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# Using Hydrological Model and Energy Balance in Estimating Groundwater Table, Case Study: Varamin Plain

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**Abstract**

The main factors that limit agricultural development and food production in Iran are improper and noneconomic use of water as well as water limitation. Improving current conditions and managing water resources require the use of hydrological models which require a lot of field data. Satellite images are appropriate tool to provide required data with the lowest cost that are compatible with improved areas. Therefore the integration of hydrological models and remote sensing techniques can cause better results with the highest compliance with real conditions. In this paper groundwater model of Varamin Plain is produced by integrating remote sensing techniques (SUTSEBAL) and MODFLOW. The results indicate that by using remote sensing techniques, the amount of water which is extracted from the aquifer due to irrigation and evaporation can be identified for each pixel of the model. So, the level of uncertainty of this parameter will decrease and the level of certainty of the result of the model will increase.
**Keywords: MODFLOW, SUTSEBAL Algorithm, Varamin Plain, Hydrological Model**

## 1. INTRODUCTION

Each country needs water for growing and developing. Water is necessary not only for expanding the cities and industries; but also, it is considered as a major factor for agricultural development. Agriculture uses more than 90% of surface water and groundwater yields. Since the population of Iran is growing like other parts of the world, water and soil resources must be exploited optimally and sustainably.

The main factors that limit agricultural development and food production in Iran are improper and noneconomic use of water and water limitation which shows the necessity of making reasonable decisions to optimize water use. So, continuous assessment of water use at different levels in the basin, field and irrigation network is essential for determining the current status and knowing its strengths and weaknesses and finding practical solutions to improve existing conditions. [1]

The first step in evaluating the water use efficiency in the existing condition is estimating the amount of water used in each sector. Evapotranspiration (ET) is one the basic hydrological processes from the viewpoint of agriculture and the net amount of water used in agriculture is equivalent to evapotranspiration from farmlands. So, it is very important to consider this parameter in planning and management of water resources and irrigation development, specially, in arid and semiarid areas such as Iran. Besides, evapotranspiration, as a part of water balance, is effective on hydrological conditions of the study area. Thus, the calculation of evapotranspiration is helpful in management of groundwater withdrawal. On the other hand, available hydrological data is not enough for calibrating the hydrological models and evapotranspiration can be used in adjusting these models.

Several methods have been expanded and tested so far to estimate ET. But the existing methods require a lot of field data that sometimes in many areas are neither available nor compatible with recent changes. Satellite images are appropriate tools to provide required data with the lowest cost that are compatible with improved areas. These images provide reasonable results to make decisions in steering irrigation development by monitoring changes in water use and vegetation land cover in different time intervals and places. Therefore, the integration of hydrological models and remote sensing techniques cause better results with the highest compliance with real conditions. SEBAL (Surface Energy Balance Algorithm for Land) is one of the remote sensing techniques for processing satellite images. This algorithm is a thermodynamics-based model and can be used for estimating evapotranspiration, one of the key components of water balance, in large areas which are faced with lack of field data. SEBAL Algorithm is developed by Bastiaanssen in 1995 and was applied in different studies in many areas to estimate the rate of the evapotranspiration.[2,3] In this paper, using an algorithm similar to SEBAL entitled as SUTSEBAL, net agricultural water consumption has been estimated through calculation of actual ET ($Et_a$) in Varamin plain. This algorithm has been developed at Sharif University of Technology, Civil Engineering Department by changing some of the relations defined in SEBAL algorithm .SUTSEBAL algorithm has been applied successfully in Sistan and Ghara Soo Subbasin by EWRC (Environment and Water Research Center).

By estimating agricultural water consumption, as a key element of groundwater balance, the hydraulogical models such as MODFLOW can be produced, performed and calibrated more precisely, and such models could be used in evaluating various managerial policies.

Different studies have been carried out in this respect in various parts of the world:

Immerzeel et al. (2007) using SEBAL algorithm and SWAT (hydrological model) have estimated water consumption efficiency in upstream of Bhima basin in southern part of India. In this report, the ET which has been estimated from SEBAL algorithm is used for calibrating SWAT model. Then the calibrated model has been used for evaluating the efficiency and rate of water consumption. [4]

Khan et. al. (2007) using SEBAL algorithm, RS and MODFLOW model have examined water productivity in the level of irrigation system at Yellow River basin in China. The results of SEBAL show that significant amount of water is withdrawn from the region due to ET. So, by reducing the amount of ET, the water use efficiency could be improved and as a result water would be stored in the aquifers. [5]

Bastiaanssen et al. (2006) have used SEBAL algorithm to examine the irrigation system performance in Zayandeh Rood River basin in Isfahan. The calculated ET by this method has been used in order to estimate groundwater discharge and uncontrolled withdrawal from the river. [6]

Study on Varamin groundwater is limited to two research projects. N.A.de Ridder et al. at International Institute for Land Reclamation and Improvement have conducted a research in 1977 entitled "Optimal use of water resources in Varamin Plain". First, they simulated groundwater resources of Varamin Plain using a mathematical method. The results indicate that the groundwater table calculated by the model is matched well with the actual values.[7] Mahab Ghodss Consulting Engineering Company (MGCE) has produced a quantitative groundwater model of Varamin Plain in 1998 based on the results of the existing groundwater studies and using finite difference method. [8]

Many approximations, which have been considered in these studies for estimation of agricultural water use, have reduced the reliability of this groundwater model. Therefore, in order to reduce the uncertainty of the agricultural water use, in this study satellite images and remote sensing techniques have been used for estimating the actual agricultural water use.

## 2. STUDY AREA

Varamin Plain is situated on the southern slopes of the Aburz Mountain Range, some 30 km southeast of Teheran. Its geographical length is between 38.75 and 39.40 and its latitude is between 54 and 59. Varamin Plain represents an intermountain basin that is bounded on the north by the Elburz Range, on the south by the Siah Kuh Range, on the west by the Pishva Hill, and on the northeast by Eyvanakey Plain. The area of this plain is roughly 1,200 $Km^2$ and its average height is about 950 m above mean sea level. This area is cold in winter and dry and hot in summer with desert climate. The forty-year average precipitation (1967 to 2007) of the plain has been recorded 131 mm of precipitation by Javad Abad Synoptic Station in Varamin. Jajrood River and Shoor River constitute Surface water resources of Varamin Plain which provide 40 percent of agricultural water demand in Varamin. Underneath the entire Varamin Plain lies a free aquifer. Varamin is one of the agricultural products suppliers not only for Tehran but also for other parts of the country from many years ago. Wheat and barley alone constitute half of the cultivation in Varamin. Having enough and proper water and soil, Varamin Plain is suitable for agricultural development. But in last two decades, due to uncontrolled groundwater withdrawal and improper irrigation system, groundwater table has been decreased especially in the regions where there is no possibility to recharge the groundwater. The area of arable land and net area under cultivation in Varamin Plain is 75680 and 48790 ha respectively. Wheat and barley alone constitute half of the cultivation in Varamin. Cultivating during the whole year in Varamin Plain means that water is consumed in this period [9]. Figure 1 shows the location of Varamin Plain in Iran and Tehran. It should be mentioned that Varamin Plain water demand includes agricultural, industrial and urban demand. Industrial and urban sectors use only groundwater resources. While agricultural demand is supplied by both groundwater and surface water resources.

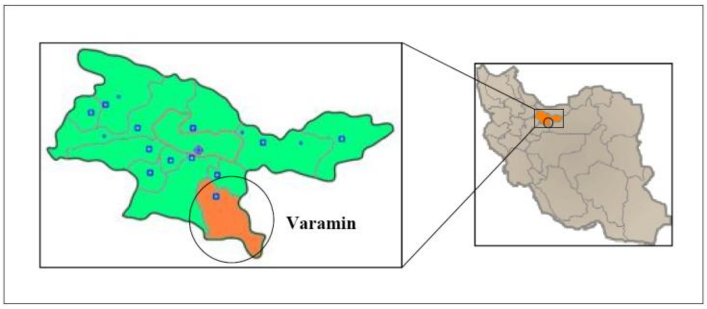


**Figure 1. Location of Varamin Plain in Iran and Tehran**

## 3. MATERIAL AND METHODS

### 1-3. SUTSEBAL ALGORITHM

SUTSEBAL algorithm, which is a thermodynamic-based model, solves the surface energy balance pixel by pixel using remote sensing image and a few ground data. The radiation absorbed by the surface of the earth minus the amount of radiation that is released from the surface, the net radiation Rn, (equation 1) is the amount of radiation that is transformed into heat. This heat is divided into three different parts: soil heat (G), sensible heat (H) and latent heat (λET). This algorithm solves the surface energy balance equation by considering Rn, G and H successively. The λET is the residual term of the balance equation. Figure 2 shows the Components of energy balance equation at ground level. Additional information about SEBAL and SUTSEBAL algorithm is available in other references.[1]

$$\lambda ET = Rn - G - H \tag{1}$$

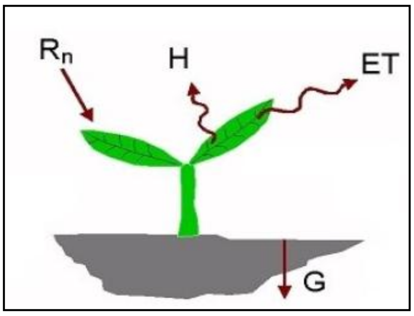


**Figure 2. Components of energy balance at Ground Level**

In this study, satellite images of Varamin Plain during 2002-2003 to 2004-2005 water year with 1Km spatial resolution are derived from NOAA-AVHRR. These satellite images are available in the NOAA satellite active archive's website (http://www.saa.noaa.gov). Then cloud-free images have been processed to estimate evapotranspiration. The number of processed images per month is shown in Table 1 during the study period.

Then, using the estimated evapotranspiration and considering the vegetation land cover in each pixel of the image, net volume of water used in agriculture has been estimated.

**Table 1- No. of processed images per month**

| Year | Oct. | Nov. | Dec. | Jan. | Feb. | March | Apr. | May | June | July | Aug. | Sept. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2002-2003 | 3 | 3 | 2 | 1 | 1 | 1 | 1 | 3 | 3 | 3 | 3 | 3 |
| 2003-2004 | 3 | 3 | 1 | 1 | 1 | 1 | 1 | 2 | 3 | 1 | 3 | 3 |
| 2004-2005 | 3 | 2 | 1 | 1 | 1 | 1 | 3 | 1 | 2 | 3 | 3 | 1 |

## 2-3. GROUNDWATER MODELING OF VARAMIN PLAIN USING MODFLOW

MODFLOW is a computer program that simulates three-dimensional groundwater flow through a porous medium using a finite-difference method. Three-dimensional groundwater flow with constant density through a porous medium is defined with the following partial-differential equation: [10]

$$\frac{\partial}{\partial x}(K_{XX}\frac{\partial h}{\partial x})+\frac{\partial}{\partial y}(K_{yy}\frac{\partial h}{\partial y})+\frac{\partial}{\partial Z}(K_{ZZ}\frac{\partial h}{\partial Z})+W=S_S\frac{\partial h}{\partial t} \qquad (2)$$

In which $K_{xx}$, $K_{yy}$ and $K_{ZZ}$ are values of hydraulic conductivity along the x, y, and z coordinate axes, which are assumed to be parallel to the major axis of hydraulic conductivity (L/T), h is potentiometric head (L), W is volumetric flux per unit volume representing sources and/or sinks of water with W<0 for flow out of the groundwater system and W>0 for flow in ($T^{-1}$). $S_S$ is the specific storage of the porous material ($L^{-1}$), and t is time (T).

Equation 2, when combined with boundary and initial condition, describes transient three-dimensional groundawater flow in a hetrogeneous and anisotropic medium, provided that the principal axis of hydraulic conductivity are aligned eith the coordinate directions.

In this study the groundwater model of Varamin Plain has been established using MODFLOW during 2002-2003 to 2004-2005 water year. The model is discretized horizontally with a cell resolution of 1000 m×1000 m and a matrix of 51 rows × 51 columns × one layer. The natural boundaries of Varamin and the schematic of Varamin Plain Groundwater Model is presented in Figure 3 and Figure 4 respectively. There are different inflow/outflow components that affect groundwater balance. Considering the natural boundaries of Varamin Plain, groundwater balance components of the plain could be determined. Rainfall, infilltration from Jajrood River bed and Shoor River bed, grondwater inflow and municipal and industrial return flow are the inflow components of Varamin Plain. Outflow components include agricultural water consumption, sanitary and industrial well and groudwater outflw.

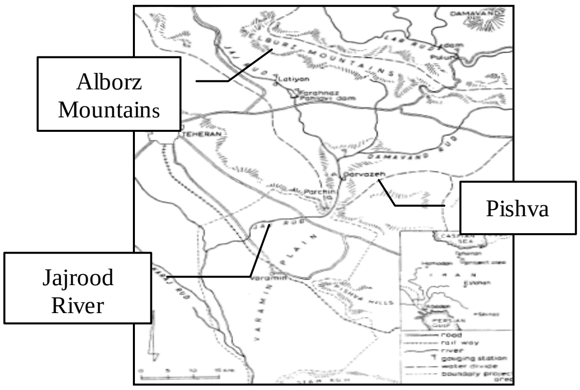


**Figure 3 –The natural boundaries of Varamin**

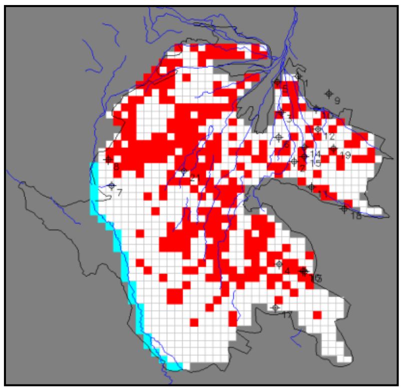

**Figure 4 – The Schematic of the Groundwater Model of Varamin Plain**

## 4. RESULTS AND ANALYSIS

### 1-4. RESULTS OF USING SUTSEBAL ALGORITHM IN ESTIMATING ACTUAL AGRICULTURAL WATER CONSUMPTION

As mentioned, agricultural water consumption is equivalent to the amount of actual evapotranspiration at the ground level. In this study actual evapotranspiration is estimated using energy balance algorithm (SUTSEBAL) and remote sensing techniques. In this way, actual evapotranspiration can be calculated more precisely in different time intervals and places. Using this method, agricultural water consumption in 2002-2003, 2003-2004 and 2004-2005 water year in Varamin Plain is equal to 394, 436 and 453 MCM respectively. It should be noted that these values are equivalent to agricultural water use plus the amount of water used by vegetation. Figure 5 shows monthly variation of agricultural water consumption in Varamin Plain in the study period. According to the study done by Yekom Consulting Engineers the amount of water withdrew from surface and groundwater in Varamin Plain is equivalent to 694 MCM [11]. Considering irrigation efficiency, the net agricultural water consumption is 320 MCM which shows good consistency by the results of the SUTSEBAL algorithm.

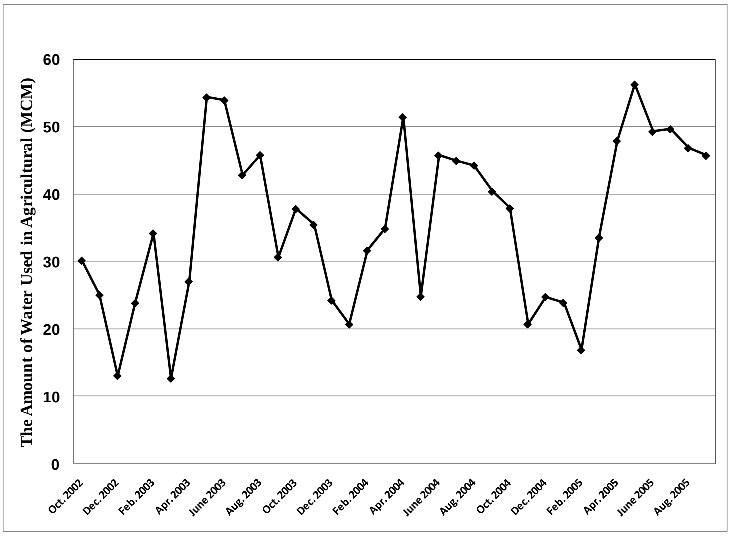


**Figure 5 – Monthly Variation of Agricultural Water Use during 2002-2005 (MCM)**

## 1-4. RESULTS OF THE GROUNDWATER MODEL OF VARAMIN PLAIN

As mentioned before, groundwater model of Varamin Plain has been established using MODFLOW during 2002-2003 to 2004-2005 water year. Groundwater model includes 51 rows, 51 columns and an unconfined aquifer. The boundaries are presented in Figure 3. All outside boundaries of the modeling area being the physical limit of the aquifer are set as impermeable except the left boundary where Shoor River is located. The distribution map of the initial head is produced using available piezometer data in Sep. 2002.

Rainfall, infilltration from Jajrood River bed and Shoor River bed, grondwater inflow and municipal and industrial return flow are the inflow components of Varamin Plain. Outflow components include agricultural water consumption, sanitary and industrial well and groudwater outflw. It is assumed that 5% of total precipitation in wet months and 3% in dry months infiltrate to the groundwater. So, the total amount of groundwater inflow due to precipitation is equivalent to 10 MCM per year. It also assumed that 50% of water withdrawal for industrial and municipal usage infiltrate to the groundwater.

Because there are multiple parameters in groundwater flow equation and each of these parameters are faced with uncertainty, the result of the Model should be calibrated. In this study the automatic calibration tool PEST which is nonlinear and model-independent parameter estimation software, is used in the calibration process. Simulation results show that the total reduction in groundwater storage in Varamin Plain during study period is 355 MCM which is equivalent to nearly 10 m of groundwater level decrease.

It should be mentioned that the reduction rate of the groundwater table is not uniform (the groundwater level reduction take place unevenly); it is more severe in the northeast of the plain. Groundwater table in the western side of the plain, due to variations in Tehran waste water flow, has large fluctuations with an increasing trend. The results of the model matches well with the results of the study done by Yekom Consulting Engineers in Nov. 2009 in which the annual reduction rate of the groundwater table is 3.73 m.[11] Also, data collected from piezometeric well in the Varamin Plain shows that the groundwater table in the northeast of the plain decreases more than 10 m during the study period which is consistent with the result of the groundwater model. Figures 5 and Figure 6 show examples of groundwater table in Varamin Plain. Table 2 shows groundwater balance components of Varamin Plain during the study period.

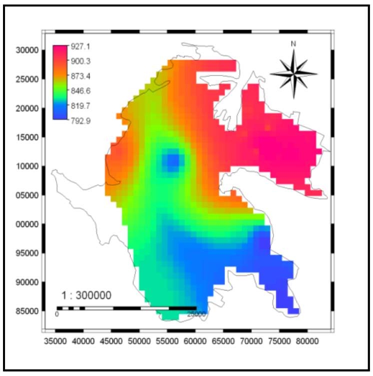


**Figure 6 – Groundwater Level of Varamin Plain, Apr. 2004 (masl)**

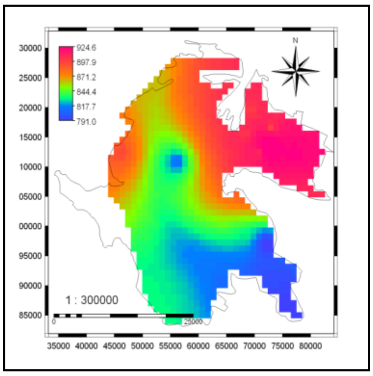


**Figure 7 – Groundwater Level of Varamin Plain, Sep. 2005 (masl)**

**Table 2- Groundwater Balance Components of Varamin Plain (MCM)**

| Inflow/Otflow Components | 2002-2003 | 2003-2004 | 2004-2005 |
|---|---|---|---|
| Agricultural Water Consumption | -393.8 | -436.5 | -453.5 |
| Recharge from Jajrood River Bed | 177.6 | 99.9 | 142.8 |
| Recharge from Shoor River Bed | 116.6 | 63.4 | 88.5 |
| Industrial Well Withdrawal | -15 | -15 | -15 |
| Municipal Well Withdrawal | -53 | -53 | -53 |
| Rianfall | 10 | 10 | 10 |
| Industial Return Flow | 7.5 | 7.5 | 7.5 |
| Municipal Return Folw | 26.5 | 26.5 | 26.5 |
| Groundwater Inflow | 121.7 | 121.9 | 122.2 |
| Groundwater Outflow | -18 | -18 | -18 |
| **Sum** | **-19.9** | **-193.1** | **-141.9** |

In next step, the sensitivity analysis of the model is done in order to examine the behavior of the model due to changes in the input parameters. The sensitivity analysis results show that changes in the amount of municipal and industrial return flow do not have a significant impact on the results of the model. It is, also, concluded that changes in the amount of the groundwater inflow (outflow) just affect the areas near the inflow (outflow) stream (around inflow and outflow areas**)**. Regarding sensitivity analysis, it is concluded that the changes in the amount of the groundwater recharge from Jajrood River bed and Shoor River bed have small effect on the groundwater table, consequently it shows that the considered value in this study is appropriate.

Next the established model is considered as a reference scenario in the current situation and then two different scenarios are examined and the results are compared with the reference scenario.

In the first scenario, the effect of the construction of Malmoo Dam on the groundwater level is inspected. The location of Mamloo Dam is observed in Figure 7. Mamloo Dam is located on the Jajrood River, one of the surface water resources of Varamin Plain, and it will regulate 90 MCM water each year for sanitation use in Tehran. So, after the construction of Mamloo Dam, the amount of available water for agriculture will be reduced and consequently, groundwater recharge from irrigation system will decrease. Assuming that Mamloo dam would be constructed in 2000-2001 water year, groundwater model of Varamin Plain has been established during 2000-2001 to 2006-2007 water year. The results show that transferring water from Jajrood will intensify the reduction rate of the groundwater level. The maximum decrease of the groundwater table respect to the current condition in this scenario is about 10 meters and the reduction rate of the groundwater level is more sever in the northeast of the plain.

In the second scenario, the construction of an artificial groundwater recharge pond in the northeast of Varamin Plain, which is faced with severe groundwater table decrease, is examined. The location of artificial groundwater recharge pond in Varamin Plain is shown in Figure 8. It is assumed that 12 MCM water enters the pond every year and 75 percent of this amount of water will infiltrate into the aquifer. According to the results of this scenario, the groundwater table will increase about 5 meters in the northeast of Varamin Plain respect to the reference scenario. But the level of the groundwater does not change noticeably in the areas far from artificial recharge pond. Therefore, it is concluded, the artificial recharge pond can compensate the problems resulting from groundwater table reduction to some extent. On the other hand, supplying required water for artificial recharge pond from Tehran waste water treatment plant can reduce the fluctuation of the groundwater table in the western side of the plain.

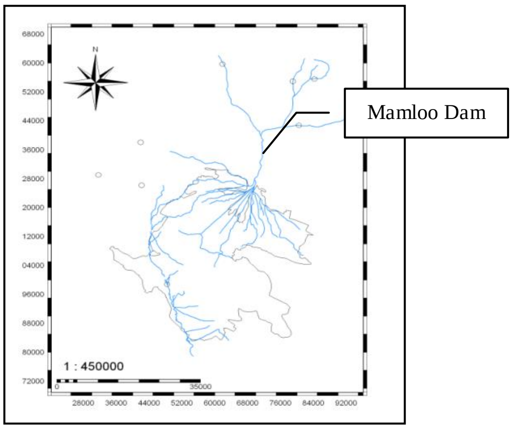


**Figure 8 – Position of Mamloo Dam in Varamin Plain**

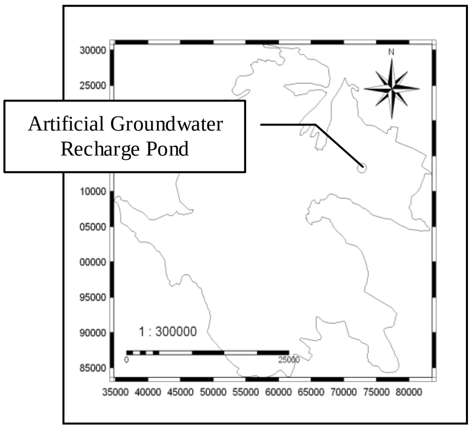


**Figure 9 – Position of Artificial Groundwater Recharge Pond in Varamin Plain**

## 5. CONCLUSION

As mentioned above, the net amount of agricultural water use as well as accurate information about the amount of agricultural return flow and its effect on the aquifer is not often available. The results of this study show that the net agricultural water consumption can be estimated more precisely using SUTSEBAL Algorithm in different time intervals and places. Thus, the amount of water which is extracted from the aquifer due to irrigation and evaporation can be identified for each pixel of the model. So, the level of uncertainty of agricultural water consumption will decrease and the level of certainty of the result of the hydrological model, which is established using the results of the SUTSEBAL Algorithm, will increase.

In this study, after estimating agricultural water consumption in Varamin Plain using SUTSEBAL Algorithm, groundwater model of the study area is established. The results of the groundwater model show that the level of the groundwater is decreasing in most areas in Varamin Plain especially in northeast of the plain. With increasing population and, as a result, an increasing need of water in agricultural as well as industry and sanitation, the reduction rate of the groundwater table will be intensified. So, it is concluded that if some efforts aren't done to improve the groundwater situation in Varamin Plain, it will face serious problems in the near future.

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