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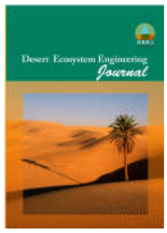

Developing a Framework for Ecosystem Health Assessment in Arid Lands based on the CVOR Model: A Case Study of Abarkuh, Iran

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Abstract

Being highly vulnerable, arid ecosystems require conscious management worldwide. Therefore, as health assessment studies on such ecosystems can help landscape planners develop effective strategies in this regard, the current study sought to localize an ecosystem health assessment model for arid lands using the CVOR model to assess the health of Abarkuh city, an arid (desert) region located in the central part of the Iranian plateau. To this end, a set of criteria reflecting the ecological conditions of the study area in particular and arid lands, in general, was selected, including C (Water and wind erosion, quantity and quality of water resources), V (the amount of primary production under natural conditions and soil organic carbon), O (landscape heterogeneity and connectivity), R (vegetation percentage, changes in underground water level, and soil salinity). The results of the study revealed that the quantity and quality of groundwater, water erosion, and wind erosion were of greatest importance in the health status of arid ecosystems. On the other hand, the result of the ecosystem health assessment in the study area specifically showed that the development of land uses in the area had posed great challenges to its ecosystem's health conditions, with 48% and 9% of the region's area being marked with a relatively unhealthy condition and unhealthy condition, respectively. Moreover, the status of land use in the region indicated that many gardens and agricultural lands had been left under the influence of such an unhealthy ecosystem, aggravating the health of the region. Therefore, the region has turned into the origin of dust phenomenon at the local level.

Keywords: Ecosystems Condition, Ecosystems Vigor, Landscape Structure, Resiliency, Vulnerability.

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1. Introduction

Considering biophysical limitations and inappropriate human exploitation, arid areas can be regarded as fragile ecosystems worldwide, where climate change, excessive exploitation of natural resources, and the process of industrialization have placed considerable pressure on the environment. Consequently, a number of ecological, economic, and social problems have been caused, including a significant decrease in water resources and their quality, soil erosion, desertification, salinization, abandonment of agricultural lands, unemployment in villages, and migration to metropolises. Therefore, it could be argued that an increasing number of problems and crises are being caused by the health of the arid ecosystems of the world, especially in Iran (Kalele et al., 2021; Rafiei-Sardooi et al., 2022).

During recent decades, concerns regarding the health of ecosystems have gradually increased worldwide due to environmental destruction and various types of pollution, highlighting the significance of assessing the health of all kinds of ecosystems. In this regard, many studies have already been conducted on ecological health at the scale of agricultural lands, lakes and rivers, bays and wetlands, watersheds, forests, and pastures (Su et al., 2010).

The idea of ecosystem health was first introduced by D.J. Rapport in 1989 (Abbaszadeh Tehrani et al., 2022; Burkhard et al., 2008; Chen, 2022; He et al., 2022; Jørgensen et al., 2016; Lu et al., 2015; Ma et al., 2022; Wang et al., 2020; Wu et al., 2021), who considered it as parallel to human health (Lu et al., 2015). According to his opinion, “Ecosystem Health” is actually the ability of the ecosystem to preserve and maintain its structure, and to self-regulate and restore its power after the occurrence of tensions over time (Jørgensen et al., 2016). Moreover, Costanza (2012) has defined a healthy ecosystem as a stress-free ecological complex that can maintain its structure and remain resilient to stresses and disturbances. Therefore, it appears that the health of the ecosystem is closely related to its stability and resilience, which can be determined by comprehensive, dynamic, and hierarchical measurement of three indicators, including **vigor**, **organization**, and **resilience** (the VOR model) (Costanza, 2012). In other words, The VOR model is a comprehensive theoretical model with a high potential to represent complex issues related to ecosystem health. Other indicators regarding ecosystem health monitoring include Reliability, Resilience, and Vulnerability (RRV), Pressure, State, Response (PSR) model, the Holistic Ecosystem Health Indicator (HEHI), and Exergy Index (Burkhard et al., 2008).

Several other studies have also been carried out on ecosystem health. For instance, Wu et al (2019) assessed the health of the Xilinhot pasture around a mining area at the scale of the landscape using the CVORE model, adding the index of ecosystem services and status to the VOR model (Wu et al., 2019). Furthermore, Wang et al. (2020) assessed the health of “the World Natural Heritage of Bayanbulak” (Wang et al., 2020) using the VORS framework that measures the ability of an ecosystem to provide services to humans. Das et al investigated the dynamics of ecosystem health in Kolkata metropolitan, India from 2000 to 2019 using the VOE model (Das et al., 2021).

Also, Malik et al. assessed the ecosystem health of Abha City in Saudi Arabia using a combination of the fuzzy model and VOR (Mallick et al., 2021). On the other hand, Wu et al. examined the effects of urbanization on ecosystem health in the Beijing-Tianjin-Hebei Region, adding ecosystem service value (ESV) to the VOR model (Wu et al., 2021). Moreover, Xie et al. measured the relationship between urban land use efficiency and ecosystem health in China (Xie et al., 2021), and Yashangjiang et al. assessed the ecosystem health in Central Asia using the VOE model at multi-spatial and temporal scales (Yushanjiang et al., 2021).

Although the reviews in this research showed that the VOR framework has been widely accepted among scientists and used in regional assessments (Li et al., 2022; Ren et al., 2022; Wu et al., 2021), the assessment of ecosystem health in arid and semi-arid lands such as the central plateau of Iran has rarely been the subject of academic studies, and such ecosystems have not been systematically investigated in terms of their health status (Yushanjiang et al., 2021). Therefore, the present study developed a framework for assessing ecosystem health in arid lands, which was then tested in an area called Abarkuh in the central plateau of Iran to ensure its effectiveness.

Therefore, localizing the VOR model based on the conditions of arid and semi-arid regions could be one of the goals of the current study which sought to select those criteria that represent the ecological conditions of arid lands in general and those of the study area in particular. Another goal of this research was to set suitable protection policies and help manage arid and desert regions. It should be noted that the study area was selected as the case for the current research because it comprises more than fifteen villages in the vast deserts of central Iran, and it can be considered a clear example of the rural areas under development pressure in dry lands in the central plateau of Iran.

2. Materials and Method

2.1. The Study Area

Located in Yazd province, Iran, the study area, that is, Abarkuh city, Bahman district (Figure 1), possesses an area of 69887 hectares, whose average height is 1558.46 meters above sea level (Abkhan Consulting Engineers, 2015). The area has an arid climate where the precipitation rate is extremely low (0 mm in most months of the year) and rarely exceeds 20 mm in rainy seasons. Moreover, the scarce water resources of the region are limited to underground water (with a very shallow depth in most parts of the area). It should be noted that the current land uses in the region include agricultural, garden, barren, abandoned, man-made structures, water and soil protection structures, hand-planted forests, and desert pastures (Abkhan Consulting Engineers, 2015).

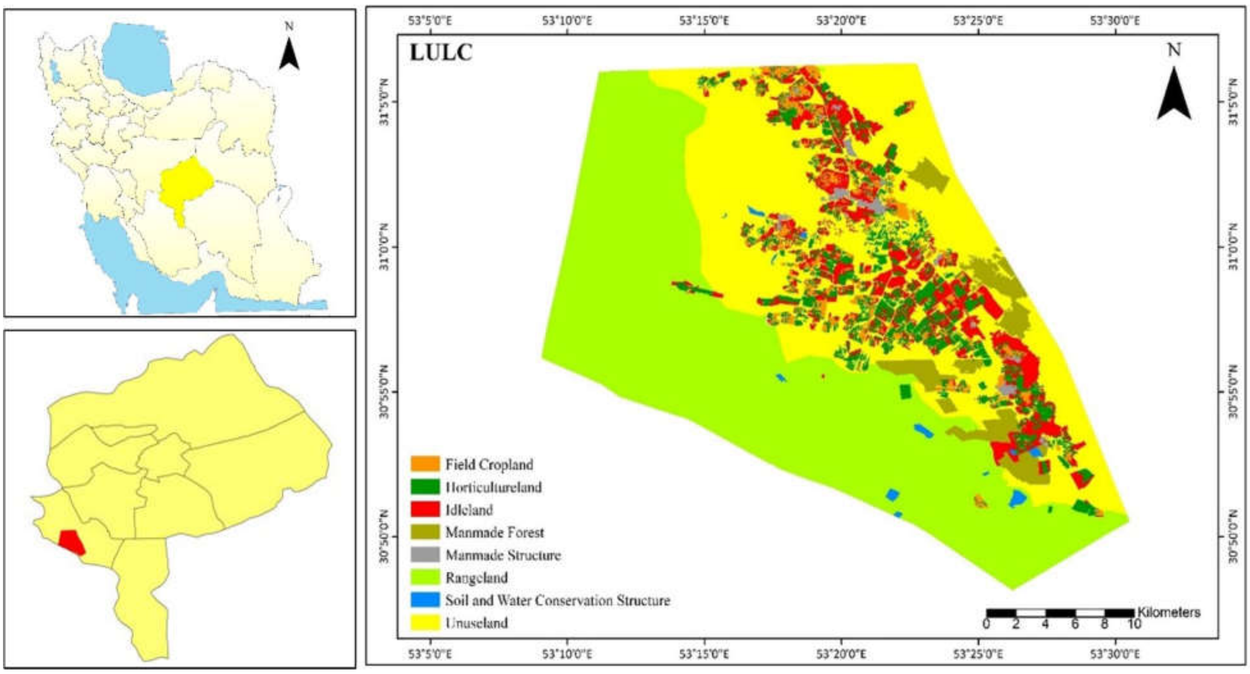

Figure (1): Location and Land Use Map of Abarkouh City, Yazd Province, Iran

2.2. Data

This study used satellite images to prepare the base map and analyze the landscape organization. In fact, environmental planners use tools such as geographic information systems (GIS) and remote sensing (RS) to show the changes caused by disturbances in the landscape, considering the fact that remote sensing provides a comprehensive, stratified, and rapid tool to understand the dynamic changes, interactions, and interrelationships between the lithosphere, atmosphere, hydrosphere, and biosphere. Therefore, the land cover map for this study was prepared in ERDAS IMAGINE 2014 using the Landsat satellite images obtained from the United States Geological Survey (USGS) database with a spatial resolution of 30 meters and Google Earth images with a spatial resolution of 1 meter.

Also, the basic data for calculating the criteria including (Water and wind erosion, Quantity and quality of water resources, Soil organic carbon, vegetation percentage, changes in underground water level, and soil salinity) have been calculated based on the extraction of statistical data and the estimation of changes during the study period.

2.3. Method

2.3.1. Ecosystem Health Assessment

In this study, the ecosystem health assessment is based on the expanded version of the VOR model (Costanza, 2012; Rapport et al., 1998) which was developed based on the model presented by Zhenhua Wu (Wu et al., 2019). Accordingly, the "Condition" subsection was added to the main model, and the corresponding calculations were performed (Burkhard et al., 2008; Costanza, 2012; Das et al., 2020; Das et al., 2021; Ekumah et al., 2020; He et al., 2019; Kang et al., 2018; Li et al., 2013; Liu et al., 2022; Lu et al., 2015; Peng et al., 2017; Rapport et al., 1998; Su et al., 2010; H. Wang et al., 2020; Z. Wang et al., 2020; Wu et al., 2021; Wu et al., 2019; Xiao et al., 2019; Yan et al., 2016; Yang et al., 2020). Finally, quantitative (numerical) values of the study area's ecosystem health were calculated using Equation 1:

1: $EH = \sqrt[4]{C.V.O.R}$ (Wu et al., 2019)

where "EH" stands for the ecosystem's health, "C" shows the ecosystem condition, "V" represents the ecosystem's vigor, "O" is the ecosystem's structure, and "R" shows the ecosystem's resilience. The method for calculating each component via effective criteria is as follows. Moreover, Figure 2 shows the research process.

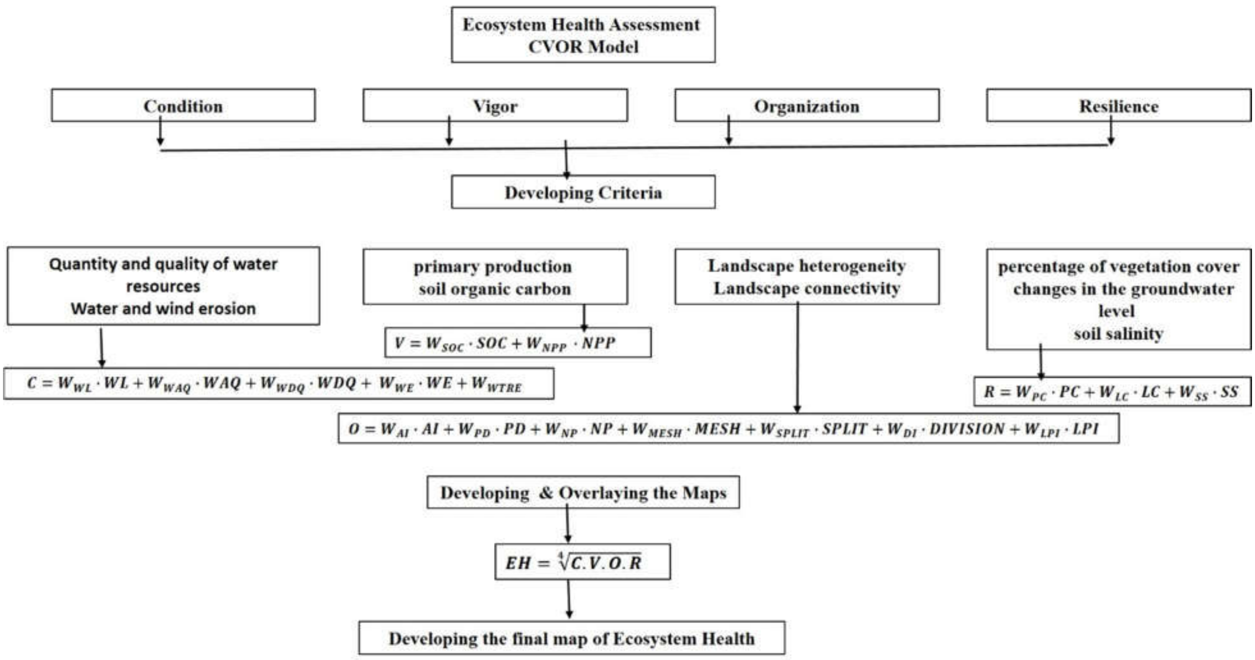

Figure (2): The Research Process

2.3.2. Proportionate metrics to determine the "Ecosystem's Conditions" in drylands

One of the key challenges in assessing the conditions of an ecosystem is to identify the most appropriate metrics concerning its type in such a way as to reveal the essential aspects of a particular ecosystem's quality. In general, the criteria should be available and related to the conditions and status of an ecosystem, reflecting human activities while being simple, reliable, and replicable in other regions. Moreover, it is necessary to demonstrate the biophysical characteristics of the ecosystem as the basis of ecosystem services (Czúcz et al., 2021). The Condition can be considered as a criterion that is formed by a combination of different factors in an ecosystem, including atmospheric and terrestrial factors (Wu et al., 2019).

2.3.2.1.Water and Wind Erosion

Soil plays an important role in maintaining and managing degraded and arid ecosystems. Therefore, wind erosion and water erosion were measured as two main factors in desertification and land degradation. To this end, first, the map of the geomorphological facies of the region was prepared to determine the intensity of water erosion. Furthermore, the base map of geomorphological facies and the IRIFR model were used to determine the intensity of wind erosion (Ekhtesasi and Ahmadi, 2005). It should be noted that the RPSIAC (RCS, 1998) is an experimental model approved by the Natural Resources and Watershed Management Organization for studies conducted on Iranian watersheds.

2.3.2.2.Quantity and quality of water resources

Considering the significance of the quantity and quality of water resources in arid lands and their essential role in the ecological, economic, and social aspects of a region, the quantity and quality of water resources in the study area was assessed in terms of irrigation water quality (to be used for agricultural purposes), drinking water quality, and underground water level. To this end, the standard method of classifying the quality of underground water in Iran ($IRWQI_{GC}$) was used to check the quality of water for drinking purposes in terms of electrical conductivity (EC), sodium absorption ratio (SAR), and acidity (pH).

Accordingly, the water quality was classified as very good, good, relatively good, average, bad, and very bad. Moreover, this study used the FAO classification system to determine the quality of water for agricultural purposes in terms of electrical conductivity (EC), dissolved solids (TDS), sodium adsorption ratio (SAR), sodium (Na), chloride (Cl), bicarbonate (HCO3), and acidity (pH). It should be noted that the FAO classification system has three classes, including no restrictions, moderate restrictions, and severe restrictions, which were marked 1 to 3 in the current study to quantify the results.

2.3.2.3.The equation for calculating "Ecosystem's Condition"

Equations 2 and 3 were used to calculate the **"Ecosystem Condition"** as follows.

Equation 2:

$$C = W_{WL} \cdot WL + W_{WAQ} \cdot WAQ + W_{WDQ} \cdot WDQ + W_{WE} \cdot WE + W_{WTRE}$$ (Wu et al., 2019)

Equation 3:

$$W_{WL} + W_{WAQ} + W_{WDQ} + W_{WE} + W_{WTRE} = 1$$ (Wu et al., 2019)

where C stands for the **"Ecosystem's Condition"**, WL shows the groundwater level in the region, WAQ is the quality of irrigation water, WDQ represents the quality of drinking water, WE stands for the amount of wind erosion, RE shows the amount of water erosion, and W_{WTRE}, W_{WE}, W_{WDQ}, W_{WAQ}, W_{WL} are the weighting coefficients of their criteria.

The results suggested that wind erosion, water erosion, underground water level, drinking water quality, and irrigation water quality were the most effective measurements for the "Ecosystem's Condition" of the study area, with their rate being 53%, 20%, 10%, 9%, and 8%, respectively. It should be noted that since such criteria represent the effect or unfavorable conditions on the region, all of them were considered negative.

2.3.3. Proportionate metrics to determine the "Ecosystem's Vigor" in drylands

The "Ecosystem's Vigor" in ecological systems is measured through criteria such as the total or effective amount of primary material production, metabolism, and energy stabilization (Costanza & Mageau, 1999; Das et al., 2021; Ge et al., 2022; Pan et al., 2020; Peng et al., 2017; Z. Wang et al., 2020; Wu et al., 2019), which can be measured via parameters related to plant products (Costanza, 2012; Kang et al., 2018; Mallick et al., 2021; Wu et al., 2021; Yushanjiang et al., 2021). This study proposed the amount of primary production in natural conditions and soil organic carbon as two criteria for assessing the "Ecosystem's Vigor" in arid ecosystems. Composed of decomposed plant, animal matter, and microorganisms in the soil (Chan, 2008), soil organic carbon is a carbon in the soil in an organic form that playing a significant role in soil fertility. Moreover, it is an important index for evaluating soil quality from biological, chemical, and physical fertility perspectives (Ramesh et al., 2019).

2.3.3.1. The method for estimating the amount of plant production in the Study Area

The current study used regional observations and field harvesting to measure the amount of plant production in the study area. On the other hand, the percentage of vegetation was measured via plotting. Moreover, the frequency and percentage of the canopy were determined and its map was prepared.

2.3.3.2. The method for estimating the percentage of organic carbon in the soil

To determine the percentage of organic carbon in the soil, 33 soil profiles were dug and sampled during field studies. The samples were then transferred to the laboratory and analyzed. Finally, the data zoning was performed using the kriging interpolation method.

2.3.3.3. The equation for calculating the "Ecosystem's Vigor"

Equations 4 and 5 were used to calculate the "Ecosystem's Vigor".

Equation 4: $V = W_{SOC} \cdot SOC + W_{NPP} \cdot NPP$ (Yushanjiang et al., 2021)

Equation 5: $W_{SOC} + W_{NPP} = 1$ (Wu et al., 2019)

where V stands for Vigor, SOC shows the amount of organic carbon in the soil, NPP represents primary production, and WSOC and WNPP are the weight of organic carbon in the soil and the weight of primary production, respectively.

In general, as the amount of production was not significant in the study area, it was not considered as a component affecting vigor. On the other hand, due to the annual manual addition of animal manure to gardens and agricultural lands, the vigor is highly dependent on the amount of carbon in the soil.

2.3.4 Proportionate Metrics to Determine the "Organization" in Drylands

The Organization can be evaluated based on the two main criteria of landscape structure, including heterogeneity and connectivity (Chang et al., 2021; Kang et al., 2018; Peng et al., 2017; H. Wang et al., 2020; Wu et al., 2021; Wu et al., 2019; Xiao et al., 2019; Yushanjiang et al., 2021). In this study, the heterogeneity and connectivity of the landscape were measured based on landscape metrics.

2.3.4.1. Landscape Metrics

The metrics have been used to measure the landscape structure (47-50). In this study, land landscape metrics, including AI, PD, MESH, SPLIT, DIVISION, CA, LPI, and NP, were used to measure the composition and configuration of the landscape in the study area. The metrics were calculated in FRAGSTATS software at class and landscape scales. Table 1 shows the specifications of the landscape metrics.

Table (1): Landscape Metrics

Landscape Metrics	Abbreviations	Unit	Variation Range
Aggregation Index	AI	percentage	0≤AI<100
Patch Density	PD	meters in 100 hectares	PD>0
Effective Mesh Size	MESH	hectares	Number of cells ≥MESH≥ total area
Splitting Index	SPLIT	No units	≥SPLIT≥1
Landscape Division Index	DIVISION	percentage	0≤DIVISION<1
Core Area	CA	hectares	0≥CA
Largest Patch Index	LPI	percentage	0≤LPI<100
Number of Patches	NP	No units	1≥NP

2.3.4.2. The equation for calculating the "Organization"

Equations 6 and 7 were used to calculate the Organization.

Equation 6:

$O = W_{AI} \cdot AI + W_{PD} \cdot PD + W_{NP} \cdot NP + W_{MESH} \cdot MESH + W_{SPLIT} \cdot SPLIT + W_{DI} \cdot DIVISION + W_{LPI} \cdot LPI$ (Peng et al., 2017; Wu et al., 2019; Xie et al., 2022)

Equation 7:

$W_{AI} + W_{PD} + W_{NP} + W_{MESH} + W_{SPLIT} + W_{DI} + W_{LPI} = 1$ (Wu et al., 2019)

In the above equations, AI stands for Aggregation Index, PD stands for Patch Density, NP is the Number of Patches, MESH represents separation degree index, SPLIT shows the splitting index, DIVISION represents Landscape Division Index, LPI stands for the Largest Patch Index, and W_{MESH}, W_{NP}, W_{PD}, W_{AI}, W_{SPLIT}, W_{DI}, and W_{LPI} are the weight coefficients of each landscape structure metrics.

2.3.5. Proportionate metrics to determine the "Ecosystem's Resilience" in drylands

As a widely used interdisciplinary concept among scientists and experts in various fields, especially in the field of social and economic systems (Ferro-Azcona et al., 2019), ecological resilience was first introduced by Holling (1973). Accordingly, the resilience of a system refers to its ability to maintain the structure and response patterns of the system when a disturbance occurs. Moreover, it often refers to the description and explanation of the response of ecosystems to disturbances or other changes in the presence of environmental stimuli (Albrich et al., 2020). As resilience is influenced by factors such as climate, vegetation, biological areas, and human activities (Wu et al., 2021), the current study considered some criteria to show the factors affecting the vulnerability of arid ecosystems. In this regard, vegetation percentage, changes in underground water level, and soil salinity were considered as effective factors involved in the resilience of arid ecosystems in general and the study area in particular.

2.3.5.1. The equation for calculating the "Ecosystem's Resilience"

Equations 8 and 9 were used to calculate the Ecosystem's Resilience.

Equation 8:

$R = W_{PC} \cdot PC + W_{LC} \cdot LC + W_{SS} \cdot SS$ (Wu et al., 2019)

Equation 9:

$W_{PC} + W_{LC} + W_{SS} = 1$ (Wu et al., 2019)

Where PC represents the percentage of vegetation, LC shows the changes in the groundwater level (in a 15-year period), SS stands for soil salinity, and WPC, WLC, and WSS are the weight factors for each parameter.

The results showed that the underground water level change had the highest impact (70%) on the resilience index in the study area, followed by soil salinity (22%) and vegetation (3%).

2.3.6. Standardization and determination of the weighting coefficients of the criteria

Determining the weight of indices is crucially important in assessing the ecosystem health (Li et al., 2013), which is carried out through various methods (Abbaszadeh Tehrani et al., 2022; Ayers & Westcot, 1985; Costanza, 2012; Costanza & Mageau, 1999; Czúcz et al., 2021; Das et al., 2020; Ekumah et al., 2020; Ge et al., 2022; He et al., 2022; Li et al., 2022; Liu et al., 2022; Ma et al., 2022; Pan et al., 2020; Peng et al., 2017; Rapport et al., 1998; Ren et al., 2022; Wang et al., 2022; Z. Wang et al., 2020; Wu et al., 2019; Xie et al., 2021; Yang et al., 2020; Yushanjiang et al., 2021; Zhang et al., 2022), with entropy method being widely used in different studies. Therefore, the current study used the entropy method to determine the weight coefficients in two stages. In the first stage, all criteria were standardized based on equations 10 and 11, varying from 0 to 1.

Equation 10: Standardization of positive criteria

$PI = (pi-pi_{min})/(pi_{max}-pi_{min})$ (Das et al., 2020; Liu et al., 2022; Z. Wang et al., 2020; Wu et al., 2019)

Equation 11: Standardization of negative criteria

$NI= (ni_{max}-ni)/(ni_{max}-ni_{min})$ (Das et al., 2020; Liu et al., 2022; Z. Wang et al., 2020; Wu et al., 2019) Where PI and NI represent the standardized rates of each index, ni, and pi are the initial values of each index, and pi_{max}, pi_{min}, ni_{min}, and ni_{max} are the minimum and maximum initial indicators.

In the second stage, the entropy value of each index was calculated using the following equations (12 and 13).

Equation 12:

$E_i = -\sum_{X=1}^{m} B_{ix} \ln B_{ix} / \ln m$ (Wu et al., 2019)

Equation 13:

$B_{ix} = V_{ix} / \sum_{X=1}^{m} V_{ix}$ V_{ix} is X (X=1,2, 3,….m) object i (i=1,2,3,….n) (Wu et al., 2019)

Where V_{ix} stands for the numerical value of each cell.

Finally, equations 14 and 15 were used to calculate the entropy weight (W) and the weight of each evaluated index (w_i).

Equation 14:

$W= (w_i)\ 1\times n$, (Wu et al., 2019)

Equation 15:

$w_i= (1-E_i)/(n-\sum_{i=1}^{n} E_i)$ (Wu et al., 2019)

2.3.7. Overlay Mapping Method

The study area was gridded so that its ecological health status can be homogenized, integrated, and more easily calculated. Accordingly, each grid unit was divided into 231 x 231 meters, equivalent to approximately 5.34 hectares. The indices were then measured in each grid cell and the CVOR model was calculated for each cell. The results of the CVOR model were classified into five categories, including the healthy, relatively healthy, moderate, relatively unhealthy, and unhealthy classes. Finally, the results were re-entered into ArcGIS 10.8 software and the network and landscape health maps were prepared for each criterion.

3. Findings

3.1. Evaluation of "Ecosystem's Condition" in the Study Area

As mentioned in the method section, the condition component was evaluated based on five criteria, including ground water level, wind erosion, water erosion, drinking water quality, and irrigation water quality (to be used for agricultural purposes). Figure 3 shows the status of the Ecosystem's Condition in Abarkooh. Accordingly, based on the condition component, rangeland (45.3%) and water and soil conservation structures (0.4%) are relatively unhealthy in the study area. However, agricultural (field croplands) (3.2%), garden (horticultural lands) (6.4%), barren lands (32.0%), hand-planted (man-made) forests (3.7%), idle lands (8.2%), and man-made structures (0.8%) fell under the moderate class.

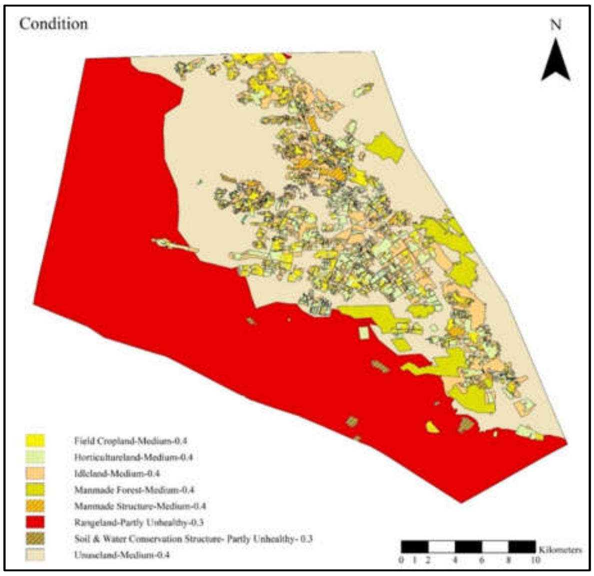

Figure (3): The Status of Ecosystem’s Condition in Abarkooh

3.2. Evaluation of “Ecosystem’s Vigor” in the Study Area

As mentioned in the method section, the vigor component in the study area was evaluated based on two criteria, that is, the amount of plant production and soil carbon. Figure 4 shows the status of the Ecosystem’s Vigor in Abarkooh. Accordingly, all land uses have average conditions in terms of health. However, soil and water protection structures, abandoned lands (idle lands), crops (croplands), and gardens (horticultural lands) have better conditions in this regard than other land uses.

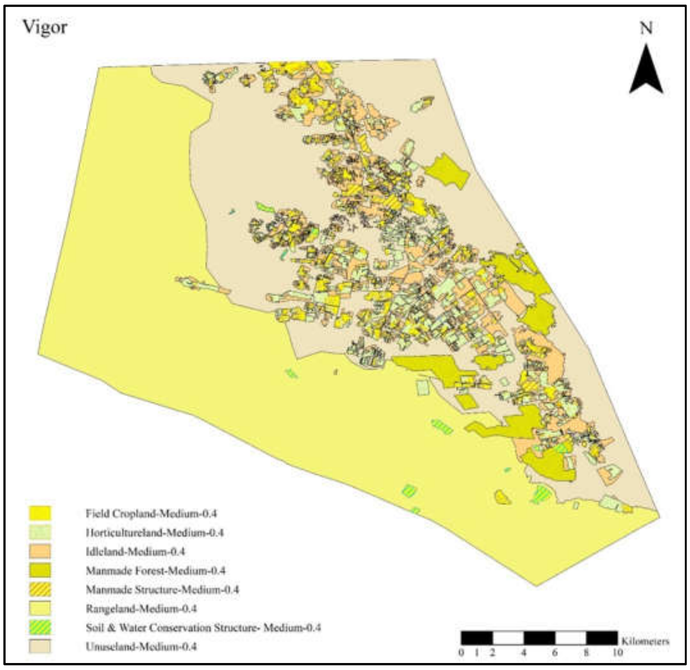

Figure (4): The status of the Ecosystem’s Vigor in Abarkooh

3.3. Evaluation of “Organization” in the Study Area

As mentioned in the method section, the Organization in the study area was evaluated in terms of eight metrics. Figure 5 shows the status of the Landscape structure in Abarkooh. It should be noted that due to the undesirability of existing land uses in the region (poor pastures, almost Monoculture agriculture, large areas of abandoned lands, the very high amount of soil harvesting and erosion in the fields, the loss of parts of the hand-planted forests, and the existence of only one plant species (*Haloxylon*) in such forests) AI, CA, LPI, and MESH metrics were included in a negative equation, and Division, Spilt, Pd, and NP metrics were embedded in a positive equation. As shown in map No. 5, all land uses are ranked moderate in terms of organization. However, pasture and barren land uses have better conditions than other uses.

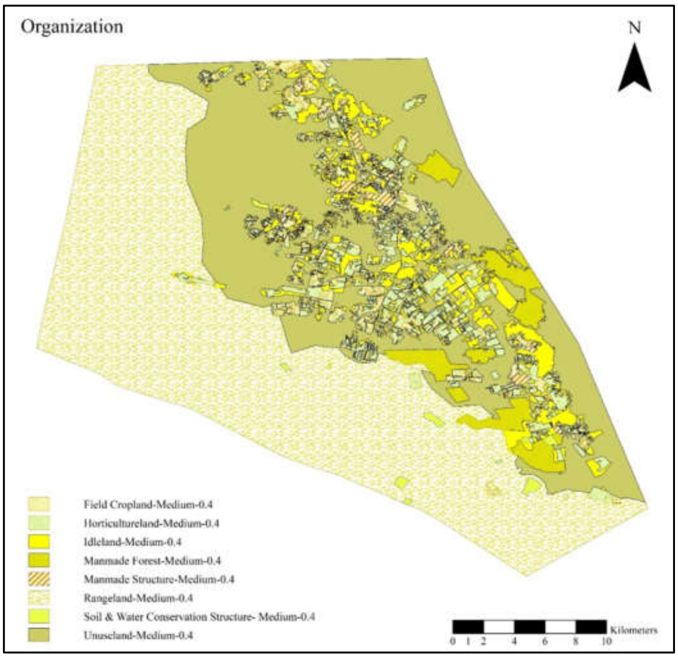

Figure (5): The Status of Landscape Organization in Abarkooh

3.4. Evaluation of "Ecosystem's Resilience" in the Study Area

Resilience components were calculated in terms of soil salinity, underground water level change, and vegetation percentage. Accordingly, soil salinity and underground water level changes were considered negative and vegetation percentage was considered positive according to their type and nature. Figure 6 shows the status of the Ecosystem's Resilience in Abarkooh. As shown in Figure 6, all land uses in the region have relatively unhealthy conditions in terms of resilience.

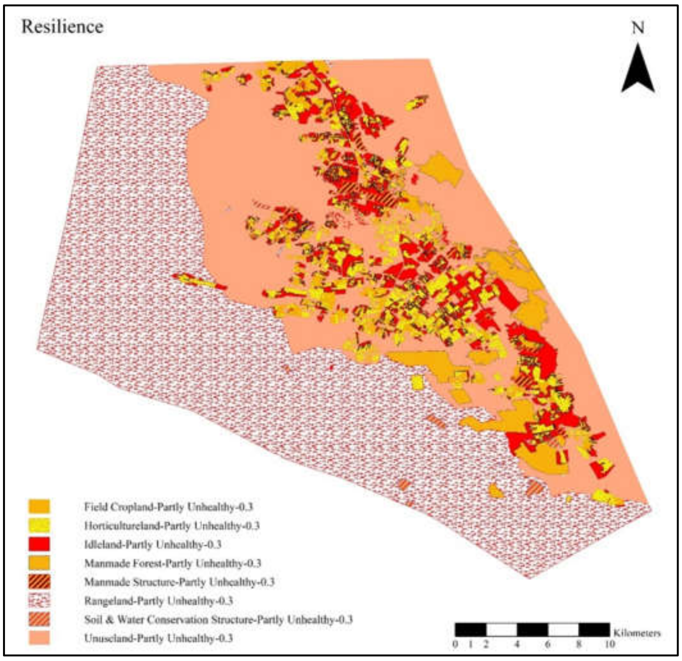

Figure (6): The Status of Ecosystem's Resilience in Abarkooh

3.5. Evaluation of "Ecosystem's Health" in the Study Area

The study area's ecosystem health map was prepared Based on the results obtained from the CVOR model. Figure 7 shows the status of Ecosystem Health in Abarkooh. Accordingly, the ecosystem health status of the agricultural, garden, and barren lands of the region was ranked as moderate (0.4). On the other hand, the abandoned lands and pastures in the western part of the region and man-made structures, water, soil protection structures, and hand-planted forests were categorized under the relatively unhealthy (0.3) class.

The point to consider is that there were no areas under healthly conditions in the region, with 60% of the area (equivalent to 40 thousand hectares) being in relatively unhealthy condition. According to the output of the ecosystem health assessment model, the area's gardens and agricultural lands have better conditions than barren lands. On the other hand, the unhealthiest status of the land uses is primarily related to human structures for water and soil protection, followed by pastures, hand-planted forests, and abandoned lands, respectively.

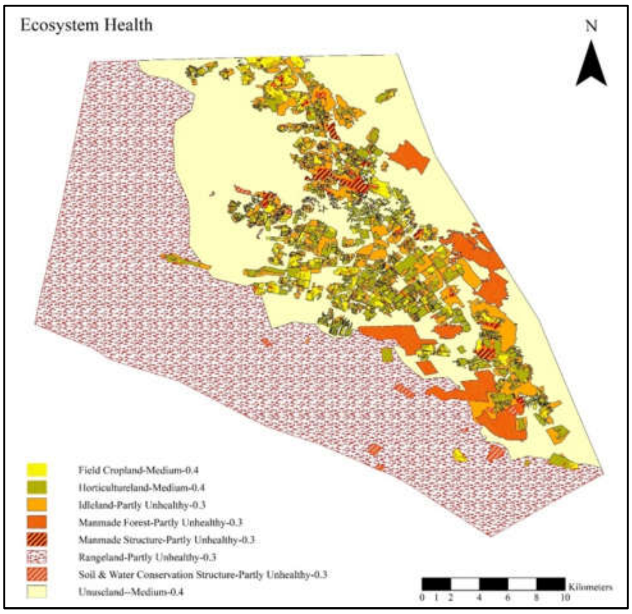

Figure (7): The Status of Ecosystem Health in Abarkooh

4. Discussion

Representing the overall status of an ecosystem in relation to environmental conditions and types of disturbances (Z. Wang et al., 2020), ecosystem health is a tool for measuring and evaluating the sustainability characteristics of an ecosystem (Peng et al., 2017). As mentioned in the method section, the basic model for ecosystem health assessment is the VOR model which is measured based on the three components of vigor, organization, and resilience. However, different studies have added other components to the model based on the type of ecosystem and regional conditions.
For instance, Wu et al (2019) (Wu et al., 2019) and Wang et al. (Z. Wang et al., 2020) used CVORE and VORS models to assess ecosystem health in natural ecosystems, respectively. Moreover, Das et al. (Das et al., 2021) and Malik et al. (Mallick et al., 2021) used the VOE and VOR models to evaluate urban ecosystem health, respectively. However, the results of the current study showed that the CVOR model was more suitable for evaluating the ecosystem health in arid lands, which are affected by natural stresses caused by drought and human disturbances.

Therefore, based on the conditions of the study area and its arid fragile ecosystem, the comprehensive CVOR model was used to assess the ecosystem's health. On the other hand, to evaluate each component, the required criteria were considered based on the type of arid and desert ecosystems. Therefore, the criteria selected in this study represented the conditions of arid and desert regions, exerting major effects on the ecological and social status of arid lands. The criteria included water erosion, wind erosion, water quantity, and quality, amount of primary production, soil carbon, heterogeneity and continuity of land surface structure, and soil salinity. Figure 8 shows the framework of ecosystem health assessment criteria in arid and desert areas.

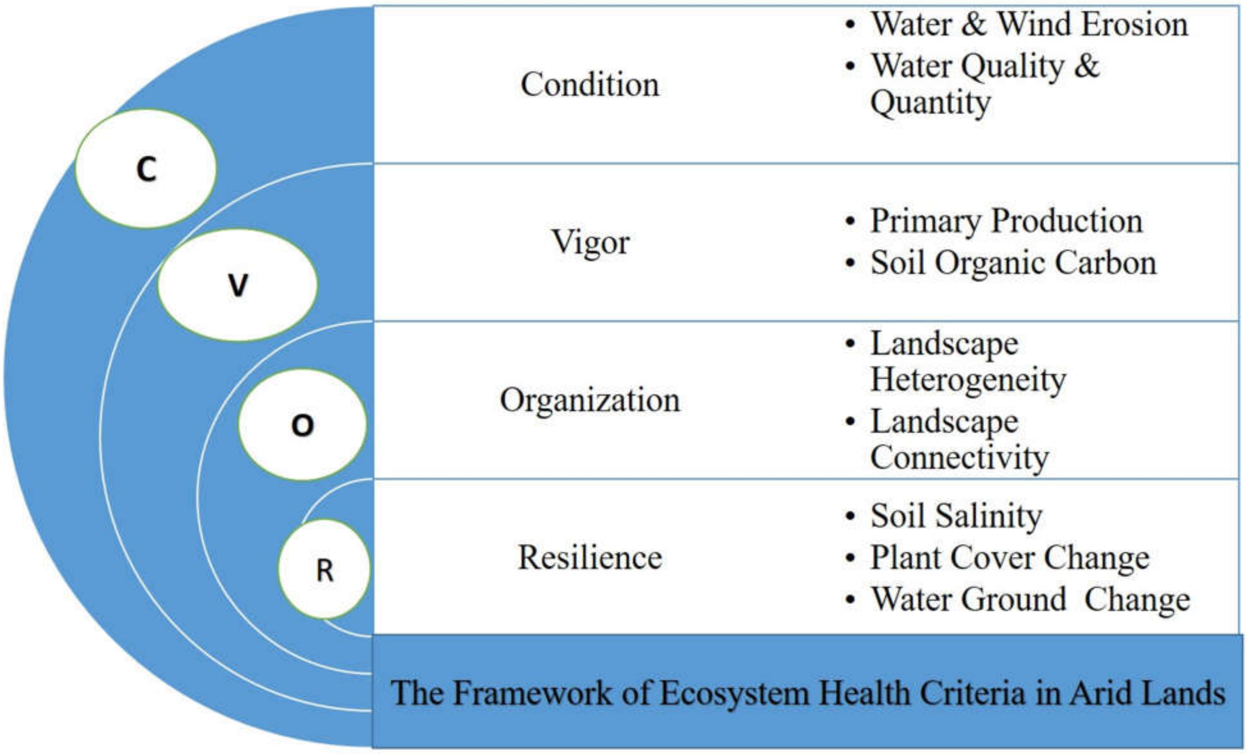

Figure (8): The framework of ecosystem health assessment criteria in arid areas

The review of the resources used in this research suggested that most of the studies conducted in the field of ecosystem health assessment were based on remote sensing data. However, the current study used extensive field studies, whose collected data were analyzed together with the data obtained from remote sensing, thus making the final results much more accurate. It should be noted that if such data were available for other periods, it would be possible to assess the health of the ecosystem over time.

Determining the CVOR model weight coefficients is another important point to consider in ecosystem health assessment, which exerts a considerable impact on the assessment results. In other words, as the influence of each parameter on ecosystem health differs in different regions and ecosystems, the conditions of the evaluated region must be examined locally to determine such coefficients (Yushanjiang et al., 2021). Therefore, the current study used the entropy method and the evaluation of local conditions to determine the weight of each criterion. Accordingly, it was found that water and wind erosion had the greatest influence on the condition of the study area, followed by underground water level changes.

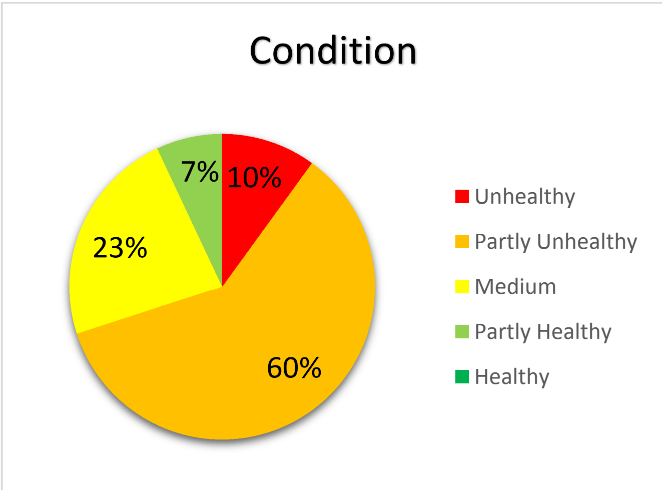

Figure (9): The Classification of the Health Condition Percentage in the Study Area

On the other hand, according to the climatic conditions of the study area, the amount of vegetation production exerted minimal effects on the vigor factor. However, unprincipled agriculture exerted a significant influence on the reduction of soil organic carbon and fertility in abandoned lands. Moreover, the results of the assessment of the condition component indicated that 60%, 23%, and 7% of the area had a relatively unhealthy, moderately healthy, and healthy conditions, respectively (Figure 9).

The results of the Vigor assessment showed that 38%, 35%, and 5% of the study area had relatively unhealthy, moderately healthy, and healthy Vigor, respectively (Figure 10).

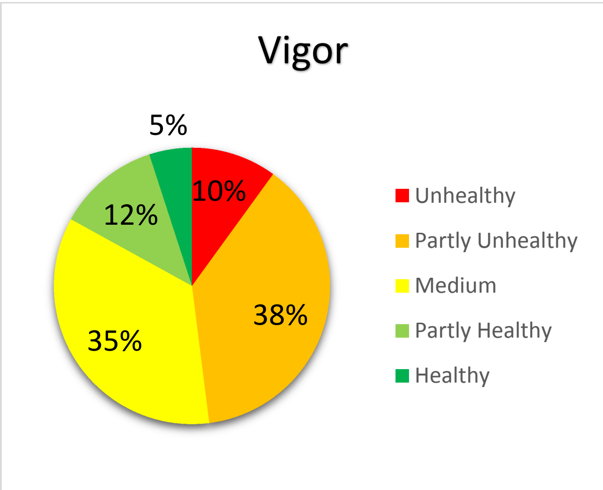

Figure (10): The Classification of The Vigor Health Percentage in the Study Area

The results of the Organization assessment indicated that 48%, 31%, and 13% of the study had a relatively unhealthy, moderately healthy, and healthy Organization, respectively (Figure 11).

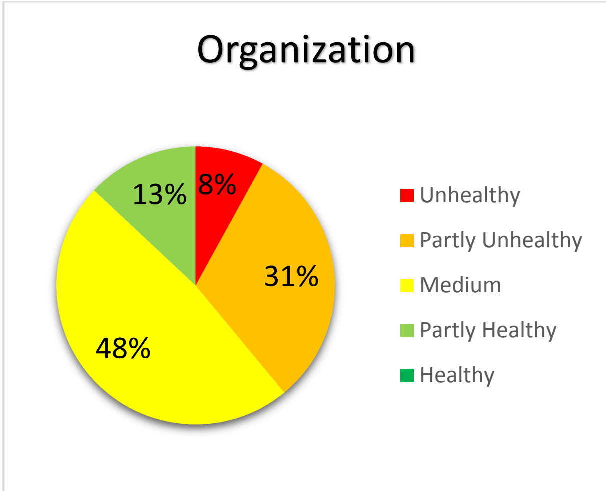

Figure (11): The Classification of Organization Health Percentage in the Study Area

The results of the resilience assessment showed that 45%, 41%, and 13% of the study were in unhealthy, relatively unhealthy, and relatively healthy conditions in terms of resilience, respectively. It was also found that there was no zone in the healthy resilience area (Figure 12).

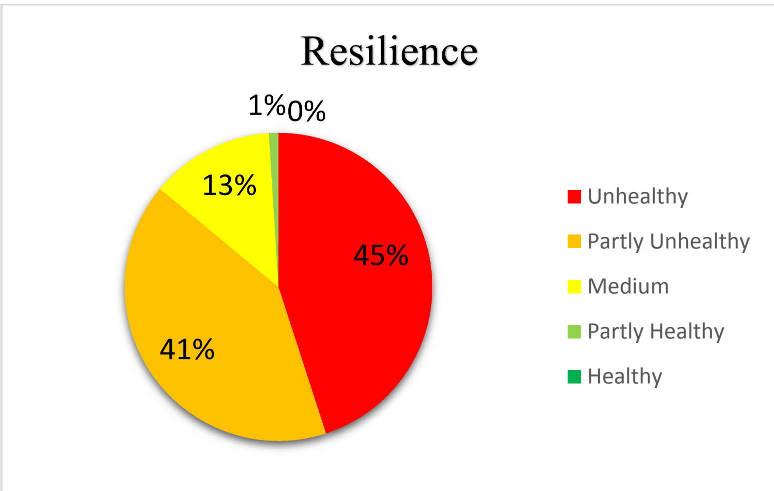

Figure (12): The Classification of Resilience Health Percentage in the Study Area

The results of the region's ecosystem health assessment indicated that 9%, 48%, and 43% of the study area fell in the unhealthy, relatively unhealthy, and moderately healthy categories, respectively. Moreover, no part of the study area was identified as being under healthy or relatively healthy conditions (Figure 13).

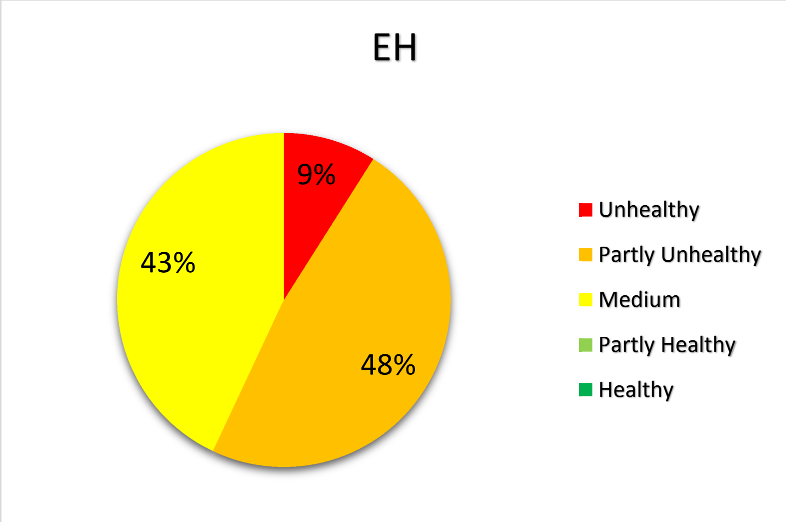

Figure (13): The Classification of Ecosystem Health Percentage in the Study Area

The results of the assessment of the health status of the study area's ecosystem suggested that the decrease in underground water level exerted the greatest influence on the health status of the area's ecosystem and that excessive water consumption in the agricultural sector led to the salinization of groundwater aquifers and a sharp decline in the level of underground water. On the other hand, the continued irrigation of agricultural lands with low water quality has caused soil salinization, making the farmers abandon such lands.

The findings of the study also indicated that the extent of sediment harvesting has increased in agricultural lands due to the abandonment of the lands and increased wind and water erosion, turning the study area into one of the centers of the dust phenomenon. Therefore, the issue has become a great concern for the relevant officials in recent years.

5. Conclusion

In recent years, the assessment of ecosystem health via the VOR model has attracted the attention of researchers. Although this method is still in its early stages, it can be used as an efficient method in environmental management. This study used the CVOR model to assess the ecosystem's health. The framework and criteria used in the study have been expanded according to the vulnerable conditions of arid ecosystems. However, to adopt this framework in different regions, it should be adjusted according to the ecological characteristics and land use of the region. One of the achievements of this research is that field measurements together with the use of such tools as RS and GIS can make the results of ecosystem health assessment more accurate. Nonetheless, many studies have merely used remote sensing data in assessing the ecosystem's health.

The results of the ecosystem health assessment in the current study revealed that arid lands were highly vulnerable to human development. In other words, development programs in arid ecosystems such as agricultural lands and gardens are not sustainable due to the continuous drop in underground water resources and the accumulation of large volumes of sediment under the influence of water and wind erosion, thus aggravating the ecological problems in arid and desert areas. Therefore, it could be argued that the decrease in underground water resources and the salinization of soil and water have led to the abandonment of gardens and agricultural lands in the study area, turning such lands into centers of dust.

In general, the findings of this study can help land managers and planners limit land use in arid ecosystems. Moreover, to improve the condition of underground water resources in arid lands, managers need to consider the conditions of the land and the erosion status, observe the principles of land preparation, and implement watershed management projects.

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