The Study on the water budget of Hashtgerd Plain in North West of Tehran, Iran (Kordan Basin)

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

Abstract: As Iran has semi-arid to arid climate, ground water resource application is of significance importance. The Hashtgerd plain is also one of the areas that due to excessive application have faced a sharp fall of 2 - 4m in the ground water level in the last 30 years. Thus, in order to determine the parameters affected the water level fall and to study the plain aquifer situation, a water budget is needed to be prepared.
Hashtgerd Plain is located in 36º- 05´ to 36º-45´ latitude and 50º -30´ to 50º-55´ longitude. The budget area is 468.45 km² and located in the north west of Tehran.
The budget elements were examined one by one by applying different methods and the present equations for the ground water. Then having applied the general budget equation, the reservoir volume changes for the water year 1996-97 were studied and calculated. In the calculations, two items were considered: first, it was confirmed that there has been a fall in ground water level and a decrease in aquifer reservoir volume of Hashtgerd plain, secondly, the reasons for the fall and reduction were studied and clarified.
Based on the present situation of the plain it is necessary for the relevant organizations esp. the Ministry of Power and Agriculture to have a joint project with a joint planning together. There should be some short, mid and long term projects and the mid and short term there must be a strategic management to keep the water level stable. For the long-term projects, the objective should be focused on both water and agricultural. In order to increase the volume of the aquifer since if the present utilization from the aquifer is continued, it will no longer meet the people's requirements in the near future or might be totally vanished.

Key-words: water budget, budget elements, budget area, water year, Kordan basin, Hashtgerd plain

1. Introduction

As Iran has arid and semiarid climate, water is an invaluable asset and using it needs proper programming and sometimes a critical management. In order to accomplish any type of water plans, the first step of programming will be gathering data. Afterwards, having applied different approaches, the plan can be put into effect.
In hydrological plans, water budget is considered as one of the main elements as it is essential for optimized utilization and water resource management. Thus, the water budget of Hashtgerd plain (Kordan Basin) is prepared due to its critical situation and status.
During the past forty years, the water consumption of Kordan basin has dramatically increased because of the increasing number of population, which has been migration, expansion of farms, establishing numerous factories and because of being close to Tehran and having good weather, which has changed it to a famous countryside, etc. Consequently, excessive water consumption has caused not only water pollution in this area, but also a fall in the level of ground water, which is more significant.
The sharp fall in the level of ground water in Hashtgerd plain has been studied by different researchers, private companies and state organizations and in the papers where the fall in ground water level and the decrease in aquifer volume and pollution can be read.
In the present study, the water budget of water year 1996-97 has been prepared based on the previous information and measurements [12, 14].

2. The study approach of water budget preparation

In order to examine the ground water budget of the area of the study, there should be precise information about recharge, input flow, discharge and utilization of water resource, draining, evaporation and finally changes in the ground water level and volume of the reservoir in a certain period and area. In the present study, the following equation1 has been applied [1, 2, 10, 15, 16, 17]:

$$Q_{in}+Rp+Rr+Rw-[Qout+D+E+W] = \pm\Delta V \quad (1)$$

In equation 1, the budget parameters are defined as follows:

Qin: ground water input to the budget area
Qout: ground water output from the budget area
Rp: rate of direct rainfall water infiltration
Rr: rate of recharge from the floods
Rw: rate of infiltration of agricultural water return
D: draining from the aquifer by any draining
E: rate of evaporation from the shallow water aquifer surface in the budget area
W: ground water discharge
±ΔV: the changes in the reservoir volume of aquifer in a certain time and place

2.1 The geographical, geology and the climatic situation of the budget area

Hashtgerd plain is situated at 36º-05′ and 36º-45′ latitude and 50º-55′ to 50º-30′ longitude (Fig. 1).

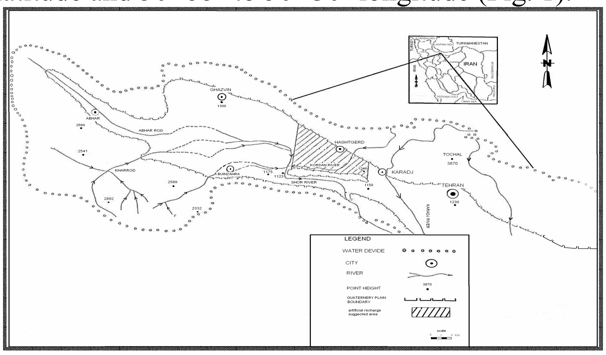

Fig. 1 the geographical situation of the study area

The budget area is 468.45 km² wide and in North West of Tehran between Kordan and Abyek (Fig.2). The area is formed by plio-quaternary alluvia and is of great significance from the hydro-geological point of view (Fig. 2) which is chronologically as follows in table 1[4, 6, 9]. In order to examine the climatic condition and by using the meteorology stations in the study area and its surroundings, the average annual temperature of Hashtgerd Plain is 13.2ºC. The annual evaporation rate based on the present statistical information is 2000 to 2300 mm and has its upper most time in June-July and the lowest amount in Jan and Feb [1,9, 11, 13]. The 25 year statistical information (1971-1996) shows that that average gradient of annual precipitation of Hashtgerd Plain has been obtained by using the equation 2;

$$P = 0.3006H - 132.12 \quad (2)$$

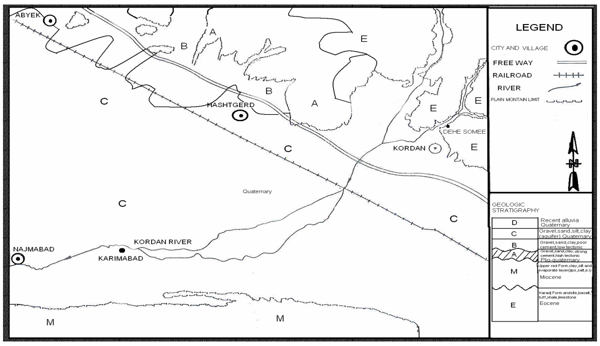

Fig. 2 the geological map of budget area

Table 1 geological specification of budget 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, 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

Based on the equation 2, the average precipitation of Hashtgerd Plain is 240 mm and in the water year 1996-97 this rate is 130.5mm. To determine of the climatic situation of Hashtgerd Plain, De Martonne and Emberger approached have been used. The plain is semi-arid according to De Martonne, dry, and cold according to Emberger [1, 9, 12, 14].

2.2 The Budget Elements Calculation

The budget elements have been examined one by one in this section [2, 12, 14, 15]:

2.2.1The input ground water flow into the budget area (Qin)

The input sections of the ground water were studied, examined with respect to the budget area map (Fig.3), the transmissibility coefficient map (Fig. 4) and based on the Darcy equation. Darcy equation is **Q=T.L.I** that can be used in table 2. According to table 2, the rate of input water into the aquifer reservoir in water year 1996-97 is 37.118 MCM.

2.2.2 Surface recharge of the budget area

In the budget area, precipitation, floods, agricultural water return, sewage and the base flow of the river, which depend on climatic situation, weak plants coverage and geological structures, do the surface recharge.

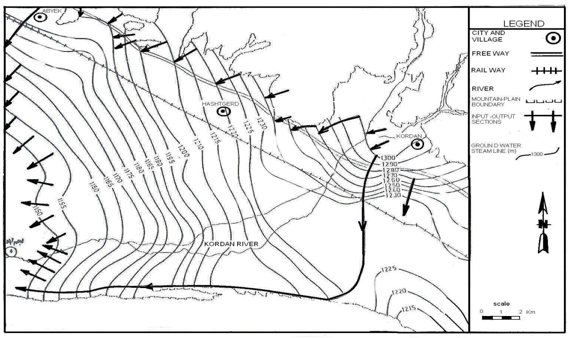

Fig.3 the ground water input – output direction of budget area in Hashtgerd plain

Table 2 the input ground water flows in different sections into the budget area of Hashtgerd Plain in water year 1996-97(* Million cubic meter) [12, 14].

Section no.	(L) (Km)	(I) 1.1000	(T) m²/day	Budget Period (day)	(Q) MCM*
1	0.77	12.94	810	365	2.946
2	1.65	8.8	624	365	3.307
3	1.7	7.85	360	365	1.753
4	0.88	13.75	360	365	1.590
5	1.02	10.47	250	365	0.955
6	2.2	12.94	270	365	2.805
7	2.97	13.75	280	365	4.174
8	3.63	4.4	960	365	5.596
9	1.92	5.79	1350	365	5.478
10	1.18	6.28	1100	365	2.975
11	1.15	6.47	840	365	2.281
12	1.37	3.66	500	365	0.915
13	2.31	2.75	480	365	1.113
14	1.65	3.55	480	365	0.737
15	1.54	2.44	360	365	0.493
Total	25.94			365	37.118

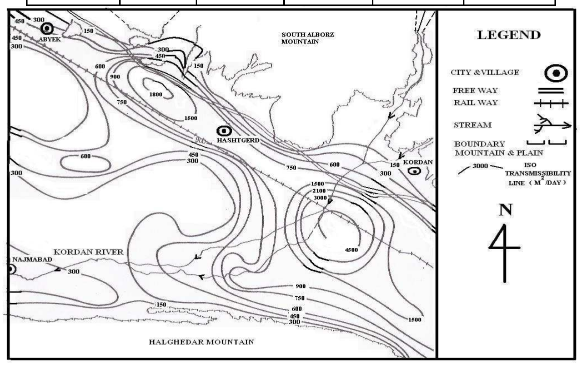

Fig.4 the transmissibility map in the budget area

- Recharging the budget area by precipitation (Rp)

In order to calculate the budget area recharge by precipitation or the rate of infiltration, two methods, Thronthwhite and referring to F.A.O periodicals are used. In these two methods, parameters such as precipitation, temperature and potential evaporation are considered.

A. Calculating the recharge by referring to F.A.O periodicals and using the following equation 3[5,14]

$$F = 0.8\,(R - C \log E)^{1.5} \qquad (3)$$

In equation-3, the parameters are defined as follows: **F:** the rate of infiltration in a month (mm),**R:** monthly precipitation, **C:** temperature coefficient of infiltration, which depends on temperature, **E:** Monthly potential evaporation (mm).

The summary of the calculation can be seen in table 3. In water year 1996-97, the total infiltration was 8.31 MCM that has been added to the aquifer reservoir (table 3).

B. Recharge calculation applying Thronthwhite approach, the summery of which can be seen in table 4. In this table, Ep is potential evaporation and Etr is real evaporation [12].

Having compared the above approaches, we come to a result that the rates of infiltration are approximately equal; the differences, however, are due to first the faults in measurement and, secondly the shortcomings in the measurement spots.

Considering the 468.45 Km² the budget area and the height of precipitation in the water year 1996-97, this was 130.5 mm. The amount of water Infiltration into the aquifer in F.A.O. method is 8.31 MCM and for Thronthwhite is 8.75 MCM. Considering both methods, the average rate of infiltration in Hashtgerd plain has been 8.53 MCM annually.

Table 3 calculation of infiltration rate in the budget area applying F.A.O for 1996-97[5, 14]

Parameter Month	°C	C	R (mm)	Ep (mm)	F (mm)	F (MCM)
Oct.	16.1	2.08	11.5	110	2.15	1
Nov.	9.3	1.68	2	91.9	0	0
Dec.	5.5	1.34	0	48.7	0	0
Jan.	5.4	1.32	20	48.3	3.37	1.6
Feb.	-0.8	0	5	29.4	1.78	0.83
Mar.	4.7	1.26	33	45.7	4.44	2.08
Apr.	9.6	1.7	46.5	100.3	5.25	2.46
May.	17.1	2.12	5.5	166.5	0.71	0.91
Jun.	23.1	2.34	2.5	214.1	0	0.33
Jul.	26.9	2.38	4.5	249.1	0	0
Aug.	27.8	2.39	0	421.6	0	0
Sep.	21.2	2.28	0	200.6	0	0
Total			130.5	1726.2	17.70	8.31

Table 4 Calculation of infiltration rate in the budget area applying Thronthwhite approach for 1996-97

Parameter Month	°C	Etp (mm)	R (mm)	Etr (mm)	I (mm)	I (MCM)
Oct.	16.1	60.7	11.5	11.5	0	0
Nov.	9.3	23.04	2	2	0	0
Dec.	5.5	10.2	0	0	0	0
Jan.	5.4	0	20	10	5	2.34
Feb.	-0.8	0	5	0	2.5	1.17
Mar.	4.7	11.7	33	11.7	5.6	2.62
Apr.	9.6	25.2	46.5	25.2	5.6	2.62
May.	17.1	15.5	5.5	15.5	0	0
Jun	23.1	2.5	2.5	2.5	0	0
Jul.	26.9	4.5	4.5	4.5	0	0
Aug.	27.8	0	0	0	0	0
Sep.	21.2	0	0	0	0	0
Tot.		789	130.5	82.9	18.7	8.75

2.2.3 Budget area recharge by surface flows and floods (Rr)

Concerning the climatic and the very weak plant coverage situation of the area, one of the most important ways of recharging the aquifer of the budget area is by the surface flows and floods. In the studying area of the Kordan River, there are the main river and many seasonal rivers. By taking the 44-year statistical information of the Kordan River into account, the average discharge is 3.52 m^3/s. The discharge for the other seasonal rivers is obtained by using various discharge methods due to the lack of measurement stations. Considering the amount of river discharge, the physiographic, morphologic situations and the configuration of riverbed soil, the rate of recharge for the Hashtgerd plain aquifer in the water year 1996-97 is totally 39.76 MCM(total recharge amount of rivers, floods and the connecting canals of the Kordan River for agriculture) [9, 11, 12, 14].

2.2.4 The returned water of agriculture and city sewage (Rw)

There are 2099 active wells for agricultural and drinking consumption in the Hashtgerd Plain area. Out of this number of wells in the water year of 1996-97, about 200.59 MCM of water has been discharged. The total amount of water used for agriculture is 166.78 MCM and by considering the type and the texture of soil and the watering system in Hashtgerd Plain and if we consider the agriculture water return as %40, then there would be 66.7 MCM water return into the aquifer. Concerning the information about the studying water year, about 33.81 MCM of water has been used for drinking and industrial applications. This is, however, in such a way that the city and village swage and also the factory wastes are discharged through the absorbing wells and consequently, the returned water into the aquifer i.e. its recharge can be estimated as 21.97 MCM with regards to the soil configuration condition which is about %60 [5,7,9, 13, 14].

2.2.5 The ground water output flow from the budget area (Qout)

Once the budget area is cleared, as was explained in the input sections, by using the budget area map (Fig. 3) and Darcy equation, the output section was determined and the volume of output water was calculated (table5). As could be seen in Fig. 3, the hydraulic gradient (I) and the rate of transmissibility coefficient (T) for each output section length (L) was extracted. For the 1996-97 water years the 8.16 MCM, water has exited as output flow from the aquifer of the budget area [8, 12, 14].

Table5 the output flows of ground water in different sections of the budget area in water year 1996-97

No. Sect.	(L) (Km)	(I) (%)	(T) m^2/day	(day)	(Q) MCM*
1	1.77	5.55	250	365	0.896
2	1.25	4	240	365	0.438
3	1.17	2.66	350	365	0.397
4	2.2	3.22	350	365	0.931
5	1.8	3.07	360	365	0.686
6	2.65	2.83	340	365	0.876
7	1.81	2.85	320	365	0.606
8	1.15	2.77	330	365	0.384
9	1.56	3.27	320	365	0.596
10	1.4	3.48	300	365	0.533
11	1.26	3.84	320	365	0.565
12	0.9	4.08	320	365	0.429
13	0.85	4.6	300	365	0.428
14	1.2	4.54	200	365	0.398
Total	20.98			365	8.160

2.2.6 The evaporation from the ground water in the budget area (E)

In order to measure the amount of evaporation in the ground water, it is necessary to draw the iso depth map of ground water level for to determine the depth of under 5-meter deep spots. As the map shows, those spots are mostly seen in the west and southern west of the budget area, i.e. in the outer part of the area. Having determined those spots based on White studies [14], which examines the relation between the percentage of evaporation in relation with pan and the ground water level depth, the volume of evaporated water from the aquifer has been estimated. The volume of the evaporated water in those spots in water year 1996-97 is 1.87 MCM [2, 12, 14].

2.2.7 Discharge from the ground water of the budget area (Qw)

According to the statistical information of the Local Water Organization of Karaj, there are 2099 active wells in the budget area. The working hours, consumption rate and the annual discharge rate of each well have been measured. Based on above inspection, about 200.59 MCM water has been discharged annually [9, 11, 12, 14].

2.2.8 Calculating changes in aquifer reservoir volume in the budget time and area (±ΔV)

To measure the changes in the reservoir volume the flowing equation has been used (equation 4) [7, 12]:

$$\pm\Delta V = [\pm\Delta h].A.S \quad (4)$$

In above equation:

±ΔV: changes in the reservoir volume (MCM)
±Δ h: water level fluctuation (m)
A: the area of the budget (Km^2)
S: the storage coefficient (%)

The water level fluctuation in the budget area have been constantly measured during the study time and also, beside drawing the water level and water level exchange map, the local unit hydrograph (Fig. 5)for the year 1996-97 is drawn by applying the graph of water level fluctuations. Based on the above, as can be seen in the unit hydrograph the water level has risen 1.24 m in wet period and declined 2.94 m in dry period. Generally, the water level in the study year has declined 1.7 m compared with the previous year. According to equation 4, one of the most important parameters is determining the aquifer storage coefficient. Due to the major economical problems, working out on this coefficient depends only on a few pumping test and slug test, which do not include all budget area. By trial and error, approach there has been an attempt to calculate the coefficient [9, 11, 12, 14].

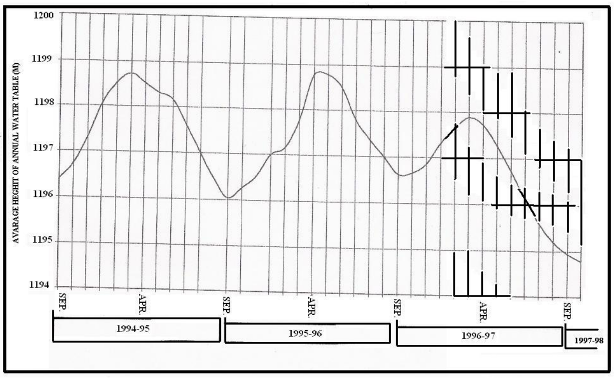

Fig. 5 the unit hydrograph of the ground water level of budget area

As a result, concerning the approaches applied the average storage coefficient for the studying area has been estimated as about %4.5. Knowing the size of the budget area and changes in the aquifer volume in water year 1996-97, in wet period the (Δh = 1.24 m) which equals to 26.13 MCM and in dry period (Δh =-2.94 m) which is -61.975 MCM [14]. Generally, concerning the above calculations in that year when the rate of ground water fall is 1.7 m, the changes in the aquifer reservoir volume of Hashtgerd Plain is 35.83 MCM, which indicates that in water year 1996-97 there has been excessive consumption from the reservoir volume.

The summery of calculations of water year 1996-97 budget parameters are presented in table 6.

One of the main reasons is lack of economical facilities to have explorations in different spots in order to precisely examining the hydrodynamic characteristic of the aquifer. Accordingly, most characteristics have been estimated based on the present information that has also caused some errors. Another reason of having errors is most probably the faults in measurements. The measurements include the ground water level and rivers discharge measurement, and having incomplete meteorological stations, etc.

Table 6 Summery of the calculations of budget parameters of water year 1996-97 in Hashtgerd Plain (Figures are in MCM R: recharge, D: discharge**)**

Descript		Wet Period		Dry Period		Budget Period	
Paramet		R	D	R	D	R	D
Qin		16.22		21.65		37.118	
R. Surface	Rp	4		4.35		8.53	
	Rr	35.25		4.511		39.76	
	Rw	10.64		56.06		66.7	
	Rw	8.188		13.78		21.97	
	Rr	1.277		4.50		5.78	
Qout			3.4		4.76		8.16
Qw			26.6		140.18		166.78
Qw			12.59		21.21		33.81
E			0.29		1.58		1.87
±ΔV		26.138		61.975		35.83	
Total		101.72	42.88	167.01	167.74	216.47	210.63

Moreover, lack of discharge measurement stations for the seasonal rivers, which has made the measurements based on only estimations, is considered as reason for having errors in budget calculations.

Beside the above errors, the number of monthly and annual measurements is few due to the shortage of work force and consequently, changes in aquifer and the rivers cannot be pursued suitably.

3. Conclusion

Iran has arid to semi-arid climate and the percentage of its rainfall is normally low in some areas and very low in some other areas.

Regarding to different reasons such as being near to Tehran which has made it as a summer residence, fertility of its soil for agriculture and the rapid industrial development have caused a lot of people migrate to this area and choose it as their residence, thus, this causes the growth of population. Considering the climatic conditions, the area has limited rainfall. However, with this limited rainfall, firstly because of the absence of infrastructures and then because of the economical problems and also not implementing the related water projects to control and prevent this source from wasting would be impossible and as a result it wouldn't be possible to make a good use from the present potentials of the area. In a way, that consuming the water of Kordan River and other seasonal rivers during the cold months of the year would be impossible and these rivers would finally join the salt rivers and will be destroyed. According to long term statistics and different budgets prepared in the recent years, for instance in the water years 1993-94 and 1996-97 it can be found out that from the year 1994 to 1995 the consumption of water has increased an average of 30-40 MCM. This fact has been proved by the decline of the ground water level .Because during the past 30 years in different areas of the balance sheet the level of the ground water has declined about 2-4 meters. Following to the decline there has been such problems like intrusion the salt water into aquifer, which has penetrated the budget area from the southwest. On the other hand, the everyday increase of the population, increase in the lands under agriculture and increasing number of the factories have caused polluted civil and rural sewage, factory and agriculture wastes enter the aquifer and pollute them.. The budget prepared in the water year 1996-97 shows that in the same year the amount of 35/83 MCM extra water has been used in the aquifer reservoir. The capacity of aquifer reservoir has decreased and this matter has been proved in the plain hydrograph unit with a decline of a 1.7 m.

As explained above, beside the recharge of Hashtgerd Plain aquifer from returned water of industrial, agricultural and drinking applications. It will be done through the infiltration of the surface water especially in the wet months of the year from the bed of Kordan River and other seasonal rivers from alluvial fan southern side of Alborz mountain range. In addition, recharge will be done through the direct infiltration of rainfalls in the rainy months. On the other hand, the aquifer will be recharged through side-recharge of the plain and from the north highlands. In return, there is no side-recharge in the southern heights of the plain due to clay, marl and gypsum sediments in this area, which are considered as impermissible texture. Contrastively, because of decline in the ground water level in this section, salt water has intrusion into the aquifer, which has increased dramatically the amount of salt of the aquifer in the south and south west of the plain.

As was mentioned in the previous sections, because of such a fast growth of population, which has been scarce in the past 30 years, and meantime, equipping cities with such facilities such as sewage canalization system for both cities and villages. Dumping system for the agricultural and industrial wastes has all caused the wastes to be discharged through the absorbing wells. Moreover, concerning the texture and specifications of the soil of the studying area, the wastes would be gradually mixed with the aquifer, which would be considered as one of the main contaminators of the budget area. The farmlands would become bigger as the population grows and on the other hand, in order to produce much more products, more chemical fertilizers would be used whose wastes could be changed into the other source of contamination for the aquifer.

One can conclude from the above discussions that some precise and certain short mid and long-term projects and plans to be planned by some organizations like Ministry of Power and Agriculture together. Also applying some strategic management in the first phases could prevent the increase in losses and damages made so far and would keep the reservoir volume stable. Beside all these long-term issues, informing people via media could help change and improve their viewpoints. Eventually, the above plans can be accomplished by turning such issues into national wills.

4. Suggestions

The explanations given about Hashtgerd Plain budget showed that in order to make the best use of the aquifer, it is necessary to make suggestions as follows to save this aquifer from its critical situation. In this case, before taking the suggestions into consideration, it is necessary to mention that one of the major and the most important problems is lack of enough expert human resource and if this fact is considered as one of the problems, i.e. measurement faults, will be minimized. Beside this problem, the instruments used by experts must be updated according to the latest standards. If possible, the places for measuring could be equipped with the automatic instruments that have been joined to the central computerized system.

- Installation of complete weather forecast and hydrometric stations
- By using GPS, we can find the exact place of the present wells
- In order to prepare a precise budget, it would be better to dig more wells for every 25 km^2 of every individual observation well to get accurate information about water level and specification of the aquifer.
- In preparing the budget the amount of water, input -output are of the great importance. For the conditions being with this few number of exploring wells, we cannot find information about the hydrodynamic coefficients of the aquifer. It is suggested that for every 5 to 10 km^2, an exploring well will be dug and pump testing will be performed in order to have more information for a more accurate budget.
- It is suggested that in order to modify the exact hydrodynamic specifications of the aquifer and the

flow of the ground water the relevant authorities mainly the Ministry of Power and Agriculture carry out more experiments and testing in the area under study to obtain more precise information. In addition, to modify the soil humidity and in order to calculate the rate of the soil infiltration, it is necessary to make a number of lysimeters to cover the whole area cause having this information for the non-saturation part of the soil would be obligatory.

- In the first stage one of the major tasks which should be carried out by the relevant authorities (Ministries of Power and Agriculture) is:

1. Identifying illegally dug wells and blocking them in the budget area.
2. It would be better if legally dug wells could be equipped with gauge instruments to let the well owners utilize with an issued license.
3. To any possible extent prevent people from expanding and utilize the ground water.

- To prepare a budget, having information and statistics from surface water resource would be obligatory thus it is suggested that by considering the critical conditions of the budget area, sampling and collecting statistical figures of the present water resource of the area should be done at least twice a month and in normal conditions once a month.
- In the east coast of Kordan River, a soil canal to give water to the farmers has been built, whereas, being exposed and its soil-like surface, especially in hot seasons a great amount of this water will be evaporated and the left part will penetrate and as a result this way of watering would be less efficient. It is suggested that this canal could help the farmers through closed pipes. In most places of this area, agriculture is being carried out traditionally and in this regard

References

[1] Alizadeh, A., the Principles of Applied Hydrology, Astan Ghods Razavi, Mashhad, Iran, 2004

[2] Castany, G., Traite Pratique des eaux souterraines, Dunod, FRANCE, 1963

[3] C.G.G. Co, Geophysics Study report of Hashtgerd Plain, Tehran, Iran,1967

[4] Darvishzadeh, A., the Geology of Iran, Danesh-e-Emrooz, Tehran, Iran, 1991

[5] F.A.O. Publication No. 38, Geneve, Switzerland, 1980

[6] Geology Organization of Iran, geological map of Tehran, Ghazvin and Saveh with scale 1/250000, 1991

[7] Honarmand E.,I., hydrogeology Educational Curricular, Kavab Engineering Consultancy, 1991

[8] Honarmand E.I., calculating transmissibility coefficient of the aquifer of ground water by using Piezometric and geophysics studies, Bulletin No. 4, 1981

[9] Kavab Engineering Consultancy, Hydrology Report of Hashtgerd Plain, 1998

[10] Ministry of Power, the Office of Water Resource, Observation ways to prepare budget, bulletin No.85, Tehran, Iran,1994

[11] Ministry of Water and Electricity, Head Quarter of ground water, semi descriptive report of Hashtgerd Plain, Tehran, Iran,1972

[12] Moghimi, H., Tahran batisi Karaj ovasinin hydrojeoloji incelemesi, Doktora tezi, Ankara universitesi, Ankara, Turkiye,1996

[13] Pazhouhab Engineering Co., Report of water resource development of Kordan River basin, 1992, Tehran, Iran

[14] Sadjadian, M.,R., Hydrogeology Studies, Artificial recharge and Mathematical Model of Hashtgerd Plain ground water resources, MA Thesis, The Science of Earth Faculty, Shahid Beheshti University, Tehran,Iran,1998

[15] Schwartz,F.W. , Zhang,H., Fundamentals of Ground water, john Wiley &sons, New York, U.S.A.,2002

[16] Todd, D.K., Ground water hydrology, john Wiley &sons, New York, U.S.A., 1980

[17] Torabi T., P. , Ground water Geo-hydrology, Boo Ali Sina University Publication No. 131, 2000