

Assessment of Aridity Using Geographical Information System in Zayandeh-Roud Basin, Isfahan, Iran

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Abstract: Rapid growth of population and human activities has caused a perceptible change in the climate in some parts of Zayandeh-Roud Basin (Z.R.B.). High temperatures and aridity in some parts are a growing environmental problem. Assessment and monitoring of aridity is essential to protect desertification and mitigate drought. A Geographical Information System (GIS) was used in this paper for the assessment of (Z.R.B) using climatic data collected from 11 stations situated in the basin. In order to assess aridity, three well-known aridity models, viz De Martonne Aridity Index, Thornthwait Precipitation Effectiveness index and UNESCO Aridity Index, were used. Result showed that climate of Z.R.B is mostly becoming drier. There exists a small climatically wet zone in the area.

Keywords: Zayandeh-Roud basin, UNESCO, geographical information system, Aridity Index

1. INTRODUCTION

Drought has long been known to impact people's living conditions and is being alleged to be increasing in frequency due to climate change. In the past, dry lands recovered from long droughts and dry periods. Under modern conditions, however, they tend to lose their biological and economic productively quickly, unless they are managed in a sustainable manner (GOI, 2001). It is difficult to recover when aridity or dryness of an area increases beyond a certain level. The study of dryness of an area is essential to manage land degradation and desertification. Measurement of aridity is important for assessing drought vulnerability, evaluating drought severity, monitoring climate change, assessing bio-environment, monitoring soil moisture, and planning agriculture (Shahid, et.al. 2010). Hence, it is important to have updated dryness maps for planning and management. Geographical information System and climate data are used in this paper for the mapping of aridity or dryness of Z.R.B. from long- term climatic data.

Climate of (Z.R.B.) is characterized by high temperature, low rainfall spatially in large parts east of the area. Different places in the basin have different climates. On the basis of climatic condition, Consultant Engineering (1997) divided Z.R.B. into seven distinct climatic zones. However, different methods were used for the classification of climate. Recently, there has been a serious concern on the extent of aridity in the basin and nowadays development of drought in the area is a serious issue. Rapid growth of population and human activities along with industries, construction, modification of landforms and decline of ground waters have been impacting the biophysical environment of the region and this has also caused a noticeable change in the climatic condition of the basin. The aim of this paper is to get a comparison of standard methods and reliable picture of aridity of Z.R.B.

A number of methods have been used for mapping aridity of an area. The methods are based on precipitation and temperature; precipitation, evaporation, and relative humidity; number of dry days; and precipitation-evapotranspiration ratio. Among these methods, the precipitation-temperature based method, proposed by De Martonne (1926), is widely used for measuring aridity of an area. Another widely used method is Thornthwaite's method (Thornthwaite, 1931) based on precipitation and temperature. UNESCO (1979) has proposed a rainfall-evapotranspiration ratio based method for the estimation of dryness. In this paper all the three methods are used for the aridity mapping of Z.R.B.

2. STUDY AREA

The Zayandeh-Roud Basin (Z.R.B.) is located in the central part of Iran with a longitude of 52° 1' to 52° 7' E and a latitude of 32° 36' to 32° 40' N (Figure 1). The maximum precipitation in the basin occurs during winter in January and February, while the minimum is during summer in July and August. The average annual precipitation is 105.84 mm, the average annual temperature is 14.9°C and the average evaporation is 2,219.3 mm. (Khodagholi, 2006). The most important factors during a drought in the basin are geographical location, non-normative exploitation of the surface mineral of gypsum, non-normative exploitation of land, reduced entrance of runoff from upstream regions, a sharp drop in the groundwater level, winds, and storms laden with chalk, dust and suspended particles, low precipitation, and high evaporation.

In this region, precipitation starts when high-pressure-air massif on the Iran plateau moves to lower latitudes. In Z.R.B., rain starts in the middle of October and continues into May, while the source of rain is the Mediterranean cyclone. However, in some areas, regional cumulus clouds cause squall in late spring and summer; in the mountainous areas, this causes rain. Data show that rainfall varies greatly from area to area so that some areas receive 20 times more rain than do other regions. The average annual precipitation in the low land (around GAV KHOONI marsh) is about 72 mm, while it is more than 1,550 mm in high altitudes and western heights. The average annual precipitation is about 2,095 mm. The maximum annual precipitation recorded is about 2,375 mm at CHELGERD station in the northwest and the minimum annual rainfall is about 25 mm in the east in MOORCHEH KH ORT.



Figure1. Location of Z.R.B. in Iran (Maryam M. B., Khairulmaini O S, (2013)

3. ARIDITY MEASURING MODELS

For the aridity index mapping of Z.R.B. three aridity-indexes, namely De Martonne’s aridity index, Thornthwait’s precipitation effectiveness index, and UNESCO aridity index, were used. Each index is given below:

De Martonne’s Aridity Index

This index can be expressed as

$$AI = [P / (T + 10) + 12p / (t + 10)] / 2$$

where:

P is the mean annual precipitation in mm,

T is the mean annual temperature in C° ,

P the precipitation of the driest month in mm, and

t the mean temperature of the driest month in C°

According the AI value, De Martonne (1926) classified the climate into six types, namely, arid, semi-arid, dry sub-humid, moist sub-humid, humid, and very humid. Classification of dryness based on De Martonne’s aridity index is given in Table 1.

Thornthwaite’s Precipitation Effectiveness

Thornthwaite (1931) defined precipitation effectiveness index (PE), which is calculated from monthly values of precipitation and temperature. The index is given as:

$$PE Index = \sum_{i=1}^{n=12} 115 * (P / (T - 10))^{10/9}$$

Where, P = monthly precipitation in inches;

T = temperature in F° ; and

N = months =12.

The classification of climate regions is based on Thornthwaite’s precipitation effectiveness index, as shown in table 2.

UNESCO aridity index

The UNESCO (1979) proposed a method for aridity mapping from the ratio of precipitation (P) to potential evapotranspiration (PET), i.e.,

$$AI = P/PET$$

where PET is calculated by Penman’s formula.

Based on the AI values, five climate regions of aridity are proposed, as shown in Table 3.

4. MAPPING ARIDITY OF ZAYANDEH ROOD BASIN

The aridity mapping of Z.R. B. is carried out from the climate data of 11 hydrometeorological stations situated in and around the area. The data obtained from meteorological organization of Iran were used in this paper. Locations of climate stations are shown in figure 2. The aridity mapping is carried out by incorporating the aridity measuring models in a geographical information system. Procedures of mapping using De Martonne's, Thornthwait and UNESCO methods are shown in Figures (3), (4) and (5).

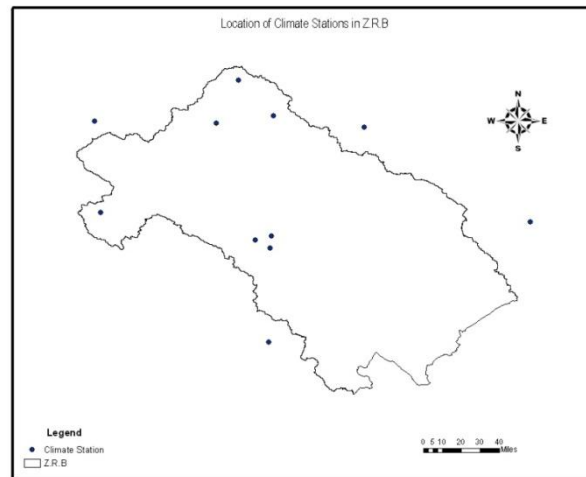


Figure2. Locations of Climate Stations in Z.R.B

De Martonne's aridity modeling carried out by calculating the mean annual precipitation and temperature, and the driest month of the year was identified from monthly mean climate data. Thematic maps of mean values of annual precipitation and temperature, and precipitation and temperature of the driest month were obtained from the average of sixty-years of climatic data of 11 stations using the kriging method. The thematic maps were integrated by using the index equation. Finally, the AI values were classified into different layers following the ranges given in Table 1 to prepare De Martonne's aridity index map of Z.R.B., which is shown in Figure 3.

Table1. Classification of dryness based on De Martonne's Aridity Index (De Martonne, E., 1926).

Climate Class	AI Value
Arid	≤ 5
Semi-arid	5-12
Dry Sub-Humid	12-20
Moist sub-Humid	20-30
Humid	30-60
Wet	≥ 60

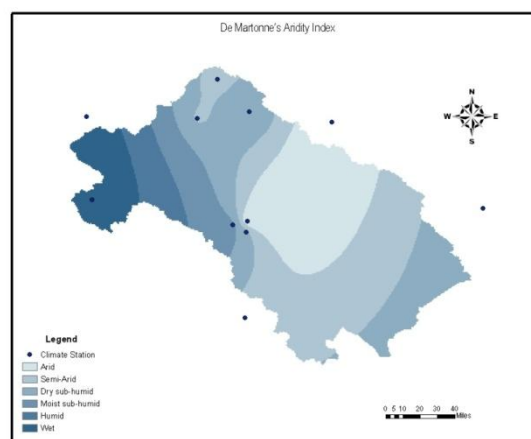


Figure3. Dryness map of Z.R.B. carried out by using De Martonne index

For Thornthwait’s aridity modeling, first the PE index values for all the 11 stations were calculated. The PE values were krigged and classified following the ranges given in Table 2 to prepare the thematic map of Thornthwait’s precipitation effectiveness index of Z.R.B., which is shown in Figure 4.

Table2. Classification of the dryness based on Thornthwait’s Aridity Index (Thornthwaite, C.W., 1931)

Climate Class	AI Value
Arid	Greater than 128
Semi-arid	100-127
Dry Sub-Humid	64-99
Moist sub-Humid	32-63
Humid	16-31
Wet	Less than 16

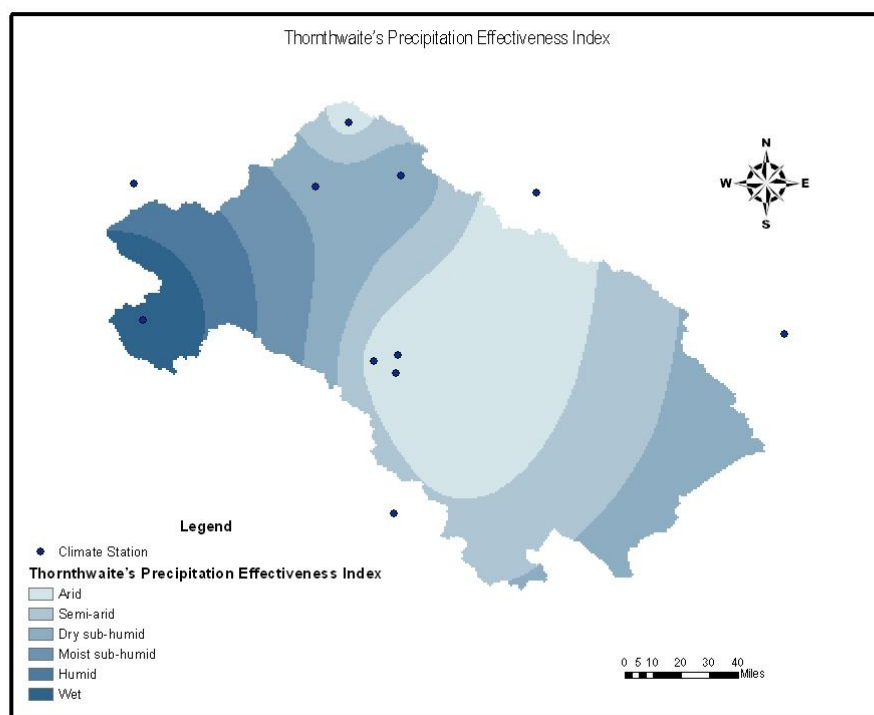


Figure4. Dryness map of Z.R.B. carried out by Thornthwait’s index

In the UNESCO aridity index modeling, first the potential evaptranspiration (PET) was calculated at 11 climate stations using Penman’s formula. The PET and precipitation values were used to make the thematic maps of PET and precipitation using the krigging method. Finally, the maps were integrated and the generated aridity index values were classified using the ranges given in Table 3 to develop the UNESCO aridity index map of Z.R.B. (shown in Figure 5).

Table3. Classification of dryness based on UNESCO’s Aridity Index (UNESCO, 1979)

Climate Class	AI Value
Hyper Arid	≤ 0.03
Arid	0.03-0.2
Semi-arid	0.2-0.5
Dry sub-humid	0.5-0.65
Humid	> 0.65

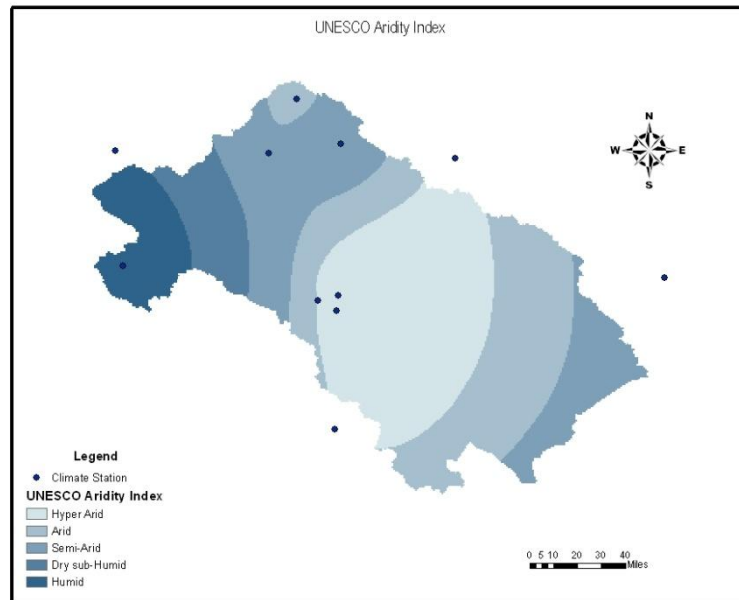


Figure5. Dryness map of Z.R.B. carried out by UNESCO index

5. RESULTS AND DISCUSSION

The aridity index maps were prepared using De Martonne's, Thornthwait's and UNESCO indexes that occur on arid, semi-arid or dry sub-humid zones in Zayandeh Rood basin. Most of the area of Z.R.B. belongs to the dryness class except for some parts on the northwestern side which belongs to the wet class. The statistics of aridity index values obtained by using the three models are given in Table 4. The least AI values obtained by De Martonne's, Thornthwait's, and UNESCO models were 20.89, 64.04 and 0.98, respectively, in the central-western and northwestern parts of Zayandeh Rood basin. As the AI values in the region were close to the AI value of the dry zone, the climate of these regions of Z.R.B. can be said very close to dry. The total annual evapotranspiration in this region was also lower than or equal to annual rainfall. The region which is very close to the dry sub-humid climate is shaded on the aridity maps.

Based on the maps, climate in the central eastern, southeastern, northeastern and north side of the area was close to dry climate. However, the climate of the area was inching towards more dryness. Rapid population growth and human activities with land use in the region have been degrading the biophysical environment and consequently changing the climate of the region. Rainfall has decreased and the high temperature between the hot daytime and cooler late night has increased. Since the area has low rainfall, extraction of groundwater as the main source has increased. It has caused the successive lowering of the groundwater table of the region, which has consequently been greatly affecting the environmental quality and land subsidence.

Sustainable measures like micro-watershed management for the promotion of in situ moisture conservation should be taken in the region. Programs that have relevance to environmental and sustainable development of natural resources have to be expedited. Local people have to be educated and social awareness should be grown about deforestation and its environmental consequences (Shahid, et al, 2010).

Results show that the northwestern side of Z.R.B., which is close to ShahreKord, belongs to the wet climate. The mean annual rainfall in this region is three-times more than the mean annual evapotranspiration. The maximum AI values obtained in this side are 117.84, 139.2 and 23.49 by De Martonne, Thornthwait and UNSECO models, respectively.

Table 5 shows areas belonging to different AI ranges. The climate of 56.84 % to 77.3 % area of the Z.R.B has been identified by different aridity index models as near dry sub-humid, 7.88 % to 23.52 % area as moist sub-humid, 5.16 % to 6.6 % area as humid, and 4.94 % to 7.74 % area as wet. Therefore, it can be said that the climate of the area is mostly dry type, except for a few areas in the northwest of the area.

Table4. Aridity index values obtained by different models

	AI value by different models		
	De Martonne	Thornthwait	UNESCO
Minimum	46.95	40	6.1
Maximum	117.84	139.2	23.49
Mean	66.19	66.05	10.055
Standard Deviation	17.29	20.88	3.74

Table5. Percentages of area belonging to different climate zones as demarcated by models

Climate	Percentage of area by different models		
	De Martonne	Thornthwait	UNESCO
Near Dry Sub-Humid	73.81	77.3	56.84
Moist Sub-Humid	7.88	6.73	23.52
Humid	5.16	5.57	6.6
Wet	7.74	4.94	7.67

6. CONCLUSIONS

Aridity index mapping of the dryness of Z.R.B. has been done by using a geographical information system. Three well-known models are used. Results show that the climate of Z.R.B. is mostly dry. However, some parts on the eastern side of the area have dry climate close to that of dry zone of Iran. Desertification and other environmentally harmful activities in the region might cause a noticeable change and consequent increase of aridity in the region. If the aridity of the area increases, it might cause harm to the environment and ecosystem in the arid region. It is therefore essential to manage the basin in a sustainable, planned manner.

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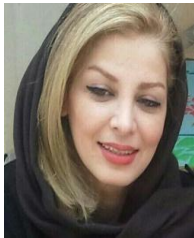


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