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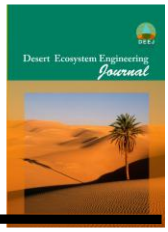


# Temporal water balance of precipitation behavior in the sand dunes of Hares-Abad area, Sabzevar, Iran

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**Abstract**

With announcing of the condition of water balance in sand dunes, it is easily possible biological reclamation and sustainable management of arid lands. To this end, a survey with eight vertical profiles was conducted in the sand dunes near Hares-Abad, Sabzevar, Iran, taking into account the effective factors in water balance in the soil moisture control section. Considering the morphology of sand dunes, the measurements were concentrated on two kinds of sand dunes including affixed sand dune and an active one, where the samples were distributed well on the different slopes of the active dune (three samples each from both the windward slope and the leeward slope, and one sample from the crest of the dune, and a sample as control from the fixed sand dune). Monthly moisture variations in the soil moisture control section were measured by TDR (time-domain reflectometry sensors) over two water years from 2014 to 2016. Besides, evapotranspiration rate was also calculated by the equation of water balance based on temperature and precipitation data. The findings show that the sand dunes in the study area are classified as non-infiltrative; that is to say that excess water does not reach aquifer.

**Keywords**: Moisture, Drought, Rainfall, Percolation, Evaporation.

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## 1. Introduction

Arid lands cover about one-third of the Earth's continental surface and are expanding rapidly, due to climate change and land degradation (Dregne, 1991). Moreover, drought events and water scarcity in drylands are becoming a more frequent environmental problem(Dong et al., 2013). The water stored in sand dunes is an important resource for plants in desert areas where it can be brought through the meteoric precipitation(Berndtsson et al., 1996; Wen et al., 2014). In semi-arid and arid regions, where evapotranspiration is always higher than rainfall, information about water balance is important(Pedram et al., 2017). Because of evapotranspiration in the revegetated sand dunes and evaporation from bare sand dunes, water deficit is considered the main determinant of success in vegetation restoration and sand dune stabilization programs. In general, surveying the water balance in sand dunes can be acquired from weekly to yearly timescales. The survey of water balance and the status of the moisture regimes are important in determining soil hydrological groups. Additionally, collecting information about the effective parameters in water balance such as rainfall, infiltration, evapotranspiration and any moisture variations within soil profile will help restoration programs, leading to the implementation of a sustainable land management. This information will also help determine accurate timing of seeding, seedling transfer, and supplementary irrigation, and even the utilization of the fixed sand dunes for agricultural purposes. Therefore, based on the water balance potential usage of sand dunes needs to be assessed on a scientific basis. This may lead to effective establishment and production of plants in desert rangelands (Tsoar and Zohary, 1985). In other words, in considering rain use efficiency in sand dunes, acquiring knowledge about the spatiotemporal distribution of water is necessary; this can greatly improve the procedure of plant establishment and calculation of their water requirements(Rummel and Felix-Henningsen, 2004; Rouhipour et al., 2008). In many cases, re-vegetation and biological stabilization of sand dunes fail due to paying no attention to the water balance. Additionally, plant species have different water requirements(ChunWang and GuangSheng, 2001).

In addition to annual precipitation, moisture content of the root zone is controlled by other resources including groundwater, and air humidity; they can play a significant role in the supply of the water needed for plants in sand dunes. Additionally, land management systems affect the moisture content in arid lands; water infiltration has a positive correlation with precipitation in all land uses; while there exists a lag time in response to rainfall in deeper soil layer. Despite this lag time, moisture content of the deep layers (80-120 cm) is stable(Niu et al., 2015).

Stabilization of sand dunes changes hydrological characteristics of dunes; hydraulic conductivity is reduced in fixed dunes owing to the changes in clay, silt and organic matter content resulting in lower infiltration rates in inactive dunes(Hugenholtz and Koenig, 2014). Biological crusts have also a great influence on water regime in dunes. They can deter water infiltration, redistribute runoff and reduce evaporation and wind erosion in dune systems (Coppola et al., 2011). Their presence will improve vegetation cover due to higher volumes of fine particles as well as favorable microclimatic conditions(Yair et al., 1997).Morphology of dunes could also affect infiltration rate; as findings in the moisture and temperature profiles of sand dunes after rainfall in Tengger Desert in Northwestern China show the infiltration mainly occurs in flat sections, explicitly in dune crests and interdune area. Rainfall alters temperature pattern of dunes from horizontally layered to vertical form. Vegetation and soil texture also influence the status of water balance. Monitoring soil water balance and aquifer recharge on the Hanford Research Site in southwestern Washington, DC, for a six-year period (2004-2009) showed that the rates of groundwater recharge or percolation varied from about zero in well-vegetated fine-textured soil to more than 86 mm per year in the barren and coarse-grained surfaces (Rockhold et al., 2009). Water deficit in drylands might relate to air condition; as the studies of moisture balance using the Thornthwaite-Mather Model in Nebraska sand dunes (Sridhar V. and Hubbard K. G, 2010) showed that even though the annual rainfall was about 420mm, water loss through evapotranspiration was 861mm, and the evapotranspiration potential was 1214mm. There was a surplus of water in wet season (December and March), while there was water shortage at the beginning of growing season in May, and this shortage prolongs until September and October; there, water deficit might be compensated by the upstream aquifer.

The horizontal variation of water balance in megadunes and lakes, and hydrologic cycle might be controlled by topography and geomorphic features; firstly, vegetation strips on the leeward slope of the sand dunes reflect the hydrological regime inside the sandy vadose zone. Then the leakage of wet sand sediments and secondary salinized sediments indicate the pattern of water movement. Thirdly, the groundwater seeps and the springs near the lakes in the sandy hills reflect the local effects(Dong et al., 2013).

Based on the soil water balance theory, soil water dynamics and evapotranspiration (ET) of artificial sand-fixing *Caragana microphylla* and *Caragana korshinskii* shrubs with three different densities were researched in Horqin sandy land during the growing season. Results showed that mean soil water content of three shrub densities changed with time, different density caused spatial changes of soil water content in the deep soil horizon, but brought little influence on soil water temporal trends(Zhang et al., 2013).

The active sand dunes and inactive ones in Iran are about 5 million and 12 million hectares, respectively (IFNRCBD, 2000), where only a small portion has actively been managed by the Forestry and Rangeland Organization, through planting drought-tolerant species or the utilization of mechanical approaches such as windbreak and oil mulch. Irrigation operations have been carried out by tanker for some distant areas where precipitation could not support water requirements of plants. Some projects have failed due to neglecting water balance principles. In other words, in vegetation restoration plans and biological stabilization of sand dunes, study of water balance is necessary. Better understanding of the sites, water regime and vegetation response will improve the conservation and restoration programs in combatting desertification.

For this reason, this research aims to investigate the vertical variations of water balance in fixed and active sand dunes. The results will be useful in restoration and revegetation of sand dunes as well as in groundwater recharge.

## 2. Materials and Methods

### 2.1. Study Area Characteristics

The study area (geographically on 36˚6' 46" N and 57º 42' 55" E) with an altitude of 948m above sea level is located in the sand dunes of Hares-Abad, about 5 km south of Sabzevar in northeast of Iran. The project was conducted in an area of 1000 square meters (100m×10 m). As the effect of prevailing winds, which blow from the east to the west, the sand dunes stretch from northeast to southwest, with a mild slope in the windward direction in the eastern part, and a steep gradient in the leeward slope on the western side (Figure 1).

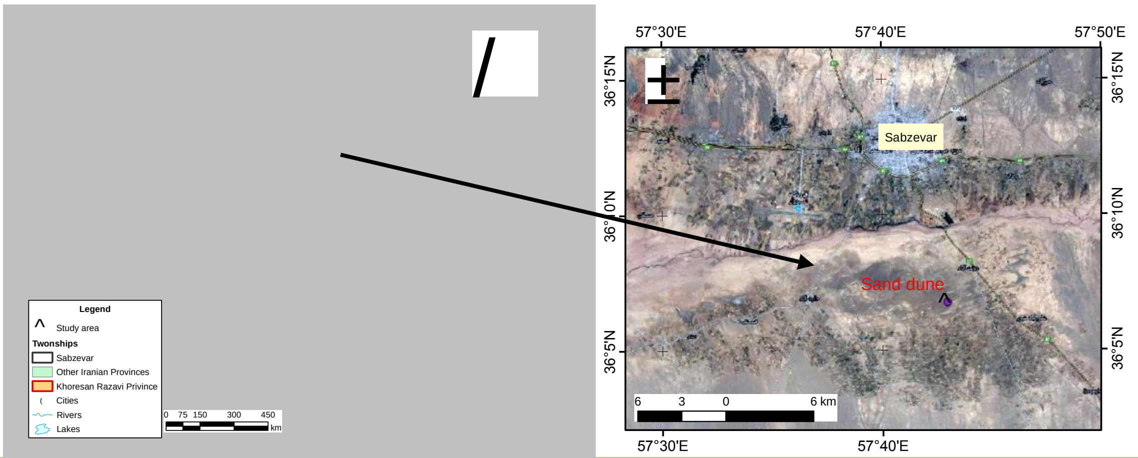


**Figure 1: the geographical location of the study area in the southern sand dune near Harsabad, Sabzevar, Iran**

According to the meteorological data from Sabzevar synoptic station, spanning from 1966 to 2016, mean annual precipitation and potential evapotranspiration (ETP)are 188.6 and 995.9 mm, respectively, and mean annual temperature is 17.4° C. Soil moisture regime and soil thermal regime of the study area are aridic and thermic, respectively. Dry season in the region starts in late March and continues until the end of November.

### 2.2. Sampling and Measurements

This scientific research aims to estimate the water balance in the sandy dune's vertical profile, therefore, four parameters such as precipitation (mm), evapotranspiration (mm), soil moisture, and groundwater recharge (mm) are measured though laboratory method, field survey and climatology station (Figure 2).

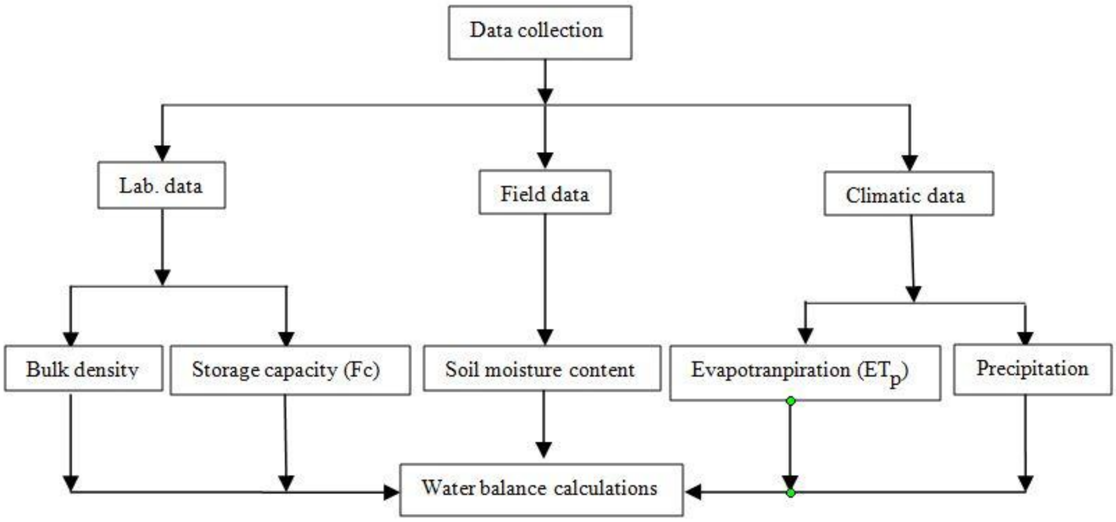


**Figure 2: Flowchart of research procedure**

#### 2.2.1. Position of samples on the dunes

Water balance of sand dune ecosystems is important in recharging the soil moisture control section (Rummel and Felix-Henningsen, 2004). Considering abiotic factors such as local relief and dune morphology, this project was conducted to determine water regime. For this reason, we selected an area of typical dune-interdune area as the experimental site.

#### 2.2.2. Moisture content of the profiles

Eight profiles with 120 cm depth (seven profiles on an active dune, and one on a fixed dune as a control profile) were studied. The profiles on the active dune were distributed in different positions on the dune; three profiles are located on the windward slope and three are on the steep slope, and one is on the top of the dune. Soil moisture contents were measured at fixed intervals (equally defined distances of 60-cm layers) using time domain reflectometry equipment (Figure 3).

**Figure 3: Measuring soil moisture by time domain reflectometry (TDR)**

The difference between ambient temperature and sand dune temperature controls the dew point in dry lands. The effect of dew on soil moisture is substantial in some arid regions of the world and cannot be neglected(McHugh et al., 2015; Wen et al., 2014). For this reason, in order to investigate dew effect on soil moisture, a control experiment was conducted at the beginning of autumn (2014) in the profiles on three considered sites, in the fixed sand dune and the active dune; the volumetric soil moisture is measured in the determined horizons at 4am and 12:30 pm. Finally, it was proved the dew formation in the study area is insignificant in water supply(Agam and Berliner, 2006)

### 2.2.1. Precipitation data

Precipitation can be measured directly by rain gauge; however, the effective rainfall might be controlled by wind and evaporation from gauge itself(Kaczmarek and Krasuski, 1991).Snow accumulation, snow melting and the water interception of the canopy are negligible in arid lands, as there occurs rare snow, and the vegetation canopy is also sparse. Following from these, the rain gauge was installed in the study area even though the monthly rainfall statistics of the synoptic station of Sabzevar were used. Considering the wet and dry seasons, the hydrological year is considered in this research. Rainfall data were measured in two water years of 2014-2015 and 2015-2016; the yearly mean values of rainfall were 226 mm and 181 mm, respectively.

### 2.2.2. Actual evapotranspiration

Monthly potential evapotranspiration was calculated using the temperature data from the synoptic station of Sabzevar. Following the measurement of the sand's water storage capacity and monthly moisture, actual evapotranspiration ($E_a$) was obtained according to Eq. 1;

Eq. 1 $$E_a = ETP\frac{S}{S_c}$$

where ETP is potential evapotranspiration, and S and $S_c$ represent the soil's moisture content and water holding capacity (field capacity and pit retention), respectively. Since the actual evapotranspiration calculated by indirect methods is different from the actual evapotranspiration obtained by the lysimetric method (Novák, 2012; Rana and Katerji, 2008; Zhao et al., 2013), a correction coefficient was applied for the evaporation from the sand surface; this coefficient is calculated using the differences in soil moisture at 120 cm depth for the consecutive months in the summertime, and its average calculated after division by the evapotranspiration potential of each month. The evaporation coefficients for the bare and active sand dune and the fixed one were about 0.02 and 0.04, respectively.

### 2.2.3. Groundwater recharge

Groundwater recharge, percolation or gravitational infiltration shows the amount of water seeping into groundwater; it is the excess of incoming monthly rainfall and outgoing evapotranspiration. In humid seasons, it is positive, but in arid regions with shallow groundwater table, groundwater recharge is negative during dry seasons. That means the recharge of groundwater table is impossible(Tallaksen and Lanen, 2005).

## 2.3. Numerical Modeling

According to the law of conservation of energy and mass, the water balance in sand dunes is affected by precipitation, actual evapotranspiration, water holding of soil horizons, groundwater recharge and possible vapor water. The amount of vapor water is very low, therefore it is negligible in this context (Tsoar and Zohary, 1985). Water balance is useful in managing water supply as well as in determining water shortage. The water balance model, proposed by Penck in 1896, is based on precipitation, evaporation and streamflow. The characteristics of the soil horizon of water holding take into account all the input and output of water to the sand dune system; hence, the water balance is formulated as in the Eq.2, below (Kaczmarek and Krasuski, 1991; Rouhipour, 2005; Zhou et al., 2017).

Eq. 2 $$\frac{dW}{dt} = [\mathrm{VP} + \mathrm{HP}] + [AP + GI + C] - (PR + PE + SE + Tr + Go)$$

where, $\frac{dW}{dt}$ is the temporal variations of soil moisture as water holding capacity in the soil horizon,

$[\mathrm{VP} + \mathrm{HP}]$ (mm day $^{-1}$) is the effective vertical and horizontal precipitation and snow budget estimates,

AP (mm day $^{-1}$) represents the water runs on from neighborhood,

GI (mm day $^{-1}$) represents the subsurface the water runs on from groundwater,

C (mm day $^{-1}$) is the air vapor (humidity) given to vegetation and soil,

PR (mm day $^{-1}$) represents the surface water runs off,

PE (mm day $^{-1}$) is transpiration,

SE (mm day $^{-1}$) is evaporation,
Tr (mm day $^{-1}$) is water intake by vegetation,
Go represents subsurface water.

Considering the water balance of the soils in arid lands, some of mentioned parameters are often insignificant (Rockhold et al., 2009),since some parameters such as snow occur rarely. Therefore, concerning the law of mass and energy, the equation can be converted into Eq.3:

Eq. 3 $\Delta M = P - S - \Delta D - U - \int_0^t E dt$

where ΔM (mm day $^{-1}$) represents the variation of water holding of horizon,
P (mm day $^{-1}$) is precipitation entering the horizon,
S (mm day $^{-1}$) represents runoff,
ΔD (mm day $^{-1}$) is surface detention,
U (mm day $^{-1}$) is groundwater recharge, percolation in case of excess or deficit water,
E (mm day $^{-1}$) is evapotranspiration,

Due to high permeability of sand dunes, two parameters of surface detention (ΔD) and runoff are out of importance. Eventually, the water balance is simplified as inEq.4, below;

Eq. 4 $\Delta M = P - U - \int_0^t E dt$

By determining the measurable parameters of Eq. (3), we can calculate the amount of percolation, which is the amount of water seeping through the soil from upper to lower layers and might possibly recharge groundwater if the water is in surplus. As the parameters in the water balance equation are estimated, it is possible to judge the hydrologic group of the sand dunes, as well as the nature of water requirement by the plants.

## 3. Results

### 3.1. Water balance parameters in the sand dunes of Hares-Abad

For a two-year period of the study, Figure 1 and Figure 2 display the variations of water balance parameters in the active and fixed sand dunes, respectively. The findings in the sand dune of Hares-Abad show that percolation has a positively direct relationship with the amount of precipitation. Inversely, it is negatively related to actual evapotranspiration and absolute magnitude of moisture variation of the water holding horizon. In fact, it is observed that percolation is positive when water is in excess of field capacity during wet months of the year (winter and early spring). However, the groundwater recharge data in sand dune in dry months (summer and early autumn) show negative values, meaning water deficit.

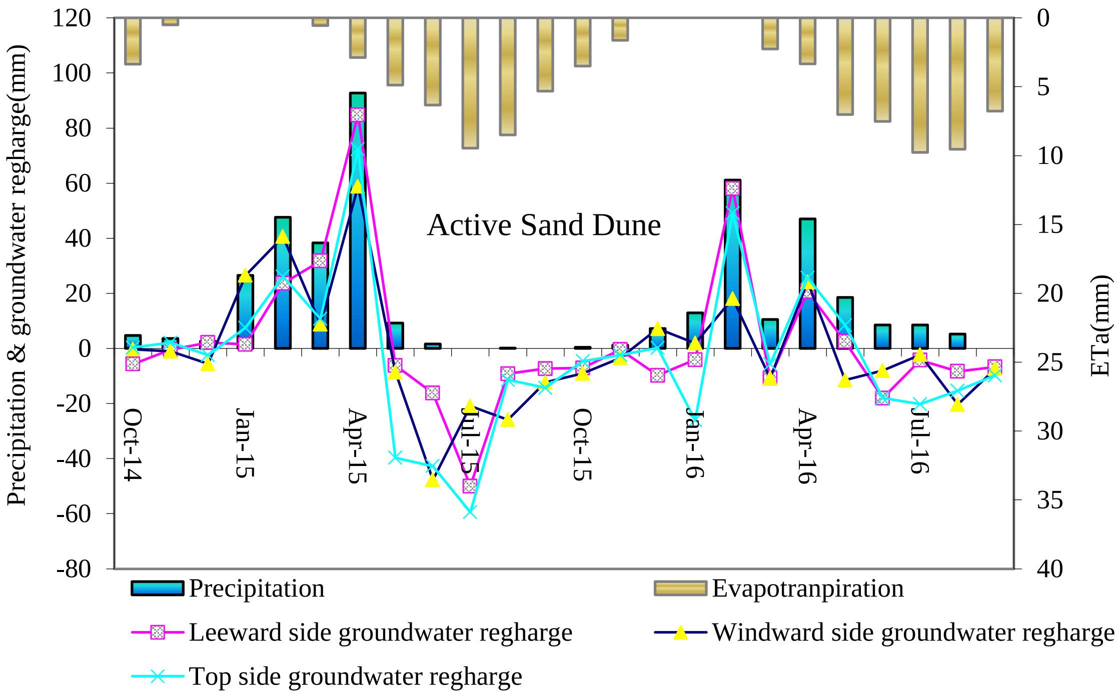


**Figure 4: Precipitation, evaporation, and groundwater recharge (in three positions including dune crest, windward and leeward slopes) for the active dune**

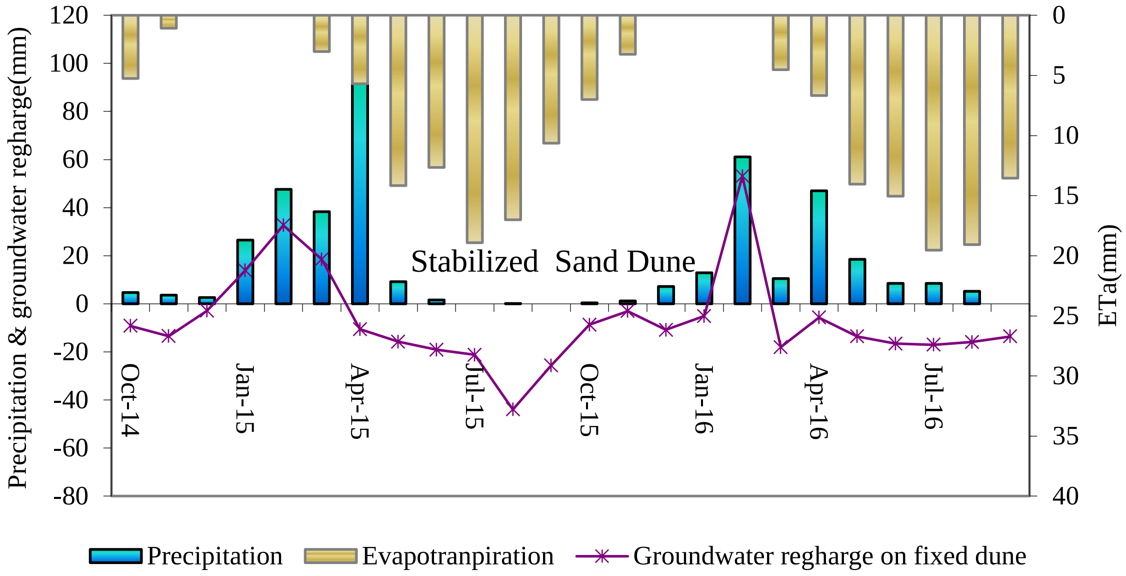


**Figure 5: Precipitation, evaporation, and groundwater recharge for the fixed dune**

The correlation between precipitation and percolation / water deficiency in three positions (windward, leeward and dune crest) is illusterated in Figure 6 for the active sand dune in Hares-Abad. Groundwater recharge, percolation, in the active sand dune correlates well with rainfall, but its impact on the percolation in the fixed sand dune is not significant.Consumption of water storage due to precipitation in fixed dunes by psamophile plants(*Holoxylon spp.*, *Smirnivia iranica*) is the main reason for meaningless of correlation while in active dunes there is not any plant that uses water storage. So, in active dunes the majority of preicipitation percolates into deep layers which leads to positive correlation between them.

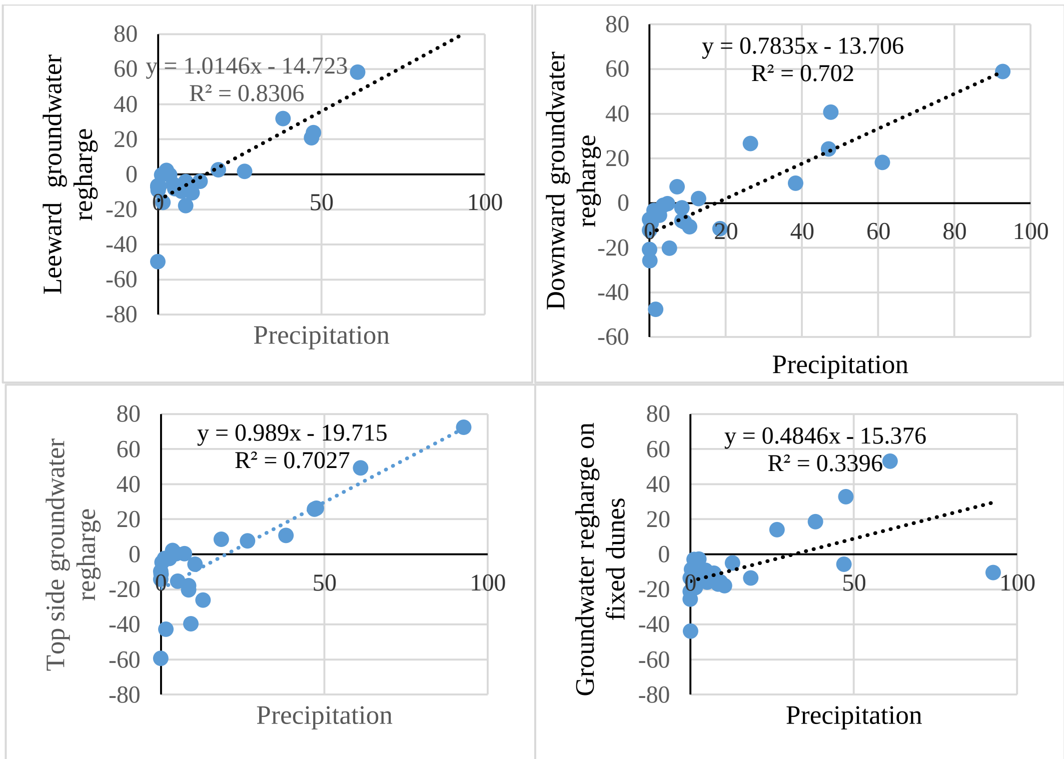


**Figure 6: Correlation between precipitation and groundwater recharge in the active dune (in three positions including dune crest, windward and leeward slopes) and the fixed dune**

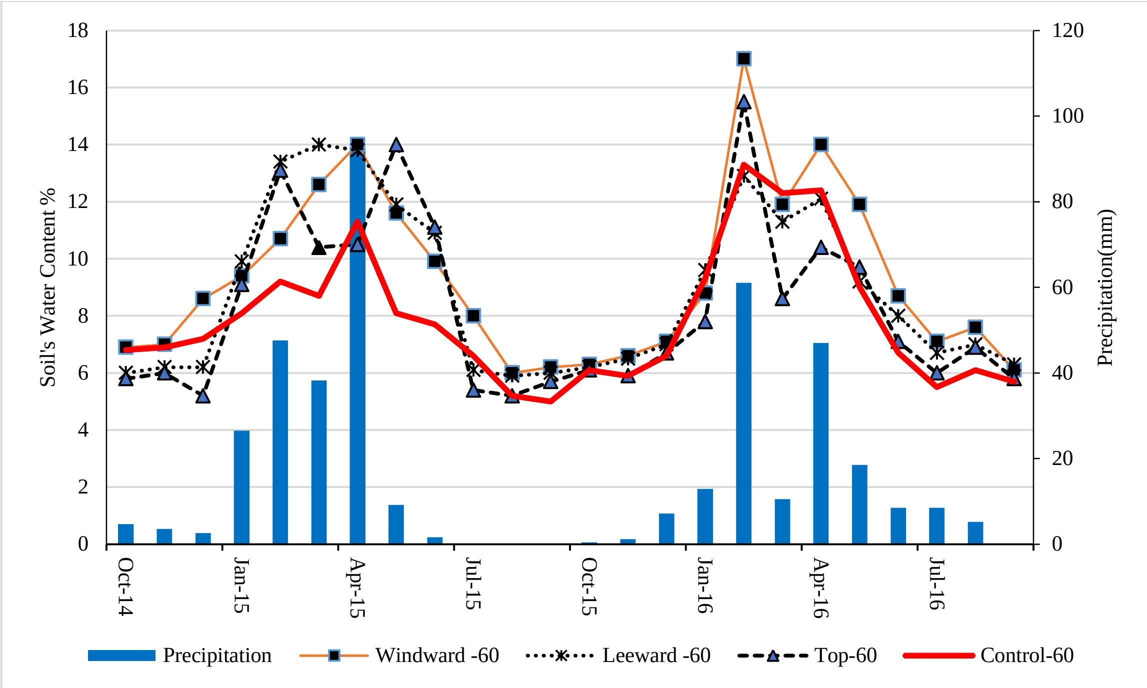


**Figure 7: Temporal distribution of rainfall (right axis) and percentage of water content (left axis) in 0-60 cm depth for active (in three positions including top, windward and leeward slopes) and fixed dunes (red line)**

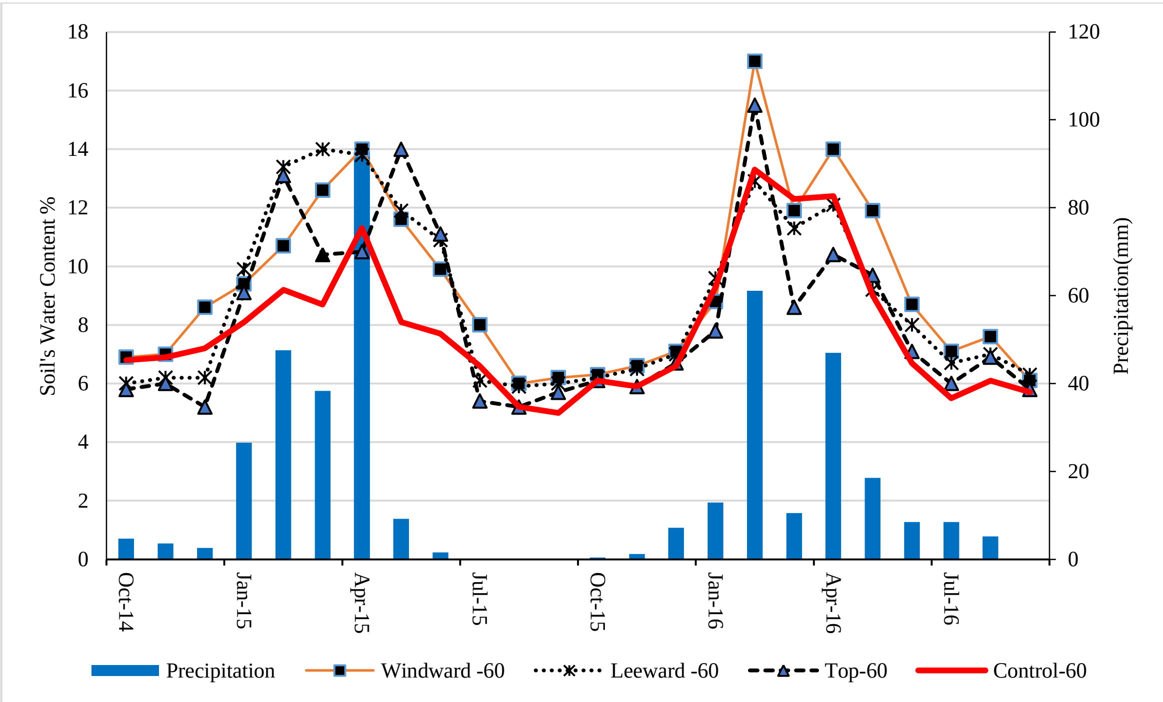


**Figure 8: Temporal distribution of rainfall (right axis) and the percentage of water content (left axis) in 60-120 cm depth for active (in three positions including top, windward and leeward slopes) and fixed dunes (red line)**

### 3.2. The relationship of precipitation and moisture content in sand dune layers

Variations of moisture content in various sectors of the active and fixed dunes are illustrated in Figure4 and Figure5.They indicate, firstly, that moisture fluctuations in both types of sand dunes follow the patterns of rainfall (its amount and distribution). As the amount of precipitation increases, soil moisture increases in each horizon. Secondly, the pattern of moisture variation in different parts of a sand dune is related to its dynamic conditions. Precipitation and moisture content have higher correlation in the upper layer of sand dune (more than 0.67) than the lower layer. Moisture content in the lower layer of the active dune crest has the lowest correlation with rainfall. The dune crest and windward slope, due to instability of the particles and their high mobility, have low moisture, and the moisture content difference between upper and lower layers is high, especially on the top of the dune.

Similarly, the comparison of moisture content and its fluctuations at different depths on windward (gentle slope) and leeward (steep slope) sites indicate that although the amount of moisture absorbed in different slopes does not demonstrate a significant difference, local displacement of particles (movement and accumulation) has helped the moisture in the gentle slope be more stable than the steep slope.

The pattern of monthly moisture content in fixed dune shows lower values for it than in the active one; it is apparently related to the vegetation effects, especially shrub species which affect hydrological characteristics such as interception, evapotranspiration, and microclimate formation by plant canopy, and finally the absorption of moisture in deeper layers. Therefore, the amount of moisture absorption and holding in the fixed dune is more than the active one in wet seasons, and inversely, during dry periods, due to water consumption by plants, moisture content stored in fixed dune is lower than the active dune(Wang et al., 2004; Koenig, 2012).

## 4. Conclusions

The results from this study indicate that, firstly, as there exists a negative water balance in the fixed sand dune, precipitation is the only source of water supply for plants. It is demonstrated that the presence of plants reduces percolation as they increase evapotranspiration (Zhang et al., 2008) . In the study area, there are no supplementary water sources such as groundwater, dew water, and runoff. This is very different from the findings by Rouhipour et al. (2008); where due to subsurface recharge by the Karke River, groundwater has a considerable role in water supply, and is useful for trees and shrubs. However, there is water surplus in the active sand dunes beyond evaporation loss, especially during wet months, and it percolates through dune layers and recharges the groundwater. Similar results were reported from Badain Jaran Desert, China, where the amount of infiltration varies from 11 to 30 millimeter per year(Hou et al., 2016). Therefore, before taking any biological/revegetation action in the sand dunes of Haresabad, the distribution of precipitation and water balance should be considered. Native drought-tolerant species need to be planted in a position where enough moisture exists. Secondly, there is an extreme fluctuation of moisture content in surface layer (0-60 cm depth) in sand dunes, and this is inevitable and has a worsening effect on erosion. Furthermore, the wind in this area limits any biological action. The deep layer (60-120cm depth) has a stable moisture condition. This is consistent with the report of a study assessing the water balance in a linear sand dune in the Negev desert, where in addition to the role of biological agents especially vegetation, abiotic factors such as relief and wind has been emphasized(Rummel and Felix-Henningsen, 2004). Similarly, it is revealed that soil moisture content is stable in deep layers (about 80-100 cm) as shown in sandy dunes of Khuzestan(Rouhipour, 2005), and Horqin sand dunes, northern China (Niu et al., 2015). Moreover, particle size analysis of aeolian sediments indicates that the dominant particles range in size from 0.1 to 0.25 mm in diameter, which is very vital in maintaining moisture content. An investigation in Badain Jaran Desert (Hou et al., 2016) showed that high proportion of particles of fine-sized sand up to 74.6% improved the soil moisture content up to 4%. For this reason, in order to stabilize sand dunes of the study area, physical measures are of priory. For instance, wind speed needs to be reduced by windbreaks as a first step. Plants can be cultivated in a sheltered area afterwards. In addition, the spatiotemporal variation of moisture should be considered in order to identify best timing for the success of seeding and seedling plantation to guarantee the establishment of plants on sand dunes. For instance, Niu et al. (2005) suggested the wintertime as the best time for the cultivation of *Caragana korshiniskii.* due to low organic matter in the dunes. Initially some pioneer plants such as *Stipagrostis spp.*are to be planted to improve the soil. Then, native shrubs and bushes are to be used such as *Astragalus Squarsus, Astragalus Squarsus, Smirnovia iranica, Calligonum spp., and Haloxylon persicum*, as Wang et al. (2004) used *Salixgor dejevii* in China.

Finally, it is recommendable to begin the biological stabilization of the dunes from the windward side; as the moisture content in this part of the dunes is more stable. This is consistent with the findings of a study on hydrological cycle and water balance in the Badain Jaran Desert sand dunes (Yan-Dong et al., 2017). Latterly, dune restoration plantation leads to discharge the water contents through escalating evapotranspiration (Oliphant et al., 2011). It seems that fixed dunes pumps water storage from deeper layers into upper layers and then it vapors under evapotranspiration phenomenon unless roots of plants reaches to groundwater. As, in study area the depth of groundwater is greatly deep, so survive of plants depends on amount of precipitation. But in active or non- fixed dunes slightly amount of water storage evaporates from surface layer (maximum 45 cm based on capillary measurements on dunes) and the remains of water easily percolate into deep layers and safely conserved.

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