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# Development of a new model for health assessment in agroecosystems

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**Abstract** Healthy agroecosystems provide a range of ecosystem services, and the lack of information about the importance of their health degree leads to the unsustainability of these agroecosystems. To assess the health status of agroecosystems, a model was developed using spatial analysis–based procedures in Geographic Information System (GIS) media, surveyed data, and field monitoring at Gorgan University of Agricultural Sciences and Natural Resources. Initially, a survey-based study was conducted in 50 barley fields of Bandar-e-Torkaman County, north of Iran, during the 2016–2017 years. Then, the health index maps were provided by spatial analysis–based functions in GIS media. For accurate estimation of health status in barley agroecosystems, some meteorological variables were layered. Finally, the health status of the agroecosystems was determined based on six indices, including pesticides consumption rate, chemical fertilizers consumption rate, crop yield, and cultivar type, soil organic matter, and biodiversity indices. When all the layers overlaid, only 12% of the surveyed agroecosystems were located in the healthy class. The use of proper tillage methods, the appropriate weed control operations, the optimum consumption of high-quality pesticides, high soil organic matter, and grain yield > 2.6 ton ha$^{-1}$ were the main reasons for obtaining of health degree in these agroecosystems. In contrast, the consumption of low-quality pesticides, the use of inappropriate tillage tools and machinery, the little knowledge of the farmers about the optimum rates and consumption methods of pesticides and chemical fertilizers, and resistance of some weeds to herbicides were identified as the most essential reasons for non-health status in the most surveyed barley agroecosystems.

**Keywords** Agroecosystems · Biodiversity · Climatic variables · Cropping management · Geographic Information System (GIS) · Health status

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## Introduction

Ecosystem health is a concept that integrates environmental conditions with the impacts of anthropogenic activities to give information for sustainable use, and management of natural resources (Berrios et al., 2018). Because healthy ecosystems provide a range of ecosystem services, focusing on the design, protection, and restoration of healthy ecosystems provide sustainably of different ecosystem services (Costanza, 2012).

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There are many different definitions of agroecosystem health. "A healthy agroecosystem is economically viable, managed in a socially responsible manner, and environmentally sustainable for present and future generations" (Peterson et al., 2017). Research on agroecosystem health has gained increasing attention in recent years. There are different concepts of ecosystem health. Primarily, system organization, resilience, and vigor, as well as the absence of signs of ecosystem distress, are a necessity for a healthy ecosystem (Costanza, 1992). These concepts have been described by Costanza (1992). Then, other researchers such as Rapprot et al. (1998) accepted these concepts, and developed healthy ecosystem concepts (Yan et al., 2016). In general, ecosystem health describes the state in which all processes operating within an ecosystem are functioning at a level of optimum efficiency to maximize the strength and confidence of the system (Berrios et al., 2018).

There are several approaches used to measure agroecosystem health in the world. Most of the studies on ecosystem health were focused on the conceptual definition and problem comments that arose (Meng et al., 2018; Peterson et al., 2017). They are generally designed to make comparisons at coarse spatial scales or report on specific management actions implemented at the local scale (Peterson et al., 2017). Berrios et al. (2018) hypothesized that ecosystem health describes the state in which all processes operating within an ecosystem are functioning at a level of optimum efficiency to maximize system empower. Ma et al. (2001) concluded that ecosystem health assessment methods include both indicator species method and indicator system method, and the indicator system method is widely used. The metric of ecosystem health refers to the state, condition, or performance of an ecosystem defined by the appropriate goals (Rapport et al., 1998). Based on study of Zhu et al. (2012), agroecosystem health assessment includes evaluation of agroecosystem health, linkages between soil and water quality and agroecosystem health, and the relationship between agroecosystem health and human health.

Recently, some guides have been established based on indicator species sampling results, effectively compensating for the errors arising from the unilateral perspective of indicator system methods (Zhao et al., 2019). Vadrevu et al. (2008) described and analyzed agroecosystem health using a combination of geographical variables by extensive use of GIS software and spatial analysis techniques. They used some variables to quantify agroecosystem health such as biodiversity, topography, soil health, farm economics, social organization, and land economics. In another study, Peterson et al. (2017) presented a simple assessment framework that can be used to monitor the specific impacts of agricultural management practices on the environment. The general principles were drawn from environmental monitoring and experiences of environmental assessments. The comprehensive indicator assessment models and GIS spatial methods were applied by Meng et al. (2018) to analyze the rural ecosystem health status and spatial differentiation of 57 counties in Jiangsu province (China). Their results showed that the rural ecosystem health scores of 57 rural counties were in a higher range of 0.686–0.882 and fluctuating increased from north to south and counties in southern Jiangsu were healthier than those in central and northern regions.

VoPham et al. (2015) applied an improved GIS, remote sensing (RS), and Landsat products to estimate agricultural pesticides in California. The results of this study demonstrated that the Landsat products could improve GIS-based pesticide exposure estimation by matching more pesticide applications to crops classified using infrequently updated land use survey crop data.

Some studies were carried out in Iran on health agroecosystems assessment. For example, Kamkar et al. (2014) evaluated the health status of wheat production agroecosystems in Gorgan County, north of Iran, based on weed biodiversity, crop yield, and pesticide consumption rate. According to the results of this study, only 11% of total wheat fields were obtained a health degree. In another study, Jannati Ataei et al. (2017) investigated the health status of canola fields in Gorgan County. According to their results, only 3% of the canola fields were located in suitable health conditions.

Barley (*Hordeum vulgare* L.) is cultivated for the production of grain and forage. It has many uses in human and animal nutrition. The value of forage of barley is comparable to corn. Barley straw is used in feeding animals, and the value of its forage is more than wheat straw (Noormohammadi & Kashani, 1998). The area of barley cultivation in Iran was around 1,473,420 ha in 2016–2017, and the average grain yield under irrigation and dryland farming was reported 3274 kg ha$^{-1}$ and 1075 kg ha$^{-1}$, respectively. Also, the average yield of barley in Golestan province was recorded as 3369 kg ha$^{-1}$ in irrigation cropping systems and 1691 kg ha$^{-1}$ in dryland farming systems. The cultivation area of barley has been reported about 83,907 ha in this province in 2016–2017. Also, the barley cultivation area in Bandar-e-Torkman was about 1650 ha (Jihad Agriculture Ministry, 2017). The lack of information about the importance of the health of the agroecosystems led to the unsustainability of these agroecosystems. Considering the importance of barley in human and animal nutrition, it is essential to assess the health of its cropping systems. This study is developing a model for health assessment by spatial analysis in GIS media based on five main indicators including biodiversity, chemical fertilizer consumption, crop production and cultivar type, soil properties, and pesticides consumption. These biophysical variables were hypothesized to provide a minimum set of conditions required to quantify health in the agroecosystem.

## Materials and methods

### Study area

The research site was located in Bandar-e-Torkman County of Golestan province in the north of Iran. The region coordinates range from 36° 58′ and 38° 49′ N latitudes and 54° 1′ and 54° 2′ E longitudes (Fig. 1). The total county area covers approximately 28,000 ha. The western extension of the county surrounds the coastal plains of the Caspian Sea and Gorgan Gulf. Thus, the land slope decreases from the east towards the sea. Bandar-e-Torkman has a semi-humid climate and the average annual rainfall in the study site is 473 mm year$^{-1}$.

### Selected agroecosystems

This study was carried out in 50 barley agroecosystems. These agroecosystems were selected in four main directions of the county with normal distribution in agricultural areas under barley cultivation. All geographic coordinates of sites were recorded by a GPS (Garmin 60 series). The location of sampling sites is shown in Fig. 1. According to data recorded in the study, the size of fields was varied from one to five ha. In Bandar-e-Torkman County, usually, barley seed is sown during October and November, and grain yield is harvested in May and June every year.

### Health agroecosystem assessment model

To assess the health status in barley agroecosystems, a scenario was structured in GIS media. According to this scenario, the health status of fields was determined based on 5 important indicators, including pesticides consumption, chemical fertilizers consumption, grain yield amounts, soil organic matter, and four biodiversity indices (Table 1). The thematic layers of these indicators matched and overlaid in ArcMap 10.3; then, the scenario was performed by selecting function. A schematic diagram of the health assessment model is shown in Fig. 2. In this research, scenario details were identified from scientific literature and local experts' opinions. Based on the model, the fields with a health degree had the lower consumption of pesticides and chemical fertilizers, higher organic matter percentage, lower weed biodiversity, unused genetically modified cultivars (transgenic crops), and higher grain yield per hectare than other barley fields (Table 1). These criteria were measured and classified according to their average amounts of county scale. Finally, the selected fields in GIS media were identified as health agroecosystems in Bandar-e-Torkman County.

### Soil sampling

The soil property data were obtained from 50 sites distributed in barley croplands of Bandar-e-Torkman County including organic carbon, followed by converting it to organic matter (OM%). Soil samples were taken at depths of 0–30 cm from each plot before sowing and after crop harvesting, in autumn 2016 and spring 2017, respectively. All geographic coordinates of points were recorded by a GPS (Garmin 60 series). After that, all samples were moved to the crop research laboratory of Gorgan University of Agricultural Sciences and Natural Resources (GUASNR). Then, those were dried and analyzed. The concentration of soil organic carbon was determined using the Walkley and Black (1934) method. In continue, the soil-related layers were generated by Geostatistical Analyst tools in the ArcGIS var. 10.3.

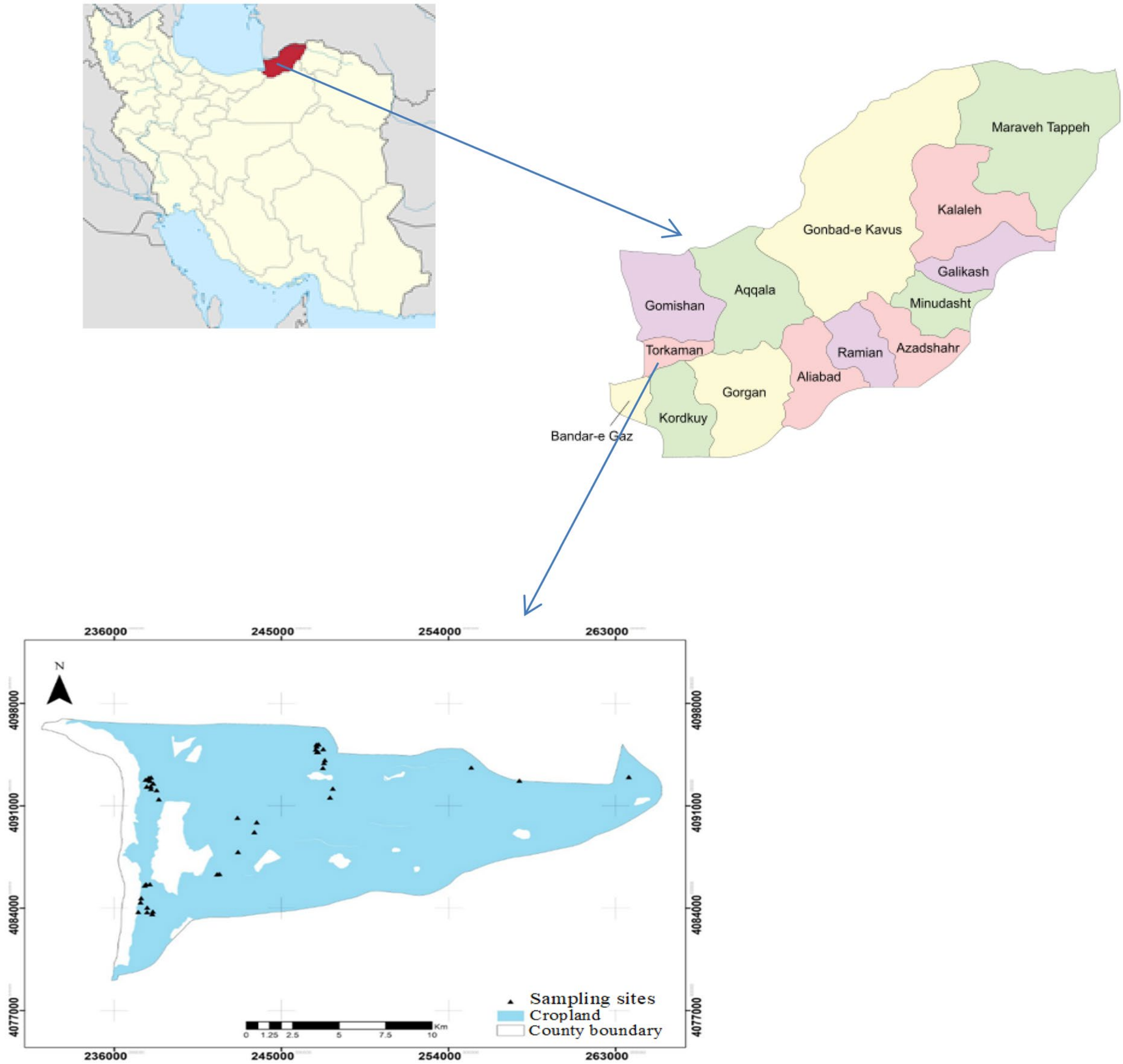


**Fig. 1** The location of the selected fields in Bandar-e-Torkman County, Golestan province, Iran

**Table 1** Scenario details for health assessment in barley agroecosystems of Bandar-e-Torkman County, Iran

| Details | Value |
|---|---|
| Consumption of pesticides | Lower than average amounts of county scale |
| Consumption of chemical fertilizers | Lower than average amounts of county scale |
| Soil organic matter | Higher than average amounts of county scale |
| Weed biodiversity | Lower than average amounts of county scale |
| Cultivar type | Unused genetically modified cultivars |
| Grain yield | Higher than average amounts of county scale |

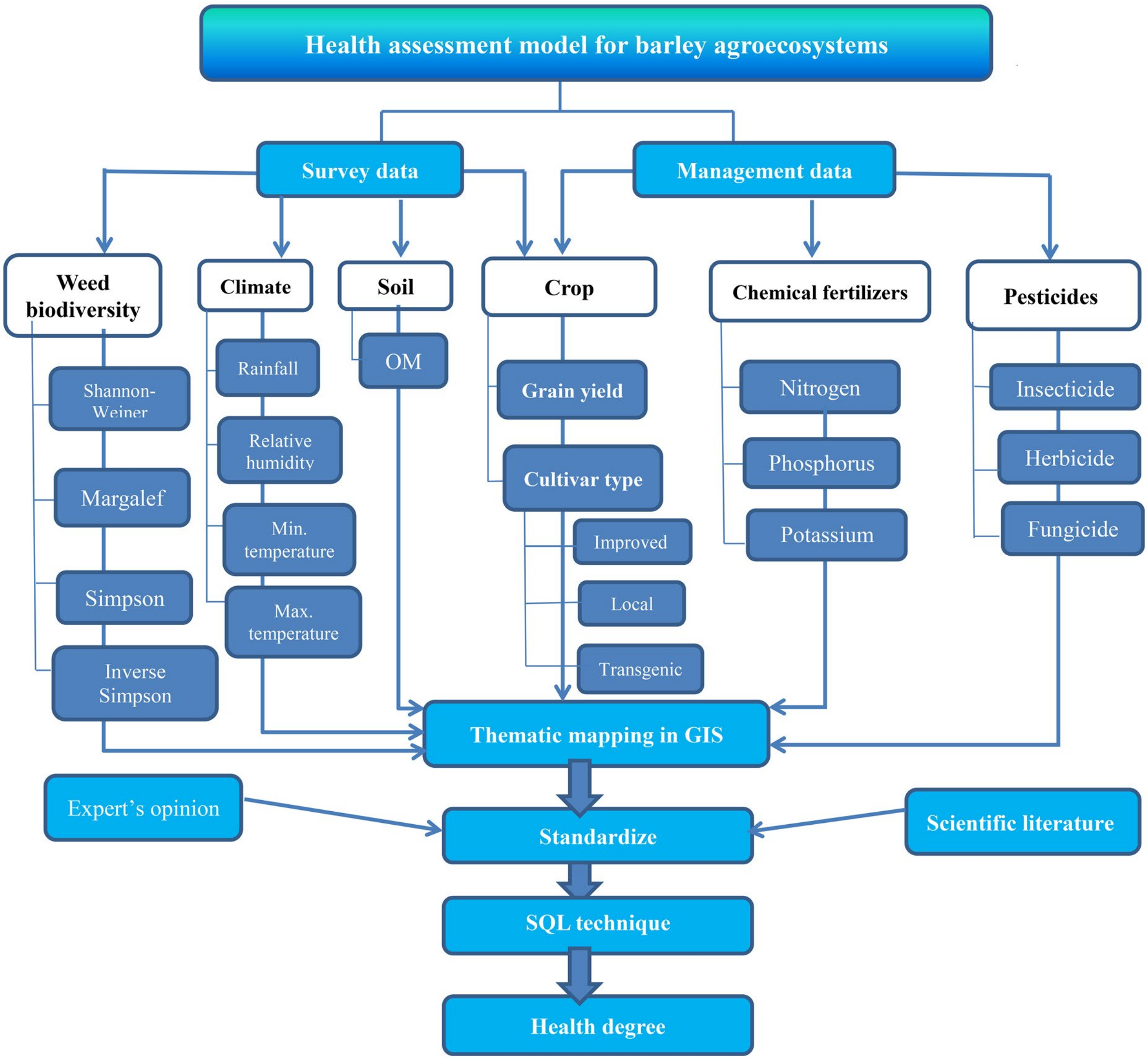


**Fig. 2** A schematic diagram of the health assessment model in agroecosystems

Climatic data

The last 15-year climatic data were obtained from 11 meteorological stations. These stations were located within the study area and the surrounding regions (Table 2). The data were averaged from 2001 to 2016. Then, some meteorological variables such as minimum and maximum temperatures, relative humidity, and total annual precipitation layer were prepared in GIS. These layers were provided by different geostatistical and classic methods such as ordinary kriging (OK), inverse distance weighted (IDW), radial basis functions (RBF), and local polynomial interpolation (LPI).

Plant biodiversity

Plant samples were randomly taken from 50 fields based on the W-shaped pattern by a $0.5\times0.5$ $m^2$ quadrate, during April 2017. The geographic coordinates of all plots were recorded by a GPS. Total weed samples were moved to the weed research laboratory of Gorgan University of Agricultural Sciences and Natural Resources (GUASNR) and identified in terms

**Table 2** The geographic location of used weather stations in Golestan province, Iran

| | **Longitude** | | **Latitude** | **Station type** | **Station name** |
|---|---|---|---|---|---|
| Minute | Degree | Minute | Degree | | |
| 4 | 54 | 9 | 36 | Climatology | Gorgan Airport |
| 86 | 54 | 9 | 36 | Climatology | Aliabad Katool |
| 05 | 54 | 9 | 36 | Climatology | Bandar-e-Torkman |
| 16 | 55 | 25 | 37 | Climatology | Gonbad Kavous |
| 26 | 54 | 85 | 36 | Climatology | Hashemabad Gorgan |
| 48 | 55 | 36 | 37 | Climatology | Kalaleh |
| 93 | 55 | 8 | 37 | Climatology | Maraveh Tappeh |
| 43 | 54 | 87 | 36 | Synoptic | Goragn |
| 5 | 54 | 01 | 37 | Synoptic | Aq-Qala |
| 25 | 55 | 32 | 37 | Synoptic | Aqtoghe |
| 24 | 55 | 13 | 37 | Climatology | Minoodasht |

of scientific and family names based on taxonomical classification procedure. Then, some biodiversity indices included Margalef, Shannon-Weiner, Simpson, and Inverse-Simpson were calculated. The spatial distribution of these indices was interpolated by ArcGIS software, var. 10.3.

### Crop sampling

The barley yield samples were harvested by a $0.5 \times 0.5$ $m^2$ quadrate from 50 recorded fields, during May and June 2017. Total harvested samples were transported to crop research laboratory, then oven-dried at 70 °C for 48 h and weighed to obtain grain yield. Also, the type of used cultivars (local, improved or transgenic) was identified based on field management data.

### Field management data collection

Field management data were collected by face-to-face interviews by barley growers of surveyed fields in this study and filling the questioners. These data included cropping rotation, amount of chemical fertilizers consumption, amount of pesticides consumption, organic fertilizers consumption, manure rate, seed rate, tillage type, cultivation type, and cultivars type (improved or transgenic). Also, the raw data of some variables were obtained from the agricultural management office of Bandar-e-Torkman County. Then, all data detailed data of the questionnaires entered into Microsoft Excel spread sheets var. 2010, and were averaged and arranged.

### GIS-based procedures

The spatial distribution of collected data was interpolated by different geostatistical and classic interpolation procedures such as ordinary kriging (OK), inverse distance weighted (IDW), radial basis functions (RBF), and local polynomial interpolation (LPI) in ArcMap var.10.3 software, using geostatistical analyst wizard. After the production of thematic layers, all layers were converted into raster format with 25 m resolution and UTM-georeferred (WGS-84) coordinate system in ArcGIS media. Then, all the raster layers from biodiversity indices, soil, crop, climatic, and field management data were standardized for the health assessment model. Finally, to perform the health assessment model and produce the final map, the SQL technique by raster calculator, selection, insert, and geoprocessing tools and functions were used.

### Statistical analysis

We used the Canoco software (var. 5) for the determination of relationships between variables according to Redundancy Analysis (RDA) producer. This analysis was conducted to graphically interpret the relationship between weed biodiversity indices and grain yield with field management data. The interpretation of redundancy analysis graphs is based on the canonical correlation of the studied factors with the axis of the graph and based on the angle of the variable and dependent factors in the graph (Legender & Legender, 2012).

## Results

### Weed biodiversity

Based on the obtained results, 23 weed species from 11 plant families were identified in the barley agroecosystems of Bandar-e-Torkman County. The most of weeds species belonged to Poaceae family. Also, the important weeds of these fields were included *Lolium multiflorum*, *Phalaris minor*, *Medicago sativa*, and *Polygonum patulum*. Results of Simpson, Inverse-Simpson, Margalef, and Shannon–Wiener indices are shown in Fig. 3. The range of the Simpson index was 0.23–0.62, and the highest and lowest amounts of this index were estimated in west and east of the county, respectively. According to the results of geostatistical methods, the LPI method with the constant function was used to provide the Simpson index map (Fig. 4). This map showed that most fields had low amounts of Simpson index than the average amount at the surveyed county level. The average of this index was obtained about 0.37.

In this research, the range of the Shannon–Wiener index was 0.53–1.27. We found that 47% of total fields had a lower value of the Shannon–Wiener index than the average value (1.00) of the surveyed county. The highest Shannon–Wiener index was found in the western part, and the lowest amount was calculated in the east of the study area (Fig. 3). The LPI method with the constant function was used to generate the Shannon–Wiener map in Bandar-e-Torkman County because this method had the lowest error and root-mean-square error (RMSE) among geostatistical methods.

The LPI method with the constant function was the best method for mapping of Inverse-Simpson index (Fig. 3). The range of this index was about

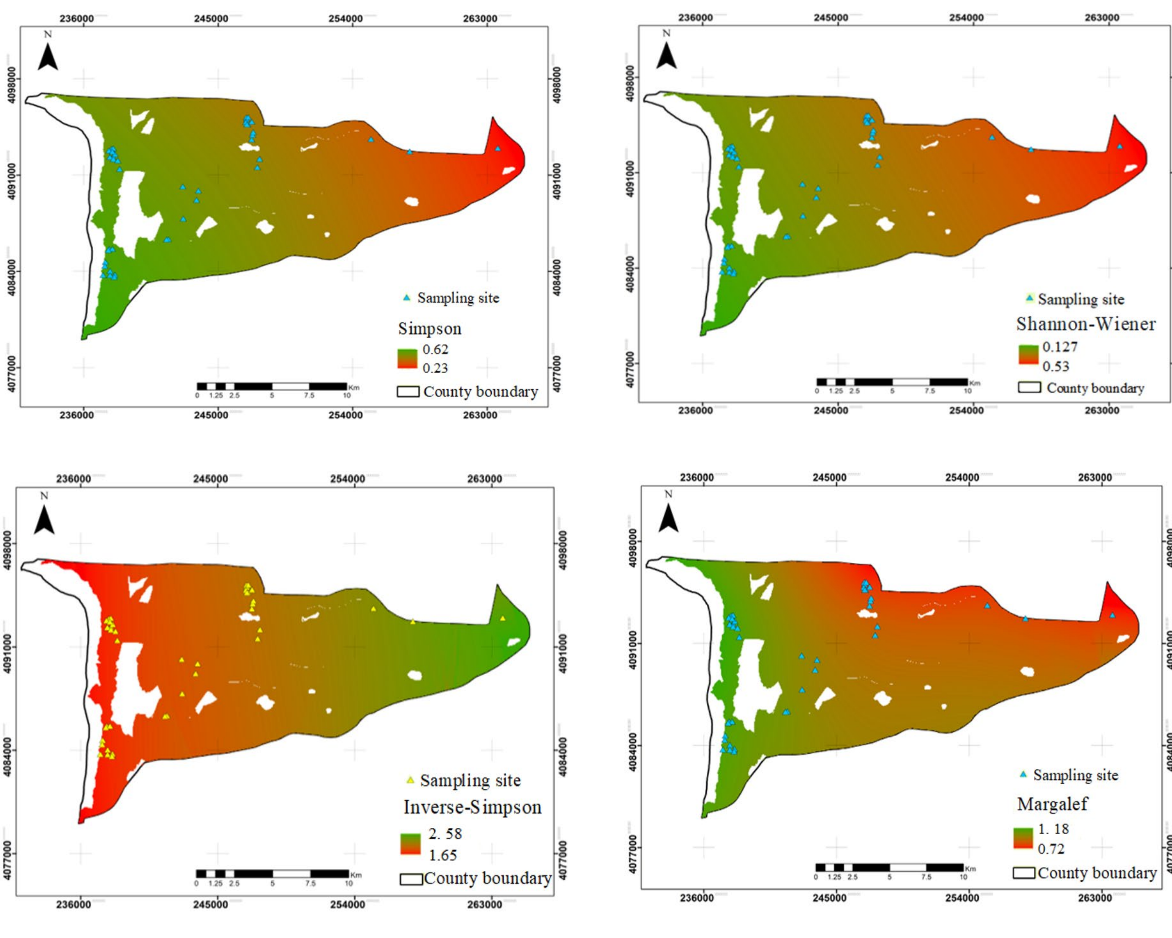


**Fig. 3** Maps of weed biodiversity indices in barley agroecosystems in Bandar-e-Torkman County, Iran

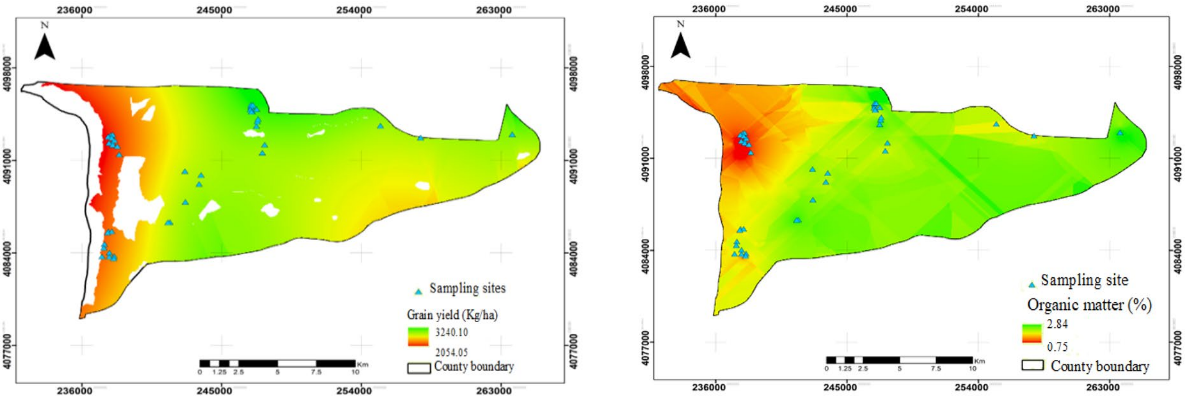


**Fig. 4** Map of grain yield and organic matter (OM) in barley agroecosystems in Bandar-e-Torkman County, Iran

1.65–2.58 with an average of 2.11. According to Fig. 3, the highest uniformity based on the Inverse-Simpson index was observed in the east of the county, and in the west of the studied area, the biodiversity of weed species was higher than other regions. In addition, the results indicated that 77% of the barley fields had lower amounts of this index than the average amounts of county level.

In this research, the Margalef index (which indicates species richness) was calculated based on the total number of weed species and the total individuals for all species. According to geostatistical analysis, the LPI method with the exponential function was selected as the best method for interpolation of the Margalef index in barley agroecosystems of Bandar-e-Torkman County (Fig. 3). Based on this map, the highest and lowest of species richness was estimated in the west and east of the county, respectively. The range of the Margalef index was 1.65–2.58, and approximately 60% of the sampling sites had lower values than the average value of this index on the county scale (Fig. 3).

## Crop yield and cultivar type

In this study, the LPI method with the constant function was selected as the best geostatistical method to prepare the crop yield map (Fig. 4). Principally, the polynomial interpolation method as a weighted interpolation method can show the trend of the changes in the investigated variable. The results indicated that about 13.3% of the barley agroecosystems had a higher yield than the average county scale. These fields were observed in the central and western parts of the county (Fig. 4). The range of grain yield varied from 2054 to 3249 kg ha$^{-1}$. Also, there were no genetically modified cultivars in barley fields based on data from all the fields.

## Soil properties

To investigate soil functions such as nutrient and moisture retention, we analyzed the status of organic matter (OM) in the barley agroecosystems. According to the results of interpolation, the K-Bessel model from the ordinary kriging procedure had the least error and RMSE than other geostatistical methods; thus, it was selected as the best model for estimation of OM in Bandar-e-Torkman County. The highest amount of OM% was found in the center and east of the county, and the lowest amount of organic matter was estimated in the west of the region (Fig. 4). The soil organic matter was ranged from 0.75 to 2.84%. According to Fig. 4, the lowest amounts of OM were estimated in the agroecosystems located in the west and northwest of the region.

## Climatic maps

The ordinary kriging-circular model was the best method for interpolation of annual rainfall in Bandar-e-Torkman County, because this model showed that the least RMSE among other used geostatistical methods. In the surveyed county, the annual rainfall was ranged from 400.89 to 508.40 mm (Fig. 5). The highest annual rainfall was estimated in the southern part, and the lowest amount was recorded in the northern part of the county. According to the results, about 39% of the surveyed fields were located in regions with high amounts of annual rainfall, which this suitable condition can result in the high grain yield, species richness, and biodiversity than other fields in the western regions. These fields are found the near of Caspian Sea as a humidity source.

Based on the results of interpolation analysis, the LPI method with the constant function was the best method for the estimation of relative humidity in the study area. This climatic variable was ranged from 74.64 to 76.53% during the growing season (Fig. 5). According to this map, the highest relative humidity was interpolated in the south of the county, which in turn, was dependent on the spatial distribution of annual rainfall.

Comparison of different methods for interpolation of maximum temperature showed that the integrated ordinary kriging–rotational quadric model was the best interpolation method. The trend of maximum temperature showed that the east and west regions of the county had the highest and the lowest values of maximum temperature, respectively (Fig. 5). Based on the comparison of different geostatistical methods, the integrated ordinary kriging–J Bessel model was designated as the best model for estimating the annual minimum temperature in Bandar-e-Torkman County. The range of this variable ranged between 7.41 and 7.91 °C, and the west and east regions had the lowest and highest of annual minimum temperatures, respectively (Fig. 5).

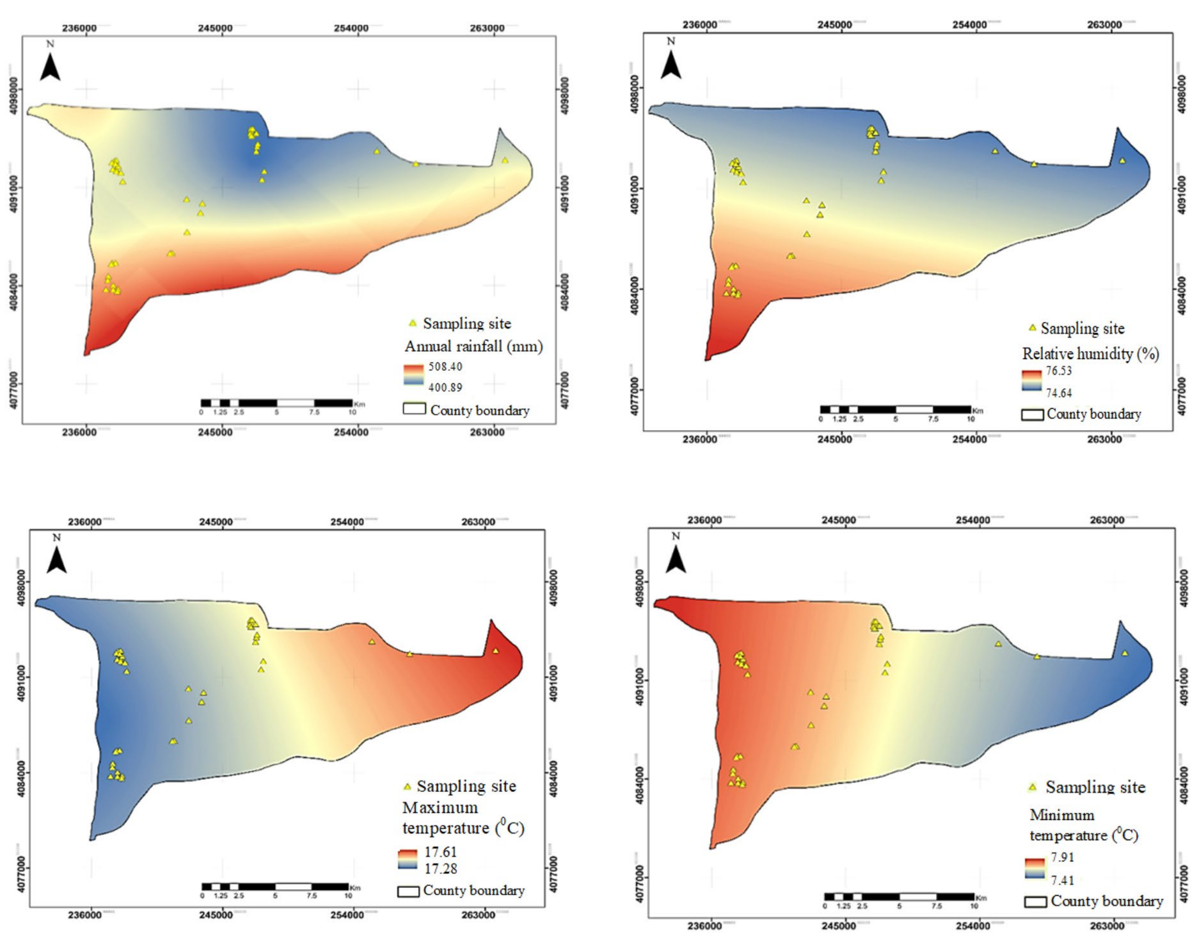


**Fig. 5** Maps of climatic variables in Bandar-e-Torkman County, Iran

### Chemical application

The results of the survey study showed that in about 11% of the barley agroecosystems, the pesticides consumption was higher than the average consumption of pesticides at the county level. Most of these barley agroecosystems were observed in the northern and central of the studied county (Fig. 6). Among the used herbicides, fenoxaprop P ethyl, 2.4.D, and tribenuronmethyl, as well as propiconazoleas fungicide, were current pesticides in barley fields of Bandar-e-Torkman. As a finding, one of the main reasons for the high consumption of herbicides was the resistance of some weeds (especially *Phalaris minor* Retz. and *Sinapis arvensis* L.) to applied herbicides.

The results showed that only 9% of the total studied fields received higher chemical fertilizers amounts than the average consumption of the fields in the county scale. The spatial distribution of chemical fertilizer and pesticide consumption was prepared using the Thiessen method in ArcMap media. Based on spatial analysis by GIS, most of these fields with excessive use of chemicals were observed in the northern, central and southern regions of Bandar-e-Torkman County (Fig. 6).

### Redundancy analysis

According to the statistical analysis results of Canoco, the correlation between management factors and biodiversity indicators was strong in the first axis of RDA (Table 3). These results indicated that there is a significant relationship between management data and weed biodiversity indices. Among the factors in the first axis, amounts of used chemical fertilizers, the amounts of sulfur, and tribenuron methyl herbicide had the highest impact on these indices (Table 3). According to results, nitrogen fertilizer, non-use of graminicides, and cow manure showed a high correlation with Shannon–Wiener and Simpson indices. Also, the use of wheat in cropping rotation had a negative effect on Shannon–Wiener and Simpson's indices.

Some management factors such as the use of phosphorus fertilizer, the use of plow and disk tillage, the use of manure, and the use of herbicide had a sound effect on the Inverse-Simpson index than other factors (Table 3). Also, rotation with fallow, non-use of Propiconazole fungicide, two-disk tillage, and consumption of sulfur fertilizer were the effective factors on the Margalef index (Table 3).

In this research, according to RDA results between management factors and grain yield, the first axis was highly dependent on some management factors such as planting method, chemical fertilizers consumption, and pesticides consumption. Among these factors, nitrogen fertilizer had the highest share of other factors (Table 4).

### Health agroecosystems

Based on biodiversity indices, pesticide and chemical fertilizer consumption, organic matter, crop yield, and cultivar type, the health status was prepared in

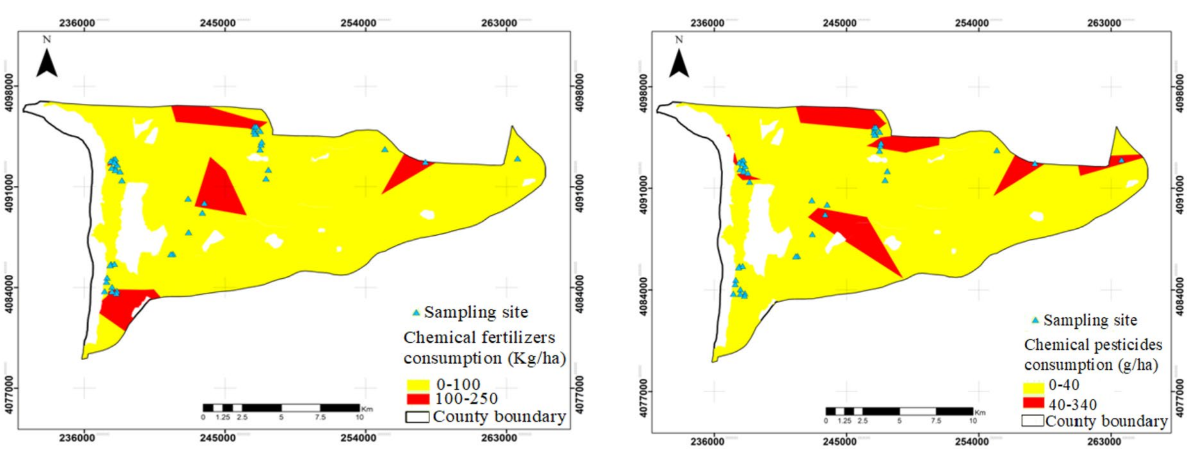


**Fig. 6** Maps of pesticides and chemical fertilizers consumption in barley agroecosystems of Bandar-e-Torkman County, Iran

**Table 3** Correlation between management factors and biodiversity indicators based on RAD analysis in barley agroecosystems of Bandar-e-Torkman County, Iran

| Second axis | First axis | Variables |
|---|---|---|
| −0.004 | −0.111 | Seed amounts |
| 0.371 | 3.096 | Chemical fertilizer |
| −0.056 | −0.292 | Pesticide |
| −0.084 | −1.061 | Phosphorus |
| −0.053 | −1.682 | Nitrogen |
| 0.067 | −2.314 | Sulfur |
| 0.176 | −0.295 | Fallow rotation |
| 0.135 | −0.535 | Rotation with canola |
| −0.036 | 0.446 | Rotation with wheat |
| −0.081 | −0.100 | Rotation with barley |
| −0.023 | −0.088 | Sowing with Santrifuzh machine |
| 0.082 | −0.052 | Sowing with labor |
| −0.017 | 0.111 | Sowing with machine |
| 0.019 | −0.077 | Cow manure |
| 0.007 | −0.167 | Sheep manure |
| −0.013 | 0.188 | Non-manure |
| −0.234 | −0.466 | Fenoxaprop P ethyl grassy weeds herbicide |
| 0.234 | 0.466 | Non-grassy weeds herbicide |
| 0.261 | 0.896 | Tribenuronmethyl broad leaf herbicide |
| −0.242 | −0.778 | Non-broadleaf herbicide |
| −0.014 | −0.172 | 2.4.D broad leaf herbicide |
| −0.004 | −0.296 | Propiconazole fungicide |
| 0.004 | 0.296 | Non-fungicide |
| 0.005 | 0.410 | Biofertilizer-1 time |
| 0.028 | −0.560 | Biofertilizer-2 time |
| −0.023 | 0.042 | Non-biofertilizer |
| −0.109 | 0.605 | Landrace cultivar |
| −0.010 | −0.269 | Sahra cultivar |
| 0.075 | −0.050 | Youssef cultivar |
| 0.110 | −0.052 | Chisel + 2 disk |
| 0.113 | 0.010 | Chisel + 4 disk |
| −0.118 | -0.317 | Chisel + 3 disk |
| −0.078 | 0.546 | 2 disk |
| −0.167 | 0.479 | Plow + 2 disk |
| 0.028 | −0.560 | Plow + 3 disk |

**Table 4** Correlation between management factors and grain yield based on RAD analysis in barley agroecosystems of Bandar-e-Torkman County, Iran

| Second axis | First axis | Variable |
|---|---|---|
| −0.197 | 0.259 | Seed amounts |
| 1.339 | 1.783 | Chemical fertilizer |
| −0.018 | −0.044 | Pesticide |
| −0.442 | −0.653 | Phosphorus |
| −0.442 | −0.071 | Nitrogen |
| −0.378 | −1.459 | Sulfur |
| −0.015 | −0.014 | Fallow rotation |
| − −0.056 | 0.005 | Rotation with canola |
| −0.084 | 0.130 | Rotation with wheat |
| 0.101 | −0.114 | Rotation with barley |
| 0.013 | −0.160 | Sowing with Santrifuzh machine |
| −0.045 | 0.127 | Sowing by labor |
| 0.010 | 0.094 | Sowing with machine |
| 0.042 | 0.049 | Cow manure |
| 0.050 | 0.101 | Sheep manure |
| −0.064 | −0.115 | Non-manure |
| −0.029 | 0.180 | fenoxaprop P ethyl grassy weeds herbicide |
| 0.029 | −0.180 | Non-grassy weeds herbicide |
| −0.026 | −0.067 | tribenuron methyl broadleaf herbicide |
| 0.010 | −0.013 | Non-broadleaf herbicide |
| 0.033 | 0.176 | 2.4.D broadleaf herbicide |
| −0.011 | −0.142 | Propiconazole fungicide |
| 0.011 | 0.142 | Non-fungicide |
| 0.021 | 0.140 | Biofertilizer-1 time |
| −0.130 | −0.234 | Biofertilizer-2 time |
| 0.068 | 0.042 | Non-use biofertilizer |
| 0.056 | −0.114 | Landrace cultivar |
| −0.104 | 0.039 | Sahra cultivar |
| 0.086 | 0.022 | Youssef cultivar |
| 0.115 | 0.189 | Chisel + 2 disk |
| 0.338 | −0.027 | Chisel + 4 disk |
| −0.025 | −0.107 | Chisel + 3 disk |
| −0.104 | 0.050 | 2 Disk |
| −0.152 | −0.065 | Plow + 2 disk |
| −0.130 | −0.234 | Plow + 3 disk |

Bandar-e-Torkman County. The overlay of all layers indicated that only about 12% of the surveyed agroecosystems obtained a health degree. Also, the overlay of soil organic matter map with health map showed that the fields with health degree had about > 1.64% organic matter. In contrast, almost all of the barley agroecosystems in the center and east of the county were located in the without health grade class.

## Discussion

According to the results, the highest and lowest amounts of Simpson index were estimated in the west and east of the county, respectively. Based on observations of surveyed fields, there are three reasons for this result: (1) in the fields located of the west, consumption of nitrogen fertilizers was higher than in other fields; (2) the barley growers usually use little amounts of herbicides in these fields; and (3) in this region, amount of annual rainfall and relative humidity percent was higher than other areas. Generally, the high Simpson index showed that environmental condition is appropriate for the growth of weeds species in this region, and management practices of weed control usually reduce this index value. Some researchers also used the Inverse-Simpson index as important index for the assessment of uniformity. For example, McLean et al. (2000) investigated the variation of soil worm species in the pine forest with the Inverse-Simpson index.

Approximately 60% of the sampling sites had lower values than the average value of the Margalef index on a county scale. Petit et al. (2016) analyzed the weed species abundance and richness in 125 winter wheat fields under a gradient of management intensity. Their analysis showed that weed richness and abundance did not respond at the same spatial scales. Weed species richness responded to factors acting at multiple spatial scales, with a predominant effect of landscape-scale management. Also, they concluded that a combination of local and longer-term landscape management can be possible to deliver reduced weed infestation levels and enhanced arable biodiversity.

The grain yield was ranged from 2054 to 3249 kg ha$^{-1}$. The appropriate humidity and maximum temperature and also the consumption of high amounts of chemical fertilizers were the main reasons for this result. In this study, there was no genetically modified cultivar in barley fields based on collected data in surveyed field and questionnaire-based data. Generally, all farmers in Golestan province use landrace and improved cultivars. Sahra, Mahoor, Khorram, Youssef, and landrace cultivars are the famous cultivars of barley in Bandar-e-Torkman County and Golestan province. Based on the study of Zhu et al. (2012), using or not using genetically modified plants (transgenic crops) is an important criterion in agroecosystem health assessment.

In this research, the soil organic matter varied from 0.75 to 2.84%. Undoubtedly, soil carbon is one of the most important soil quality–based indicators involved in agroecosystem health assessment (Mitchell et al., 2017) and loss of soil organic carbon affects the chemical, physical, and biological soil properties that seriously affect soil health (Stewart, 2017). Moebius-Clune et al. (2016) concluded that the assessment of soil health provides standardized field-specific information on agronomically important constraints and is an essential part of a broader soil health management planning structure. The lower amounts of OM were estimated in the agroecosystems located in the west and northwest of the region. There are many ways to increase OM in soils that can improve the health of the agroecosystems. For example, Stewart (2017) highlighted that applying principles of conservation agriculture is the best approach to maintain or enhance soil health in these regions. These principles are minimum soil disturbance, permanent soil cover with crops or plant residues, and diversification of crop species. Also, Rekik et al. (2018) indicated that soil health is critical for sustainable agricultural production, and its quantitative assessment provides a framework for agroecosystems management.

The ordinary kriging–circular model was the best method for interpolation of annual rainfall. Usually, ordinary kriging is introduced as the best method for interpolation of environmental variables (Hofstra et al., 2008; Kazemi & Ghorbani, 2015; Kazemi et al., 2012). In previous studies, Khosravi et al. (2014) used simple kriging, ordinary kriging, and universal kriging methods for estimation of temperature and rainfall in Iran. Their results showed that the simple kriging–exponential model and ordinary kriging–spherical models were the best procedure–models for interpolation of annual rainfall and temperature. According to previous researches, the climatic variables and their changes are important factors affecting the production of rainfed farming systems in Golestan province (Kazemi & Ghorbani, 2015). In this study, the west and east regions of the county had the lowest and highest annual minimum temperature, respectively. Generally, climatic, soil, and regional differences have a significant impact on the health assessment and require adjustment of scoring and interpretation frameworks (Congreves et al., 2015).

As a finding, one of the main reasons for the high consumption of herbicides was the resistance of some weeds to applied herbicides. Based on this reason, almost all farmers have to apply high rates of these herbicides to control resistant biotypes of mentioned weeds in barley fields. Also, it seems that some used pesticides are low quality in respect to materials used and formulation aspects; thus, they are not efficient chemicals to control of weeds in some barley agroecosystems. Previously, resistance of weeds to herbicide has been reported all over the world. For example, in Europe, 9 cases of glyphosate resistance have been proven with one of those cases on agricultural land (Collavo & Sattin, 2014; Heap, 2017). Koning et al. (2019) reported that the repeated application of reduced doses can have a selective effect on a weed community because the less sensitive plants do not get killed. In Iran, Gherekhloo et al. (2016) reported major resistance to ACCase-inhibiting herbicides in some weed species such as winter wild oat, wild out, and little seed canarygrass. Also, they indicated that continuous long-term use of tribenuron-methyl can develop resistance in broadleaf species such as *Sinapis arvensis* L. and *Rapistrum rugosum* L.

Nowadays, the extensive use of pesticides has become usual practice in almost all developing countries. These chemical materials are often associated with risks to soil health, ecosystem functioning, and human safety (Bergmann, 2019). de Queiroz et al. (2018) estimated that two-thirds of the population in the world is exposed to pesticides harmful effects. It seems that integrated management especially integrated pest management is an essential practice for reducing the impact of pesticides in the agroecosystems and natural ecosystems. The results showed that only 9% of the studied fields received higher chemical fertilizers amounts than the average consumption of the fields in the county scale. Altieri and Nicholls (2003) designated that farming practices, such as excessive use of inorganic fertilizers, can cause nutrient imbalances and lower pest resistance. Most fields with excessive use of chemicals were observed in the northern, central, and southern regions of the County. VoPham et al. (2015) concluded that GIS-based metrics are influential tools to investigate the relationship between pesticide exposure and human health outcomes. It observed that the use of cow manure in barley fields had a high correlation with the Shannon–Wiener index. Bagheri et al. (2013) reported that cow manure can spread high amounts of weed seeds throughout the fields. Results showed that weed diversity reduced under crop rotation of wheat–barley. Previously, the results of Kamkar et al. (2014) showed that one of the strategies for sustainable weed management in wheat agroecosystem is the replacement of summer crops such as soybean with wheat or canola in current rotations.

According to the statistical analysis results by Canoco, rotation with fallow, non-use of propiconazole fungicide, two-disk tillage, and consumption of sulfur fertilizer were the effective factors on the Margalef index. Koning et al. (2019) based on partial redundancy analyses (pRDA) reported that the weed species communities in Europe had a dependency on the type and timing of application of moldboard plowing, chisel plowing, and glyphosate herbicide. Among these factors, nitrogen fertilizer had the highest share of other factors. The results of another research revealed that growth, grain, and protein amount of barley increased with high nitrogen fertilizer levels (Shafagh Kohvalnq et al., 2015). Field management practices can influence the health status of agroecosystems directly and indirectly. Based on the suggested pattern of Zhu et al. (2012), the agroecosystem health assessment includes “evaluation linkages between soil quality, water quality and the contribution of management practices such as integrated soil management and integrated pest management in agroecosystems health.”

By the overlay of all layers, only about 12% of the total surveyed agroecosystems reached the health degree. The use of appropriate tillage methods, the appropriate weed control, the optimum consumption of high-quality pesticides, high soil organic matter, high grain yield ($>2.6$ ton ha$^{-1}$), and the more relation of farmers with local agricultural services centers were the main reasons for this result. In contrast, almost all of the barley agroecosystems in the center and east of the county were located in the unhealthy class. It seems that there are two reasons for this result: (1) pesticid management type and (2) applied agronomical practices. The consumption of low-quality pesticides, improper tillage tools, the little knowledge of the farmers about the agronomic practices, and resistance of some weeds to herbicides were the important reasons for non-health status in the most surveyed fields. Previously, Jannati Ataei et al. (2017) investigated the health status of canola fields in Gorgan County, north of Iran. According to their results, only 3% of the fields were located in suitable healthy condition and also about 43% of the surveyed canola fields had a high consumption of pesticides. In another study, Kamkar et al. (2014) evaluated the health status of wheat production systems in Gorgan County based on weed biodiversity, crop yield, and pesticide consumption. Generally, the health status of agroecosystems is one of the main ways to achieve sustainable agriculture in the world. Healthy ecosystems provide a range of ecosystem services. Based on the study of Costanza (2012), a focus on the design, protection, and restoration of healthy ecosystems will help to provide sustainable ecosystem services that underlie all human well-being. Zhu et al. (2012) introduced the different variables for quantifying agroecosystems health. These variables included soil health, biodiversity, topography, farm economics, land economics, and social organization.

Health assessment of agroecosystems using GIS and RS techniques can provide spatial and temporal analyses as accurate results for agroecosystems assessment in landscape-level than other current methods and models. Thus, nowadays, many researchers have been accepted and used the GIS and RS approaches in the health assessment of ecosystems. For example, Vadrevu et al. (2008) described and analyzed agroecosystems health through a combination of geographically referenced variables by extensive use of GIS software and spatial analysis techniques.

## Conclusions and further researches

Finally, the results proposed a valuable relatively simple model to estimate the health status in agroecosystems. As a practical planning tool, it can be used for the quantitative assessment and comparison of agroecosystems' health status. Based on the results of this study, calculations of biodiversity indices showed that the Simpson index ranged from 0.23 to 0.62, the Inverse-Simpson index varied from 1.65 to 2.58, Shannon–Wiener index ranged from 0.4 to 0.93, and Margalef index changed from 0.72 to 1.18. Based on the results of the identification of important weeds of barley fields in this region, farmers can select the best strategy for weed control in these fields. Moreover, it is recommended that insect biodiversity including pests, pollinators, and natural enemies as well as earthworm abundance to be considered as important criteria in the health assessment farmwork of agroecosystems.

Also, the results showed that 11 and 9% of the total studied fields had higher consumption of pesticides and chemical fertilizers than the average, respectively. In the study, the relationship between crop yield and biodiversity with management practices was investigated. According to the results, the non-use of chemicals reduced crop yield in this county. However, the survey showed that about 12% of the farms in the county obtained a health degree. These fields were located in the western part of the county. Considering the importance of using pesticides to pest control and increasing crop production and their importance in the field's health, it seems that knowledge of farmers about the optimum use of pesticides especially herbicides for obtaining appropriate yield and reducing the environmental risks is very important in this county. Also, integrated pest management is an essential practice for reducing the impact of pesticides in agroecosystems. It seems that applying sustainable agricultural practices can improve the health of these agroecosystems. In general, low-input, ecological, conservation, and organic agricultural systems increase the health of the agroecosystems, so it is recommended to improve the health of barley fields; the common production systems have to change to these mentioned systems.

In this research, the health status of barley agroecosystems was determined based on some indices such as biodiversity indices, pesticide, and chemical fertilizer consumption, organic matter, crop yield, and cultivar type using spatial techniques of GIS. It is suggested that other factors such as nitrate leaching and soil microorganism's activity also should be considered as a supplementary criterion to investigate the health status of the agroecosystems. In addition, remote sensing (RS) techniques can help to understand health conditions on a landscape scale. In the studied region, barley as the main crop is usually rotated with some crops such as wheat and canola. Thus, a comprehensive health assessment is recommended for all current crop rotations in this county.

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**Data availability** The data that support the findings of this study are available from the corresponding author, upon reasonable request.

## Declarations

**Conflict of interest** The authors declare no competing interests.

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