Research papers

A model for the assessment of the effect of mulching on aquifer recharging by rainfalls in an arid region

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ABSTRACT

In this paper, a model is proposed for the assessment of the effectiveness of various mulches in increasing deep percolation of rainfalls for enhancing arid zones aquifers. For this purpose, 8 precipitations were selected from the intensity-duration-frequency (IDF) curves of the study area with a return period of 2 and 5 years. The deep percolation of these precipitations were examined in lysimeters with gravel, sand and mixed mulches and without any mulch. Then 192 data of soil moisture, daily maximum air-temperature and deep percolation were measured for driving empirical equations. Moreover, the efficiency and accuracy of these empirical equations were investigated using Coefficient of Determination (CD) and Nash–Sutcliffe Efficiency Coefficient (NSEC). The results showed that the obtained empirical equations could estimate deep percolation and evaporation with an acceptable accuracy. Using these equations and the soil-water balance equation, a soil moisture model was developed for the assessment of deep percolation. Then it was examined to evaluate the efficiency of the mulched soils in increasing soil moisture and aquifer recharging of three years' precipitations in Shahrekord plain, Iran. The results showed that the deep percolation increased in all examined mulched soils compared to unmulched soil, its maximum and cumulative increase were in gravel mulch with 21.3% and 30%, respectively. Furthermore, groundwater modeling results showed that the mulching could improve groundwater level as 0.34 m over a three year period. Finally, this paper proposes soil mulching for enhancing groundwater resources and a model to assess it.

1. Introduction

Groundwater is one of the main sources of water supply in arid and semi-arid regions of the world. Given the growing demand of the world's population, the use of groundwater is increasing in arid areas around the world (Taylor and Howard, 1996). Due to the high contribution of groundwater to water supply in arid and semi-arid regions of the world, it is essential to enhance these valuable water resources. On the other hand, the role of deep percolation of precipitations is very important for groundwater recharging and directly impacts on groundwater balance (Liu et al., 2011). Since the deep percolation of surface water and precipitation are the main cause of groundwater recharge (Barrett et al., 1999), increasing deep percolation can enhance groundwater resources. Furthermore, in arid and semi-arid regions of the world, where surface water is rare, the deep percolation of precipitation even in small amounts can be significant for recharging aquifers (Gao et al., 2018). Therefore, the investigation of possible solutions to increase the amount of percolation of precipitations into the aquifers may have appropriate effects on the conservation and restoration of groundwater resources.

High evaporation rate is one of the greatest key factors which causes water losses, especially in dry areas. Moreover, the high evaporation losses in these areas can lead to a drop in groundwater level (Piri et al., 2009). Thus, controlling and decreasing evaporation rate as one of the key factors of water loss can have an effective role in preserving water resources in these areas (Soheylifar et al., 2013). One of the traditional methods for reducing evaporation from the soil surface is applying mulches (Li et al., 2018; Peng et al., 2016; Zhao et al., 2017). Any material that covers soil surface and protects it from sunlight for decreasing evaporation is called mulch (Yaghi et al., 2013). Literature review showed the positive effect of mulch on reducing the evaporation from the soil surface (Hou et al., 2010; Wang et al., 2014a; Wang et al., 2014b), decreasing wind erosion (Hagen, 2010; He et al., 2008), control of dust storm (Edvardsson, 2010; Goodrich et al., 2009) and reducing soil erosion by runoff (Adekalu et al., 2007; Huang et al., 2013). However, mulch's effect on deep percolation to increase aquifer recharge is not yet reported. For example, in a study by Hou et al. (2010), the effects of plastic mulch on soil temperature, evapotranspiration
rate, plant growth and crop yield were examined in a dry area in China. The results showed an increase of 2 to 9 degrees Celsius (°C) in soil temperature and decrease in the rate of evapotranspiration during 60 days of the experiment. In another study, Wang et al. (2014a), examined the effect of vegetation mulch on groundwater recharge. In this research, the increasing effect of using lawn and straw cover on the ground surface on groundwater recharge was appraised in a sand box of 1.5 × 1.3 × 1 m. In this research, the groundwater flow was experimentally tested in the box. The results indicated that the groundwater recharge by irrigation increased up to 39.1% and 42.2%, respectively, by using lawn and straw mulch. Wang et al. (2014b) examined the effect of sandy mulch thickness on a silty-loam soil temperature, evaporation from soil surface, water productivity and watermelon yield in a semi-arid region in China. The results showed that mulch thickness has a positive effect on reducing evaporation depth and control of soil temperature fluctuations. In another study, Chen et al. (2015), examined the impact of using another type of mulch (plastic mulch with straw mulch) on the crop yield and water use efficiency of winter wheat in a dry climate of China. Their results showed that the use of mulch could increase water use efficiency ranged from 25% to 35% at different time intervals. In most studies, considering the positive effect of mulch on reducing evaporation and keeping more water in the soil. It has been attempted to investigate the effect of mulch on the crop yields and reducing irrigation water consumption. However, less attention has been paid to the positive effect of mulch on storing rainwater in soil by reducing evaporation as well as increasing the deep percolation of precipitation. In some studies, the permeability rate was investigated to determine the effect of mulch on preventing soil erosion and runoff formation (Adekalu et al., 2007; Huang et al., 2013). The effectiveness of these mulches in reducing evaporation and increasing soil moisture has been well studied in previous studies and the results show their positive effect on maintaining soil moisture (Chakraborty et al., 2010; Li et al., 2009; Li et al., 2012; Zhou et al., 2011). In most of these researches, studies were carried out on experimental models like laboratory channels with high longitude and less than one meter depth of soil; in most cases less than 30 to 40 cm (cm) soil depth. However, direct groundwater recharge is always due to the percolating rainwater into the depth more than crops’ root zone which is known as deep percolation. The higher depth of precipitation has higher deep percolation and as a result the higher volume of groundwater recharge (Orr et al., 2002). Counting the root depth of some plants, which reaches even one meter, measuring the percolation rate in laboratory flumes with less than one meter depths cannot be a good supposition for measuring the groundwater recharge caused by rainwater. Considering above reviewed papers, the effect of mulch on soil moisture, crop yield and soil erosion prevention have been investigated. Nevertheless, the effect of mulch on the aquifer recharge rate by the deep percolation of rainwater by soil mulching has not been simulated physically and numerically. Consequently, in this paper, the efficiency of gravel, sand and mixed mulches on increasing the groundwater recharge by soil mulching is assessed in a semi-arid region aquifer (Shahrekord aquifer, Iran). Therefore, it reveals how mulches can be effective in maintaining soil moisture, reducing evaporation and increasing the deep percolation rate of rainwater into the soil, thus recharging aquifers.

2. Materials and methods

2.1. Case study

The study area is in the central regions of Iran between 32°5′–32°34′ N latitudes and 50°33′–51°10′ E longitude namely Shahrekord Aquifer. Fig. 1 shows the location of the study area in the center of Iran. In this research, to simulate precipitation and performing experiments, the precipitation data of the Shahrekord rainfall gauge was used which is near the center of study area. The average annual temperature of this area is 11 °C and the average annual precipitation is 414.8 mm (mm).

2.2. Tested mulch

Crop residues (leaves, straw and etc.), plastic, gravel and sand, zeolite, paper, liquid mulches and textiles are the most commonly used mulch, which have been reported in studies to reduce evaporation and prevent soil erosion. Since the purpose of this study is to evaluate the effectiveness of mulches in increasing the deep percolating of rainwater. It is necessary that the investigated mulch be able to prevent water evaporation from the soil surface and to have enough permeability for the deep percolation of rainwater. Furthermore, the selected mulch should be low cost and available in the region to be practically applicable and economic. According to the investigations conducted in the study area, the suitable mulch for these purposes are gravel and sand mulches. In this research, three types of gravel and sand compounds were used as mulches: 100% gravel, 100% sand and gravel and sand 50–50 mixture. The thickness of each mulch layer was 7 cm. Sand grain size varied from 0.07 to 4 mm and gravel grain size varied from 4 to 20 mm. The shape factor of both sand and gravel were 0.7.

2.3. Experimental setup and analysis

In this research, circular volumetric lysimeters with depths of 1.4 m and 40 cm diameter were used to assess the mulches’ efficiency in increasing the rainwater percolation into the vadose zone and aquifer media. The use of 1.4-meter depth lysimeters provides the possibility of measuring deep percolation. To control similarity of soil bulk density in lysimeters, the same weight of soil used for the same volume of lysimeters. Moreover, to control soil bulk density in various depths of lysimeters, the same weight of soil used in each layer of lysimeters. Thus, lysimeters had the same distribution of soil bulk density in their depths.

To evaluate mulch efficiency in increasing rainwater percolation into the soil, it is necessary to create artificial rain with different intensity and duration. For this purpose, a rain simulator with similar dimensions to the area of lysimeters was made in this research (Fig. 2). This rain simulator consists of three parts: tank, flow control valve and sprinkler nozzles. In this experimental setup, a nozzle was considered for each lysimeter which was connected to the tank through a separate path. The task of the tank is to create a constant water head on each sprinkler, and for this purpose, a float valve was used to control water level. This tank was connected to the urban water flow and controlling water level prevented possible fluctuations in the heads of the nozzles. Furthermore, in the water transfer path from the tank to the sprinklers of each lysimeter a flow control valve was placed that provides the possibility for changing water pressure on the nozzles’ flow separately. Accordingly, by adjusting water pressure of nozzles, it is possible to adjust the amount of their discharge, and thus regulate the intensity of simulated rainfall.

To increase the accuracy of the simulation, the soil texture of the lysimeters was selected using the average of drilling logs in the study area and the rainfall intensity was determined using the Intensity-Duration-Frequency (IDF) curves of the study area. For this purpose, four precipitation durations 2, 4, 6 and 8 h were tested. The precipitation intensity proportional to these durations was obtained using IDF curves of the study area for two return periods of 2 and 5 years which have high occurrence frequency, and these rainfall intensities were created artificially by the rainfall simulator in the experiments. In this way, each of the three mulches and a control lysimeter (the lysimeter without mulch), were tested using eight different combinations of precipitation intensity and duration, which the precipitation depths are shown in Table 1.

To measure soil water storage during the experiment, five gypsum block sensors were installed at depths of 30, 60, 90, 110 and 125 cm of the lysimeter soil surface and using these blocks, soil moisture were measured and recorded during the experiments. Detail of calibration of by gypsum block sensors and measurement by them can be found in Keyhani (2010). The effect of using mulch on increasing the rainwater...
Deep percolation was investigated by measuring the outflows from the bottom of the lysimeters with mulch cover and comparing it with the non-mulched lysimeter (control lysimeter). The effect of using mulch on groundwater recharge was investigated by measuring the soil water storage and the outflows from the bottom of the lysimeters. The evaporation from the lysimeters were determined using water balance in soil (Eq. (1)) (Piri et al., 2009).

Fig. 1. The location of the study area.

Fig. 2. The Lysimeters and rainfall simulator used in the experimental setup.
Table 1
Depth of created precipitation corresponding to each duration and return period.

<table>
<thead>
<tr>
<th>Return period (year)</th>
<th>5</th>
<th>5</th>
<th>2</th>
<th>2</th>
<th>2</th>
<th>2</th>
<th>5</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duration (hour)</td>
<td>2</td>
<td>8</td>
<td>2</td>
<td>8</td>
<td>6</td>
<td>4</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>Depth (mm)</td>
<td>15.00</td>
<td>34.39</td>
<td>11.55</td>
<td>25.63</td>
<td>21.84</td>
<td>17.97</td>
<td>22.29</td>
<td>28.73</td>
</tr>
</tbody>
</table>

Table 2
The coefficients of Eq. (8) and the CD and NSEC for each of the studied mulches.

<table>
<thead>
<tr>
<th>Mulch type</th>
<th>Empirical equation coefficients</th>
<th>Evaluation criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>a</td>
<td>b</td>
</tr>
<tr>
<td>Without mulch</td>
<td>4.58 (2)</td>
<td>−1.65 (1)</td>
</tr>
<tr>
<td>Gravel mulch</td>
<td>5.32 (2)</td>
<td>−2.22 (1)</td>
</tr>
<tr>
<td>Sand mulch</td>
<td>4.97 (2)</td>
<td>−2.24 (1)</td>
</tr>
<tr>
<td>Mixed mulch</td>
<td>5.42 (2)</td>
<td>−2.32 (1)</td>
</tr>
</tbody>
</table>

* The numbers in parentheses indicate the power of 10 in scientific notation. For example: 4.58 (2) = 4.58 × 10².

Table 3
The coefficients of Eq. (9) and the values of the CD and NSEC for the studied mulches.

<table>
<thead>
<tr>
<th>Mulch type</th>
<th>Empirical equation’s coefficients</th>
<th>Evaluation criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>a</td>
<td>b</td>
</tr>
<tr>
<td>Without mulch</td>
<td>8.57 (–4)</td>
<td>1.92 (–1)</td>
</tr>
<tr>
<td>Gravel mulch</td>
<td>2.92 (–4)</td>
<td>1.00 (–1)</td>
</tr>
<tr>
<td>Sand mulch</td>
<td>4.62 (–4)</td>
<td>2.00 (–1)</td>
</tr>
<tr>
<td>Mixed mulch</td>
<td>2.50 (–4)</td>
<td>1.53 (–1)</td>
</tr>
</tbody>
</table>

* The numbers in parentheses indicate the power of 10 in scientific notation. For example: 4.58 (2) = 4.58 × 10².

\[ E = P - O + \Delta S \] (1)

Where, \( E \) is the evaporation depth, \( P \) is the precipitation depth, \( O \) is the outflow depth from a lysimeter (deep percolation depth) and \( \Delta S \) is change in soil water storage. All parameters are in mm. Therefore, by measuring values of \( O \) and \( \Delta S \) during the experiment and given the known amount of \( P \) which is artificial rainfall, \( E \) can be obtained for an experiment. In this paper, by measuring these parameters, two empirical equations were developed using the experimental results to estimate the precipitation deep percolation and evaporation depths in soils with mulch and without mulch. Accordingly, the deep percolation depth was determined as a function of precipitation depth and soil moisture (Eq. (2)). Moreover, the evaporation depth was determined as a function of daily maximum air-temperature and soil moisture (Eq. (3)). Curve Expert Professional 2.6.3 software was used to find the best equation that expresses the relation between dependent and independent variables (Eqs. (2) and (3)). This software is able fit different equations on experimental data.

\[ O = f (S, P) \] (2)

\[ E = f (S, T) \] (3)

To evaluate the efficiency of the obtained empirical equations, Coefficient of Determination (\( R^2 \)) and the Nash–Sutcliffe Efficiency Coefficient (NSEC) were used which are shown in Eqs. (4) and (5), respectively.

\[ R^2 = \left[ \frac{\sum_{t=1}^{m} \left( X_{t,obs} - X_{t,sim} \right) \left( X_{t,sim} - \overline{X}_{sim} \right)^2}{\sqrt{\sum_{t=1}^{m} \left( X_{t,obs} - \overline{X}_{obs} \right)^2} \sqrt{\sum_{t=1}^{m} \left( X_{t,sim} - \overline{X}_{sim} \right)^2}} \right]^2 \] (4)

\[ \text{NSEC} = 1 - \frac{\sum_{t=1}^{m} \left( X_{t,obs} - X_{t,sim} \right)^2}{\sum_{t=1}^{m} \left( X_{t,obs} - \overline{X}_{obs} \right)^2} \] (5)

In these equations, \( X_{t,obs} \) and \( X_{t,sim} \) are respectively the observed and simulated values of the examined parameter at time \( t \). \( \overline{X}_{obs} \) and \( \overline{X}_{sim} \) are respectively the mean of observed and simulated values of the examined parameter and \( m \) is the number of experimental data (Singh, 1988). Furthermore, for verifying the obtained empirical equations, the Mean Bias Error (MBE) and Root-Mean-Square Error (RMSE) indices were used according to the Eqs. (6) and (7), respectively (Jacovides and Kontoyiannis, 1995; Willmott, 1982).

\[ \text{MBE} = \frac{\sum_{t=1}^{N} (X_{t,sim} - X_{t,obs})}{N} \] (6)

\[ \text{RMSE} = \sqrt{\frac{\sum_{t=1}^{N} (X_{t,obs} - X_{t,sim})^2}{N}} \] (7)

In these equations, \( X_{t,obs} \) and \( X_{t,sim} \) are respectively the observed and simulated values of examined parameters and \( N \) is the number of experimental data.

In the next step, the daily maximum air-temperature and precipitation data of the study area were obtained for a period of three years (2010–2013) and by solving the Eq. (1) and using the empirical equations (Eqs. (2) and (3)), the daily depth of precipitation, evaporation and deep percolation were modeled. Then, the daily values of evaporation from the soil and precipitation deep percolation were calculated using the daily values of daily maximum air-temperature and precipitation of the study area by using the empirical equations (Eqs. (2) and (3)). Next, using Eq. (1), the soil moisture was determined for the next day. Using this algorithm, the soil moisture, precipitation, deep percolation and evaporation for each day of the studied three years and for each tested mulch and unmulched soil were computed for the study area.

2.4. Numerical modeling

In the final step of this research, the MODFLOW code was used to assess the effect of using mulch on groundwater level. Conceptual model of Shahrekord aquifer was considered using aquifer recharge-discharge sources and boundary conditions in MODFLOW model with 500 × 500 m grid for steady and unsteady conditions. The aquifer was simulated for a 3-year period (from September 2010 to September 2013) which the first 2 years were for calibration and the last year was for model validation. The simulation time step was monthly, September 2010 was used for initial condition.

The values obtained for deep percolation were calculated for each precipitation daily for three years were used as input recharge data for the MODFLOW model. Finally, the groundwater levels were evaluated monthly for each of the three mulched and unmulched soils.

3. Results and discussion

During the experiments, soil moisture was measured at 5 different depths and maximum air-temperature along with precipitation deep percolation measured on daily basis, thus 192 data were recorded for the parameters. Using these data and Eq. (2), an empirical equation was established to estimate the aquifer recharge using soil moisture and precipitation rate for each mulched and unmulched soil which is shown as Eq. (8). The coefficients of this empirical equation for different mulches are according to Table 2.

\[ O = \frac{P \cdot S}{a + b \cdot P + c \cdot S} \] (8)

Where, \( O \) is the drained water depth from the soil (groundwater recharge), \( P \) is the precipitation depth and \( S \) is the soil water storage (all
Using Eq. (8) and the coefficients of Table 2, it is possible to estimate the deep percolation caused by different precipitations in each studied mulched and unmulched soils. In various soil profiles, it is possible to calibrate Eq. (8) and obtain the corresponding coefficients in the same way.

Later, the efficiency and accuracy of the obtained empirical equations were evaluated by calculating CD and NSEC using Eqs. (4) and (5), respectively. The results are shown in Table 2. Table 2 shows the values...
of CD in all studied mulched and unmulched soils are between 0.97 and 0.98 which indicates that the Eq. (8) defines experimental data properly. It is worth mentioning, the highest value obtained for CD is for mixed mulch and the lowest is for unmulched soil. Furthermore, the calculated Nash–Sutcliffe efficiency coefficients indicate the high efficiency of the obtained empirical equation (Eq. (8)) for estimating the amount of water drained from the soil and consequently the groundwater recharge. An unit value for this index indicates a perfect match between the simulated value and the observed data (Singh, 1988). According to Table 2, the highest value of this index is for gravel mulch and the lowest is for unmulched soil. Therefore, according to the high values of the used two evaluation indices, it seems that in all three mulched soils and the unmulched soil the Eq. (8) can estimate the rate of deep percolation with acceptable accuracy. Consequently, this equation can be used to estimate the amount of deep percolation for various precipitations.

Consequently, the evaporation depths of the lysimeters which determined using Eq. (1) were used to develop an empirical equation to compute the evaporation depth of three mulched and unmulched soils using daily maximum air-temperature and soil water storage. This empirical equation is shown in Eq. (9) and the coefficients of this empirical equation for each of the soil mulches are in Table 3.

\[ E = a \cdot S^b \cdot T^c \quad S, T > 0 \]  

(9)

Where, \( E \) is the evaporation depth in mm, \( T \) is daily maximum air-temperature (°C) and \( S \) is the soil water storage (mm).

Thus, using Eq. (9) and its coefficients in Table 3, the evaporation depth for each of the mulched soils as well as unmulched soil can be assessed using daily maximum air-temperature and soil moisture. Then, the efficiency of obtained empirical equation was evaluated using CD and NSEC (Eqs. (4) and (5)). The evaluation results are shown in Table 3. As shown in Table 3, the values of CD in all studied mulched and unmulched soils are between 0.92 and 0.96, which indicates the good fit of the Eq. (9) on experimental data. The highest value obtained for CD is for gravel mulch and the lowest is for unmulched soil. The calculated values for NSEC also indicate the high efficiency of the obtained empirical equation (Eq. (9)) for estimating the evaporation depth. According to Table 3, the highest value of this index is for mixed mulch and the lowest for unmulched soil. According to the values of Table 3, it seems that the Eq. (9) could estimate the evaporation depth using soil moisture and daily maximum air-temperature with acceptable accuracy in all mulched and unmulched soils.

Subsequently, Eqs. (8) and (9) were validated with observed data. For this purpose, four different precipitation durations of 2, 4, 6 and 8 h were examined. The rainfall intensities corresponding to these durations were also obtained from IDF curves of the study area for the return period of 50 years. Then, the values of daily maximum air-temperature, soil moisture and precipitation deep percolation were recorded daily, the results were compared with the calculated results from Eqs. (8) and (9) (Fig. 3). The estimation error of these empirical equations was also calculated by using Eqs. (6) and (7) as shown in Table 4.

According to Table 4, the highest MBE index value in estimating evaporation is for unmulched soil, −0.34 and the lowest value is for sand and mixed mulch, 0.11. The negative value of this index in sand mulch indicates that the average of the estimated values for evaporation is lower than observed values. Conversely, the positive value of this

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**Table 4**

The values of MBE and RMSE indices for each of the examined parameters.

<table>
<thead>
<tr>
<th>Mulch type</th>
<th>Evaporation</th>
<th>Deep percolation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MBE</td>
<td>RMSE</td>
</tr>
<tr>
<td>Without mulch</td>
<td>−0.34</td>
<td>0.05</td>
</tr>
<tr>
<td>Gravel mulch</td>
<td>−0.13</td>
<td>0.05</td>
</tr>
<tr>
<td>Sand mulch</td>
<td>−0.11</td>
<td>0.03</td>
</tr>
<tr>
<td>Mixed mulch</td>
<td>0.11</td>
<td>0.02</td>
</tr>
</tbody>
</table>

---

Fig. 4. The daily values of depth and deep percolation percentages in gravel mulch and unmulched soils in the first year of modeling.
index indicates that in mixed mulch the average of the estimated values for evaporation parameter is higher than the observed values. Besides, the lowest value of RMSE index in estimating evaporation is for mixed mulch, 0.02. The highest value of MBE index in estimating depth percolation is for mixed mulch, 0.25 and the lowest value is for unmulched soil and sand mulch with −0.14. The negativity of these values indicates that the average of estimated values is lower than observed values. Considering the values of the MBE and RMSE indices as well as Fig. 3 which indicates the concentration of data around the bisector, it can be concluded that the proposed models have been able to estimate the parameters of evaporation and deep percolation in each of the examined mulched and unmulched soils with an acceptable accuracy.

Accordingly, the daily values of evaporation and deep percolation were computed by solving the Eqs. (1), (8) and (9) from the daily maximum air-temperature and precipitation data of the study area that were obtained for three years. Fig. 4 shows the daily values of depth and deep percolation percentages from 9/23/2010 to 4/30/2011 in unmulched soil and gravel mulch. Gravel mulch had the best efficiency in increasing the daily deep percolation in this research as discussed above in this paper. In this figure, the dry period of year (without precipitation) are not displayed.

In Fig. 4, the horizontal axes show days of the rainy period during the first year of modeling (9/23/2010 to 4/30/2011). The daily precipitation depth and the deep percolation are shown in the upper and lower diagrams, respectively. According to Fig. 4, the precipitations that occurred at the beginning of the period have longer intervals between occurrences than the precipitations in the middle of the period (from the hundredth day to the last day). In both of gravel mulch and unmulched soils, the percentage of deep percolation is higher in the middle precipitations of the period (shorter intervals between rainfall occurrences) than the initial precipitations (longer intervals between rainfall occurrences). For instance, precipitations with a depth of less than 10 mm at the beginning of the period had percolation rate of less than 5% but toward the middle of the period this value is gradually increased to more than 10%. Therefore, it can be said that the percentage of deep percolation is higher in precipitation with shorter intervals between their occurrences than the same precipitation with longer intervals between occurrences.

Fig. 5 presents the increase rate in soil moisture, decrease rate in evaporation and increase rate in deep percolation of precipitation in the gravel, sand and mixed mulches compared to the unmulched soil.

Table 5
The amount and percentage of deep percolation, soil moisture and evaporation losses during the three-year period using the results of modeling.

<table>
<thead>
<tr>
<th>Mulch type</th>
<th>Percolation (mm)</th>
<th>Percolation (%)</th>
<th>Evaporation losses (mm)</th>
<th>Evaporation losses (%)</th>
<th>The increased soil moisture (mm)</th>
<th>The increased soil moisture (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unmulched soil</td>
<td>142.68</td>
<td>16.4</td>
<td>727.82</td>
<td>83.6</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Gravel mulch</td>
<td>185.56</td>
<td>21.3</td>
<td>501.92</td>
<td>57.6</td>
<td>183.02</td>
<td>21.1</td>
</tr>
<tr>
<td>Sand mulch</td>
<td>152.12</td>
<td>17.4</td>
<td>718.38</td>
<td>82.6</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Mixed mulch</td>
<td>177.27</td>
<td>20.3</td>
<td>555.68</td>
<td>63.9</td>
<td>137.55</td>
<td>15.8</td>
</tr>
</tbody>
</table>

Fig. 5. The increase rate in soil moisture, decrease rate in evaporation and increase rate in deep percolation of precipitation in the gravel, sand and mixed mulches compared to the unmulched soil.
mulches compared to the unmulched soil for monthly precipitation depth in the first year of modeling. As shown in Fig. 5c, the monthly precipitation depth in September is about one millimeter and much lower than the other months. Therefore, when the amount of precipitation is insignificant, there is no significant change in soil moisture increase, evaporation reduction or increase in deep percolation when using mulch compared to soil without mulch. In October, increase in precipitation depth and the low soil water storage in the

Fig. 6. The observed and modeled values of groundwater level in observation wells.
soil, a significant percentage of precipitation is stored in soil. As shown in Fig. 5b, the gravel and mixed mulches increase the soil moisture compared to unmulched soil by 40%, where this value for sand mulch was 10%. Evaporation depths also decreased in this month by using gravel and mixed mulch by more than 30% compared to unmulched soil (Fig. 5a). Therefore, in this month the use of mulch was able to preserve precipitation water in the soil and reduce the amount of evaporation loss compared to unmulched soil.

In November, although the total precipitation depth was decreased compared to the previous month (Fig. 5c), the deep percolation of
precipitation in all three examined mulches increased compared to the previous month (Fig. 5d). This could be due to preservation of soil water storage in the soil by using mulch in the previous month and thus increasing deep percolation of precipitation in this month. According to Fig. 5d, the increase in deep percolation in November was gravel mulch and mixed by 1.3% compared to unmulched soil.

Increase in precipitation depth in December, January and February (Fig. 5c), the deep percolation also increased in all three examined mulches. In these months, the greatest effect on increasing deep percolation is gravel mulch, the highest value is in February of more than 4% compared to unmulched soil (Fig. 5d). For gravel mulch, February soil water storage was increased by more than 5% and evaporation was decreased by more than 10% compared to unmulched soil (Fig. 5b and a, respectively). This shows that during the cold months of the year, when the amount of evaporation decreases and the precipitation depth increases for the mulched soils compared to soil without mulch. The increase can be due to increase in moisture storage of mulched soils caused by precipitations with a lower depth and higher time intervals that occurred in the previous and warmer months of the year. As mentioned earlier, the evaporation depth from mulched soils decreases and this increases the soil water storage in these months in mulched soils when compared to unmulched soil. Thus, it increased deep percolation in mulched soils in December, January and February. Furthermore, due to increase in daily maximum air-temperature in March, the increase of moisture storage caused by precipitation was 40% and the reduction in evaporation depth was the same amount comparing to

Fig. 8. a to c respectively represent the increase in groundwater level (m) in the studied aquifer by applying gravel, sand and mixed mulches compared to unmulched soil.
Numerical simulation of the studied aquifer was modeled by using MODFLOW code of GMS10.2 software. In this modeling, the RMSE of calibration in the steady state was 0.43 m and in unsteady state was 1.28 m which indicated that the modeling errors rate are acceptable. In Fig. 6, the observed and calculated values of the model is shown in selected observation wells at the plain. These observation wells were selected because they are scattered on the plain, having observation wells from various parts of the plain (north, south, east and west). Fig. 6 represents a suitable estimation for groundwater level of observation wells for different time steps.

To identify suitable areas in the plain for mulching, the land use map of Shahrekord plain was prepared (Fig. 7). To model the impact of mulching on the groundwater level, it was assumed that, in the plain area, the agricultural land and rangeland were fully covered by the gravel mulch. Using this assumption, the groundwater level was modeled by applying GMS to find the impact of mulching on the groundwater level. In Fig. 8, the increase in groundwater level at the end of the three-year period is shown for each of the examined mulches. As shown in Fig. 8, the mulching could increase the groundwater level compared to unmulched soil. The values of increase in groundwater level for gravel, sand and mixed mulches are equal to 0.9, 0.2 and 0.7 m, respectively. In order to determine the exact values of increase in groundwater level during the three-year period, the average of groundwater level change throughout the aquifer due to mulching was calculated monthly for each of the examined mulches (Fig. 9). As shown in Fig. 9, the increase in groundwater level for examined mulched soils compared to unmulched soil at the beginning of the period starts from zero and reaches its maximum value in March 2013. In the three examined mulches, these changes begin from lowest values at the beginning of each year and at the end of the rainy season reach their maximum values and then begin to decrease at the end of the wet months. The maximum groundwater level increase is 0.34 m in gravel mulch and the lowest groundwater level increase is 0.09 m in sand mulch. Therefore, it can be said that the gravel mulched soil could increase the mean groundwater level compared to unmulched soil with a maximum of 0.34 m over a 3-year period. This means that gravel mulch can be proposed to restore aquifers in arid regions among the examined mulches.

4. Conclusions

In this study, using the data obtained from the experiment, two empirical equations were developed to estimate the deep percolation of precipitations (using the soil moisture and precipitation depth) and soil evaporation (using the daily maximum air-temperature and soil water storage) for the examined mulched soils as well as unmulched soil. To evaluate the efficiency of the proposed empirical equations, CD and NSEC were used. The results of this evaluation showed that the obtained empirical equations were able to estimate deep percolation and evaporation from mulched and unmulched soils with an acceptable accuracy. Using the proposed empirical equations and the soil-water balance equation, the soil moisture model was developed. Then, this model was tested using three-year precipitation and daily maximum air-temperature data of the region to evaluate the efficiency of mulching in increasing soil moisture and deep percolation of precipitation. The results of the model showed that applying the mulches increases soil moisture (caused by precipitation), decreases evaporation and increases the deep percolation of precipitation. The highest percentage of increase in deep percolation was in gravel mulch with 21.3% which is 30% increase compared to unmulched soil.

Furthermore, the evaporation loss decreases in all three mulched soils compared to unmulched soil, and the highest values of reduction was for gravel and mixed mulches as gravel and mixed mulches increased soil moisture by 21.1% and 15.8%, respectively. According to the results of this study, it was found that the percentage of deep percolation is higher in precipitation with shorter time intervals between
rainfall occurrences than the same precipitation with longer intervals between occurrences. Groundwater modeling results showed that the mulched soils could improve deep percolation and increase the groundwater level by 0.34 m in a three-year period.

In conclusion, by using gravel mulch, groundwater as one of the water supply sources in arid areas can be improved by maintaining soil moisture and increasing deep percolation of precipitation, and thus gravel mulch can be proposed for restoring aquifers.

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