Reconstruction of spatiotemporal change of Hoz-e-Sultan playa

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Abstract. Hoz-e-Sultan playa is one of the lowest points in the center of Iran, and its size and shape rely on the amount of inlet and outlet discharged water in different seasons of the year. The temperature fluctuations are the significant variations in the surface of the playa that increases the maximum salinity and saline layer level. Therefore, the present study aimed to investigate the spatial-temporal changes and salinity rate obtained from 11 sedimentary cores in the study area by principal component analysis, Normalized Difference Salinity Index (NDSI), and Land Surface Temperature (LST) method. The results indicated that the level of playa decreased about 33.598 km² during 26 years. The spatial changes occurred in the eastern margin in the south of playa. Finally, a significant relationship was observed between the SI and the real salinity, and the NDSI and LST also increase the salinity rate related to temperature decrease. © The Authors. Published by SPIE under a Creative Commons Attribution 3.0 Unported License. Distribution or reproduction of this work in whole or in part requires full attribution of the original publication, including its DOI. [DOI: 10.1117/1.JRS.12.035009]

Keywords: Hoz-e-Sultan; salinity index; playas; principal component analysis.

1 Introduction

Playas have undergone a new transformation in many arid and semiarid regions of Iran due to the recent climatic changes and human activities including the removal of mineral resources and irregularities in the inlet water. Bobek first studied Hoz-e-Sultan and estimated the water level at that time 20 m higher than the amount now due to the flooding of the western part of the lake because of the diversion along the Ghareh-chay River. Bobock reported that the western part of the lake was filled only by mud due to the overflow in 1879, whereas the rest was covered by water. Thus, the lake existed before the overflow in 1879. At that time, the surface of the lake estimated about 40 m above the surface of salt lake in Qom.

The results of the studies conducted on Hoz-e-Sultan playas indicated that its size and shape rely on the discharge of inlet and outlet water, which is different in four seasons of the year. The phreatic zone of water is very high in the region, whereas it is a few centimeters in the saline ground and about 1 m in the ecological area at the end of the dry season. The phreatic zone, along with the salinity slope, determines the status of diversity and the establishment of vegetation. Due to the annual evaporation rate and the absence of active rivers in the region and the activity of playa even in the dry and warm seasons, it seems that water resources and aquifers are regarded as the major sources of water supply. The ecological range, which actually lies in the outer layer of the marshy margin, includes a dense cover of halophytes creating numerous communities based on the salinity slope at different intervals of playa. For example, seven plant
communities on the north-western side of playa are found in less than one kilometer as those layers surrounding playa, which are different from fully salty species to drought tolerant species. This area has been a habitat for a large number of plant and animal species including Hubert in the current situation and Jabir in the past and constitutes the dynamic part of playa ecosystem. Vegetation decreases in the north, northeast, and southwest of playa and disappears in the south and west. Sometimes, human activities create some changes in the natural environment and the results are not predictable. Spatiotemporal change analysis of semiarid regions is vital for understanding major threats to the ecosystem. The changes taking place in the playa of Iran due to the withdrawal of mineral resources and the change in the amount of inlet water can lead to environmental changes and risky outcomes. The reduction in the amount of inlet water leads to some changes in soluble minerals, which results in collapsing the biological order.

In general, human interventions such as the construction of highways have resulted in air pollution, sewage pollution, as well as the disconnection of the natural ecosystem of plains adjacent to playa. In addition, plain lands surrounding the highway near the playa in recent years have been widely cultivated by digging wells and have progressed to the vegetation belt near the playa. However, the withdrawal of aquifers could be a major threat to water resources of playa, which will destroy its ecosystem by decreasing the aquifer level. Further, the withdrawal of these aquifers results in returning the saline water of playa to the surrounding areas, which can strongly threaten the agricultural use of the area as the well water becomes saltier. Excessive grazing can play some important damaging effects on vegetative growth. During the last years, the damages caused by the exploitation of the jobber people, the effect of recent drought, and excessive exploitation of existing resources have led to some changes in the region appearance and the condition of the plants and animals, and accordingly the destruction of the habitat and ecological changes in the current situation of playa and its margins. Therefore, the present study considered the surface changes in the playa by Normalized Difference Salinity Index (NDSI), principal component analysis (PCA), and temperature analysis over a 26-year period.

Due to an extensive coverage of the area, the use of remote-sensing techniques and satellite imagery can play an important role in the correct recognition of the past, the availability of information in time intervals, the appropriate radiometric and space separation, and quick access to remote areas. Therefore, effective steps are taken and appropriate management decisions are made and the obtained results can be used to preserve and restore the natural conditions of this natural effect. Remote sensing (RS) data and techniques, along with GIS and landscape metrics are used to analyze and characterize land cover (LC) and its changes. For example, in Avellino (Southern Italy), a multitemporal set of images including aerial photos (1954), and Landsat scenes (MSS 1975, TM 1985 and 1993, ETM+ 2004) was processed to characterize the dynamics of the changes during 1954 to 2004. Different satellite data can help specify the relationship between electrical conductivity and sodium concentration of soil in Jasmourian region, prepare the soil salinity map by establishing a correlation between satellite data and numerical values of soil salinity in Qazvin plain, and determine the methods for soil salinity mapping in Marvast region of Yazd. In recent sources, the main variables include brightness index, SI, normalized SI, and maximum likelihood method for displaying soil salinity. Generally, in some studies, RS technique was used to examine soil salinity. Some researchers focused on zoning soils in arid regions based on the silty sediments and gypsum hills and barricade, through determining soil and water resources of arid regions based on chemical properties of the materials in soil surface including magnetic inductance index, vegetation index and surface plaster index, and zoning the evaporative minerals of gypsum and halite according to satellite image. In another study, a computerized parametric methodology was used to monitor, map, and quantify land degradation by salinization risk detection techniques at a 1:250,000 mapping scale using geoinformation technology. Multitemporal remotely-sensed materials of both Landsat TM and thematic maps (ETM+) were used as the bases for providing comprehensive views of surface conditions such as vegetation cover and salinization detection. The NDSI and SI were computed and evaluated for land degradation by salinization. Hadeel et al. determined the environment change indicators in southern Iraq during the last 20 years. In the present study, NDSI was adopted and used to retrieve its class boundary. To determine the soil characteristics and
SI, Fallah Shamsi et al. used soil samples and moderate resolution imaging spectroradiometer (MODIS) imagery. Spatial information on soil salinity is considerably necessary for decision-making and management practices in dry environments. Vermeulen and van Niekerk evaluated the efficacy of very high-resolution WorldView-2 imagery to map the areas affected by salt accumulation. In this regard, they used salinity indices to discriminate between salt and affected soils in Vaalharts, South Africa. In the arid and semiarid areas, sustainable development is restricted by land degradation processes such as secondary salinization of soils. In addition, Afrasini et al. implemented appropriate methods to assess the identification and detect the changes in salt-affected areas in the Wadi Biskra areas such as the SI using Landsat imagery. The analysis undergone for the 1984 to 2015 images. Soil salinity is a complex problem that can influence groundwater aquifers and agricultural lands in the semiarid regions. Abdellatif and Mourad used an automated spectral detection in order to identify salt minerals using a monochromatic waveband concept from multispectral bands Landsat 8 Operational Land Imager (OLI) and Thermal InfraRed Sensor (TIRS) and spectroscopy United States Geological Survey database. Taghizadeh Mehrjardi et al. determined the soil diversity in the Central Iran using Landsat images and grid sampling. In some other studies on the land surface temperature (LST), the soil moisture (SM) relationship was analyzed at a variety of LST acquisition times and its influence on SM disaggregation algorithms. Xiao et al. conducted another study on the surface temperature extraction and examined spatial-temporal changes of the surface water temperature (SWT) index in the Qinghai Lake during 2001–2010 using the MODIS data. In addition, they calculated the temporal SWT variations and long-term trends based on each pixel, compared with the spatial patterns of annual average SWT in different years. Finally, they mapped and analyzed the seasonal cycles of the spatial patterns of SWT. Yang et al. estimated the atmospheric transmittance empirical models of the existing split-window algorithm by focusing on the features related to Landsat-8 thermal infrared channels in 2013 and studied the ground emissivity with the help of the LC classification map in the study area. In addition, they reconstructed split-window algorithm using the estimation model of the updated atmospheric transmittance and the ground emissivity, as well as an RS retrieval for the LST of Shihezi City in Xinjiang Uygur autonomous region of Northwest China. They specified that the LST retrieval from Landsat-8 data had a higher credibility and the retrieved LST was more consistent with the MODIS LST products. Another study demonstrated an LST retrieval methodology, which makes use of only Landsat 8 image data. In this methodology, the split-window covariance-variance ratio technique was introduced to derive water vapor content from Landsat 8. A comparison between the retrieved LST and in-situ LST measurements indicated a good accuracy. Yue et al. emphasized the relationship between LST and Normalized Difference Vegetation Index (NDVI) associated with urban land-use type and land-use pattern studied in Shanghai using the data collected by the Enhanced Thematic Mapper Plus (ETM+) and aerial photographic RS system. The studies on multitemporal MODIS thermal imagery isolate geothermal from seasonal LST variability in Afar depression and identifies localized LST thermal anomalies in seismo-volcanic crisis during September 2005. Thermal image downscaling algorithms use a unique relationship between LST and (NDVI). Mukherjee et al. evaluated local model using seasonal (February 25, 2010, April 14, 2010, and October 26, 2011) Landsat thermal images. Maeda developed a simple methodology for downscaling 1-km moderate resolution spectroradiometer (MODIS) LST pixels, by accounting for sub-pixel LST variation related to altitude and land-cover spatial changes. The approach tested in Mount Kilimanjaro, Tanzania, where changes in altitude and vegetation can take place over short distances. Daytime and night-time MODIS LST estimates were separately considered. A digital elevation model (DEM) and NDVI at 250-m spatial resolution were used to assess the altitude and land-cover changes, respectively. Simple linear and multivariate regressions were used to quantify the relationship between LST and the independent variables, altitude and NDVI to compare the methods for retrieving the LST (T_s) from Landsat-5 TM (Thematic Mapper) data. Zhou et al. analyzed 10 years of NASA-MODIS day-time and night-time 1-km LST data over southern Italy to quantify the influence of factors such as topography and the LC on LST spatiotemporal variations. In addition, Ozelkan et al. demonstrated the relationship between the long year monthly average (LYMA) LST and the LYMA air temperature (Ta), the total precipitation (Pt), and the relative humidity (RH). The data were collected from 27 meteorological
stations in the Eastern Thrace region and using the corresponding thermal infrared images from Landsat-5 (TM) and Landsat-7 (ETM+). Several studies were conducted on the spectral unit isolation of the playa, especially in dry areas such as Yardang margin of the Lut desert. The digital processing methods, such as PCA, pseudocolour images, as well as field studies and global positioning system, the extraction of the physical quantities of temperature and physical transformations, the values of papers recorded in the thermal band to the thermal values on the earth, and the comparison of thermal map in the area were used in the recent studies. The present study aimed to exploit the multispectral Advanced Spaceborne Thermal Emission and Reflectance Radiometer (ASTER) and Landsat 8 OLI data in order to map lithological units at the Moroccan Anti Atlas. The task was completed using PCA, band ratios (BR), and support vector machine classification. Zhang and Zhou focused on the deposits in the Baogutu region using ASTER data and analyzing the PCA for the detailed hydrothermal alteration mapping. However, the MODIS sensor was used to estimate the temperature related to the Lute Plain. IRS satellite imagery and Landsat ETM+ and SRTM imagery were used to examine the evidence of morphological effects of surface changes in Hoz-e-Sultan and Meghan playa. The PCA, the optimum index factor and other visual methods were used in other studies.

In recent years, wetlands and playas in Iran have become drier due to the excessive use of surface water and climate change. Consequently, the dryness has led to an increase in the deposition of sodium and magnesium chlorides and accordingly the amount of salinity. As increase in the salinity is regarded as the most important parameter that can be an alarm to indicate the risk of drying in wetlands and playa. Further, the salinity is correlated with temperature variations, and both are indicators that can be calculated in RS. Therefore, the monitoring of such changes is necessary for a country like Iran including lakes and wetlands remained from the cold and rainy period. Therefore, the present study investigated the changes in Hoz-e-Soltan Lake during 1991 to 2016 using PCA, NDSI, and LST.

2 Materials and Methods

2.1 Study Area

The playa of Hoz-e-Sultan with the area of 104.4 km², located in 85 km in the southwest of Tehran, has a catchment area of 195 km² and is situated between the longitude 50° and 68° to 51° and 50° of East, and the latitude 34°, 74° to 35°, and 17° of North (Fig. 1). Orogeny motions and volcanic eruptions at the end of the Cretaceous and the beginning of the Eocene led to the formation of Eocene volcanoes in the north and central parts of Iran, especially around this playa. The fault caused by volcanic activities led to the formation of a graben in the area, which was later filled with salt lake. This graben has formed a closed basin, where partially filled with destructive and evaporative sediments in the form of interlayer. Long and continuous faults are observed in the southern mountains in the west of the pit. The main direction of this fault disappears only in some places by coniferous sediments, which itself represents new tectonic movements in the region.

This playa is considered as a part of the catchment area of the salt lake enclosed by the volcanic mountains from the southwest, west, and the northwest. A mountain range of igneous rocks of the Miocene period is extended from the end of northeast to the east. Currently, this playa is drained by a narrow duct in the southeast. Hoz-e-Sultan playa includes two separate parts, that are connected by a narrow drainage channel. The western part with an altitude of 806 m above the sea level receives the surface irrigation from the neighboring heights and additional floods in the eastern part through drainage channels. The eastern part receives its water from the mountains along the northern margin, from the northernmost branch of the coniferous of Saline River, as well as the northern branch of coniferous Ghareh Chay. Other branches of the mentioned coniferous lead their water toward the southeast and into the Qom Desert. Mostofi and Frei reported that water first enters into the Hoz-e-Marreh, which passes from two ponds and inter into the Hoz-e-Sultan after filling. In addition, the water rising a few meters in Hoz-e-Sultan returns toward the Hoz-e-Marreh and the overflow of these two ponds is drained to the salt lake.
In general, this area has a small annual rainfall of about 100 mm. Ghareh Chay River shedding into Hoz-e-Sultan Lake is salty, and sewages pass through salty domes. Hence, moisture sources do not play an important role in reducing the salinity on this lake. Thus, it is necessary to attend to this area due to biodiversity as well as various species and specific environmental features including fragility, vulnerabilities, and water and drought crises of natural and human origin. The vast playas of Hoz-e-Sultan lakes are located within a short distance from the capital and the small towns of Tehran suburb and are regarded as the sources of microorganisms, especially salt particles.

### 2.2 Datasets

In the present study, satellite images of Landsat 5, 7, and 8 dating back to 1991, 2000, and 2016 in the 26-year period were used to determine the changes in Hoz-e-Sultan playa. Table 1 indicates the characteristics of these images, along with the meteorological information related to

<table>
<thead>
<tr>
<th>Year</th>
<th>Month</th>
<th>Sensor</th>
<th>Frame</th>
<th>Sun angle</th>
<th>Precipitation</th>
<th>Station temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>June 16, 1991</td>
<td>June</td>
<td>TM5</td>
<td>164–36</td>
<td>61.04</td>
<td>0</td>
<td>31</td>
</tr>
<tr>
<td>July 02, 2000</td>
<td>July</td>
<td>ETM+</td>
<td>164–36</td>
<td>65.76</td>
<td>0</td>
<td>34</td>
</tr>
<tr>
<td>June 08, 2016</td>
<td>June</td>
<td>OLI-TIRS</td>
<td>164–36</td>
<td>68.08</td>
<td>0</td>
<td>30</td>
</tr>
</tbody>
</table>

Fig. 1 (a) The location of Hoz-e-Sultan playa in Iran, (b) the Landsat 5: June 16, 1999, and (c) the Landsat 8: June 8, 2016.
the synoptic station of Qom at the moment of taking images by sensors. According to meteorological statistics, no precipitation has occurred in the region at least 2 weeks before the date of the photographs. In contrast, the end of the warm and dry season is the best time to detect the land with saline soils by satellite imagery because the spectral reflection of these soils considerably depends on the soil moisture. Therefore, the crystallization and sediment of salts in the surface of the soil particles increases when the soil becomes drier and consequently the surface reflection increases while salts become soluble, leading to a decrease in the intensity of soil illumination and its spectral reflection as the soil becomes wetter.

2.3 Overall Workflow

2.3.1 Normalized Difference Salinity Index and principal component analysis indices

In the present study, geometric, atmospheric, and radiometric corrections were made on the images in the preprocessing stage. In this regard, the maps of 1:25,000 topography of Mapping Organization of Iran were used for geometric corrections. The dark subtract method was implemented for haze corrections on the values of image pixels (DN) and reflection conversion or band reflectivity was used for radiometric corrections on the values of image pixels.

The most important feature of Hoz-e-Sultan playa is related to its high salinity. Therefore, to determine the amount of salinity changes over a 26-year period, the salinity boundary of this playa, along with its surrounding areas, was specified on satellite imagery using the NDSI (Fig. 2). Further, the amount of marginal changes created on Hoz-e-Sultan playa was determined by the principal components analysis on all three images in the area about 10 km from the playa (Fig. 3). The SI is based on the difference in spectral reflectance of objects at different wavelengths. The results of some studies on gypsum (CASO$_4$,$\text{2H}_2\text{O}$), sodium chloride (NACL), and carnalite ($\text{KMgCl}_3$,$\text{6H}_2\text{O}$) in laboratory controlled conditions indicated that gypsum and salt in the area about 2 to 2.2 and 1.5 to 1.7 $\mu$m, consistent with the band center of Landsat 5 and 7 sensor, have a strong and recognizable absorption region. The SI is calculated according to

$$\text{NDSI} = (R - \text{NIR})/(R + \text{NIR}),$$

(1)

Fig. 2 Overall workflow of the NDSI and real salinity.
where $R$ represents the reflection in the middle infrared range (band 5 of Landsat 5 and 7 and band 6 of Landsat 8) and NIR indicates the reflection in the short-wave infrared range (band 7 of Landsat).

The data related to 6 TM and ETM+ band and 7 OLI band in Hoze-e-sultan lake were studied to investigate the amount and type of component information and extract the playa border during 1991 to 2016. Six components based on six bands and seven components based on seven bands were extracted and the share of each PC to the total variation was compared named “variance percentage or Eigenvalue.” The results showed that a reduction occurs in the information related to PCs when they are located in lower rank. PCs containing more information were employed to extract the border. The images were classified based on frequency and playa border was extracted (Fig. 3).

2.3.2 Land surface temperature methods

LST is a key variable in the interactions and energy fluxes between the Earth surface and the atmosphere. In the present study, thermal atmospheric correction on thermal images was used for radiometric corrections on the values of image pixels and only the brightness conversion or brightness (radiance) was utilized on the values of thermal bands based on the following equations. Equation (2) was corrected to convert the digital values of the image to thermal radiation values

$$l_λ = Gain \times DN + Bias = \left( \frac{L_{\text{max}} - L_{\text{min}}}{255} \right) \times DN + Bias,$$

where $l_λ$ represents the natural radiation affecting the satellite sensor diaphragm, $L_{\text{min}}$ indicates the bias, and $L_{\text{max}}, L_{\text{min}}$ are regarded as the maximum and minimum detectable spectral radiation in the sensor header band with the unit (W/m²/sr/μm), respectively.

In this study, LST calculation methods requiring the exact radiation power of surface effects in two bands were used so that an error of 0.01 in radiation power can create an error of about 1.6°C in LST.

$$T_s = \frac{k_2}{ln\left( \frac{L_{\text{max}}K_1}{R_c} \right) + 1},$$

where $T_s$ indicates the surface temperature in Kelvin, $R_c$ represents the radiance of the reformed thermal band, $NB$ is considered as surface emission of thermal band, and $K_1$ and $K_2$ are
related to the equation constants, the units of which are $\text{W/m}^2/\text{sr}/\mu\text{m}$ and Kelvin’s degree, respectively.

Table 2 represents the values related to $K_1, K_2$ calibration coefficients in order to calculate the LST. Furthermore, Landsat 8 satellite imagery was used based on the relationship expressed by the Landsat satellite site from

$$T_s = \frac{k_2}{\ln\left(\frac{K_1}{L_\lambda} + 1\right)},$$

where $T$ describes the temperature of the satellite lighting in Kelvin, $L_\lambda$ displays the spectral radiation, and $K_2, K_1$ represent the calibration coefficients.

### 2.4 Sampling in the Study Area

In the present study, soil salinity was measured in a laboratory to compare the real salinity calculated by the NDSI index, and relationship between LST (Figs. 2 and 4). For this purpose, four field observations were conducted during the spring and autumn of 2014 and the spring and summer of 2016 (Fig. 5).

Hoz-e-Sultan playa is made of facies with different morphologies. Therefore, facial change method was used, by which 11 cores of the identified facies were selected.

To determine the amount of salt in the selected subsamples of the sediment cores, the NaCl of the samples was eliminated and weighted with scale 0001/0 gr precision using weight method.

Salt wash method was used in the present study and salt was measured using Sartorius Typ2842 Germany scale. To this aim, the samples were weighted using Sartorius Typ2842...
Germany with the accuracy of 0.0001 g after drying in Elektro Helios Typ NR 28208 Sweden oven and rinsing with distilled water for five times and distillation and removal of salt from the sample two times. Then, it was dried in oven and weighted with the scale and accordingly the salt weight was obtained given the difference in its weight.

3 Results and Discussion

Figure 6 shows the SI and the amount of marginal changes created on Hoz-e-Sultan playa obtained from the principal components analysis on all three images in the area of about 10 km. In addition, Fig. 7 displays the surface temperature of Hoz-e-Sultan playa during 1991, 2000, and 2016, as well as their image extracted from the thermal bands 6, 61, and 10, respectively.

By examining the PCA index, the boundary of playa in 1991, 2000, and 2016 equals to 0.1, −0.06, and 0.07, respectively. Therefore, these ranges were separated from the whole PCA range in all three images. Table 3 indicates the results of the area changes over the 26 years. As shown, a reduction of 10.10 km² occurred in the area of playa during 1991 to 2016, which is about 33.59 km² higher than the amount in 2000. Thus, the largest changes in the boundary of playa happened in the eastern regions. Further, as shown in Fig. 8, the reduction in marginal area during 1991 to 2016 and the significant retreat of playa in the eastern part during 1991 to 2000 is considerable. Furthermore, the results of changes in salinity level over the 26 years indicated a reduction of about 1296 km² during 1991 to 2000 and an increase of 1579.277 km² during 1991 to 2016 at this level. The results of the SI are in the range of −1 to +1 and the salt percentage increased by moving toward +1. The study area of salinity level of playa demonstrated that the boundary of the salinity level of playa from the range of 0.18 to 1+ belongs to the marginal areas. The most salinity changes were in the eastern margin.
toward the south of playa. In addition, the salinity area of playa increased during 1991 to 2016 and retracted from the west part during 1991 to 2016. Some minor changes in playa, such as a reduction in salinity level, occurred during 1991 to 2000.

As shown in Table 4, the results of the thermal studies at the surface of playa and their comparison with the meteorological statistics of the synoptic station of Qom indicated no significant changes in the thermal regime of playa. According to the temperature enhancement recorded at the synoptic station of Qom, an increase occurred at the maximum surface temperature of Hoz-e-Sultan playa indicating a significant correlation at the results of surface temperature. Further, a significant correlation was observed between temperature changes and the density enhancement rate of salt layers in surface of playa. In other words, the surface temperature rate decreased while increasing salt layers. To compare the results of salinity rate measurement in the laboratory

Fig. 6 NDSI and PCA indices in Hoz-e-Sultan playa, (a) NDSI-1999, (b) NDSI-2000, (c) NDSI-2016, (d) PCA-1999, (e) PCA-2000, and (f) PCA-2016.
through the SI, a linear regression relationship was established at the same points of the coring. As shown in Fig. 9, R² rate is higher than 0.5, and the relationship is nearly meaningful. In these points of the sample, the temperature changes were calculated and the results are shown in Table 5. The regression relationships chart was designed to understand the relationship between the salinity measured at the sample points and temperature rate in 1999, 2000, and 2016. Based on scatterplot and boxplot, a significant relationship was found between the temperature

Fig. 7 The surface temperature of the Hoz-e-Sultan during (a) 1991, (b) 2000, and (c) 2016.
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<table>
<thead>
<tr>
<th>Changes in surface area compared with 1991</th>
<th>Area (square kilometer)</th>
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<tbody>
<tr>
<td>114.498</td>
<td>1991</td>
<td></td>
</tr>
<tr>
<td>Decrease to square kilometers</td>
<td>33.598</td>
<td>2000</td>
</tr>
<tr>
<td></td>
<td>10.098</td>
<td>2016</td>
</tr>
</tbody>
</table>

Fig. 8  Spatial changes in Hoz-e-Sultan playa in (a) 1991, (b) 2000, (c) 2016, and (d) during 1999–2016.

Table 4  Results of temperature changes in Hoz-e-Sultan playa during 26 years.

<table>
<thead>
<tr>
<th>Station temperature</th>
<th>Average temperature</th>
<th>Maximum temperature</th>
<th>Minimum temperature</th>
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<td>31</td>
<td>41</td>
<td>49</td>
<td>34</td>
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<td>34</td>
<td>28</td>
<td>54</td>
<td>2</td>
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</tr>
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<td>30</td>
<td>43</td>
<td>52</td>
<td>34</td>
<td>2016</td>
</tr>
</tbody>
</table>

extracted from the images and the measured salinity rate (Figs. 10–12). In the recent charts, the best fit of the quadratic model is fitted. As box plots show, the average salinity level was measured and the temperature changes of the samples were inconsistent. In other words, an increase in salinity rate could decrease the temperature. In addition, the surface temperature of Hoz-e-Sultan playa decreased by increasing the SI so that the lowest surface temperature was allocated to the saline area, the salty mud zone, and the central and marginal region of the playa. Furthermore, this area has the highest density of salt layers and SI, compared with the total area.
4 Conclusion

The results indicated that the area of Hoz-e-Sultan playa decreased during 1991 to 2016, which is more considerable in the first 10 years and the rate of reduction in these changes was different in different parts of the playa. Based on the measures, the greatest changes in the playa occurred in the eastern regions due to the gentle slope of the eastern part of the playa, with the large distance between the facies. These changes are such that the facies are distant from puffy lands to the mudflats within a kilometer distance. However, due to the steep slope and the proximity of the west and southwest facies, and the arrival of the main part of the water supply of the playa from these parts, the largest withdrawal of the salinity level happened in the west and southwest of the playa. In this part of the playa, the facies are extremely close to each other so that the immediate change of facies from sandy to puffy salty facies, with a few dozen meters, led to the salty mud

![Fig. 9 The relationship between measured salinity and SI in 2016.](image)

**Table 5** The results of data extraction in sampling from the playa surface based on SI, measured salinity and the surface temperature rate.

<table>
<thead>
<tr>
<th></th>
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<tbody>
<tr>
<td>Measured salinity</td>
<td>Temperature</td>
<td>SI</td>
<td>Temperature</td>
</tr>
<tr>
<td>2.21</td>
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<td>0.11</td>
<td>43.61</td>
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Fig. 10 The relationship between the measured salinity in 2016 and the surface temperature rate of playa in 1991.

Fig. 11 The relationship between the measured salinity in 2016 and the surface temperature rate of playa in 2000.
facies and the salty mud facies appeared on the margin of the salty zone immediately. In other words, the greatest increase in salinity area during 1991 to 2016 occurred in the eastern and southeastern margin and retreated from the west and southwest of the playa. Accordingly, Hoz-e-Sultan playa had spatial changes from the east to the west. Based on the results, these spatial changes were more severe about 15 years ago. The results of regression analysis between the measured salinity of 11 sedimentary cores and LST at this time interval indicated that the central facie belongs to the mud and salty zone and these zones are situated in the wettest zone of the playa. Therefore, in Hoz-e-Sultan playa, an increase in salinity levels decreased the temperature and the decrease in temperature cannot be related to an increase in the height because the difference in height around the Hoz-e-Soltan is very low (about 45 m) with its center. Thus, the temperature decreases due to the increased salinity is in such a way that the lowest level of surface temperature is related to the saline and salty mud zones. In addition, the central and marginal regions of the playa had the highest density of salty layers, compared with the total area of the region.

Further, the results of measuring salinity rate in the laboratory indicated a significant correlation with the SI. Regarding the main reasons for the salinity reduction of Hoz-e-Sultan playa from the eastward of the playa over a 26-year period, we can refer to receiving water in the eastern part of Hoz-e-Sultan playa through the mountains, along the northern margin, the northernmost branches of coniferous Rode Shor and the northern branches of coniferous Ghareh chay, as well as surrounding the playa from the southwest, west and northwest by volcanic rocks. Finally, the spatial displacement of the playa from the east to the west and southwest highlands is justified regarding the role of increasing salt concentration in decreasing temperature.

References


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