and silt; darker and more heterogenic than A (Rieben, 1955), unconformity with A series	plio-Pleistocene
A	Conglomerate, sand and gravel and lime, semi-hard cement; Dip 5° to 20° toward the south (Rieben, 1955) unconformity with Upper Red Form. & E Form.	Pliocene
M	Upper Red formation; evaporative sediment (gypsum, anhydrate) Clay & Silt stone, unconformity E&A series	Upper Miocene
E	Volcanic Material (Andesine, Tuff, Basalt, Shale), limestone and agglomerate	Eocene

2.1 Meteorology of Hashtgerd Plain

The average annual temperature of the Kordan River drainage basin is 8.7° C and of Hashtgerd plain is13.2° C (Karimabad station). To analyze the annual range of evaporation in this area, Karimabad station is used. This range is about 2000 to 2300 mm in the plain area; the maximum range refers to June and July and the minimum range refers to January and February. Regarding the 25 year precipitation statistical information in Karimabad and Kordan (Dehesomee) stations, the annual average precipitation is 196.5 mm in Karimabad, and 331.3 mm in Kordan. Moreover, the annual average precipitation gradient in Hashtgerd plain follows the equation [1, 5] (1):

$P = 0.3006\ H - 132/12$ (1)

In this equation: P, average precipitation in mm and H, altitude of mean sea level, m. so, annual precipitation of Hashtgerd plain is 240 mm. The climatic conditions of Hashtgerd plain are used De Martonne and Emberger [1] methods. Applying these methods, Hashtgerd plain is semi arid, dry and cold.

2.2 The Kordan River Discharge and Sedimentation

According to a 44year report, the Kordan River has annual average rate of flow of about $3.52 m^3/s$ [6, 7]. The maximum rate of flow in April and May is $12 m^3/s$, and the minimum in August and September is measured about $0.5 m^3/s$ [5]. In order to have an artificial recharge in this region, we can use $3.5 m^3/s$

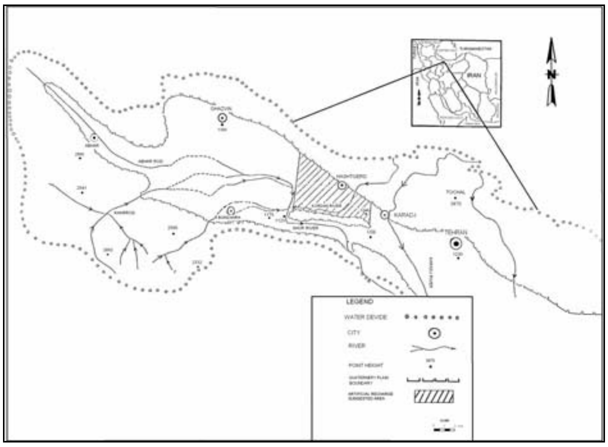

Fig. 1Drainage basin map of the Shoor River

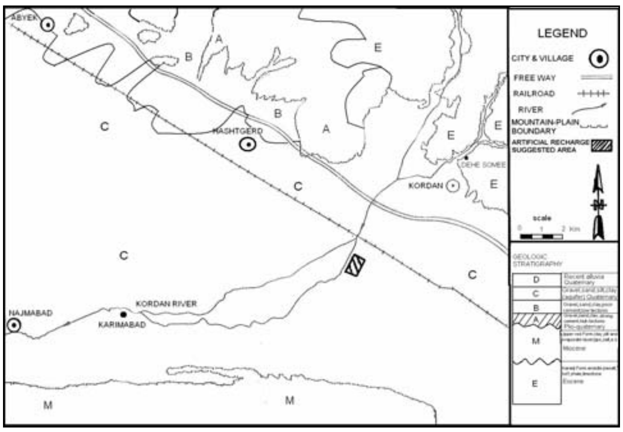

Fig. 2 Geological maps and the optimal location for Hashtgerd plain artificial recharge.

water, on average, from February to May. Regarding the run-off, the chemical quality of the river water and geological specifications of the region, it carries 123.28 thousand tons sediment (suspensions and load bed) during the four months recharge time [5].

2.3 Hashtgerd Plain and Kordan River Hydrogeology and Water Quality

Hashtgerd plain(budget area) is located in 70 km of NW Tehran and is over 583.4 Km^2.The supplying resources of Hashtgerd plain aquifer are generally the Kordan River, seasonal rivers, and agricultural water recursion and urban sewage. The local Water Organization has recently drilled 45 piezometric wells to monitor the ground water level fluctuations. Drawing the level maps and analyzing the ground water budget maps (fig. 3), the direction of ground water in the area is from NE to SW and has a hydraulic dip of 0.025. Also, the depth of ground water surface is between 50-60m in the artificial recharge area. In order to determine the annual fluctuations of ground water level and changes in water supply of Hashtgerd plain aquifer reservoir, and applying the information of piezometric wells of area, a four-year hydrograph has been achieved. As can be seen in the hydrograph, during these four years, various changes are seen; especially, there is a 1.7m drawdown in 1996-97 water years [8]. Generally, during the last 10 years, there has been a 2-4m drawdown. In recent years, due to excessive use of water, there is a 0.4-0.6m drawdown annually in ground water on average. Therefore, to gain accurate information about the characteristics of the aquifer, some exploration wells have to be drilled in the area. The geological and hydro-geological specifications of Hashtgerd plain are defined in table 2[5].

To know this, there has been a regular sampling of ground water and the samples have been examined by chemical analyzing. Considering the direction of the water flow, the quality deteriorates as we go from recharge to discharge, however, the amount of EC increases. Regarding the amount of EC, pot ability, agriculture and industry, we can conclude that artificial recharge by the Kordan River does not cause any change in the quality of ground water [5] (table 3).

2.4 The Budget of Hashtgerd Plain Water

To analyze the budget of ground water resources, the information of 1993-94 water budgets are used.

Regarding the unit hydrograph, there is a rise in water storage compared to the previous years.

Table 2 Hydrogeological and hydrodynamic Specifications of Artificial recharge.

	Hydrogeological Specifications	S %	K m/day	T m²/day	Porosity %
Permeable	Significant in terms of water resources	7- 9	5-20 in the **N**, 0.86-1.5 in the **S**	3000 - 4000	25 - 50
Semi permeability	Series B Poor water resources	_	1.5 – 4.5	50 – 900	25 -40
low permeability	Series A	_	1- 0.86	160	35
Impermeable	M & E Insignificant in terms of water resources			very low	very low

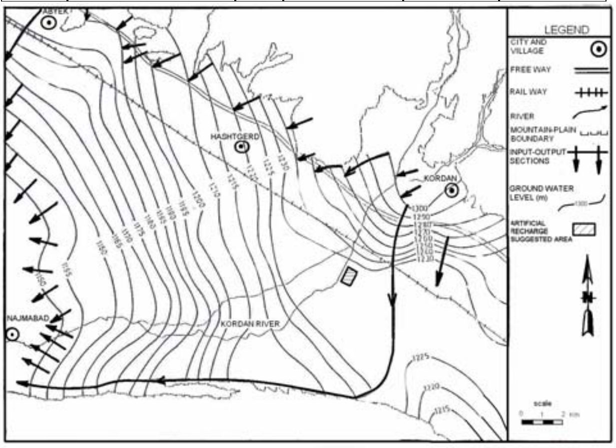

Fig.3 Water level map of ground water and Hashtgerd plain budget area.

Table 3 Chemical quality of Kordan River and ground water around artificial recharge area.

Location Quality	Kordan River	Ground water (artificial recharge)
Schoeller	Potable	Potable
Wilcox(Agriculturally)	C_2 S_1	C_2 S_1
Langelier	Corrosion & sedimentation	Corrosion &Sedimentation
Ec(μmho/cm)	150-500	>300
Water type	HCO3	HCO3

Having applied unit hydrograph method [8] and drawn water level change map (1993 min- 1994 min) the level of ground water has a rise of 76cm (Δh). The volume of input water to the aquifer is 276.8 MCM and of output is 259MCM. In order to calculate the storage coefficient of the plain, the budget method and below formula (2);

$$\Delta V = \Delta h \times A \times S \qquad (2)$$

are used. In this formula ΔV stands for storage volume changes, Δh for ground water level changes, A for the budget region area and S for storage coefficient. Considering the storage coefficient as the unknown, the average of total Hashtgerd plain is 4.5% and as for the artificial recharge area is between 7-9% taking the soil texture, transmissibility and permeability coefficient into consideration. In the last 25 years, due to excessive use, Hashtgerd plain has had a decline in ground water level. Although in some years there has been an increase in the water level, it generally has an average annual fall of 0.4-0.6m. In this regard, to prevent the fall, the artificial recharge plan in Hashtgerd plain is suggested [5].

2.5 The Artificial Recharge of Hashtgerd Plain

Generally, aquifers can be used as natural storages to store surface water in wet periods for dry periods. In the studied area, considering the growing population, building constructions and industrial and agricultural foundations have led to a decline in ground water level and basically in aquifer storage volume and, therefore, in near future, Hashtgerd plain will face water supply problem. Accordingly, to prevent such problem, there must be a careful study to analyze and determine the exact location for artificial recharge. In the present study, the method, the optimum location, and the effects of the artificial recharge on the aquifer are analyzed. The specifications of the suggested place [5]:

1. The depth of ground water is between 50- 60m.
2. In last ten years, the decline of ground water in the area has been on average between 2- 4m.
3. The direction and dip of ground water is from northeast to southwest.
4. The transmissibility in the area is on average 3500 m² / day and aquifer thickness about 250 m.
5. The electric conductivity of ground water and Kordan River is about 300 μ mho/cm and the quality of water for potation is acceptable according to agricultural viewpoint it is classified as C_2 S_1.
6. Considering the gradation and pumping tests, in the artificial recharge area, the horizontal and

vertical hydraulic conductivity (K) are about 14 and 2 m/ day.

7. Concerning the high transmissibility coefficient and the storage coefficient of the artificial recharge area is on average % 8.
8. The aggregation of the wells and consequently the water consumption in the aquifer is relatively high.

Having mentioned the reasons, the location specified in fig. 2 is suggested as the best place for the artificial recharge. The calculation of the infiltration basins dimensions and the range of ground water level rise in recharge area. To determine this (mound) there are several experimental methods. In this study we can use Houisman [4], Hantush [5] and Todd [10] methods. The explanations are as follows:

2.5.1 The Houisman Method

The equations are for unconfined and deep aquifer with large gradation (Fig. 4).

$q_0 = H \sqrt{KS_0P/T}$ (3) , $B = Q_0 / 2q_0$ (4)

$W = q_0 / V_e$ (5) , $L = \sqrt{KS_0T/P}$ (6)

$A = 2b\,(L+W)$ (7) , $V = \mu\, S_0(L+2W)\, B$ (8)

Q_0: discharge into the basins (m²/ day)

q_0: The amount of permeability in width meter unit of artificial recharge basin (m³/day/ m).

B: Length of the basin , **W:** Width of the basin

V: The volume of infiltration part of influence in the aquifer (m³) , **T:** Time of permeability (day)

L: Radius of influence of artificial recharge near the basin (m), **P:** Porosity(%), **μ:** Storage coefficient (%)

K: Horizontal hydraulic conductivity (m/ day)

V_e: Vertical hydraulic conductivity (m/ day)

H: The thickness of saturation layer (m)

A: The vastness of the infiltration area in the aquifer (m²)

S_0: The maximum height of aquifer level rise in artificial recharge area (m)

The result gained by Houisman method is shown in table 4 plan economic basin dimensions, the water rise is calculated by trial and error method. The maximum height of the aquifer level, considering the basin dimensions, is assumed as 25 m and so the entire vastness of the basins is 79562.12 m^2, which is equal to six basins with 60 m width and 200 m long. Estimating the rise rate as 25 m, the radius of influence around the basins is 374.12m and the hydraulic dip above the water table is about % 6.7 [5], which applying this formula (9);

Q= T.L.I (9)

Q: Discharge (m^3/day), L: Length of aquifer (m)

T: Transmissibility coefficient (m^2/day)

I: Hydraulic dip (%)

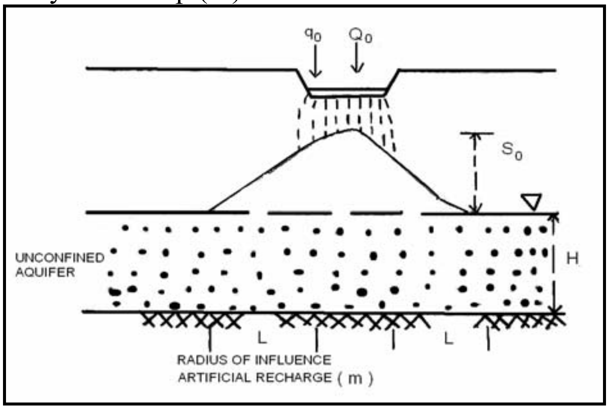

Fig. 4 The rate of ground water level rise caused by artificial recharge with Houisman method.

The volume of infiltrated water by artificial recharge in four months (120 days) is 21055473.6 m^3. Also, the discharge from the Kordan River in the time of artificial recharge is measured as 36288000 m^3 and consequently, the infiltration efficiency will be %58. As was explained before, there is average annual drawdown of about 0.4 to 0.6 m due to excessive use in Hashtgerd plain. By artificial recharge $21\times10^6 m^3$water will be added to the aquifer in 120 days.

Table 4 The summary of the results gained by Houisman method [5] in Hashtgerd plain.

Parameter	Calculated
The discharge for artificial recharge (Qo) m^3/ s	3.5
The storage coefficient in artificial recharge (μ) (%) (S_y)	8
The aquifer thickness (H) (m)	250
Porosity (p) (%)	30
The average transmissibility (T) m²/ day	3500
Horizontal hydraulic conductivity (K) m/ day	14
Vertical hydraulic conductivity (V_e or V_{am}) m/ day	1.9
Maximum rise height in recharge time (S_o) (m)	25
Infiltration duration in artificial recharge area (t) month	4
Radius of influence from basin wall (L) m	374.12
The rate of infiltration in length of artificial recharge basin (q_o)m³/day/ m	259.2
The width of artificial recharge basin (W) (Bre)(m)	136.4
The length of artificial recharge basin (B) (Lre) (m)	583.3
The vastness of artificial recharge basin (A_o) (m²)	79562.12
The vastness of aquifer rise for recharge (A) m²/ recharge time	595572.6
The volume of aquifer rise by recharge (V) m³/ recharge time	754696.8

For instance, in water budget 1996- 97, the rate of drawdown in the whole plain was 1.7 m and the storage volume shortage was 35 million m^3. It follows that by artificial recharge we can add 21 million m^3 which can prevent the drawdown [5].

2.5.2 Hantush Method

The Hantush equation for the height of rising water in hydrated layers and under rectangular basins (Fig. 5) is as follows (10):

$h_{x,y,t} - H = V_{am} / 4S_y [F(\alpha_1\beta_1) + F(\alpha_1\beta_2) + F(\alpha_2\beta_1) + F(\alpha_2\beta_2)]$ (10)

$\alpha_2 = [B_{re}/2 - X] \sqrt{S_y/4Tt}$, $\alpha_1 = [B_{re}/2 + X] \sqrt{S_y/4Tt}$

$\beta_2 = [L_{re}/2 - Y] \sqrt{S_y/4Tt}$, $\beta_1 = [L_{re}/2 + Y] \sqrt{S_y/4Tt}$

S_y: Storage coefficient (%)

$h_{x,y,t}$: Rise level anywhere in **t** (m)

H: The aquifer thickness (m)

x, y: the basins coordinate in relation to the basin center (0, 0)

B_{re}: The basin width (m)

L_{re}: The basin length (m)

$h_{x,y,t}$ - H: Ground water level rise in t (m)

V_{am}: Infiltration speed (m/ day)

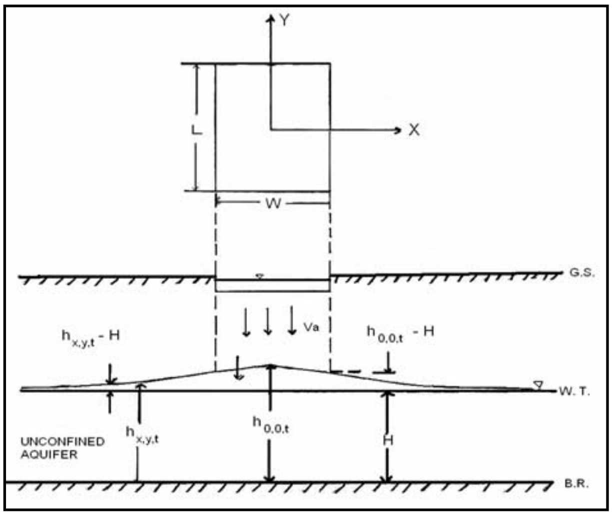

Fig.5 Ground water rise under rectangle basin by Huntush method.

The results gained by Hantush equations can be found in table 5, with storage coefficient of %8, infiltration rate of 1.9 m/ day and transmissibility coefficient of 3500 m²/ day. The length and width of the basins measured by Houisman method for basin center of X= 0, Y= 0 and the time of 120 days. In the second row the rise is measured by X= 20, Y= 0 in 120 days, and for the third row X=0, Y= 200 in 120 days. Table 6 shows the results gained for drawdown 30 days after the infiltration stop.

Table 5 The height of ground water rise during recharge by Hantush method [5].

Rate of rise	F	S_y (%)	V_{am}(m/day)	m²/ day)
$h_{0,0,120}$ -H 25.36m	0.0364	8	1.9	3500
$h_{20,0,120}$ -H 24.22m	0.034	8	1.9	3500
$h_{0,200,120}$ -H 24.72m	0.0347	8	1.9	3500

Table 6 Drawdown 30 days after infiltration stop by Hantush method [5]

T(m²/day)	3500
V_{am}(m/day)	1.9
S_y(%)	8
F	0.032
$h_{0,200,120}$ - H	28.5
($h_{0,0,150}$- H)- ($h_{0,0,120}$-H)	3.14
Drawdown(m)	22.22

2.5.3 Todd Method

Applying the relations and equations given by Todd and using the diagram, one can estimate the variations of ground water level effected by artificial recharge in the recharge area [10] (Fig. 6).

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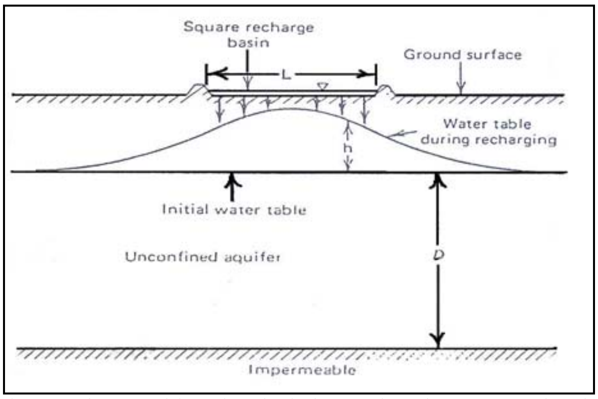

Fig. 6 The aquifer rise height under the square basin in Todd method.

The relations are as follows (11),

$L / \sqrt{4Tt / S}$, $h S / Wt$ (11)

In this relation;

t: Time of recharge (day)

L: The length of square equal to artificial recharge basin (m)

W: Rate of infiltration (m/ day)

h: Height of water level rise after artificial recharge (m)

T: Transmissibility coefficient (m^2/ day)
S: Storage coefficient (%)
The rate of rise 120 days after starting the recharge calculated by Todd method are shown in table 7.
In Houisman method, the basin dimensions are calculated by considering the gradation, permeability and transmissibility coefficient specifications of unsaturated part, and regarding the fact that the ground water rise has been measured by try and error method. In Hantush and Todd method, by specifying the basin dimensions, the water rise is determined. The difference between Hantush and Todd method is in the shape of the basins, i.e. rectangular for Hantush and square for Todd method. Table 8 shows the comparison of the three methods regarding the rise after 120 days.

Table 7 The height of ground water rise during the recharge by Todd method [10].

h (m)	t (day)	S (%)	T (m^2/day)	W (m/day)	L (m)
25.65	120	8	3500	1.9	282

Table 8 The comparison of the three methods 120 days after the beginning of recharge and the water rise rate.

Method	Time (day)	Rate of rise (m)
Houisman	120	25
Hantush	120	25.36
Todd	120	25.65

As can be seen in table- 8, the difference of the rate of ground water level, calculated by three various experimental methods is very low. In Houisman method, the length and width of the basin are measured by the maximum rate of rise. Accordingly, the whole basin is 120 m × 600 m, which is equal to six 60 m ×200 m basins [5] (table 9).

Table 9 The number and dimensions of artificial recharge basins based on ground water rise rate.

Type of recharge	number	Artificial recharge basins Length (m)	width (m)
basin	6	200	60

Regarding the average of other two methods, the water rise rate in Hantush method seems more acceptable. Considering the dip of the artificial recharge area, the rectangular basins and consequently the Hantush method are more suitable. In this study, we are not supposed to concern the basin design hydraulically.

2.6 Results and Suggestions

2.6.1 Results

The suggested location that is hydrologically and geologically suitable for artificial recharge is in the south of Kordan village.

- Based on the De Martonne method, the area has semi-arid climate.
- The ground water level in the artificial recharge area is 50 to 60m deep and the saturation part thickness is 250m on average. T, K and S have high potentiality, See table 4. The storage coefficient of the artificial recharge area is %8.
- The water needed for artificial recharge is provided by the Kordan River, which is 3.5m^3/s and is specified for the recharge system from diverting channels in February to May.
- The chemical quality of the Kordan River is great for potation; however, the high amount of sediment which is estimated as 123.28 thousand tons in a four month artificial recharge is a restricting and problematic matter.
- Many reasons have caused a decline in ground water level (0.4 to 0.6m p.a. on average) in the area. As a result, the best method of artificial recharge for the studied area is the basin method.
- Through trail and error and applying the three mentioned methods, to measure the basin dimensions and the rate of ground water rise, the base of the calculations is 25 m and consequently, the optimum dimensions of the basins is about (120 × 600) m^2, which is equal to six (60×200) m^2 basins.
- The volume of the Kordan River water used for the artificial recharge is 3.63 × $10^6 m^3$ and the volume of the water that will infiltrate is 21× $10^6 m^3$. As a result, the efficient infiltration rate will be 58%.

2.6.2 Suggestions

- To determine the infiltration and the lithological and gradation changes of the layers, it is necessary to drill min. 2-4 wells in the artificial recharge area to take some undisturbed samples. Furthermore, pumping test for determining the exact hydrodynamic coefficients of the aquifer is essential.
- Sampling from the Kordan River water, performing all biological, hygienic and chemical experiments are necessary.

- Having experiments to determine the V_e in the artificial recharge area.
- Drilling some piezometric and exploration wells around the recharge area to measure the ground water level fluctuations during the artificial recharge.
- Regular sampling and testing of the Kordan River water in order to control the amount of the sediments (suspensions + bed load).
- Estimating the cost of planning, constructing foundation, maintenance and the project efficient lifetime.
- The relevant authorities (The Ministry of Power and Agriculture, etc.) must recognize and determine the location and ID of all illegal wells in the Hashtgerd Plain and stop drilling any further wells in order to prevent excessive consumption of ground water resources.
- There should be some proper methods to have optimum consumption of surface water in order to enrich the ground water, i.e. artificial recharge.
- Applying proper agricultural methods to have an optimum use of ground and surface water.
- Finding suitable methods for recycling urban and industrial sewage.

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