Study of desertification status based on a sub-IMDPA model for a case study in Yazd-Ardakan plain, Iran

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Abstract: Desertification control should rely first on an assessment based on reliable data and approaches (Factors and degree of degradation), and second on the use of the assessment outcome to trigger awareness and decision making towards desertification control implementations. The human factor is to be put in the center of reasoning in order to achieve reliable results. Different models have been proposed to assess desertification at different approaches and parameters such as FAO-UNEP, MEDALUS, DPSIR-framework and Iranian Model of Desertification Assessment**.**
The question seeking to address here is the extent of desertification classes in Yazd-Ardakan plain, Iran. Based on the fact that dwindling ground waters in the area and recent droughts are the main responsible of desertification in the area, a sub-model of Water-Climate mixture of the Iranian Model of Desertification Process Assessment (IMDPA) was followed to study the status of desertification in the area. Among the desertification indices studied in this research, water criteria with the weighted average of 3.44 is by far more influential than climatic criteria. Based on the findings, order of changes in the importance of desertification indices in the area is as follows: water level drop, precipitation, EC, Transo dryness index, drought persistence and SPI. Finally, based on the findings, implications for decision makers are introduced.

Keywords: desertification, climate, weather, IMDPA

Introduction

There are many ways to define a desert. Meteorologists define the desert by the amount of rainfall or biologists, from another perspective, define deserts based on rainfall and evapo-transpiration(Castaldo 2004). Deserts and semi-deserts are the most extensive of the earth’s biomes occupying more than one third of the global land surface. Of this area, approximately 4% is classified as extremely arid, 15% arid, and about 14.6% semiarid (Laity 2009). Likewise, there are definitions based on climatology, surface hydrology, plant communities and soil types (Warner 2004). In spite of the frequency with which the term is applied, there is no universally accepted common or technical definition of “desert” (Warner 2004). By definition, all deserts receive low average annual precipitation, however, with a distribution throughout the world’s inhabited continents, much diversity exists among the world’s deserts(Kingsford 2006).

As mentioned, no single, conclusive ecological definition of the term “desert” has been accepted. The different perceptions of the term “desert” can be viewed as contrasting paradigm that complicates the discussion about desertification (Arnalds and Archer 1999). In 1990, the UNEP *ad hoc* group for the “Global Evaluation of Desertification” used this definition: "desertification is land degradation in arid, half-arid and dry sub-humid areas resulting from opposite human impact”. In 1992, “the *United Nations Conference on Environment and Development (UNCED)”* in Rio de Janiro adopted this definition” Desertification is land degradation in arid, half-arid and dry sub-humid areas, resulting from various factors, including climate variations and human activities”.

In spite of the threat of desertification to be in the shadow of a doubt, most researchers agree that desertification is a menace to sustainable development in arid and semiarid areas (Brauch 2003). In the next few decades, 1.2 billion people will be affected by the loss of land productivity or land degradation (van Andel and Aronson 2012).

About 80% of Iran's area falls in arid and semi-arid category and one-third is prone to desertification. Deserts cover about 20% of the land in Iran; remaining land comprises rangeland (55%), agriculture (11%), forests (8%), and industrial and residential areas (6%) (NAP 2005).

Desertification control should rely first on an assessment based on reliable data and approaches (Factors and degree of degradation), and second on the use of the assessment outcome to trigger awareness and decision making towards desertification control implementations. The human factor is to be put in the center of reasoning in order to achieve reliable results. Different models have been proposed to assess desertification at different approaches and parameters such as FAO-UNEP, MEDALUS, DPSIR-framework and Iranian Model of Desertification Assessment But there is no consensus on the proper use of models to assess desertification (Zdruli 2010)

The formation and development of land desertification is the result of many factors, because the causes of desertification in different parts are different, so a fixed model has difficulty applying in all regions. Therefore, various research areas should establish the corresponding models to improve the simulation accuracy(Sun and Deng 2013).

IMDPA is a comprehensive desertification model that was developed by the Faculty of Natural Resources at the University of Tehran in a project entitled "Determination of Methodology of Desertification Criteria and Indices in Arid and Semi-Arid Regions of Iran" (Ahmadi 2004). IMDPA was used to study desertification status of *Jarghooyeh* region in Isfahan province , *Segzi* pediment in Isfahan province, *Mazayijan* plain in Fars province, and *Kaherkonarak* region, and *Jazinak* region in *Sistan-Baluchestan* province (Pahlavanravi and Bahreini 2013).

The question seeking to address here is the extent of desertification classes in Yazd-Ardakan plain, Iran. Based on the fact that dwindling ground waters in the area and recent droughts are the main responsible of desertification in the area, a sub-model of Water-Climate mixture of the Iranian Model of Desertification Process Assessment (IMDPA) was followed to study the status of desertification in the area.

Martial and Methods

The study area

Yazd-Ardakan plain is one the most extensive plains of Yazd province, Iran which

falls between 53 20 to 54 50 E longitude and 31 15 to 32 45 latitude. This plain includes Ardakan, Meybod, Ashkzar and Yazd cities covering 12 km and 35 km in length and width. Temperature ranges between 12 – 19 centigrade degrees with relative humidity of 30 to 50%. Sever evaporation occurs in a gamut of 2200 to 3200 mm per annum in this area. Precipitation manifests itself as low and sporadic precipitation events which dictate a desert climate. Saline geological formations also impact soil and water in the area which ultimately put influence on agricultural lands. Of the total 564 million liters well discharge volume in the area, 82% is used for agriculture. This amount has dwindled groundwater reservoirs and brought about saline water intrusion which intensifies already climatic desertification. Fig 1 depicts the geographic expansion of Yazd-Ardakan plain.

plain.

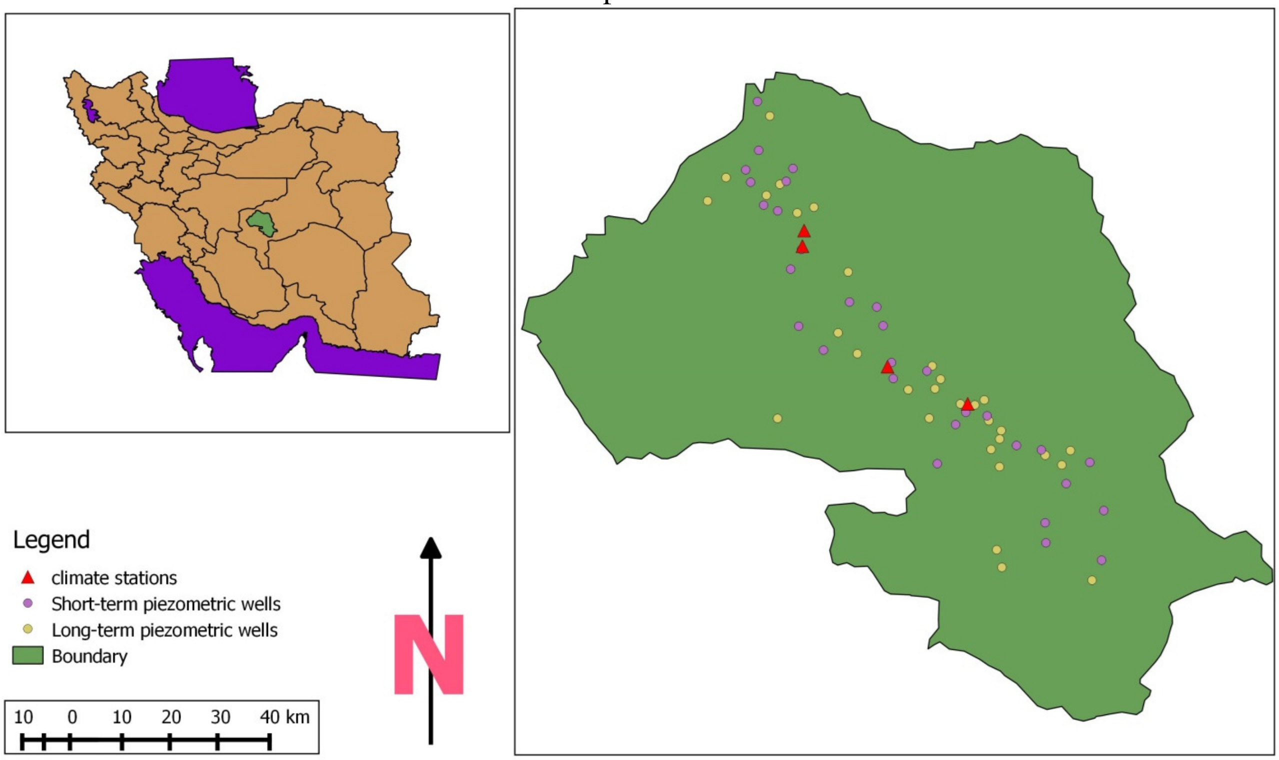

Fig1: location of the study area

Methodology

The IMDPA model consists of 9 criteria, 36 indices to evaluate desertification.This model evaluates current status and desertification potential simultaneously, without discriminating either of them. In order to combine indices into criteria and finally desertification risk, geometric averaging is used. Each indicator and any combination of criteria could serve as a sub-model to evaluate desertification for that point of view. A benefit of desertification models is that, by monitoring the changes in a period of time, one would be able to follow the trend of change and initiate the early warning phase.

Here, in the IMDPA model, all the indices and criteria were ranked in a range of 1 to 5 according to expert's judgments and summed according to the following formula:

$$\text{Index-X}=[(\text{layer-1}).(\text{layer-2})\ldots(\text{layer-n})]^{1/n} \quad \text{eq.1}$$

Where index-X denotes index of interest, layer shows indices of each criterion and n shows number of indices per criterion. In this study, two criteria of climate and water were evaluated and combined as follow:

$$Desertification\ Intensity = \sum \sqrt[2]{Climate * Water} \quad \text{eq.2}$$

Table1. Classification breaking points for desertification intensity values

Desertification Intensity Class	Symbol	Range
Negligible	1	0.0001-1
Low	2	1.1-2.5
Medium	3	1.6-2.5
Severe	4	2.6-3.5
Extreme	5	3.6-4

Desertification intensity were classified for all land-uses based on table 1. Prepared data layers for indices were combined into criterion and criteria layers and desertification risk was estimated based on eq.1. Data handling was done in Qgis 2.2 software.

Climatic condition is a natural cause of desertification which also could
Indirectly impact other desertification indices.in these study 3 indices were evaluated for this criterion including annual precipitation, dryness index and drought index. Drought index is per se broken down to drought persistence and SPI drought index. Here, four climatic stations were included and precipitation level was classified into 5 categories as provided in table … In order to study dryness index Transo index was used as follow:

I=P/ETP

Where I show annual precipitation and ETP shows Annual evapotranpiration. Evapotranspiration was estimated using Thornthwaite method. (Table 2)

Drought was evaluated using SPI index ranging from -1 to 1 in which negative values denote more intense droughts and positive values denote wet years. Classification breaking points is provided in table 1 and 2.

Drought persistence affects desertification separately from annual rainfall. Breaking points of this index is provided in table 2.

Yazd-Ardakan plain is a dry area with negligible precipitation. There are only a few seasonal rivers which dry out before reaching the plain. Thus, in order to keep up with the growing demand of agriculture and industry, remarkable pressure has been put on the ground water resources making them to drop to alarming levels. At this level, because of saline geological formations and saline water intrusion, water quality has been going down. Thus, water level drop and water quality deterioration (EC) were used as water indices. Breaking points are provided in table 2.

Table 1. SPI classification scheme

Class	Exceptionally moist	Very Moist	Moderately moist	Near normal	Moderately dry	Severely dry	Extremely dry
SPI value	>2	1.5-1.99	1-1.49	-0.99-0.99	-1 -(-1.49)	-1.5 -(-1.99)	-2 >
Class Code	7	6	5	4	5	6	7

Table 2 breaking points of the indices of the sub-IMDPA model

Symbol	Range	Desertification Intensity Class	Annual Prec. (mm)	Dryness index	SPI	Drought persistence (years)	Water table drop (m)	EC (microsiemense.cm^{-1})
1	0.0001-1	Negligible	>=600	>0.65	7	<3	0-10	<250
2	1.1-2.5	Low	280-600	0.45-0.65	5,6	3-4	10-20	250-750
3	1.6-2.5	Medium	150-280	0.2-0.45	4	4-5	20-30	750-2250
4	2.6-3.5	Severe	75-280	0.05-0.2	2,3	5-6	30-50	2250-5000
5	3.6-4	Extreme	<75	<0.05	1	6-7	>50	>5000

Results

As for climatic criteria and annual precipitation, Ardakan station has the lowest amount of long-term annual precipitation. In most cases, coefficient of variability (CV) is more than 40% which shows irregular precipitation pattern (See table3)

Table 3. Statistics of precipitation in the climatic station in the study area

Station	Max(mm)	Min(mm)	Range(mm)	Mean(mm)	SD	CV(%)
Yazd	120.2	12.9	107.3	57.84	27.22	47.06
Ashkzar	124	10	114	57.83	24.28	41.98
Meybod	94.4	10	84.4	51.46	22.9	43.31
Ardakan	102	16.6	85.4	60.72	22.9	37.71

Annual variation of precipitation could be seen in fig 2 for the climatic stations. Because of the Mediterranean pattern of precipitation in the plain, summer months are lacking precipitation, while most of the rainfall is limited to the autumn to winter months. The whole area of the plain, based on the classification of annual precipitation, falls in the “severe” desertification status.

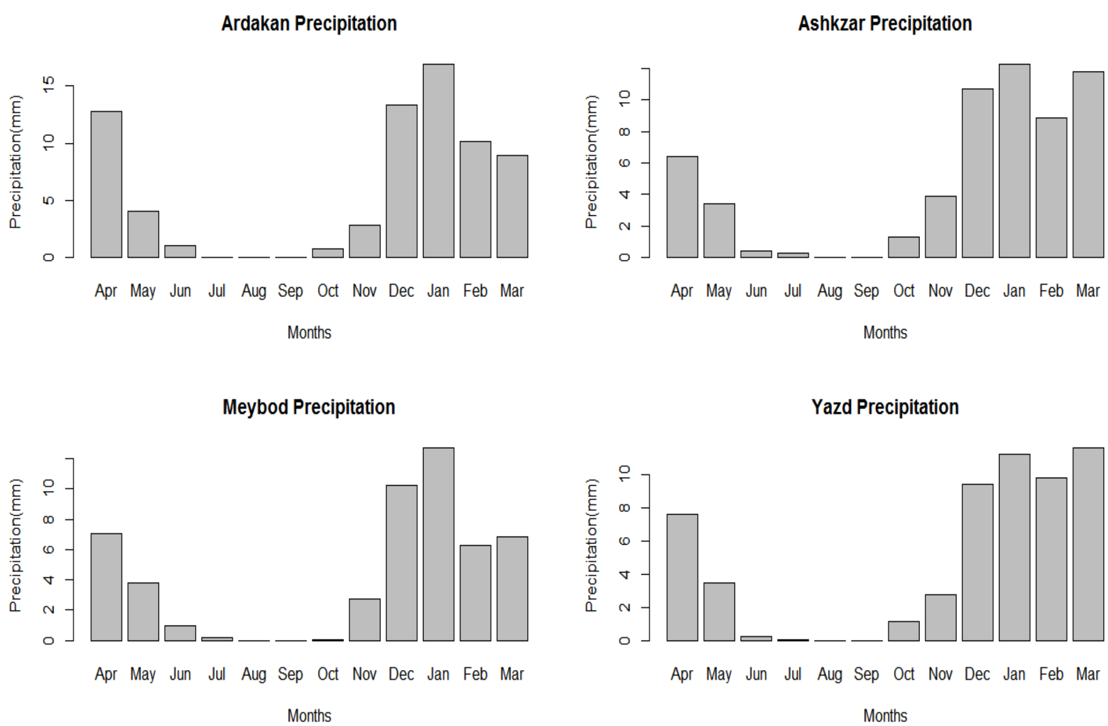

Fig.2 variation of precipitation in the climatic stations under study

Table 4. Dryness index status in the Yazd-Ardakan Plain

Station	Dryness Index	Desertification status
Yazd	0.026	Extreme
Ashkezar	0.027	Extreme
Meybod	0.022	Extreme
Ardakan	0.027	Extreme

As was said, dryness index was estimated using Transo index which is a function of precipitation to potential evopo-transpiration which is calculated using Thornthwaite formula. Results are provided

in the following table (table 4). Based on this classification the whole plain falls in the extreme desertification class.
According the results of SPI index, no extremely dry years was observed in the station. The highest SPI index, which matches the wettest year, was observed in Ashkzar. Most years fall in the normal category. An interesting point in this charts, is the relative frequencies of exceptionally wet years which brings this idea that precipitation level suffice in the plain while given the annual rainfall given in table 3, it is obvious that precipitation, even in the wettest years, is not sufficient. In case of drought index, the whole area was classified as severe desertification status. Fig. 3 shows the relative frequency of drought in the four climatic stations. In case of drought persistence, the whole plain was classified as negligible. Finally, based on the annual rainfall, drought status and drought persistence indices, the whole plain were classified as medium desertification status.

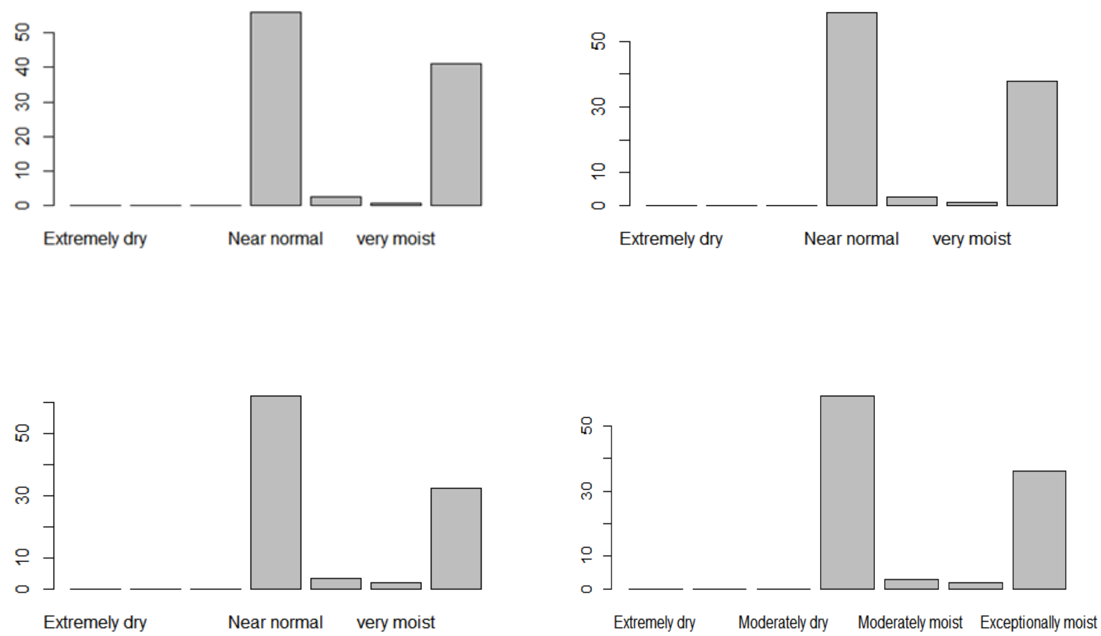

Fig3 relative frequencies of SPI index in the climatic stations in Yazd-Ardakan plain, upper left (Ardakan), Upper right (Ashkzar), Lower left (Yazd) and Lower right (Meybod)

Based on the data, there has been an annual water table drop of 45 cm. During 35 years, water table has dropped 16 m. in this study, 30 short-term piezometric and 30 long-term piezometric wells' data was studied for water table and EC. Results of water table drop and EC are provided in figures 5 to 6.Finally, based on the eq.2 final desertification status map was produced which could be seen in fig. 7.

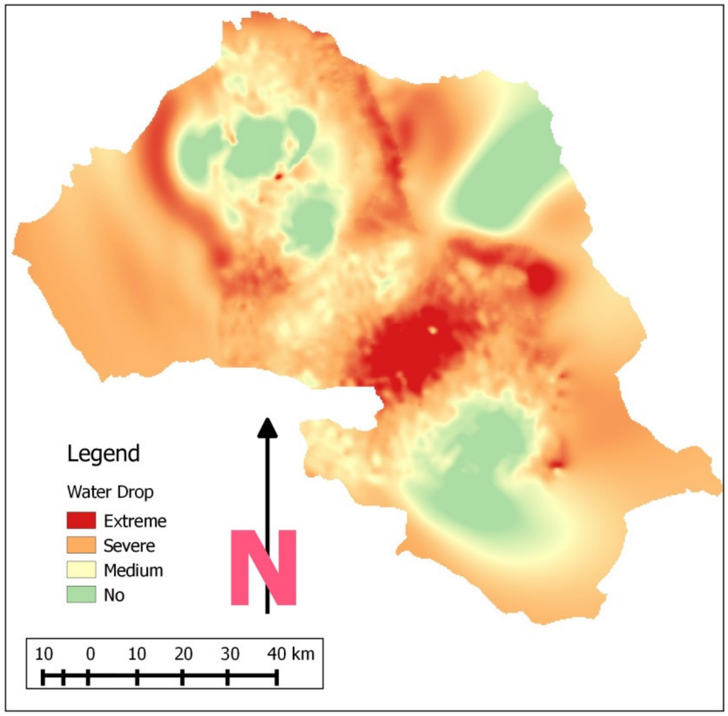

Fig. 5 Water level drop classification for 2009-2010

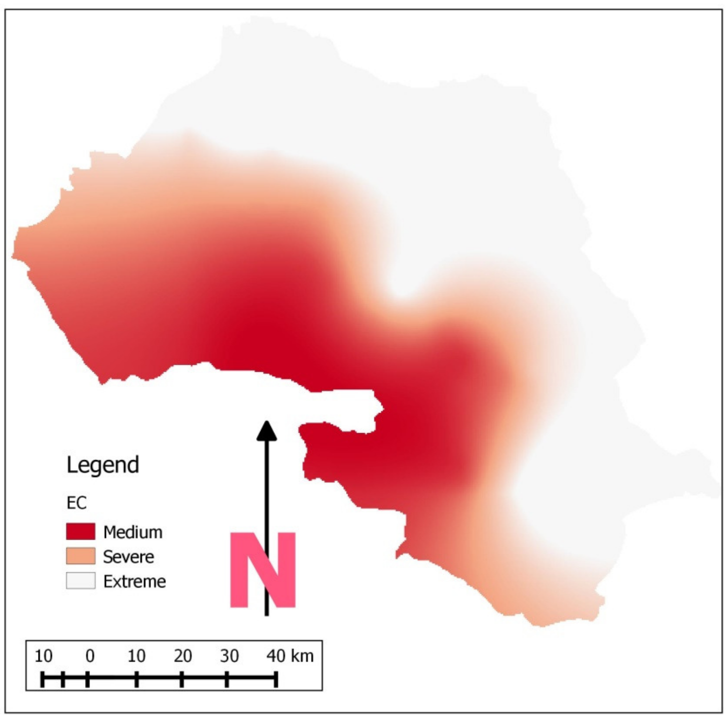

Fig. 6 EC level classification for 2009-2010 in Yazd-Ardakan plain

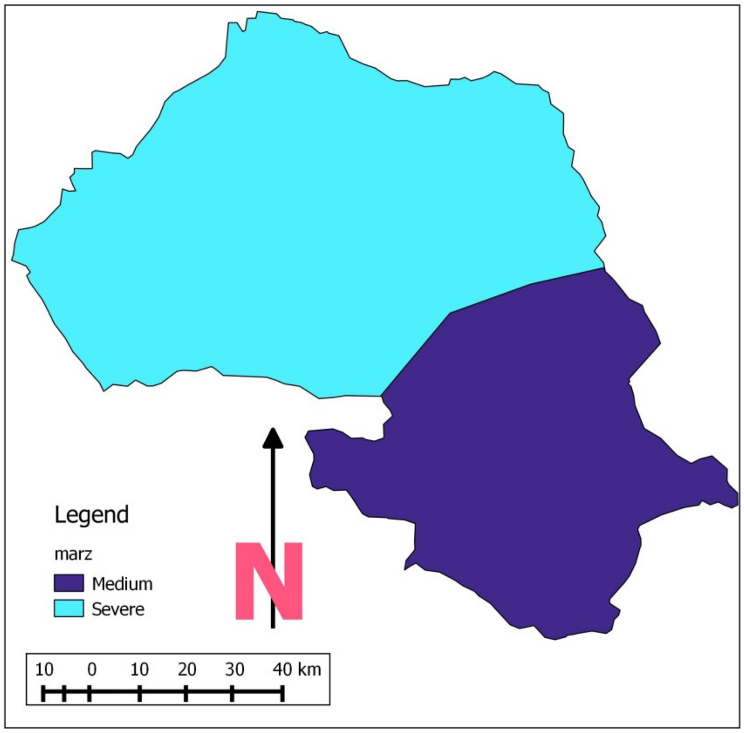

Fig. 7 Final desertification status in Yazd-Ardakan plain

Discussion and Conclusion

Among the desertification indices studied in this research, water criteria with the weighted average of 3.44 is by far more influential than climatic criteria. Based on the findings, order of changes in the importance of desertification indices in the area is as follow: water level drop, precipitation, EC, Transo dryness index, drought persistence and SPI. (Zehtabian 2007), (Khosravi 2004) also reported severe desertification status for annual rainfall, drought index and drought persistence and dryness index, as important indices for desertification assessment. In the study, desertification class of climatic criteria measured 2.4 which correspond to medium level desertification intensity.

EC levels 1300 through 11000 microsiemense.cm^{-1} which mostly falls into medium to extreme category and imply the intensity of desertification in the area. (Ahmadi 2006), (Dolatshahi 2007), (Abdi 2007) also reported severe level of desertification for EC levels. Most of the similarities between the studies is because of the same geological formations, heavy pressure of agricultural water demand on groundwater resources, high level evaporation and saline water intrusion.

According to fig… the average level of water table drop is 0.55 for 2010. 65.5% of the total area falls into severe to extreme classes. 33.02% of the area was classified as medium and 1.45% as no water table drop. Water table drop ranges between -0.8 m to +1.28. Most parts of the plain face extreme to severe water table drop. (Jafari 2001) and (RAfiei Emam 2002)) reported the same level of water table drop and desertification intensities for similar areas. Finally, for a large part of the area, with the weighted average of 3.1, severe desertification status was estimated. There are discrepancies between argues provided by (Khosravi 2004), (Nateghi 2007) for reporting medium level of desertification in their studied areas. In their studies, most medium level classes were at the initiation phase of severe desertification status and this suffices to interpret the discrepancies between this study and similar reports.

Here are some implications for decision makers based on the findings. As mentioned, water table drop because of heavy pressure imposed from agricultural activities and planting water consumptive crops and the role of ground water dwindling level these implications are provided:

- In order to harness the severe drop of water table, no other well drill permission should be issued. Moreover, water meter should be installed and preventive penalties should be seen.
- Development of industries less dependent on ground water extraction.
- Prevention of water consumptive agricultural crops.

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