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Wetland restoration prioritizing, a tool to reduce negative effects of drought; An application of multicriteria-spatial decision support system (MC-SDSS)

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ABSTRACT

In recent years, large parts of arid and semi-arid areas in the world are dealing with water restrictions. In these areas, wetlands provide habitats for migratory birds and have a critical role in socio-ecological systems. Generally, in these areas, changing water-use patterns because of land-use change and water limitation because of climate change have led to the loss of wide areas of wetlands. Wetland restoration is suggested to restore the functions and values of wetlands that have been destroyed or affected by stresses. In this paper, a new application of wetland restoration prioritizing is introduced; restoration prioritizing to reduce the negative effects of drought. In this method, areas with the highest priority for restoration will be determined in a wetland destroyed because of water limitations. Multicriteria-spatial decision support system (MC-SDSS) was used to plan a scheme for Hamun wetlands restoration prioritizing in order to reduce the negative effects of drought and to restore the wetlands. This prioritization-determined areas that are valuable for Long-term water conservation, reduce the negative effects of dust storms and conserve water bird's habitats. This method was used in a wetland that is the only water resource in the middle of a wide arid plain. Because of water limitation, it is not possible to restore the hole wetland; therefore, different parts of this wetland were prioritized for restoration. Based on the results, it is possible to produce a model to determine which priority can be restored in each amount of water volume. In this way, it becomes clear for decision-makers to select areas for restoration in different volumes of water. The result of this study shows that since MC-SDSS decreases conflicts between alternatives in a decision-making process and uses their spatial situation, it is a preferred method to balance among conflicting goals. Furthermore, because spatial data are the most important parts of MC-SDSS, this paper shows the ability of remote sensing to be used in MC-SDSS method. It seems that in the future; remote sensing will have the most important role in MC-SDSS.

1. Introduction

Wetlands are important resources of clean water, support biological diversity, control floods and increase the quality of life for local people and wildlife (Mitsch and Gosselink, 2007). Despite these valuable functions, over 50% of wetlands have been lost because of human activities (Fraser and Keddy, 2005; Nicholls, 2004), and when wetlands are destroyed, their important functions will be destroyed (Li et al., 2005; Taft et al., 2002). This is important especially in arid areas where water restriction is a critical factor for biological life (Hassan et al., 2005); and the most important reason for destroying wetlands in these areas is water limitation (Downard et al., 2014; Minckley et al., 2013). In light of this, it is important to investigate an applicable approach to reduce the negative effects of water limitation on wetlands, and in order to get the best results, this approach must be scientific.

In recent years, wetland restoration and rehabilitation are the major options selected by international community for wetland conservation (Klemas, 2013). Most wetland restoration prioritizing projects are related to the construction of new wetlands in order to develop agriculture, increase water quality and maintain floods (Darwiche-Criado et al., 2017; Li et al., 2010; Li et al., 2005; Ouyang et al., 2011; Sun et al., 2015; Widis et al., 2015). However, this paper introduces a new application of wetland restoration prioritization; restoration prioritization to reduce the negative effects of drought. In a wetland destroyed because of water limitation, which parts have higher priorities for restoration? This is also applicable in other ecosystems that face

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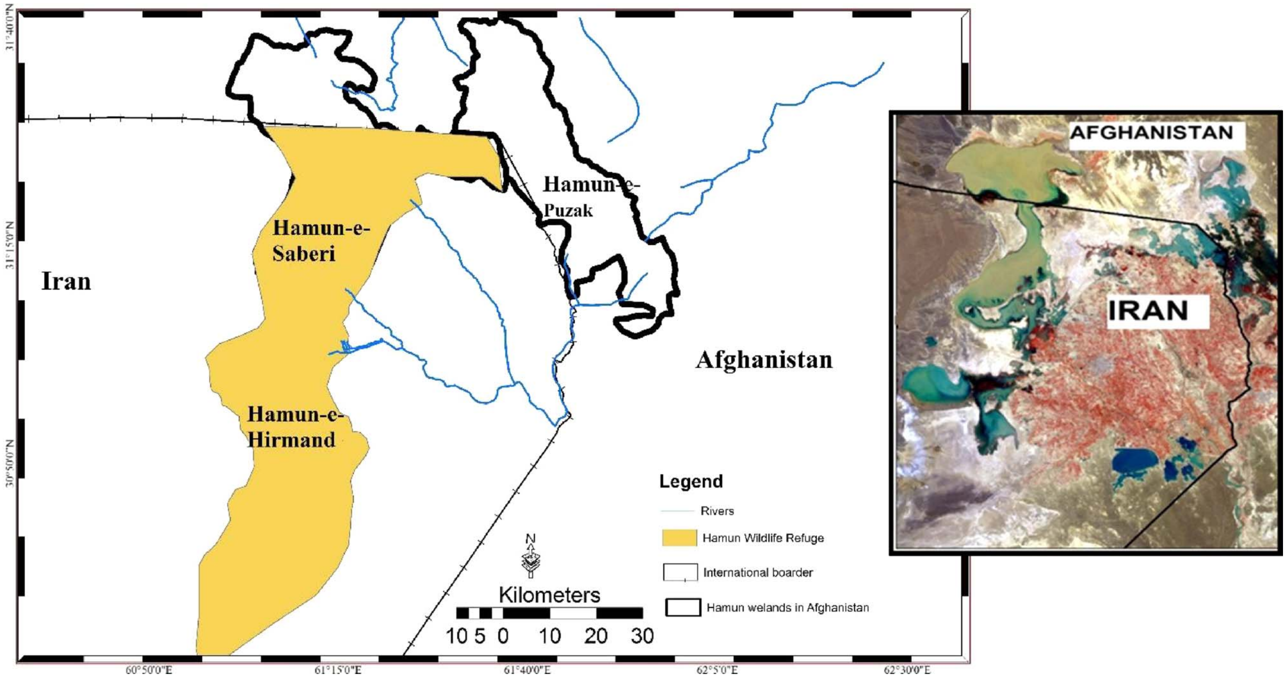

Fig. 1. The study area.

limitations. Moreover, in this study, restoration is prioritized in order to reach 3 sub-objectives: Long-term water conservation, reduction of negative effects of dust storms, and conservation of water birds' habitats.

Wetland restoration prioritization was investigated in the Hamun Wetlands, which is a valuable ecosystem because it is the only water resource in a wide arid area, it is located on the global migration route of birds and it is a valuable stop site for migrating birds (Maleki et al., 2016; Partow, 2003). The wetlands are an important source of fish and fresh water for local people, and their dense marshes and clear lakes are suitable habitats for large groups of species. Despite valuable functions in this area, Hamun is endangered because of water restriction. Irrigation expansion, coupled with droughts, has left the Hamun dried out (Maleki, 2016). The wildlife and the human communities that used to surround the Hamun have all decreased, and nearly 100 villages have been damaged by windblown dust (Partow, 2003). Agriculture is not possible and livestock and wild animals sensitive to water restriction cannot survive. All these are the results of water limitation in an arid area. These problems can also take place in other regions of the world dealing with water limitation.

Wetland restoration-prioritization has been developed using different methods. The differences between these methods are based on the objective of prioritization and the study area (McAllister et al., 2013; Schleupner and Schneider, 2013; Zhang and Song, 2014). One of these methods is a scoring system, which uses socio-economical ecological, hydrological and geographical parameters and makes scores for each parameter to restore wetland, and − is widely used in the prioritization projects (McAllister et al., 2013; Palmeri and Trepel, 2002; White and Fennessy, 2005). Another widely-used method is the Geographic Information System GIS-based method (Baban and Wan-Yusof, 2003; Holzmueller et al., 2011; Jasrotia et al., 2009; Kauffman-Axelrod and Steinberg, 2010; Palmeri and Trepel, 2002), which is a valuable tool for wetland restoration site selection using a set of spatial data. Different geographic scales are easily applied, and input data flexibility and spatial data make GIS-based wetland prioritization model an applicable method used in different wetland restoration plans (Drummond and French, 2008; Palmeri and Trepel, 2002; Widis et al., 2015). In recent years, a decision support system (DSS) that is based on GIS technology has been used in wetland restoration prioritizing. This method includes multicriteria-spatial decision support systems (MC-SDSS) that refer to those DSS systems that use geographic or spatial data (Malczewski, 1999). MC-SDSS (Malczewski, 1999) use Geographic Information System and Multi Criteria-Decision Method (MCDM) to combine spatial data and decision-maker's comments and uncertainties to provide spatial data for decision-making about the decision alternatives and their spatial attributes (Ferretti and Pomarico, 2013). MC-SDSS is different from conventional MCDM techniques because this method uses geographical data about decision alternatives (Jankowski et al., 2001). In MCDM method, the important criteria that are effective in decision making are combined based on their weight. These weights show the importance of each criterion in decision-making. In MC-SDSS method, in addition to the decision-makers' idea and a set of criteria, the spatial locations of alternatives are used. This means both decision making preferences and geographical attributes of alternatives are used to judge them; - it also includes the social participation and experts knowledge (Ascough et al., 2008). These benefits make MC-SDSS a useful method in wetland restoration prioritizing because wetland restoration is a complex project that needs all this information. In this way, accurate spatial data play an important role in MC-SDSS. In recent years, remote sensing has been applied as an important source to produce spatial data (Guo et al., 2017; Klemas, 2013; Widis et al., 2015). Its ability to produce data for a wide and remote area with enough accuracy acquires data in different spatial and temporal resolution and flexibility in method is the reason for the wide application of remote sensing. It seems that, in the future, these benefits of remote sensing will change it to a vital tool in MC-DSS.

In this study, MC-SDSS was used to plan a scheme for Hamun wetlands restoration-prioritization in order to reduce the negative effects of drought and to restore Hamun. These prioritization-determined areas - are valuable for Long-term water conservation, for reduction of negative effects of dust storms and for conservation of water bird's habitats.

The structure of this paper includes 5 sections. The next section (Section 2) is material and method. The study site and the database are presented in 2.1 and 2.2. The database is including satellite images and experimental measurements. Methods to produce the priority maps are described in Section 2.3. Results of wetland restoration prioritizing and its description are presented in Section 3. Finally, discussion is presented in Section 4 and conclusion in Section 5.

2. Material and method

2.1. Study area

Hamun wetlands are on the border of Iran-Afghanistan between 30° 25′–31° 27′ E and 60° 56′–61° 43′ N. (Fig. 1). This ecosystem consists of 3 wetlands: Hamun-e-Puzak, Hamun-e-Saberi and Hamun-e-Hirmand) in this paper, we have used the word “Hamun” and “wetland” instead of these three lakes). The study area of this paper is Hamun Wildlife Refuge, the Iranian part of Hamun, which covers an area of 300,000 ha.

Based on De Martonne classification, the climate of this area is dry, and because of severe droughts and the blockage of water flow by Afghanistan, this ecosystem has frequent inundations and drought periods even during one year. In some years, the wetland completely dries out or the existing water decreases significantly.

Since Hamun is the only source of water in an arid region, this ecosystem is a crucial one in the life of a large number of birds. Due to its importance for water birds, Ramsar Convention introduced a large part of Hamun in Iran as a protected area. In this Convention, Hamun is registered in two sites: “Hamun-e-Puzak‘ in the south end, and “Hamun-e-Saberi & Hamun-e-Hirmand’ (Ramsar, 2016). In this study, both sites were investigated.

2.2. Data

DEM (Digital Elevation Model), Landsat 7 (18/08/2000), Land use-land cover map May 2014 (Maleki et al., 2016), priority map of water birds’ habitat conservation (Maleki et al., 2016), knowledge of expertise and field studies were used in the current study. Satellite data were downloaded from the U.S. Geological Survey (USGS) website.

To achieve information about the current condition of the study area, field study data, like the previous study (Maleki et al., 2016), were used, and ecological factors such as water depth, landscape type, vegetation height and vegetation cover percentages were included.

2.3. Methods

In order to prioritize Hamun wetlands for restoration in an attempt to reduce the negative effects of drought, 3 scenarios were determined based on previous studies on this wetland: Long-term water conservation, restoration in order to reduce the negative effects of dust storms and restoration in order to conserve the habitat of water birds. After prioritizing for each scenario, prioritization for restoring the wetland to reach the 3 scenarios together was done using MC-SDSS.

2.3.1. Producing priority map for 3 scenarios

2.3.1.1. Long-term water conservation. Because these wetlands are wide areas in an arid region with a high potential for evapotranspiration, it is important to conserve water. Since deeper parts can reduce the evaporation by reducing the surface area of water, we use DEM to determine the deeper parts of the study area, which have a higher priority for long-term water conservation. Its duration is depending on the relation between volume of water and evapotranspiration. Fig. 2 shows the DEM of study area. To find the deeper parts of wetland that are homogenous, the natural break method was used to classify the DEM. Natural Breaks classes are based on natural groupings inherent in the data. This method classifies similar values in each class with maximized differences between classes(Baeza et al., 2016). Then, these classes were checked using field data.

2.3.1.2. Reducing negative effects of dust-storms. Because aerosols float in the air during each dust storm event, they could affect the radiation transfer. This alteration can be considered an index to achieve information about dust storms from satellite imagery because it

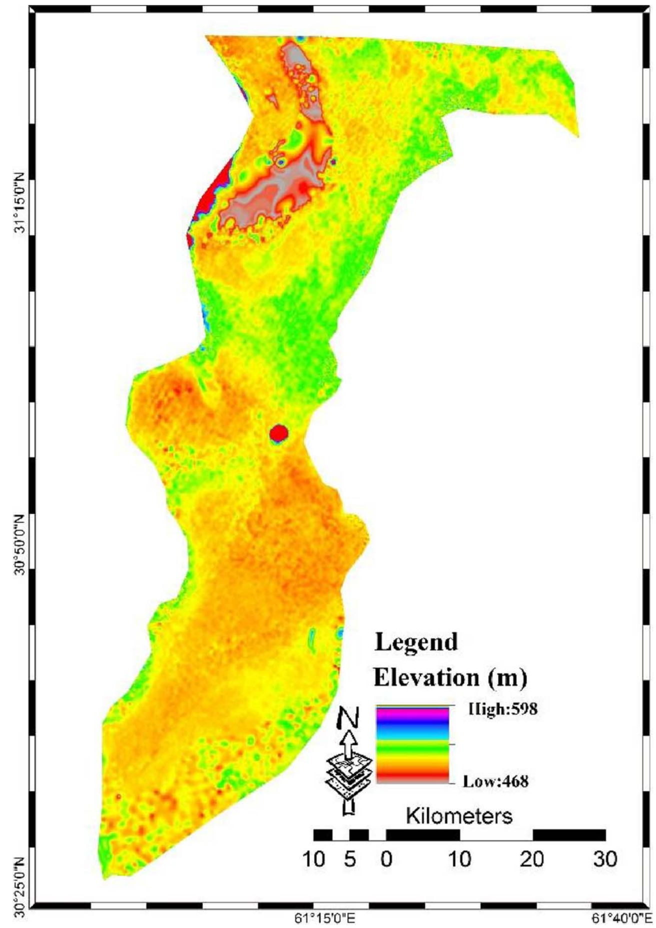

Fig. 2. DEM of study area.

changes the surface temperature (Tegen, 2003). One of the vastly used indices is brightness temperature degree (BTD) (Ackerman, 1989, 1997; Shahraiyni et al., 2015), which uses thermal bands to detect aerosol over land surfaces.

Because visibility is an efficient attribute to identify dusty days (Baddock et al., 2009), meteorological data from weather stations, including visibility, were used. These data were extracted from Islamic Republic of Iran Meteorological Organization (IRIMO). Using these data, Aug. 18, 2000 was selected as a day with dust storms. There was no cloud cover in Landsat data for this date; therefore, BTD map was derived directly from Landsat 7.

In order to produce the priority map for this scenario, dust point sources were classified based on distance from villages and cities. Each dust point source that conducts dust to cities and villages takes a higher priority. Each part of Hamun related to each point with higher priority has a higher score for restoration. Because there are 3 dust point sources in this area, 3 priority levels were determined for reducing the negative effects of dust storms.

2.3.1.3. Conservation of water birds’ habitats. For this scenario, the result obtained in the previous study was used. Priority map of water birds’ habitat conservation (Maleki et al., 2016) was used. This map was produced based on parts of the wetland which maintain their favorable conditions as birds’ habitats for longer periods. In this map, areas that are suitable for water birds in the breeding season but lose their suitability during this season because of water limitation have higher priorities for conservation (Fig. 3, shows this map). Class1 shows areas that are suitable in the first part of breeding season but turn into undesirable conditions till the end of this season. These areas require exceptional management measures. Hence, in this study, these areas

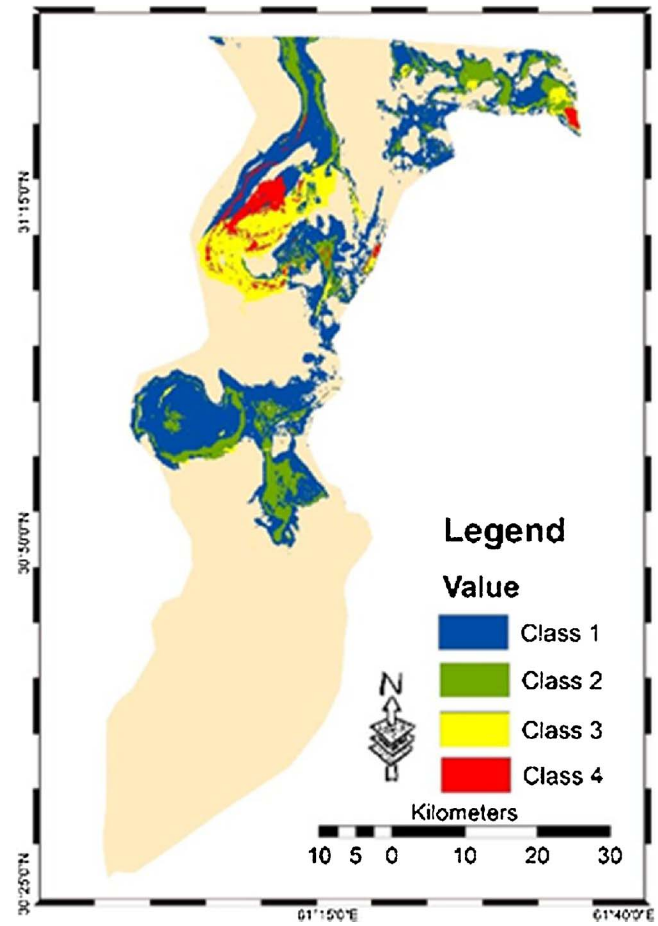

Fig. 3. Priority map of water birds' habitat conservation (Maleki et al., 2016). The recommended protected area from class 1–4. Class1 shows areas that are suitable in the first part of breading season but turn into undesirable conditions till the end of this season. These areas require exceptional management measures.

take higher priorities for wetland restoration. Based on Fig. 3, conserving water in the blue parts is the most important; therefore, these parts take higher priorities for wetland restoration.

2.3.2. Restoration prioritizing using MC-SDSS

Weighted Linear Combination (WLC) was used to prioritize Hamun restoration. WLC is one of the most common methods in MC-SDSS, in which the importance of each alternative is determined using a weight calculated by expert judgement, and scoring involves two phases: (i) obtaining knowledge from experts and (ii) evaluating the alternatives based on this knowledge. These weights are used to prioritize the alternatives.

2.3.2.1. Calculating weights for each scenario. Pairwise comparison method was used to determine the weights of the scenarios according to the analytic hierarchy process (AHP) presented by Saaty 1977,1999 (Dragan et al., 2003). The expertise evaluated the relative importance of scenarios in determining the prioritization of wetland for restoration. 25 people consisting of Hamun wetland managers, university professors, park rangers, local experts and rural people who live around the Hamun participated in this survey Expert knowledge was elicited through qualitative semi-structured interviews (Yamada et al., 2003). In AHP method, two scenarios are compared at a time and the comparisons are based on a continuous scale with values from 1/9 to 9 (Dragan et al., 2003). In the newest version of AHP software, geometric mean of weights is used to calculate the final weight of each alternative (Alessio and Ashraf, 2009). In AHP method, the final weight will be

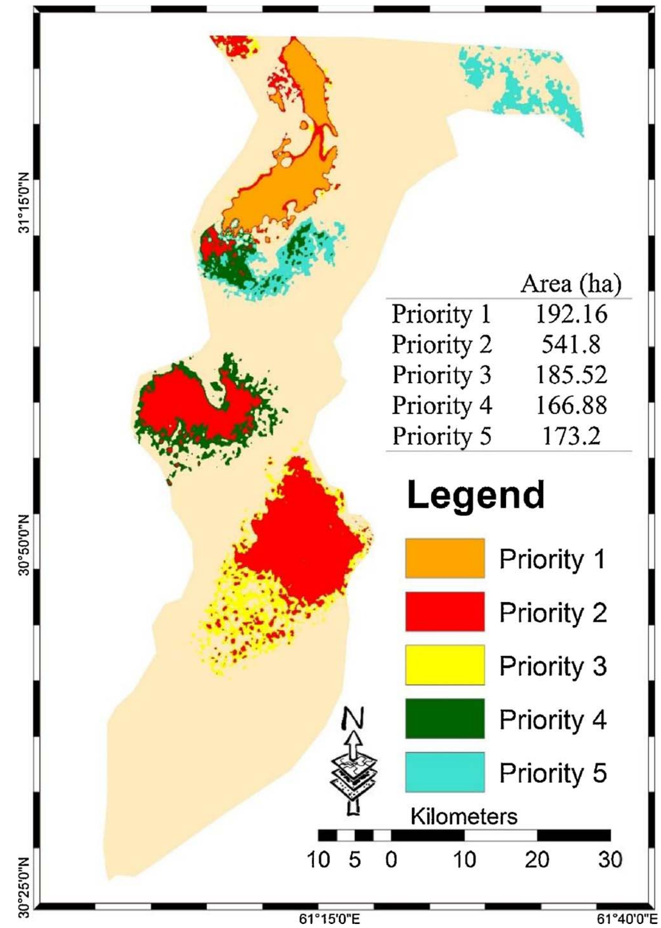

Fig. 4. The priority map for Long-term water conservation.

between 0 and 1. In this paper, Expert Choice v11.0 software was used to calculate the final weight of each scenario.

2.3.2.2. Final prioritization map for restoration. After weighing the scenarios, Eq. (1) was applied to combine 3 scenarios and compute the final prioritization map of Hamun wetland for restoration.

$$\mathrm{Mi} = \sum_{j=1}^{n} \mathrm{Wj} \times \mathrm{Xij}$$

Where, Mi is the overall priority for ith gird cell; wj is the weight of jth scenario, and xij is the value of ith gird cell for jth scenario.

3. Results

3.1. Scenario1: long-term water conservation

Fig. 4 shows the priority map for long-term water conservation, while Table 1 shows the elevation threshold for each priority. By supposing that the deeper parts reduce the surface area of water, and

Table 1
Elevation threshold for each priority.

Priority class	Elevation threshold (m)
Priority 1	468–475.155
Priority 2	475.155–476.182
Priority 3	476.182–476.688
Priority 4	476.688–478.221
Priority 5	478.221 <

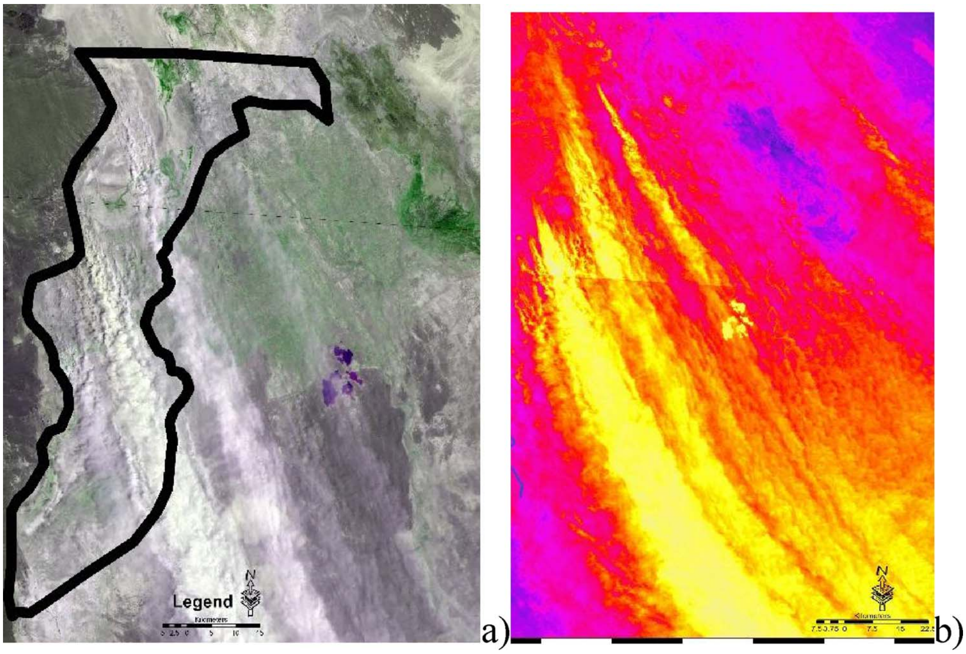

Fig. 5. a-the FCC image of the study area on a day with dust storms, b-the map of BTD for this day.

thereby evapotranspiration, water reduction is less in deeper parts. Therefore, these parts, with an area of 192 ha, have the highest priority, if decision makers want to restore the wetland just for long-term water conservation. This area will be important during drought conditions, but other priorities may be selected under better conditions of water availability.

3.2. Scenario 2: reducing the negative effects of dust storms

Based on meteorological data from weather stations, Aug. 18, 2000 was selected as a day with dust storms. Fig. 5a shows the FCC image of the study area on this day. Fig. 5b shows the map of BTD for this day. The area that is affected by dust storm is demonstrated in yellow -. Based on this map, there are 3 dust points in this area. Based on distance to villages and cities, dust point sources were classified. Each dust point source that conducts dust to cities and villages with more population takes a higher priority. Each part of Hamun that is related to each point with a higher priority has a higher score for restoration. Fig. 6 illustrates this prioritization.

Based on Fig. 6, when reducing the negative effects of dust storms are the major scenario, 677 ha has a higher priority. This is in a condition that it is necessary to avoid dust storms during water limitation period. The spatial situation of these areas is illustrated in Fig. 6. But in better conditions of water availability, other priorities can be selected.

3.3. Scenario 3; conservation of water birds' habitats

As Fig. 3 shows, the blue parts need greater management measures since their suitable conditions change during the nesting season. Thus, conserving water in the blue parts, a total of 814 ha, is of the most importance and should have the highest priority for wetland restoration (Fig. 7).

3.4. Prioritization for wetland restoration using MC-SDSS

Pairwise comparison method was used to determine the weights of the scenarios. Based on expert knowledge, compared to the other scenarios, conservation for water bird habitats is the most important scenario for wetland restoration, with a ranking of 0.5, followed by the long-term water conservation scenario, with an expert value of 0.3. Fig. 8 shows the map of the final MCDM analysis.The red part, class 1, is

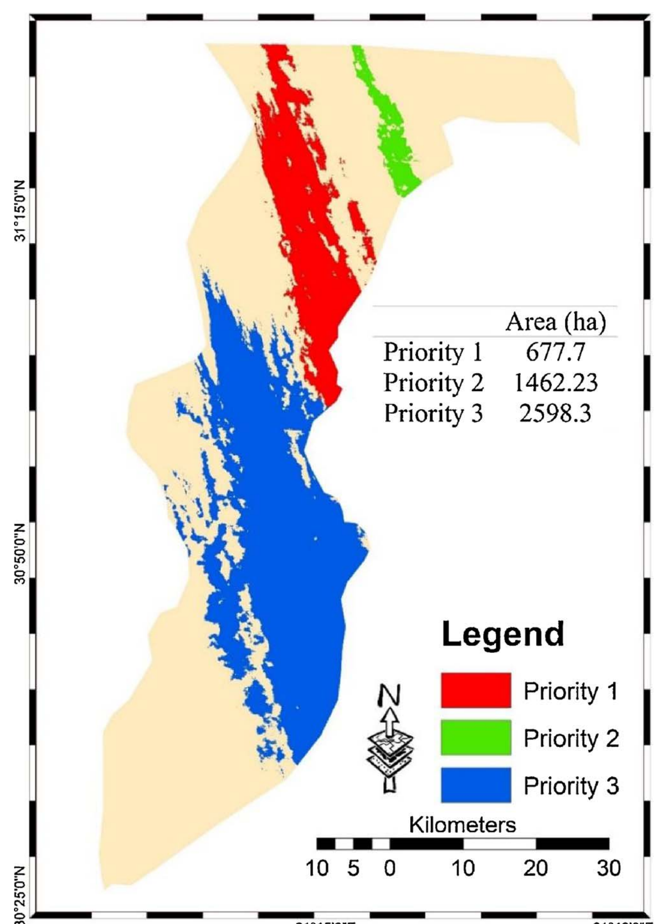

Fig. 6. The map of priority in reducing negative effects of dust storm.

the area with the highest priority for wetland restoration.

When this wetland is in the critical condition because of water limitation, restoration plan will be at least in this class. It shows, to revive the wetland in a condition that water resources are completely limited, these parts should receive water. In the next level of water

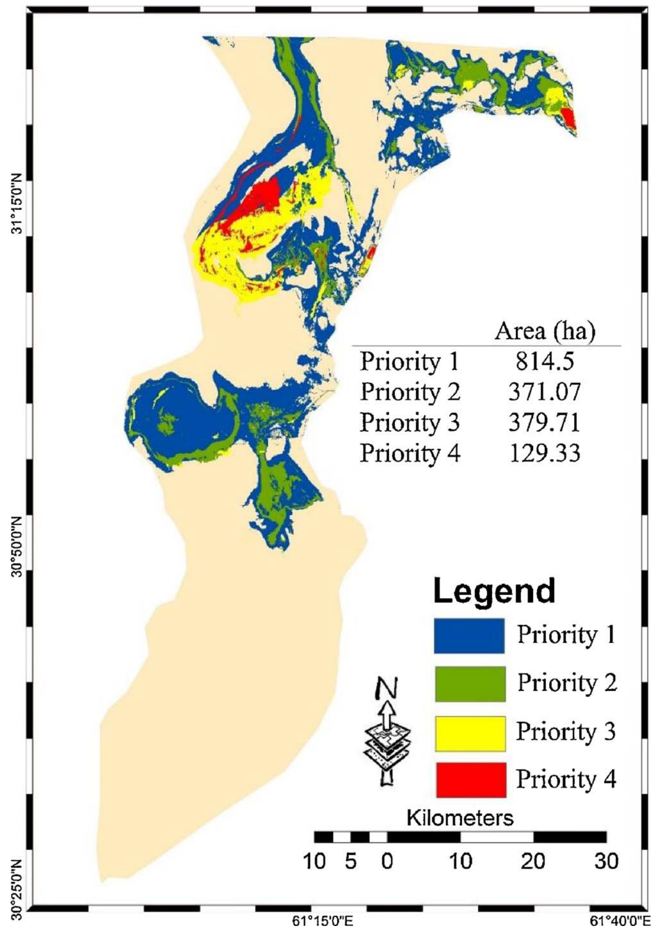

Fig. 7. Priority for wetland restoration based on conservation of habitat for water birds Prioroty1 is the higher priority for restoration.

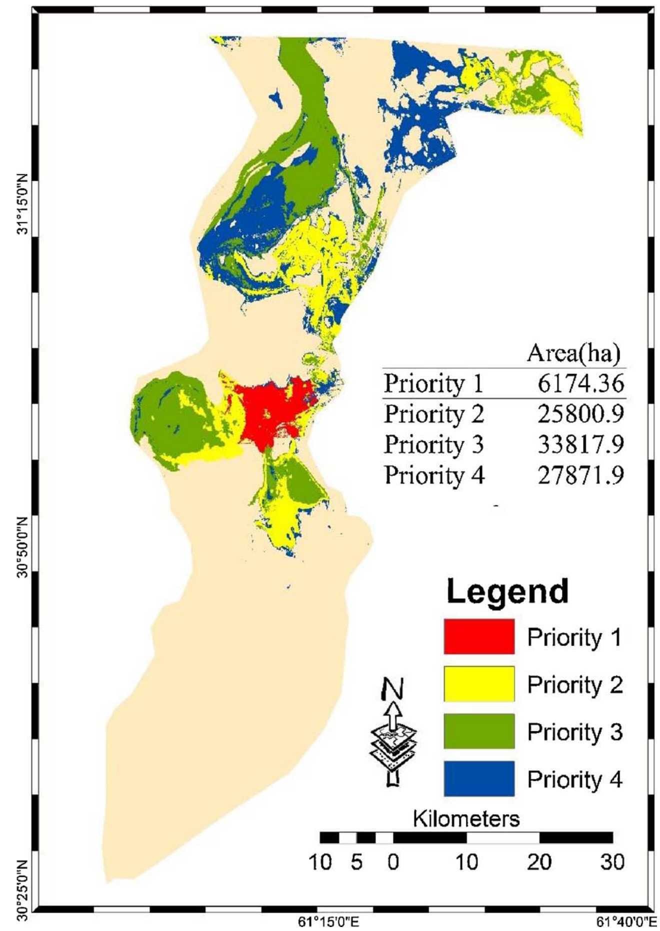

Fig. 8. The priority for wetland restoration based on 3 scenarios. Prioroty1 is the higher priority for restoration.

availability, classes 1 and 2 will be used for restoration, but in other conditions of water availability, other classes of prioritization can receive water based on the availability of water and the position of the water source.

4. Discussion

Wetland restoration is suggested to restore the functions and values of wetlands destroyed or impacted by stresses (Klemas, 2013). In arid and semiarid areas, the conditions are different because the most important factor that threatens wetlands is water limitation (Downard et al., 2014; Gatti and Richarson, 1999; Guo et al., 2017). Therefore, sometimes it is not possible to restore the whole part of a wetland and it is necessary to prioritize the restoration of different parts of it. In this study, Hamun wetlands were prioritized for restoration because it is not possible to restore the whole wetland.

4.1. Use of GIS/RS in wetland restoration

In order to achieve successful restoration, it is necessary to use scientific and accurate tools to achieve information from wetlands. In recent decades, remote sensing provides a cost-effective and accurate tool for selecting suitable sites for restoration (Guo et al., 2017; Jasrotia et al., 2009). In this study, remote sensing data were used because they have spatial information. As Fig. 8 shows, the result of prioritization is linked to their spatial data. On the other hand, many environmental indicators can be detected by remote sensing to provide quantitative estimates of wetlands phenomena; vegetation, water, dust storms etc. An applicable example of these indices used in this research to detect dust storms, is BTD. Investigation of the areas affected by dust storms is very important in an arid area. As Fig. 5 shows, BTD that is directly extracted from satellite data is valuable for monitoring dust storms. This index is used by different researchers to detect mineral aerosols over land surfaces and also completely determining the dust points and affected areas (Ackerman, 1989, 1997; Shahraiyni et al., 2015).

As Klemas, 2013, shows, advances in the application of geographic information systems (GIS) make it a valuable tool to combine with remote sensing images. and provide a convenient means for modeling. In the prioritization process of Hamun, the abilities of GIS in using different geographic scales, easy application, input data flexibility and spatial data were applied. The results of overlaying process (Fig. 8) show that a combination of GIS and RS can be the main tool in restoration studies.

4.2. The restoration priority approach

In this paper, prioritization was used in order to reduce the negative effects of drought on a wetland with water limitation. In such areas, it is not possible to conserve water to restore all parts of the wetland. Therefore, it is necessary to organize a plan for the restoration of the wetland so that the water is saved for longer periods to save human and wildlife communities. It is important to mention that this plan should be systematic enough to conserve all functions and values of wetlands. For this reason, multi-scenario models are the best choices for wetland restoration priority. In order to achieve maximum success in the wetland restoration, these scenarios were selected based on local conditions of these wetlands and their functions in the study area.

In this study, prioritization was done in two levels. In this way, decision-making for restoration is possible at both levels. At the first level, prioritization was carried out to enhance and restore three wetland functions separately: water conservation, reducing the negative effects of dust-storm and water-bird's habitat conservation. At this level, the spatial priority of restoration for each scenario was determined. At the other level, the spatial priority was determined to restore all these three functions. Thus using this prioritization scheme, wetland restoration will be accomplished to enhance water conservation, reduce the negative effects of dust-storm and conserve the water-bird's habitat. In the second level, prioritization was done based on a systematic approach which is important because, as Brander et al. (2006); Widis et al. (2015); Downard et al. (2014), mentioned, wetlands provide services for wildlife and human societies. In wetland restoration plans, it is necessary to consider these services (Brander et al., 2006; Costanza et al., 2008; Woodward and Wui, 2001). This is important especially in a damaged ecosystem where different parts of it are affected by negative impacts of damage. In arid ecosystems that are sensitive to drought, attention should be paid to provide water for all consumers of the wetland. The approach used in this paper is a systematic approach based on ecological principles for water and wetland management. In this approach, different wetland functions will be protected. This is useful in areas with water limitation to conserve different services of the wetland. Moreover, the wetland restoration is determined for different levels of priorities. Since these wetlands are transnational systems, even in unstable situation of other countries, this priority will be useful to restore the major functions of wetlands based on availability of water in Iran. If these results are combined with hydrological data, it is possible to produce a model to determine which priority can be restored in each amount of water volume. As O'Neill et al. (1997) and White and Fennessy (2005) mentioned, by using multiple scenarios, it is possible to use best professional judgement, allowing for the evaluation multiple priorities in decision-making (O'Neill et al., 1997; White and Fennessy, 2005). On the other hand, while most of the existing wetland management approaches are academic, our method incorporated both theoretical and practical aspects of wetland management.

5. Conclusion

This paper introduces a new application of wetland restoration prioritization; restoration prioritization to reduce the negative effects of drought. In a wetland which is destroyed because of water limitation, the best area for wetland restoration was determined using a systematic approach based on ecological principles. Therefore, the wetland will be restored so that the water will be saved in longer periods to protect human and wildlife communities

MC-SDSS method was used to prioritize different parts of a damaged wetland for restoration. Because this method combines the spatial data in addition to decision-makers' preferences and ecological importance, the geographical locations of alternatives were determined. This means, apart from the priority for conservation, the geographical distribution of alternatives was determined. Also, with regard to using the experts' knowledge in determining the importance of scenarios, this method of priority is flexible in different areas with different conditions and different levels of damage. Therefore, it is applicable in practical issues. In addition, it is possible to try this method with the same weight between scenarios or with another method to calculate the weight.

The method used in this study can be well adapted to plan a scheme in other wetlands with water limitation, especially in arid areas where water limitation is an important factor to limit the ecosystem process, planning such scheme in order to maintain water for important services of wetland is necessary. It provides, a sustainable water conservation plan to restore wetlands.

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