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SPATIAL ESTIMATION OF WATER BALANCE COMPONENTS WITH WetSpass MODEL

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ABSTRACT

Point estimates are among the most widely used methods in estimation of the amount of recharge of groundwater. However, for precise quantification of the spatiotemporal variability of groundwater, a flexible and reliable method was needed. This study aimed to estimate the water balance components in the Hashtgerd plain using WetSpass water balance model, which is spatially distributed. Relevant input data for the model (e.g., rainfall, air temperature, soil, groundwater level, and slope) were gathered and transformed into digitized maps. In this research, an overview of the use of WetSpass model on the quantification of groundwater recharge has been presented. The obtained results from simulations have shown that the average runoff produced in Hashtgerd basin equals to 37.7 mm/year. Also, the maximum amount of runoff, produced by the areas with bare soil plus plants coverage and residential areas in cities and villages. Annually estimated evapotranspiration (ET) amount was equal to 352 mm/year. Moreover, annual recharge during warm and cold seasons was equal to 1% and 99% of the total yearly recharge in this basin, respectively. Finally, the results showed that the WetSpass could model all parts of groundwater components. Moreover, it can be an excellent tool to determinate the areas that there is recharge groundwater potential over there.

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1. INTRODUCTION

Because of the fast-growing population, economy, and financial systems, the amount, rate, location, timing and water budget parameters, like overland flow (surface runoff), and groundwater recharge had bear significant changes around the world (Han et al, 2017). The process of recharge of groundwater (either naturally or artificially), is done when surface water infiltrates into the soil and go through the holes and cracks to reach the saturated area of the basin. Freeze (1969) defines the groundwater recharge as the entry of surface runoff, into the saturated zone beneath the earth. Penetrated water causes the groundwater table to increase, which is an essential process to provide the

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needed water for agricultural, industrial, or domestic demands. This process becomes more critical and important in the arid areas, which most of its water demands, is supplied by groundwater resources. To evaluate the constant yield of an aquifer, especially in the arid and semi-arid basins, we need to estimate the groundwater recharge (De Vries, et al, 2002; Yongxin and Beekman, 2003; Crosbie, et al, 2010). The study area (Hashtgerd basin) as a semi-arid region, which remains dry for the major part of the year. So, addressing such a crucial issue to determine the quantity and groundwater recharge rate, as it is the primary source of available water in the study area is of immense importance. The regional models (such as WetSpass), could be used to analyze the groundwater parameters (e.g., infiltration or recharge) (Szilagyi, et al, 2005). These models are often quasi-steady state and need long-term data as input to estimate the mentioned parameters (Chapman, 1999; Dickinson, et al, 2004; Haile and Kassas, 2017). Because of the significant impact of spatiotemporal variation of parameters such as land use, land cover, soil texture, weather condition, topography and slope on the groundwater recharge, we need a groundwater model that could take account all of these parameters, in calculating the rate of the recharge in different time scales such as monthly, and seasonal.

Recharge can be estimated via different methods (e.g., empirical point-based, the balance of water and lumped methodologies), which have been widely discussed in various papers (Simmers, 1988; Guimera` and Candela, 1999; Flint, et al, 2002; Ladekarl, et al, 2005). However, point-based estimation does not have clear results (Sophocleous, 1992), the distributed approaches (e.g., RS and GIS-based techniques) would enhance spatial estimates (Jackson, 2002; Gebreryfael, 2004). Zhang et al. (1999), aimed to model the recharge for a catchment by applying a biophysically based distributed model.

Cherkauer and Ansari (2005) examined the regional lumped procedure to approximate groundwater recharge using the regression equation. Fazal et al. (2005), investigated recharge by means of a model based on the relation between rainfall and runoff. Nowadays, geographical information systems and hydrological models that are based on physical concepts, have become an important tool to assess the water budget parameters (e.g., groundwater recharge and evapotranspiration). By using these models, the impact of climate change and human activities such as land-use change can also be investigated (Alemaw and Chaoka, 2003; Dragoni and Sukhija, 2013).

Thus, a physically-based model called WetSpass (Water and Energy Transfer between Soil, Plants, and Atmosphere under quasi-Steady State) was employed to estimate water budget components (Batelaan and De Smedt, 2001; 2007). WetSpass utilizes many components to quantify the long-term effects of land use and climate change on water regime in a watershed such as (land use, temperature, and precipitation) (Batelaan, et al, 1996; Moiwo and Tao, 2014). Dams et al. (2013) assessed the dynamic of hydrology by using the WetSpass model and remote sensing techniques to investigate the impervious surface changes. Mishra et al (2014), Zomlot et al. (2015, 2017) and Armanuos et al. (2016) studied the impacts of land-use change, and soil type and amount of rainfall on groundwater recharge. Recently WetSpass model applied to study the urbanization influence on the water budget elements at territorial and quadrat extent of Beijing, China (Zhang et al. 2018). Numerous researches indicated that the groundwater level has a steep decline in Hashtgerd aquifer because of over-exploitation of these resources (Sharifi, 2012; Larijani, et al, 2017; Zadeh and Godarzi, 2018). The analysis of the groundwater time series during 1993 - 2013 indicated a dramatic decrease in the level of the water table (about 13 meters) (Zade, 2015). According to the 5-year groundwater level drop-forecasting map of the plain, the highest level of groundwater level drop was more than 16 meters for areas being located in the northeast and central parts of the plain, and the lowest level was about 0.5 m for outlet areas (Taheri Tizro et al, 2016). From a volume perspective, groundwater resources supply the most water use in Hashtgerd basin (Enayat et al, 2016). Regarding the fact that the precipitation in the Hashtgerd plain occurs in a few months of the year, the river located in the study area has a transient flow during the rainy seasons. This ephemeral flow causes the population to use groundwater for drinking, irrigation and industrial water consumptions (Enayat et al, 2016; Malekian and Mirdashtvan, 2016; Jamdar, et al, 2019).

Due to rapid urbanization and population growth in Hashtgerd area, the amount of water usage increases, so the volume of stored water will decrease, and this would become an important issue to develop the local economy (Jamdar, et al, 2019). Hence, in the study area, it is necessary to estimate the recharge amount of groundwater resources for sustainable operation and protecting them of illegal abstraction. In the presented study, the water balance parameters (GW (Groundwater) recharge, runoff, and ET (Evapotranspiration)) for the Hashtgerd basin, have been estimated using WetSpass model. The main goals of this study are to address the following scientific issues:

1) What is the relationship between slope percentages and runoff? (Is there any relationship between slope percentages and runoff?)
2) What is the relationship between soil classes and groundwater recharge?
3) What are the Impacts of soil classes on aquifer recharge?
4) What is the aquifer recharge rate in cold and warm seasons?

Answering these issues will improve our perception of water budget parameters, and provide an effective way to perceive the changes in groundwater recharge of the basin in different sloped and land use.

2. MATERIAL AND METHODS

2.1 STUDY AREAS AND DATA SOURCE

The Hashtgerd Plain is located between 445667‘E and 508251’E longitudes, and 3960289’N and 3996637’N latitudes in the southern part of the Alborz province, Iran (Figure 1). The study area, the location of selected wells, and the Hashtgerd synoptic station have been demonstrated in Figure 2.

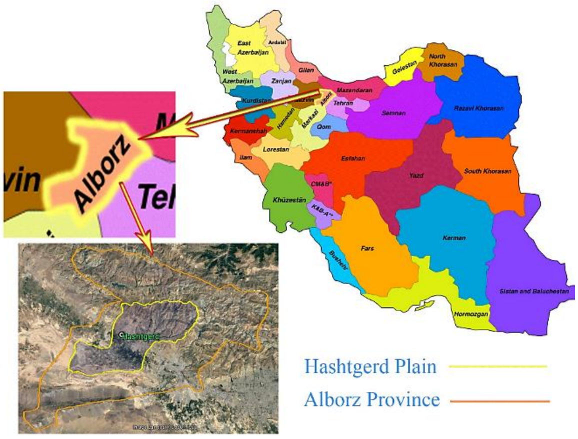

Figure 1: Study Area in Alborz province, Iran.

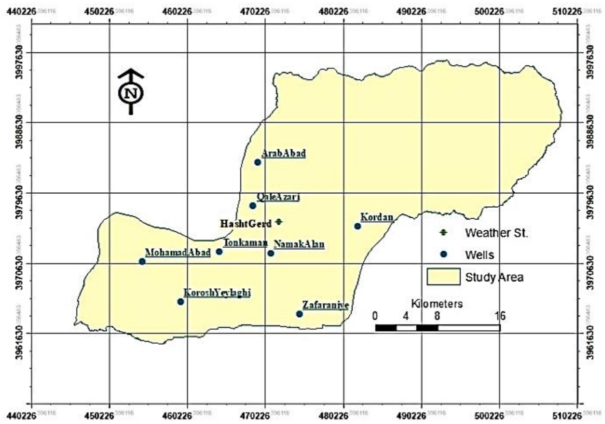

Figure 2: Location of selected wells and the Hashtgerd synoptic station

The data of eight piezometric wells and Hashtgerd synoptic weather stations (Table 1) from Hashtgerd plain and around were analyzed (Figure 2).

Table 1: General characteristics studied synoptic stations.

Name	X/ Y Coordinates (m)	Elevation	P(mm)	Mean T (c)
Hashtgerd	471426/ 3975515	1815	373	14.34
Buein Zahra	410698/ 3959984	1230	285	14.8
Karim Abad	465319/ 3965219	1160	82	17.8
Deh Some'e	484863/ 3978133	1460	267	13.6
Karaj	494112/ 3966266	1293	256	14.2
Dorvan	503012/ 3987730	2200	204	9.3
Taleghan	471077/ 4002563	1750	480	11.4

The beginning of the time span of groundwater level data was chosen based on the beginning of consistently recorded groundwater levels, and the groundwater level in December 2015 was chosen as the end of the time span. The study area (Hashtgerd plain) covering an area of 1170 km^2 and elevation ranges from 1182 to 3982 meters.

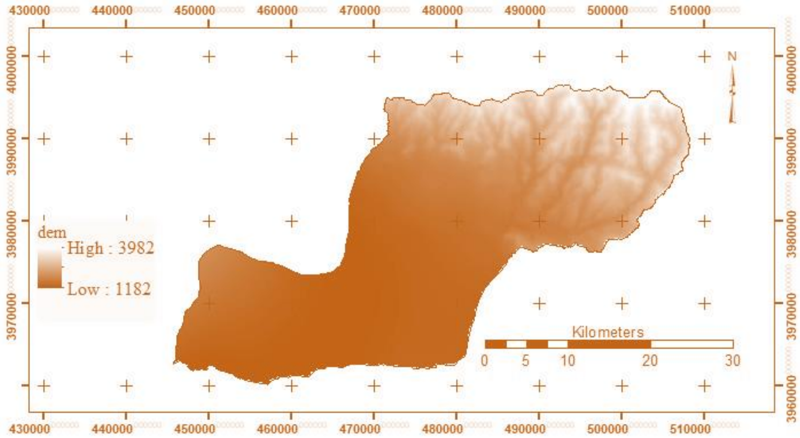

Figure 3: Digital elevation map of Hashtgerd plain

According to the De- Marton Method, the climate is predominantly dry and wet (Enayat et al, 2016). Various criteria (e.g., selection of wells with long-term data, less missing data, suitable spatial and temporal distribution, the monthly rainfall, temperature (min and max), wind, relative humidity and sunshine hours' data of 24 years' period) were taken from the synoptic meteorological stations. In addition, water table data over the selected wells within the plain were taken by the water resources company and meteorology organization of Alborz. Table 2 shows the characteristics of selected wells in the Hashtgerd plain.

Table 2: Characteristics of the selected wells

Name	X/ Y Coordinates (m)	Elevation	Min GWL	Max GWL
ArabAbad	469273/ 2983519	1313.55	117.24	118.06
Kordan	482069/ 3975315	1380.44	73.42	77.63
Korosh Yeylaghi	459354/ 3965640	1168.77	12.22	12.38
Mohamad Abad	454390/ 3970815	1149.43	8.5	8.74
Namak Alan	470943/ 3971918	1220.95	7.57	7.70
Qale Azari	468645/ 3978013	1225.51	18.33	18.53
Tonkeman	464319/ 3972125	1188.90	25.26	25.73
Zaferaniye	474572/ 3964119	1240.14	45.08	46.55

Generally, in the Hashtgerd area, based on the size of the grains in the USDA method, the soil is categorized into three classes of Silt, Silty Loam and Silty (Soil Survey Staff, 1951), as illustrated in Figure 4. The related information to each soil class is available in the software manual (WetSpass Soil parameters) (Fetter, 2001). For example, respectively, the class of number 4 is related to the silty loam or classes 6 and 8 refer to the silt and silty clay (Batelaan and Woldeamlak, 2007). Land use and land cover are the majors controlling factors of the watershed hydrology (Fetter, 2001). The land cover parameters (e.g., the land under cultivation, meadow, the land with short trees, shrub, unnavigable river, rural, industrial and residential areas) are used in the study (Figure 5). Land under cultivation (No. 21), covers about 430 million m^2 of the total study area. Most parts of the lands placed in the area of Hashtgerd are classified as number 23 (meadow). The land use map of the study area is shown in Figure 5.

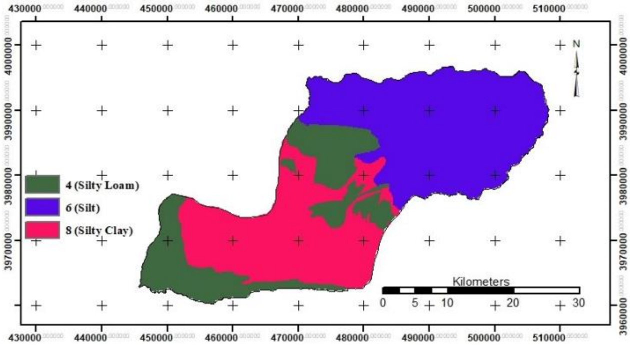

Figure 4: Soil classes map of Hashtgerd plain

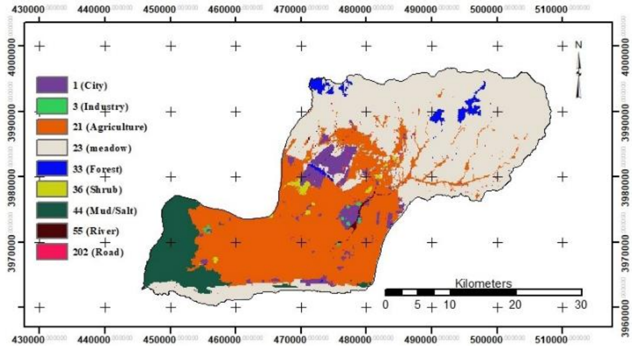

Figure 5: Land use map of Hashtgerd plain

The cultivated area (No. 21), covers about 430 Km^2 of land cover, distributed over the entire Hashtgerd study area. In addition, the major land cover of the basin, which has been located in various parts of the plain, is called grassland (No. 23). The large part of the southwest areas of The Hashtgerd plain covered by salt marsh (No. 44), while seasonally and perpetuity rivers cover only 33 km^2 of this area. After preparing raster maps, an average of precipitation, wind velocity, water level, and ET, which are calculated using the Penman-Monteith method, these raster maps, were imported into the ArcView, and thereby "WetSpass Add-In" was run.

2.2 WETSPASS MODEL

The WetSpass model integrates a water balance in a GIS, according to Batelaan and Smedt (2001). In order to make an efficient model, all data were prepared as grid maps in seasonal scale and transferred to Arc view as follows: soil texture, land cover and land use, groundwater level, rainfall, wind speed, and evapotranspiration. It should be mentioned that, the needed parameters like runoff coefficient or soil parameters presented to the model as "parameter table". By using long-term average standard hydro-meteorological parameters as inputs, the model simulates the temporal average and spatial differences of surface runoff, PET, and groundwater recharge. The model treats a basin or region as a regular pattern of raster cells (Batelaan and Smedt, 2007). Every raster cell is further sub-divided into vegetated, bare soil, open water, and impervious surface fraction for which independent water balances are maintained. The cascading process of calculation the water balance parameters in every single cell (for example vegetated cell) is shown in Equation 1, which includes Rainfall/snowfall, interception, overflow, ET and groundwater recharge.

$$R = I + OF_v + ET_v + GWR_v \quad (1)$$

Where P is the rainfall/ snowfall [mm], I is the interception [mm], OF_v is the overflow [m^3], ET_v is the evapotranspiration [mm], and term GWR_v is the groundwater recharge [mm]. Recharge can be considered as the remaining water budget (Equation 1). Equation 1 demonstrates that the recharge is a function of land cover, soil type, groundwater level, and rainfall/snowfall patterns. It should be mentioned that, in summer, the simulated recharge in discharge areas would often be negative due to the result of the high transpiration of the vegetation and the presence of shallow groundwater.

3. RESULT

After running the model, the ArcGIS platform used to make the needed maps (recharge, runoff, and ET) from various surfaces. Figure 6 shows the simulated spatial annual amount of runoff over the study area. Simulated runoff ranges from 0.0 to 361.8 mm/year.

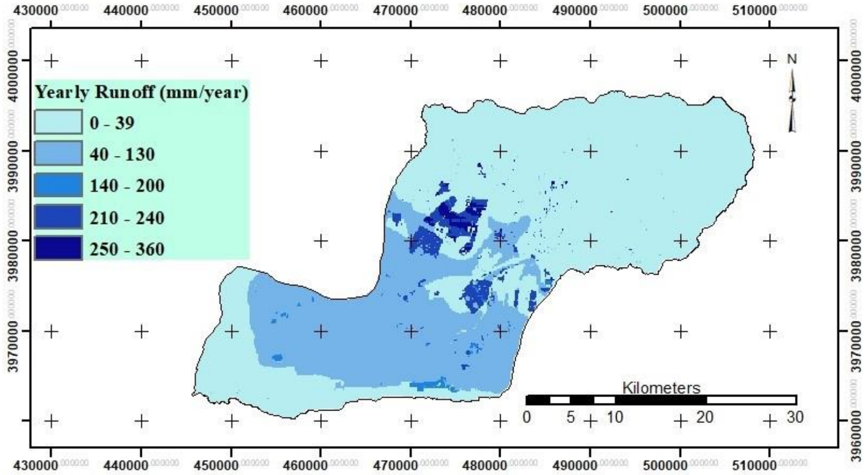

Figure 6: Simulated surface runoff map

The average runoff amount in Hashtgerd plain equals to 51.44 mm. Total runoff 139 mm (38%) was produced on impermeable surfaces. However, in parts including the coverage with bare soils, plants, and bushes, much more runoff was produced. Concerning Figure 6, it is evident that the amount of runoff in the areas with higher altitudes and the southwest parts (salt marsh) is significantly less than other parts of the basin. Moreover, the part of the area located in the slope equal to 0.2 to 0.3, has the potential of producing much more runoff (Figure 7).

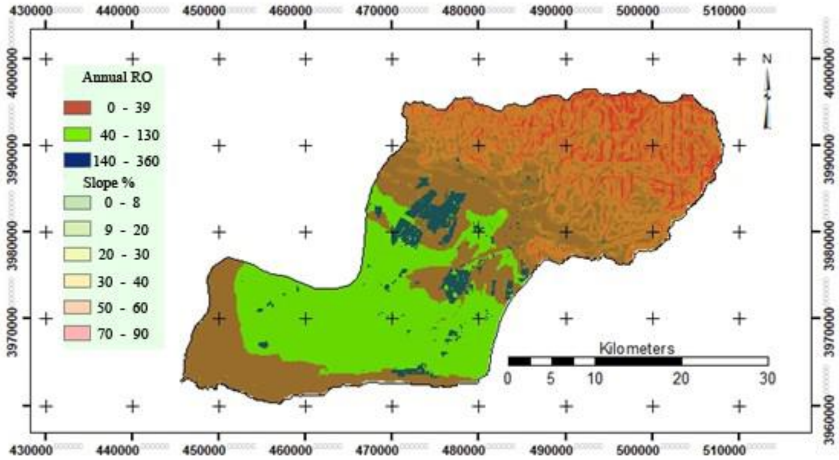

Figure 7: Simulated surface runoff map in different slopes

A huge amount of precipitation is eliminated by ET (Arefaine et al, 2012), carrying out an effective role in water loss through the dry winds, and solar radiation. The evaporation from water and soil surfaces and the transpiration from the vegetated area causes the return of the precipitation to the atmosphere in the form of vapor (Roberts, 1983). Figure 8 shows the actual yearly ET from the water body, land surface, and vegetated areas in Hashtgerd plain.

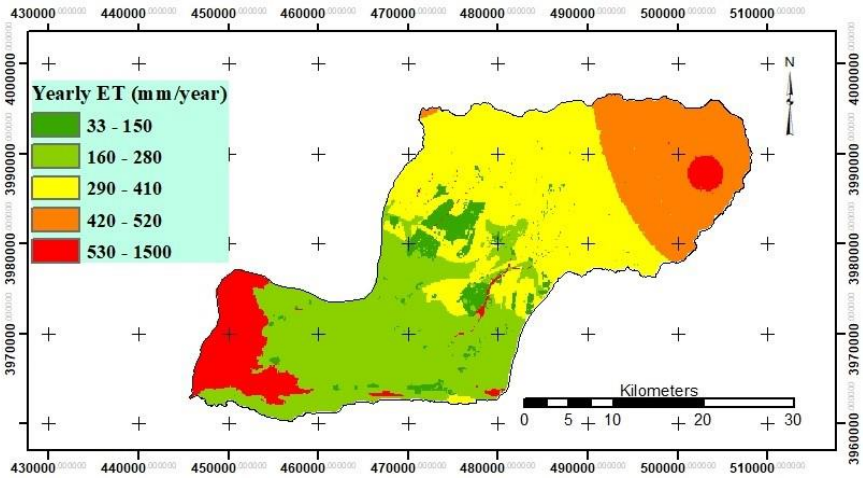

Figure 8: Simulated evapotranspiration map.

The annual ET map is representative of the intricate pattern of distribution of ET equal to 33 to 1500 mm/year. The average of ET is equal to 352 mm/year (Figure 8). The maximum amount of evapotranspiration was calculated in the area of salt marsh and the vicinity of streams. The minimum amount of evapotranspiration is also related to the area, which has the maximum amount of runoff in itself. By considering the amount obtained in the impermeable areas, the amount of evapotranspiration is equal to 10% of the annual evapotranspiration. Moreover, the maximum amount of evapotranspiration is related to agricultural land and the areas with a large number of trees. Finally, by running the model, the raster map of groundwater recharge amount is illustrated. This map shows the changes in the amount of average recharge in all parts of Hashtgerd plain, and also it shows the potential of the aquifer recharge as well. Figure 9, shows the amount of annual recharge of the aquifer, which has been estimated using the WetSpass model. It is worth mentioning that the annual recharge of groundwater is a function of input amounts (rainfall and snowfall) and outputs of the Hashtgerd basin. Outputs include the amount of evaporation, which has been released from the surface of plants, soils, and open water areas. Consequently, the residual of outputs and inputs is transferred to runoff, which may recharge the aquifer in permeable areas.

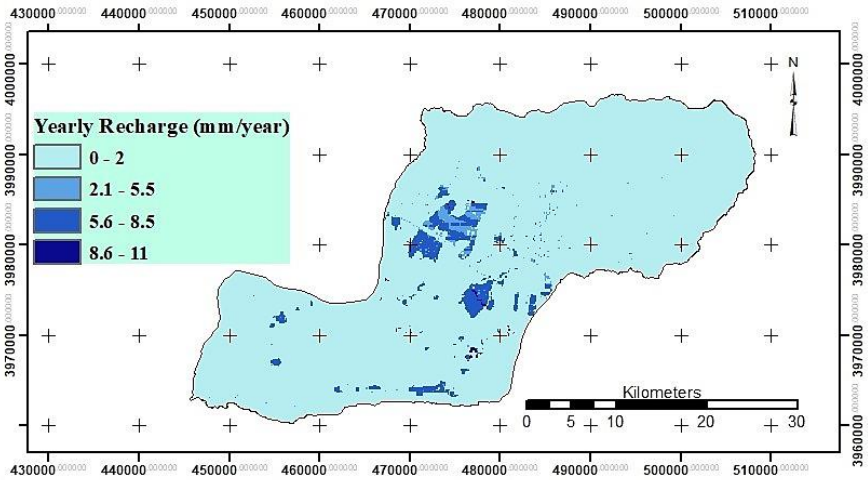

Figure 9: Simulated yearly recharge map

The consideration of the amounts (Figure 9) shows that in a few parts of the basin, the possibility of the aquifer recharge is there and its amount is equal to 2 to 11 mm/year. The maximum amount of recharge occurs in the areas of the basin, which always has the maximum potential of producing runoff. The average amount of annual recharge is equal to 0.33 mm. This amount of recharge is the average of the recharge during cold and warm seasons. Figures 10 and 11 show the distribution of spatial recharge in cold and warm seasons, respectively. It is worth mentioning that by a warm period, the first six months of the year are meant. Considering the amount of recharge raster maps show that there is less recharge during warm weather. Besides, negative amounts in the basin are representative of evapotranspiration phenomenon, which causes the release of humidity from the surface.

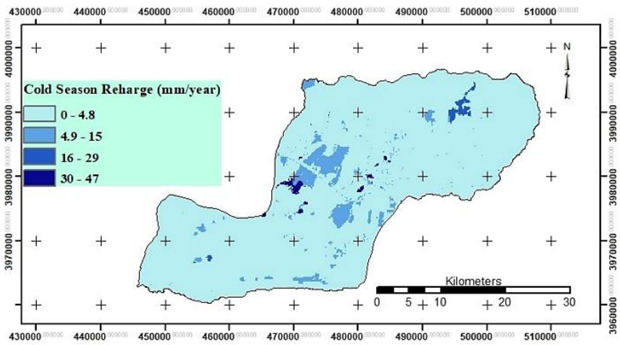

Figure 10: Simulated yearly recharge in the cold season

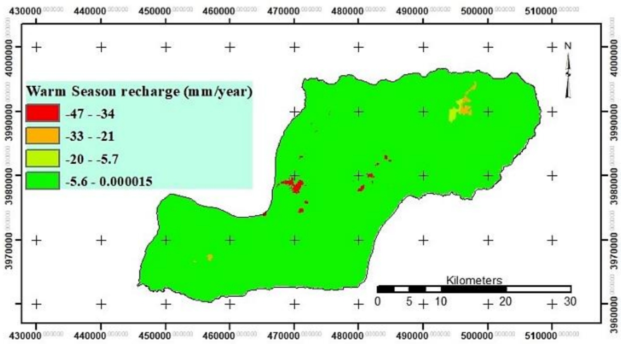

Figure 11: Simulated yearly recharge in the warm season

During the cold and glacial period, the amount of recharge is equal to 44 mm/year. Usually, about 99% of Hashtgerd groundwater recharge occurs during the cold period because of an increase in the amount of rainfall and surface runoff. On the other hand, recharge occurs in the soils with class 8 due to the penetration of water (Figure 12). By integrating the soil layer and recharge amount raster, during the cold period of the year, it can be concluded that the average recharge of the aquifer is equal to 1.33 mm. Afterward, in the soil layer of class 4, the maximum amount of recharge is equal to 1.23 mm is modeled.

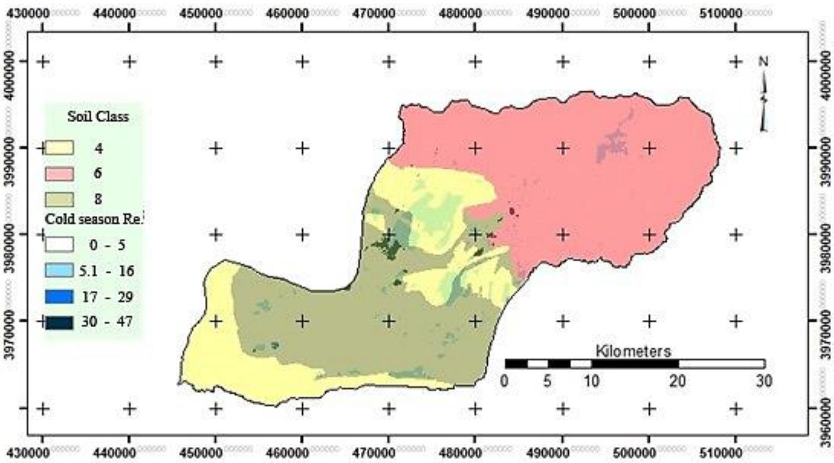

Figure 12: Simulated recharge in cold season at different soil classes

Recharge in the area with a low amount of precipitation caused by the intricate interaction of weather and earth surface condition, and vegetation across the widely ranging spatiotemporal scales. Thus, spatially-physically based water budget model (WetSpass) was designed to model the long-term groundwater recharge. As mentioned before, the results depend on the coverage of land (water body, vegetated area or other uses), soil texture, and hydro-meteorological parameters (such as rainfall, and wind speed).

4. CONCLUSION

In the current study, water balance parameters in various scales of seasonal and annual (e.g., groundwater recharge, runoff, ET, and interceptions) have been modeled and simulated using WetSpass model. The Spatiotemporal variation of water balance components relies on different parameters of meteorology, soil, topography, and land use condition (Salem et al, 2019). With respect to Figure 9, annual evapotranspiration in the southwest, northeast, and the natural streams are much more. While, in the middle part of the basin, which has the high potential of producing runoff, is a little. The main reason for the different amounts is related to the soil types. For example, silty soils have a lot of storage capacity (field capacity) and can hold large amounts of water and cause substantial evaporation. While the reason for different amounts of evaporation and fluctuation during the warm and cold years are related to the low energy received from solar radiation. It should be noted that in the warm seasons, the received solar energy at the earth's surface, does not limit the available water in the soil (which is known as "soil moisture"). The water-consuming factor, which limits before mentioned "soil moisture", is called evapotranspiration, and the factor of water in the soil is the determinant of the amount of evaporation and transpiration (Cosby, et al, 1984; Saxton, et al, 1986). In another aspect, this agent can be investigated, and the infiltration and evaporation from the open water areas and the existing rivers can be an effective factor in evapotranspiration. In the warm seasons, the vegetation land cover generally reaches the highest level. On the other hand, the open water areas are decreasing, due to rainfall reduction, which increases the amount of evapotranspiration. Finally, the results showed the importance of soil type and land use impact on the amount of runoff and evapotranspiration in seasonal and annual scale. Therefore, for future studies using the land use map with more updated details are necessary, and thereby, the more precise data into the model must be imported. These studies help us find out more information about the area. Moreover, producing the recharge maps in seasonal and annual periods help us to find the points which have the high potential of groundwater recharge. Furthermore, by using artificial recharge systems such as recharge wells or recharge pools, the groundwater level is increased. Due to the obtained results, the recharge of groundwater is affected by environmental parameters such as geology, land use/land cover types, soil and meteorological variables (rainfall, wind speed, and sunshine hours) which affect the amount of evapotranspiration. Moreover covariance of the recharge map with each of the used map in calculating water balance must be considered. The results obtained from the presented study can be taken as a primary examination of modeling the groundwater for the Hashtgerd aquifer. Furthermore, the results showed that the WetSpass model could be used to simulate the component of water balance for the Hashtgerd plain, which is known as a semi-arid area in Iran. Understanding the abovementioned, simulated long-term parameters will be useful for determining the available water in the Hashtgerd region for drinking, domestic, irrigation, and industrial purposes and modeling the relation between rainfall (as the input for water cycle), and other components of water balance such as groundwater recharge, runoff, and evapotranspiration.

5. AVAILABILITY OF DATA AND MATERIAL

Data used or generated from this study is available upon request to the corresponding author.

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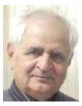

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