

Estimation Net Groundwater Extraction Using Remote Sensing based on Water Balance Method and Its Comparison by Smart Meter Data (Study Area: Abarkouh-Chahgir Plain)

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Abstract

Calculation of the components of water balance is very important in water resources management. One of the key components of balance is estimation of the amount of water drained by wells, springs and Qanats. Calculation of this parameter is too costly and time-consuming because of the need for field visit and field measurement. In order to solve these problems and to calculate the discharge amount of water resources in short period of time, using remote sensing technology and satellite images can be useful. Accordingly, actual evapotranspiration, the most important component of water-balance equation has been calculated and evaluated using this technology. The scope of the study in this research is the Chahgir plain of Abarkouh where underground water drop has caused many problems in the area. For this purpose, six Landsat 8 satellite images (OLI and TIRS sensors) during the period of June to September (2016) in Julian days 174, 190, 206, 222, 238 and 254 as well as meteorological data of two synoptic stations were used and SEBAL method was applied to estimate actual evapotranspiration. The results of the study and its comparison with the data obtained from smart meters (installed on the wells) with a 7.2 percent error indicates high accuracy of remote sensing data and used methods. Also, the amount of net groundwater extraction is estimated 1.07 million cubic meter (MCM) that comparison by pumping volume data (3.98 MCM), shows low efficiency and high water loss in the case study.

Keywords: Groundwater, Water Balance, Actual Evapotranspiration, SEBAL, LANDSAT 8.

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1. Introduction

Estimation of the balance and values for input and output components will play a decisive role in any planning for the quantitative and qualitative management of these resources (Bagheri, 2012). In recent decades, there are many qualitative and quantitative problems with groundwater resources. Overuse, lack of attention to exploitation based on sustainable development, climate change and consequently precipitation reduction and drought are the factors that have made this situation. Therefore, management of water resources especially groundwater needs to measure and control its exploitation. Unavailability of statistics on the rate of discharge of aquifers and use of it in different parts are important problems for planners and managers of the country's water sector. The common traditional method of measuring the amount of pumping out of the groundwater table, is based on direct measurement and field visit of water resources by human which in addition to being costly is time-consuming. Estimation of the amount of groundwater harvesting depends on number of active wells, outflow discharge and operating time which is difficult to determine their true value and in some cases unreliable (Ahmad, 2002; Maupin, 1999). Furthermore, lack of cooperation of farmers and unauthorized harvesting make the work more complicated. In line with this need, the legislator has ordered people to install smart meters to measure the amount of volume of water extracted from groundwater table. It is a great move that in addition to the precise measurements of devices, it requires the cooperation of the exploiters on installation and maintenance of intelligent measuring instruments. But since smart meters are installed just on the authorized wells, planners are not able to measure the amount of water extracted from other water resources like aqueducts, fountains and unauthorized wells. In order to solve this problem, collecting data in large amounts and less time, the use of satellite images and Remote Sensing (RS) technique are very effective. RS provides the possibility of estimation of hydrologic parameters on a large scale and spatially with a high accuracy (Bos et al., 2001).

In these regards, several researches has been done on using remote sensing for groundwater studies (Ghulam et al., 2004; Giroto et al., 2019; Jha et al., 2007; Sadaf et al., 2019; Salehi et al., 2018). One of the RS based approaches in groundwater components is using water balance calculation which recently applied by several research (Ahmad et al., 2005; Bagheri et al., 2017; Deus et al., 2013; Gafurov, 2010; Mekonnen, 2005; Muthuwatta et al., 2010; Senay et al., 2011; Thoreson et al., 2009 and Zhang et al., 2016).

The research by Ahmad et al. (2005) is one of the few studies that have been conducted in order to estimate the amount of net groundwater harvesting using this technology and water balance methods. In this study, net ground water use was as a passive component and rainfall, actual evapotranspiration (ET), moisture changes in the soil unsaturated area and the amount of irrigation water by channels were the computational components of their method that they were estimated from October 1993 to October 1994 using images of AVHRR sensors and Landsat satellite in the Rechna Doab in Pakistan. Eventually, the map of the net amount of groundwater used was gained by preparing spatial data, which is one of the main components of water balance. In their study, SEBAL model was used to estimate actual evapotranspiration and Scott, Bastiaanssen, and Ahmad (2003) model was used in order to estimate soil moisture. The comparison of their result with SWAP model showed high accuracy and low error of remote sensing methods in estimating of actual evapotranspiration and soil moisture (Ahmad et al., 2005). In Iran (Bagheri et al., 2017) calculated the net amount of groundwater use by remote sensing technology in the Lake Urmia basin. The satellite images used were from Modis sensor and the study took place from 2000 to 2008. The results and evaluation showed the method used for the study area has had acceptable accuracy.

Lack of ground station for analysis, are the research limitation in RS based models and algorithms, spatially in groundwater modelling. Literally, the hypothesis of the research is based on actual ET calculation, net groundwater extraction can be estimated by Landsat 8 RS-data in agriculture area. In this study, an innovation was applied. The smart meter data which has been installed on the tube wells were used. Also, in this study, using Landsat 8 data with pan sharpening technique to produce 15-meter resolution was another innovation. So, it was tried to estimate and evaluate net volume of water harvested from groundwater resources in Chahgir plain for the first time.

2. Material and Methods

2.1. Study area

The study area is the Chahgir plain which is sub-basin and a part of Abarkouh desert watershed. This plain is placed in the southwest of Yazd province and northeast of Fars province, between geographical longitudes $53^{\circ} 25'$ and 54° and between geographical latitudes $30^{\circ} 30'$ and $31^{\circ} 55'$. Its medium altitude is 1776 meters above the sea level. Average annual rainfall in this plain is 72.2 millimeters and annual evaporation is 3171 millimeters and the average annual temperature is 16.7°C . Reducing in the groundwater inflow due to drought and also overuse of agricultural wells, increasing the saltwater of playa adjacent to the plain (Abarkouh desert) have caused severe changes in the water quality of the area. In terms of water resources, 39 agricultural wells and two fountains called Beghdaneh and Darehbagh are groundwater drainage resources in this plain. In terms of agriculture, the pistachio is the dominant cultivation. The study area in terms of geology is a part of central Iran Zone and it is in the vicinity of the Sanandaj-Sirjan Zone. Old formations of the area are shale and Silurian sandstone covered by shale, sandstone, coal shale and sometimes yellow and brown Devonian Dolomite. On these formations, there is the huge Jamal formation. Totally, in this area, tectonic and stratigraphy follow the trend of Central Iran Zone. In terms of geology, Chahgir sub-basin is divided into two parts. The northwestern part that some agricultural wells are already drilled in this area and it consists of alluvium and rocks which are mainly carbonate. The wells of this area are usually shallow and they have fresh water with electrical conductivity of two to three thousand micromhos per centimeter. Of course, some wells are salty because of the proximity of evaporative formations and their electrical conductivity is between 3 to 19 thousand micromhos per centimeter.

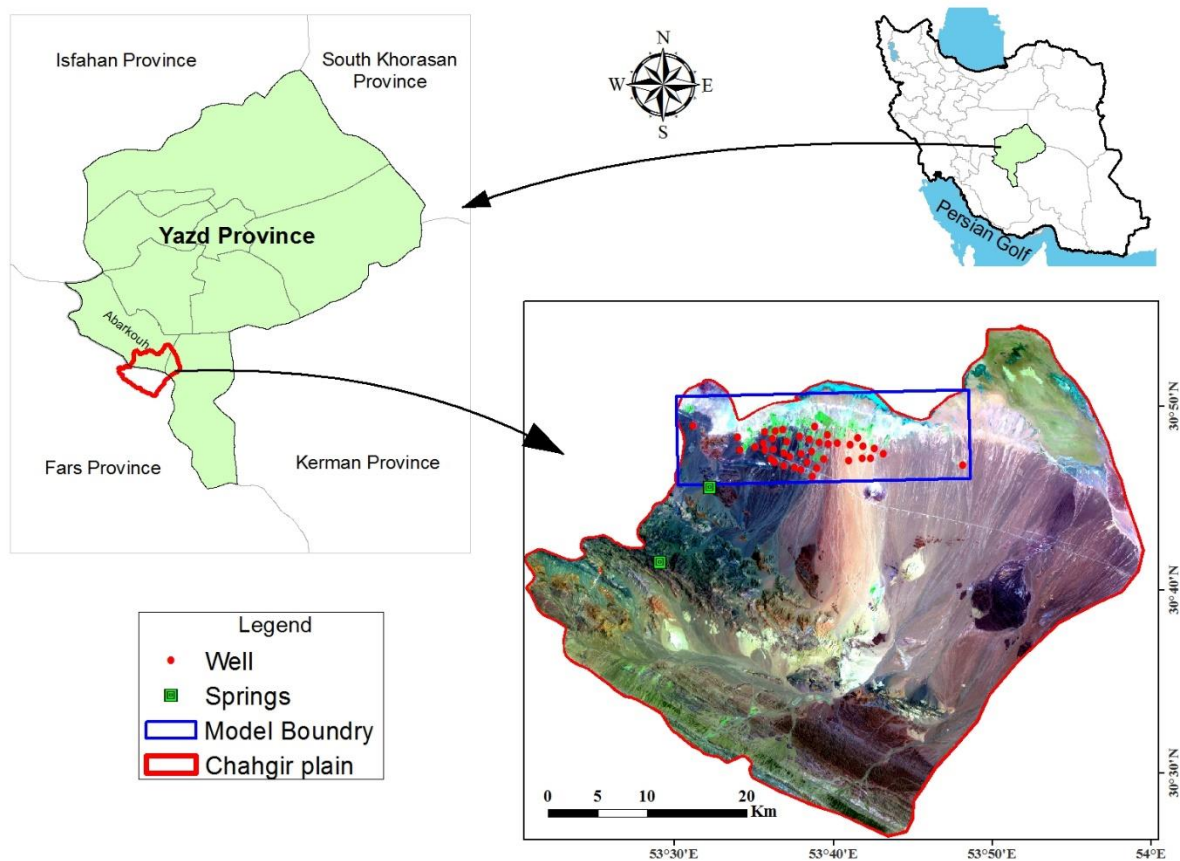


Figure 1. The study area (Abarkouh Chahgir plain)

2.2. Satellite and Ground Data

In this study, in order to use SEBAL algorithm for the quarter period (June to September 2016), six images of Landsat 8 satellite were obtained[†] and used which after pre-processing (Radiometric correction and Atmospheric Correction by FLAASH). The Julian days of satellite passed, were 174, 190, 206, 222, 238 and 254. These images included both OLI and TIRS sensors (all 11 bands except band 9-Cirrus). The times that satellite passes were varied from 6:30 to 7 AM (UTC) in all six used imagery. Also, Digital Elevation Model (DEM) were applied. The DEM image at 12.5m in resolution were obtained from VERTEX website[‡]. In addition to satellite data, ground meteorological data included air temperature (minimum and maximum), wind speed, daylight hours, and relative humidity (hourly and daily) provided by the Abarkouh and Marvast synoptic stations. This study needed amount of groundwater pumping to assess model results. For this reason, monthly smart meter data which installed on tube wells, were read and used.

2.3. Water Balance

A large amount of water used by plant mass is evaporated and transported and only a small amount of it is absorbed by plants. Accordingly, evaporation and transpiration are considered as good criteria for vegetarian water consumption (Ahmadi, 2014), as long as actual evapotranspiration is important. On the other hand, considering the net amount of consuming water per unit area (for example a pixel of an image satellite) is equivalent to the amount of water extracted from water resources, actual evapotranspiration of a pixel can be equivalent to the amount of water extracted from water resources which goes to pure vegetarian consumption (without losses). In the other words, in aquifers like the study area (Chahgir) which is lack of any rivers or surface water resources and relies on groundwater resources, the main components of water balance are rainfall (P), actual evapotranspiration (ET_a) and moisture changes in the soil unsaturated area (dW_u/dt) which ultimately leads to estimation of the net amount of groundwater use (I_{ngw}). Figure 2 represents an overview of the components related to the balance in a water resource system.

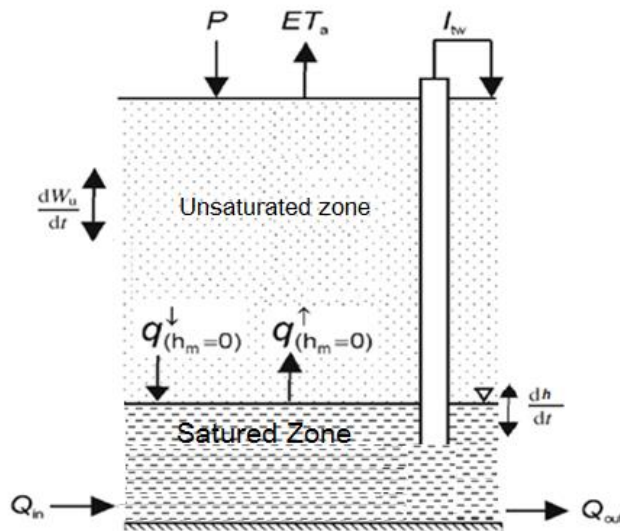


Figure 2. Schematic of balance components in saturated and unsaturated regions (Ahmad et al. (2005) and Bagheri et al. (2017)).

[†] - <https://earthexplorer.usgs.gov/>

[‡] - <https://vertex.daac.asf.alaska.edu/>

In the aquifer, except tube well extraction (pumping) (I_{tw}), two parameters of capillary penetration and capillary conduction (q ($h_m=0$) & q ($h_m=0$)) and also the amount of recharge and discharge of other aquifers (Q_{in} & Q_{out}) are considered as total input and output of the aquifer (saturation area). As regards the purpose of this study is merely related to unsaturated region, the total equation of the balance for the unsaturated region is according to equation 1:

$$I_{tw} = ET_a - P + \frac{dw_u}{dt} + q \downarrow_{(h_m=0)} - q \uparrow_{(h_m=0)} \quad (1)$$

The difference between recharge and discharge of the aquifer is equivalent to the net amount of groundwater use at a time. In the other words, the following relationship is confirmed:

$$q_{nr} = q \downarrow_{(h_m=0)} - q \uparrow_{(h_m=0)} \quad (2)$$

$$I_{ngw} = I_{tw} - q_{nr} \quad (3)$$

In the above relationship q_m is equivalent to the amount of net input water through unsaturated region to the groundwater level. In other word, I_{ngw} is assumed as the difference of all discharge and recharge value of the aquifer. Therefore, from the combination of equations 1 to 3, I_{ngw} is calculated as the follows:

$$I_{ngw} = ET_a - P + \frac{dw_u}{dt} \quad (4)$$

In order to accurately evaluate the research methodology, the period from May to September 2016 was considered. Assuming slight changes in moisture of the soil in unsaturated region and considering the lack of rain during the research period, the amount of net use of groundwater resources is equivalent to actual evapotranspiration ($I_{ngw} \approx ET_a$).

2.4. Actual evapotranspiration

SEBAL is a method based on experimental relationships and atmospheric physics, which estimates the actual evapotranspiration rate with minimum terrestrial and using satellite images with visible, infrared and thermal band. In a lot of researches mentioned SEBAL as an acceptable approach for ET calculation especially in agricultural area (Akbarzadeh et al., 2015; Bagheri et al., 2012; Bagheri et al., 2015; Ziaee et al., 2019). This algorithm represented by Bastiaanssen et al. (1998) for the first time and it was updated in 2000 and 2002 again and has been corrected in some cases. Totally, SEBAL has estimated the components of the energy flux using vegetation indices and surface parameters and their internal relationship. And finally, its passive component, latent heat flux (calculation factor of actual evapotranspiration) is estimated. Actually, in this method latent heat flux which is used for evapotranspiration, according to the amount of remaining energy is determined by the equation 5:

$$\lambda ET = R_n - G - H \quad (5)$$

In the equation above, ET is evapotranspiration, λ is latent heat of vaporization, R_n is net sunlight, H is sensible heat flux and G is soil heat flux (all the components in the equation above are in Watt per square meter). Pure sunlight, is the difference between incident radiation flux and reflected radiation flux and it is considered as a criterion from the amount of energy in the earth surface which is gained by the equation 6:

$$R_n = (1 - \alpha)R_{S\downarrow} + R_{L\downarrow} - R_{L\uparrow} - (1 - \epsilon_0)R_{L\downarrow} \quad (6)$$

In the equation above, α is surface albedo, R_s is short-wave incident radiation (0.3 to 3 micrometers) (W/m^2), R_L is long-wave incident radiation (3 to 100 micrometers) (W/m^2) and ϵ_0 is broadband surface emission. Soil heat flux (G) is the amount of heat transfer inside the soil and vegetation due to molecular conductivity which is according to equation 7 (Allen et al., 2002):

$$G = R_n \times \frac{T_s}{\alpha} \times [0.0032 \times \alpha + 0.0062 \times \alpha^2] \times [1 - 0.978 \times NDVI^4] \quad (7)$$

In this equation, T_s is surface temperature in centigrade degrees and α is surface albedo and NDVI is vegetation index. Sensible heat flux (H) as the most complicated component of the energy balance equation, is a waste of energy (or the heat) that is transferred to the air by temperature difference which is calculated

by equation 8;

$$H = \rho_{air} \cdot C_p \cdot \frac{T_0 - T_{air}}{R_{ah}} \quad (8)$$

In the equation above T_0 is Aerodynamic air temperature (Kelvin), ρ_{air} is air density (kg/m^3), C_p is specific heat (J/Kg/K) and R_{ah} is Aerodynamic air resistance. Reference evapotranspiration ratio daily per hours was used for estimation of daily evapotranspiration from instantaneous evapotranspiration of the satellite. For this purpose, reference evapotranspiration on an hour scale (millimeter per hour) at the moment of the passage of the satellite ($ET_{r-insat}$) and also its amount on a day scale (millimeter per day) (ET_{r-24}) for the meteorological station representing the area was calculated. Then the amount of daily actual evapotranspiration of satellite models (ET_{act-24}) in millimeter per day was estimated (Allen et al., 2002):

$$ET_{act-24} = ET_{r-24} \frac{ET_{inst}}{ET_{r-inst}} \quad (9)$$

It is possible to estimate total sum of periodic values of ET between two images ($ET_{act-period}$) for n consecutive days with estimating the amount of daily actual evapotranspiration (ET_{act-24}) for the days having image satellite, like equation 9:

$$ET_{act-period} = \sum_1^n ET_{r-24} \frac{ET_{act-24}}{ET_{r-24}} \quad (10)$$

In order to daily and hourly reference evapotranspiration, Mantit-Fao method was used (Allen et al. 2002).

2.5. Estimation of Net Groundwater Use

Considering the significant waste of water in the agriculture sector, irrigation efficiency plays an effective role in calculation of net groundwater use. Totally, irrigation efficiency is defined as the ratio of net water required or the consumption of the plant to the total input or extracted water (Abbasi et al., 2017). Therefore, if the extracted water (I_{tw}) is measured by smart meters and irrigation efficiency is applied, the amount of net groundwater use, according to equation 11 will be estimated:

$$I_{ngw} = E_i \times I_{tw} \quad (11)$$

It is noteworthy that in order to control and manage the use, in 2015 with following Yazd Regional Water Company, all agricultural wells of the study area were equipped with smart meters. Accordingly, tube well extraction (I_{tw}) data for the time period of study was extracted from smart meters. In Figure 3, the research methodology flowchart has been represented. IDL programming in ENVI software was used to apply all equations of the research.

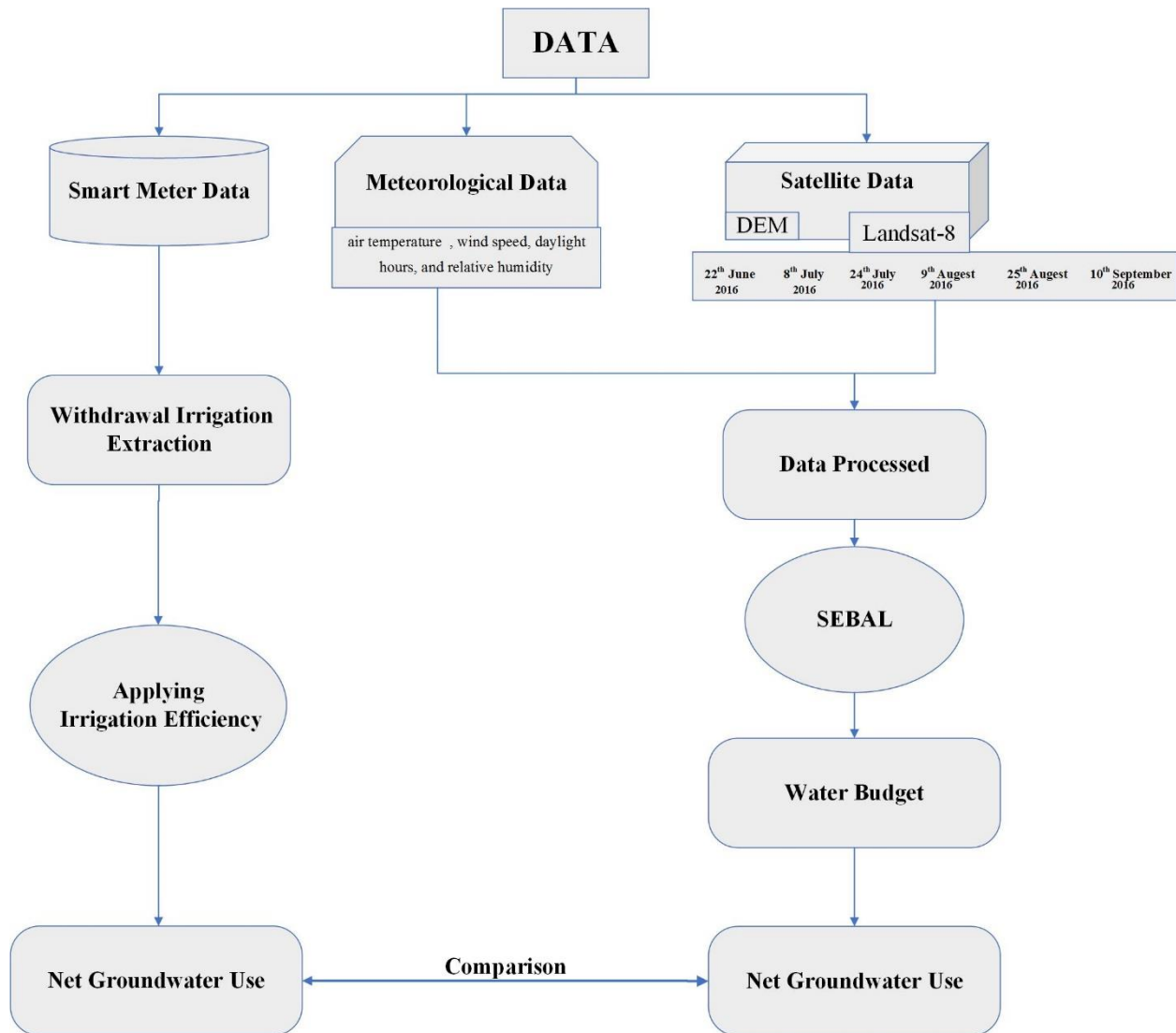


Figure 3. Flowchart of research methodology

3. Results and Discussion

The amount of periodic actual evapotranspiration was estimated with the actual evapotranspiration on a daily scale (for each of the six dates mentioned), using equation 10. Figure 4 (a) represents the spatial distribution map of daily actual evapotranspiration resulted from SEBAL algorithm as a sample for one of the modeling days. As it can be observed the highest value of actual evapotranspiration is related to agricultural land which is irrigated by groundwater resources. The lowest amount of actual evapotranspiration is related to pastures and shrubs. Also, Figure 4 (b) shows total ET from model outputs.

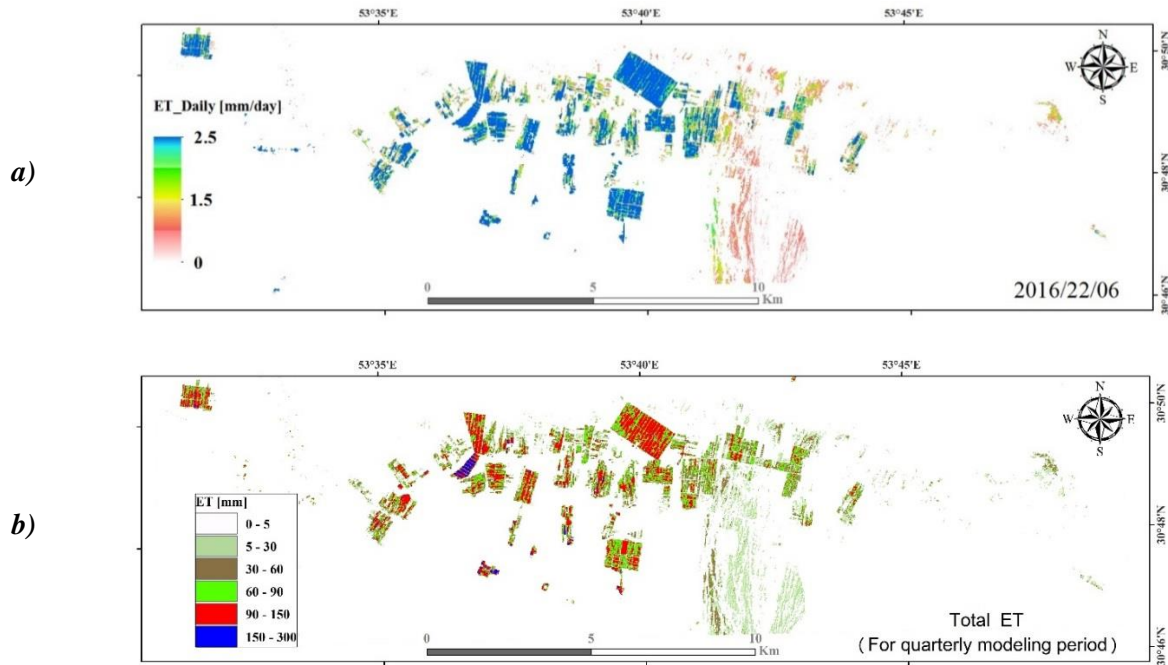


Figure 4. The spatial distribution map of a) daily actual evapotranspiration on June 22, 2016 in the study area (mm/days), b) Total ET (mm)

Figure 5 shows time distribution of actual evapotranspiration in the quarterly modeling period. Maximum chart values are related to agricultural land which according to represented results in the second half of August until mid-September, the most value of actual evapotranspiration and as a result the most amount of net groundwater use are visible.

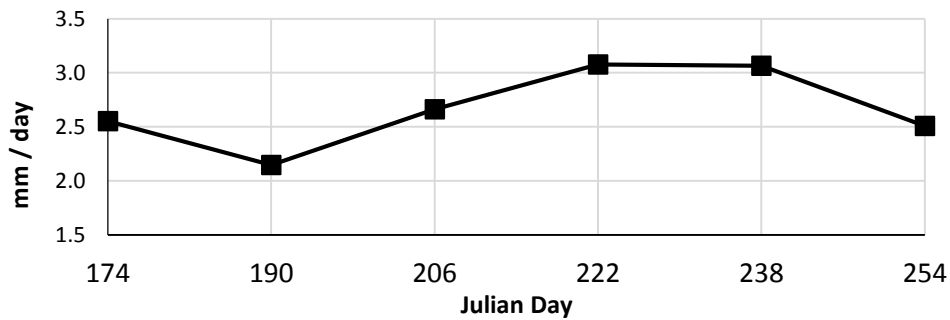


Figure 5. Time changes of the amount of actual evapotranspiration (millimeter per day)

As previously mentioned, failure of rainfall during the modeling period and a month before that (to ensure the removal of the effect of rainfall delay time) for the year, it means that any actual evapotranspiration estimated from pixels of agricultural land, is equivalent to net groundwater use due to pumping of the agricultural wells. Accordingly, Figure 7 represents SEBAL algorithm output based on net groundwater use. As shown in Figure 7, the amount of net water use is variable from 0 to 300 millimeters. In order to evaluate the results more accurately, three wells dispersed in the plain with different specifications and conditions were chosen and the amount of their output was calculated (Figure 6).

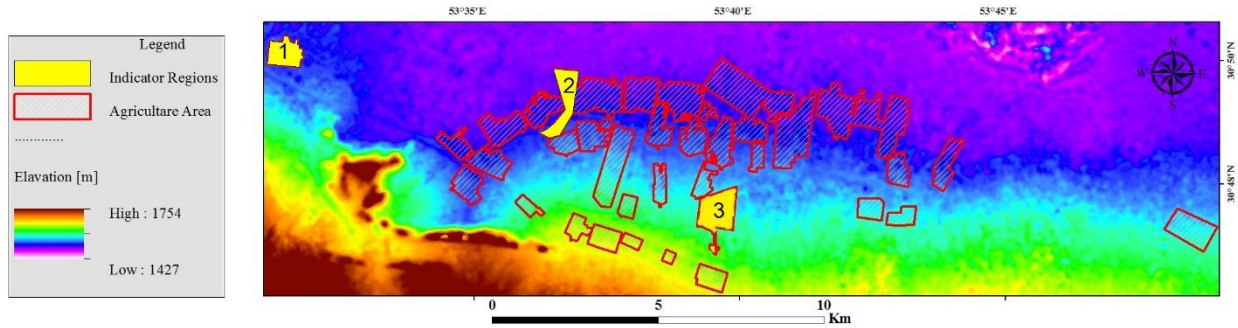


Figure 6. Agricultural land position and three indicator regions

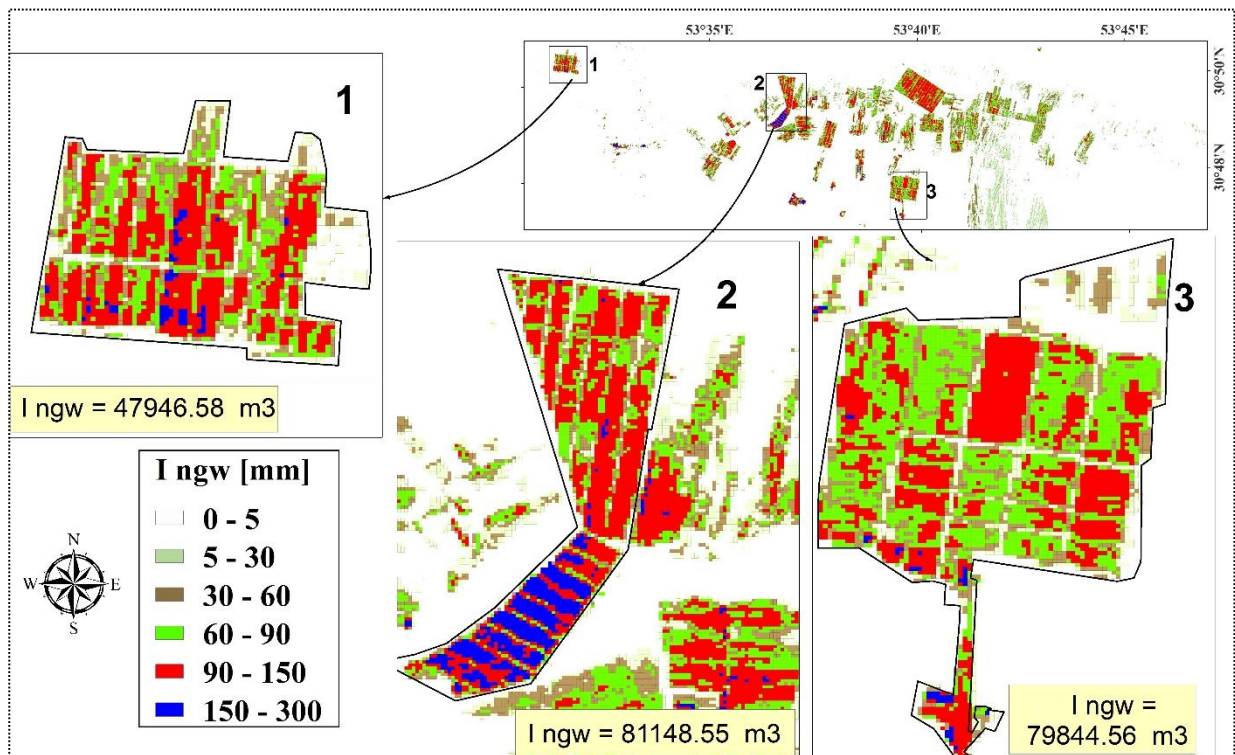


Figure 7. Groundwater net use map for the quarterly modeling period (in millimeters) and situation of research methodology output in the case of index ranges

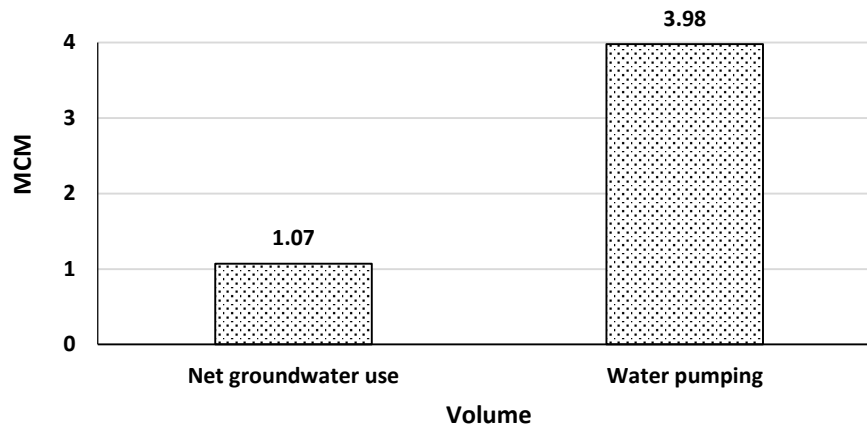
In order to evaluate and analyze the results of the research methodology, according to Figure 7, the net amount of groundwater use was estimated in the three selected wells. Irrigation efficiency of the case study was used from another research by Ebrahimi et al. (2019). Table 1 shows the specification and parameter calculation of efficiency for wells. Efficiency in each well is very different. Although the water in the well number 3 has better quality than other wells, its efficiency is lower. And this is true for well number 1 in comparison to well number 2. The well number 2 has electrically conductive, but there are increasing water efficiency and significant reduction in waste water because of proper use of low-pressure irrigation system and use of low-width and proper plotting in order to reduce evaporation losses and also setting up regular irrigation. As it can be seen in Figure 7, blue pixels in the well number 2 shows lack of water stress in the farm which expresses the impact of water use management in high productivity and more product performance.

Table 1. Profile of indicator wells with model output amount

Well No.	Water EC	Cultivated area	I_{ngw} (Model)	I_{tw}	E_i	I_{ngw} (Observation) $[\frac{I_{ngw}}{E_i} \times I_{tw}]$	MAPD [§] $[\frac{\sum_{i=1}^n [m_i - o_i]}{n} \times \frac{100}{\sum_{i=1}^n o_i}]$
	$\mu\text{mhos/c m}$	m^2	m^3	m^3	%	m^3	%
1	6430	686,242.20	47,946.58	73,435.68	60	44061.408	7.2
2	7370	878,264.1	81,148.55	112,597.4	70	78818.18	
3	4500	1,073,250	79,844.56	205,578	35	71952.3	

As shown in the Table 1, error between observed values (resulted from smart meter data and applying efficiency) and modeling values in the three wells is in average 7.2 percent which shows acceptable accuracy of research method and use of remote sensing in estimation of net groundwater use.

Figure 5 shows I_{tw} and I_{ngw} in the quarterly modeling period. As shown in Figure 8, the amount of net groundwater use and well pumping volume (I_{tw}) data for the time period are 1.07 and 3.98 MCM** respectively. These values show low efficiency and high water loss in the case study.

**Figure 8.** Total volume of I_{tw} and I_{ngw} in the quarterly modeling period

As previously mentioned, in this study high resolution of Landsat 8 imagery was used to calculate I_{ngw} while previous research used other satellite imageries such as MODIS (Bagheri et al., 2017) or AVHRR sensors (Ahmad et al., 2005) with low spatial resolution. So, accuracy of this study methodology was better than other same studies. Also, it is important to analysis ET accuracy. Base on Bastiaanssen et al. (2002), the accuracy of evapotranspiration estimation by satellite data varied from 0% to 10% on a field scale to 5% at regional level. So, the accuracy of this study with 7.2 percent error is acceptable which shows that the results from Landsat 8 imageries are better than other satellite data.

4. Conclusion

Water use management in the agricultural sector as the country's largest water consumer plays an

[§] Mean Absolute Percent Difference.

* Million Cubic Meter.

important role in water crisis management and reducing the tension that results from water crisis. Estimation of net use of groundwater resources has always been a matter of serious concern for experts and managers in water and agricultural sector. Use of traditional method for estimating the exact amount of water used and wasted has always faced many failures and errors. In this study, it is tried to estimate and evaluate net groundwater use by providing an efficient method based on available data and free satellite images. The six images processed and applied by SEBAL algorithm to calculate evapotranspiration as a major water balance component. To analysis, the smart meter data extracted. The error analysis by MAPD, showed acceptable accuracy of model with 7.2 percent. A solution which can be used both on small scales (such as a farm) and on large scales like plains and catchment basins. Also, as a result, the amount of net groundwater use and well pumping volume (I_{tw}) data for the time period were calculated 1.07 and 3.98 MCM respectively. These values demonstrate low efficiency and high water loss in the study area.

Reference

- Abbasi, F., Sohrab, F., & Abbasi, N. (2017). Evaluation of Irrigation Efficiencies in Iran. *Irrigation and Drainage Structures Engineering Research*, 17(67), 113-120. Retrieved from http://idser.aeri.ir/article_109617_56564fd7d1cdc955ba66b818cbca0d84.pdf. doi:10.22092/aridse.2017.109617
- Ahmad, M. (2002). Estimation of net groundwater use in irrigated river basins using geo-information techniques: a case study in Rechna Doab, Pakistan. *ITC Dissertation (Netherlands)*.
- Ahmad, M., Bastiaanssen, W. G. M., & Feddes, R. A. (2005). A new technique to estimate net groundwater use across large irrigated areas by combining remote sensing and water balance approaches, Rechna Doab, Pakistan. *Hydrogeology Journal*, 13(5), 653-664. Retrieved from <https://doi.org/10.1007/s10040-004-0394-5>. doi:10.1007/s10040-004-0394-5
- Ahmadi, A. (2014). *Using Remote Sensing In Calculation Of Evapotranspiration And Water Demand*. Retrieved from Isfahan University of Technology.
- Akbarzadeh, H., Haghightajoo, P., & Bagheri, M. H. (2015). Estimates of Evaporation from Surface Water Bodies with Sebal Algorithm Using Remote Sensing Techniques (Case Study: Chahnimeh's Fresh Water Reservoirs of Sistan). *Iranian Journal of Irrigation and Drainage*, 9(3), 510-521.
- Allen, R., Tasumi, M., Trezza, R., Waters, R., & Bastiaanssen, W. (2002). SEBAL (Surface Energy Balance Algorithms for Land). *Advance Training and Users Manual–Idaho Implementation, version, 1*, 97.
- Bagheri, M. H. (2012). Assessment of remote sensing technique for estimation of water balance components in basin scale, emphasizing on net groundwater exploitation: a case study on Urmia lake basin. (Master of science), University of Tarbiat Modares.
- Bagheri, M. H., Arshad, S., Majnuni, A., & Morid, S. (2012). A comparison of single-source and two-source energy fluxes models to estimate actual evapotranspiration in Tabriz Plain. *Iranian Journal of RS and GIS*, 4(13), 81-96.
- Bagheri, M. H., Morid, S., & Arshad, S. (2015). Assessment of remote sensing SEBAL algorithm to estimate actual evapotranspiration in different landuses, a case study in Urmia Lake basin. *Iranian Water Research Journal*, 9(16), 101-110.
- Bagheri, M. H., Morid, S., & Arshad, S. (2017). Application of Remotely-Sensed Data to Estimate a Water Budget for Data-Scarce Endorheic Basins: A Case Study of Lake Urmia basin, Iran. *Journal of the Indian Society of Remote Sensing*, 45(1), 101-112. Retrieved from <https://doi.org/10.1007/s12524-015-0522-9>. doi:10.1007/s12524-015-0522-9
- Bastiaanssen, W. G., Ahmad, M. u. D., & Chemin, Y. (2002). Satellite surveillance of evaporative depletion across the Indus Basin. *Water Resources Research*, 38(12), 9-1-9-9.
- Bastiaanssen, W. G., Menenti, M., Feddes, R. A., & Holtslag, A. A. M. (1998). A remote sensing surface energy balance algorithm for land (SEBAL). 1. Formulation. *Journal of hydrology*, 212, 198-212.
- Bos, M., Dayum, S., Bastiaanssen, W., & Vidal, A. (2001). Remote sensing for water management: The drainage component. Paper presented at the Report on expert consultation meeting organized by representatives of the ICID, IPTRID, ILRI, WaterWatch and the World Bank, Ede-Wageningen May.

- Deus, D., Gloaguen, R., & Krause, P. (2013). Water Balance Modeling in a Semi-Arid Environment with Limited in situ Data Using Remote Sensing in Lake Manyara, East African Rift, Tanzania. *Remote Sensing*, 5, 1651-1680.
- Ebrahimi, S., Sarkargar, A., Javadianzadeh, M. M., & Bagheri, M. H. (2019). *Calculation of water losses in agricultural sector using remote sensing (Study Area: Chahgir plain, Yazd)*. Paper presented at the 7th Iranian water resources management conference, Yazd, Iran.
- Gafurov, A. (2010). *Water Balance Modeling Using Remote Sensing Information: Focus on Central Asia*.
- Ghulam, A., Qin, Q., Zhu, L., & Abdrahman, P. (2004). Satellite remote sensing of groundwater: quantitative modelling and uncertainty reduction using 6S atmospheric simulations. *International Journal of Remote Sensing*, 25, 5509-5524.
- Giroto, M., Reichle, R. H., Rodell, M., Liu, Q., Mahanama, S., & De Lannoy, G. J. (2019). Multi-sensor assimilation of SMOS brightness temperature and GRACE terrestrial water storage observations for soil moisture and shallow groundwater estimation. *Remote Sensing of Environment*, 227, 12-27.
- Jha, M. K., Chowdhury, A., Chowdary, V., & Peiffer, S. (2007). Groundwater management and development by integrated remote sensing and geographic information systems: prospects and constraints. *Water Resources Management*, 21(2), 427-467.
- Maupin, M. A. (1999). Methods to determine pumped irrigation-water withdrawals from the Snake river between upper Salmon falls and Swan falls dams, Idaho, *using electrical power data, 1990-95*.
- Mekonnen, S. C. (2005). Assessment of catchment water balance using GIS and Remote Sensing: *Roxo, Portugal*. The Netherlands: ITC.
- Muthuwatta, L., Ahmad, M., Bos, M., & Rientjes, T. (2010). Assessment of water availability and consumption in the Karkheh River Basin, Iran-using remote sensing and geo-statistics. *Water Resources Management*, 24(3), 459-484.
- Sadaf, R., Mahar, G. A., & Younes, I. (2019). Appraisal of Ground Water Potential through Remote Sensing in River Basin, Pakistan. *International Journal of Economic and Environmental Geology*, 25-32.
- Salehi Siavashani, N., Vaquero, G., Elorza, F. J., Candela, L., & Serrat Capdevila, A. (2018). Remote sensing application for investigating groundwater recharge at Lake Chad Basin. *Paper presented at the EGU General Assembly Conference Abstracts*.
- Scott, C. A., Bastiaanssen, W. G., & Ahmad, M.-u.-D. (2003). Mapping root zone soil moisture using remotely sensed optical imagery. *Journal of Irrigation and Drainage Engineering*, 129(5), 326-335.
- Senay, G., Leake, S., Nagler, P., Artan, G., Dickinson, J., Cordova, J., & Glenn, E. (2011). Estimating basin scale evapotranspiration (ET) by water balance and remote sensing methods. *Hydrological Processes*, 25, 4037-4049.
- Thoreson, B., Clark, B., Soppe, R., Keller, A., Bastiaanssen, W., & Eckhardt, J. (2009). Comparison of evapotranspiration estimates from remote sensing (SEBAL), water balance, and crop coefficient approaches. *Paper presented at the World Environmental and Water Resources Congress 2009: Great Rivers*.
- Zhang, Y., Pan, M., & Wood, E. F. (2016). On creating global gridded terrestrial water budget estimates from satellite remote sensing. In *Remote Sensing and Water Resources* (pp. 59-78): Springer.
- Ziaee, R., Moghaddasi, M., Paimozd, S., & Bagheri, M. H. (2019). Comparison of SEBS and SEBAL Algorithms in Evaporation Estimation from Open Water Surface with the Assessment of the Salinity Effect. *Journal of Water and Soil Science*, 22(4), 317-329. Retrieved from <http://jstnar.iut.ac.ir/article-1-3570-en.html>. doi:10.29252/jstnar.22.4.317