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Multi-dimensional assessment of watershed condition using a newly developed barometer of sustainability

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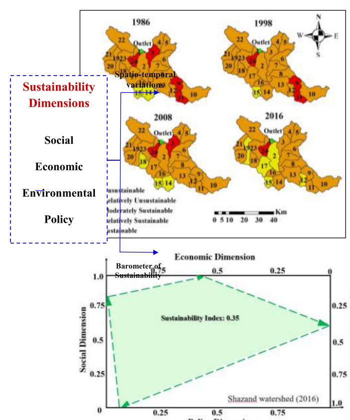
HIGHLIGHTS

- A multi-dimensional barometer of sustainability was proposed for the first time.
- Spatial and temporal variations were found in the Shazand Watershed sustainability.
- The social dimension had a high impact on sustainability in all sub-watersheds.
- The Shazand Watershed was mainly classified as a relatively unsustainable state.
- The developed barometer facilitates realistic recommendations for decision-makers.

GRAPHICAL ABSTRACT



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ABSTRACT

The present study was conducted to comprehensively evaluate watershed sustainability with the help of an initiative barometer developed based on different dimensions of social, economic, environmental, and policy. The newly developed barometer was then applied to assess the temporal variation of sustainability for the Shazand Watershed, Iran, for four-node years of 1986, 1998, 2008, and 2016. The appropriate criteria were then adapted to calculate the study dimensions. The effect sizes of selected criteria on each dimension were also determined. Consequently, the status of each dimension and integrated watershed sustainability status were mapped for four-node years. The results indicated that study dimensions were unevenly distributed over the Shazand Watershed. So that, the social dimension had high effectiveness across different sub-watersheds, and the policy dimension had a poor situation in all study years. In addition, the respective sustainability index of 0.32, 0.32, 0.35, and 0.35 for node years of 1986, 1998, 2008, and 2016 verified a slight improvement. Overall, the proposed barometer of sustainability facilitated understanding the dimensional sustainability and comprehensive watershed sustainability and provided references for policy formulations and watershed management. Besides, the developed barometer has a high potential for evaluating sustainability for other watersheds worldwide.

1. Introduction

Watersheds in developing countries are the most important source of livelihood for people in terms of goods and services (Hepelwa, 2014; Chaudhary et al., 2018). However, unsustainable and robust

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demand for land and water resources due to the uncontrolled expansion of agriculture and urbanization would increase the destruction of ecosystems and the continuation of human life and civilization (Ness et al., 2010). In this way, some promising strategies such as e-flow facilitate water resources management and help the health and sustainability of river ecosystems. This concept is essential in the ecological impact assessment of water-related projects to mitigate their environmental impacts (Kuriqi et al., 2021). So, as environmental impact assessment (EIA) reports, it is necessary to consider anthropogenic activities such as hydropower plants and projects that change the hydrological cycle (Kuriqi et al., 2020; Suwal et al., 2020).

Considering sustainability as a necessary prerequisite for the future situation of a system, the assessment of watershed sustainability is essential for proper management of the watershed to receive consistent services (Firdaus et al., 2014). Sustainability has been defined in different ways (Schröter et al., 2017). As a widely accepted foundation, sustainability was adopted into the global agenda at the Rio Summit in 1992, is defined as "meets the needs of the present without compromising the ability of future generations to meet their own needs" (Graymore et al., 2009). Sustainability assessment will help policy/decision-makers decide which managerial measurement and action to achieve watershed sustainability (Kaur and Garg, 2019).

In order to assess the watershed sustainability, it is needed to consider social, economic, and environmental dimensions as applied in previous different researches (e.g., Graymore et al., 2009; Yao et al., 2013; Mahdei et al., 2015; Strezov et al., 2017; Boggia et al., 2018; Zhao et al., 2019; Marti and Puertas, 2020). The social dimension is related to the relationship between human health, hygiene, educational services, the development of different cultures, and poverty eradication. The economic dimension is regarded to economic growth and other economic parameters, in which the wellbeing of the individual and society is maximized through the optimal use of natural resources and the equitable distribution of benefits. The environmental dimension is also referred to as the condition of renewable and non-renewable natural resources and watershed services (United Nations, 2001). Making a balance between social, economic, and environmental goals requires examining the impact of current decisions on future generations and setting rules and regulations, which infer in policy dimension (OECD, 2001).

There is a wide range of approaches depending on the objectives, the scale, and the scope of sustainability assessment, including indicators or indices, product-related assessment, integrated assessment tools, and barometer of sustainability (Ness et al., 2010). Among these, indicators are specific and powerful tools for assessing sustainability condition, and it has been recommended by international institute (OECD, 2015), decision-makers (United Nations, 2007), and scholars (e.g., Cloquell-Ballester et al., 2006; Da Silva Batalhao et al., 2018; Ameen and Mourshed, 2019). It is also used as a framework to assess sustainability in different scales of local (Moreno-Pires and Fidélis, 2012; Roboredo et al., 2016), regional (Graymore et al., 2009; Mascarenhas et al., 2010; Yi et al., 2019), national (Salvati and Carlucci, 2014), and international (Munda et al., 2009; Hosseini and Kaneko, 2011) in various researches.

At present, numerous indicators were suggested and used in different contexts for various purposes used in different researches (Roboredo et al., 2016; Wang et al., 2019). Being a multi-dimensional concept, the watershed sustainability assessment is not based on a single indicator but using a set of indicators (Boggia et al., 2018). A fundamental requisite for meaningful use of indicators and indices is the possibility to aggregate and make them comparable (Becker and Secretariat, 1997; Böhringer and Jochem, 2007; Roboredo et al., 2016; Yi et al., 2019). So, decision-making paid attention to composite indicators to support policy formulation because aggregated indicators can be unambiguously interpreted (Chen et al., 2015) and provide comprehensive information for assessing sustainability (Yi et al., 2019).

The barometer of sustainability is a tool for assessing watershed sustainability that Prescott-Allen (1997) firstly proposed. The proposed barometer of sustainability facilitated understanding, evaluating, communicating, and interacting with humans and ecosystems by combining just two indicators of human wellbeing and ecosystem wellbeing (Da Silva Batalhão et al., 2017). However, it did not collaboratively illustrate the sustainability of social, economic, and environmental dimensions.

Graymore et al. (2009) developed a sustainability assessment framework using multiple criteria analysis (MCA), GIS, and some economic, social, and environmental indicators. Roboredo et al. (2016) developed an aggregate index of social-environmental sustainability to assess the social-environmental quality in a small watershed in the Southern Amazon. They concluded that the studied watershed is socially and environmentally degraded. Qi et al. (2018) proposed a framework for the Dongting Lake area in China to improve agricultural land use and assess food insecurity risk. The results indicated that grain production was likely to threaten the sustainability of agricultural land use. In addition, da Silva Batalhão et al. (2017) analyzed the application of the barometer of sustainability proposed by the International Union for Conservation of Nature (IUCN) for monitoring the sustainability in Ribeirão Preto, Brazil. They concluded that the study region was categorized as intermediate sustainable, indicating better performance in the human subsystem. Wang et al. (2019) used 24 indicators in economy, society, and environmental dimensions to assess water resource sustainability and the relatively low-efficiency level of water resource sustainability in Beijing, China. Ameen and Mourshed (2019) developed a framework for the sustainability assessment of an urban watershed in Iraq. As a result, they identified and ranked the relevant indicators and assigned weights using the analytic hierarchy process (AHP). The results showed identified factors and their weights were significantly different from the widely-used tools.

It can be inferred from the reviewing studies that watershed sustainability assessment has a long history. However, a comprehensive multi-dimensional watershed sustainability assessment, especially in a developing country such as Iran, needs to distinguish the sustainability problem and implement appropriate watershed management strategies. In addition, most of these studies have assessed watershed sustainability in particular and limited aspects such as water resources, urban development, and agriculture. Moreover, some other studies have used only three social, economic, and policy-making dimensions for the assessment. Therefore, the current study tried to bridge this research gap of comprehensive watershed sustainability assessment and the limitation of the existing barometer of sustainability (IUCN) in showing dimensional sustainability.

In this way, the Shazand Watershed was selected as it experienced some natural phenomena (e.g., drought). However, it also faced different human-induced interventions such as enormous development in agricultural and industrial activities, rapid urban growth, land degradation, and declining health conditions (Sadeghi et al., 2020; Sadeghi et al., 2019; Kiani-Harchegani et al., 2019). The present study aimed at (a) determining the effective indicators based on reviewing the literature, geographical properties, and data availability, (b) assessing watershed sustainability using the indicator based framework in different dimensions of social, economic, environmental, and policy (c) evaluating the spatiotemporal variations of the watershed sustainability during last three decades and (d) propose a barometer of sustainability for watershed sustainability assessment.

2. Materials and methods

2.1. Study area

The study area is located in the southwest of Markazi Province, in the central plateau of Iran. The Shazand Watershed is one of the sub-watersheds of the Namak Lake of Iran and a part of Sareband Mountainous City. The total area is 1740 km^2 dissecting 24 sub-watersheds delineated based on drainage pattern and topography (Darabi et al., 2014), as shown in Fig. 1. This watershed climatically is classified as a moderate

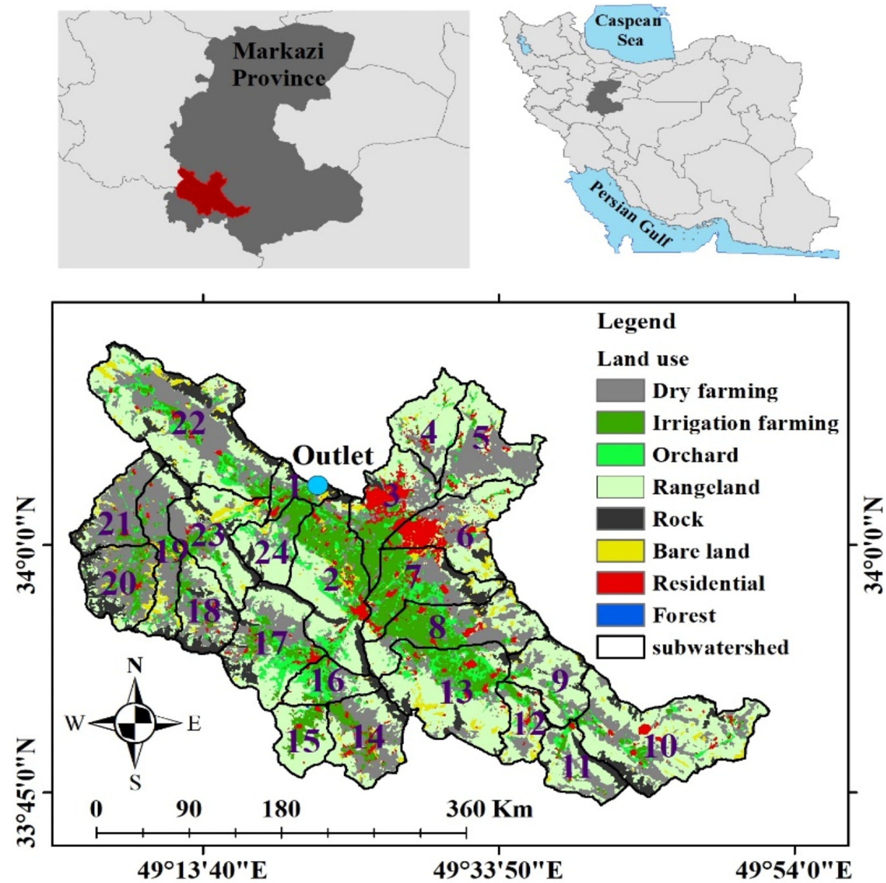

Fig. 1. General view and governing condition of the Shazand watershed, Markazi Province, Iran.

semiarid to cold semiarid region, with respective annual mean temperature and precipitation of 13.7 °C and 430 mm (Mirchooli et al., 2020). This watershed being covered mainly by rangeland, which was changed to other land uses in recent decays. The Shazand Watershed was selected as a representative study area for the semiarid regions of central Iran where high urban growth rates, industrial development, and irrigation and orchard extension have been reported (Davudirad et al., 2016). The Shazand Watershed has experienced different problems such as the critical condition of watershed health (Hazbavi and Sadeghi, 2017; Sadeghi and Hazbavi, 2017; Hazbavi et al., 2018; Sadeghi et al., 2019) and land degradation (Sadeghi et al., 2018; Kiani-Harchegani et al., 2019) during recent decades because of which further focuses on the sustainability watershed is necessitated.

2.2. Methodology

Generally, sustainability was associated with three fundamental social, economic, and environmental dimensions (Keshtkar et al., 2013; Marti and Puertas, 2020). In the current study, the policy dimension was added to consider the impact of rules and regulations. Towards that, a set of determinant indicators were selected to characterize the sustainability of the Shazand Watershed based on existing issues. The indicators were selected according to the insight conceptualization of the governing conditions on the study area, previous studies (Spangenberg, 2002; Graymore et al., 2009; Sood and William, 2011; Pérez-Maqueo et al., 2013; Hou et al., 2014; Lein, 2014; Paroissien et al., 2015; Roboredo et al., 2016; Boggia et al., 2018), and geographical knowledge of the Shazand Watershed. Though, some indicators were removed due to the unavailability of associated data.

Accordingly, 18 criteria were selected with data availability as detailed in Table 1. The criteria were organized into four different sustainable dimensions of society, economy, environment, and policy and were aggregated into a composite sustainability index. All these steps are extensively described as follows.

Table 1
Summary of criteria used for different dimension for the Shazand Watershed, Iran.

Dimension	Indicator	Abbreviation	Unit
Social	Population density	So1	Person km^{-2}
	Literacy	So2	Percentage
	Access to safe water	So3	Percentage
	Annual population growth	So4	Percentage
Economic	Percentage of employment	Ec1	Percentage
	Agricultural crop diversity index	Ec2	Dimensionless
	Production of crops	Ec3	Ton
Environmental	Mean annual rainfall	En1	Mm
	Normalized Difference Vegetation Index (NDVI)	En2	Dimensionless
	Rangeland area	En3	Ha
	Groundwater	En4	M
	Soil erosion	En5	t ha^{-1} yr^{-1}
	Patch density (PD)	En6	Dimensionless
Policy	Legal materials related to soil resources, and the environment	Po1	Percentage
	Rural cooperative company	Po2	Percentage
	Allocated budget to the environmental projects	Po3	Percentage
	Cultivation area of crops with low/high virtual water content (VWC)	Po4	Ha
	Protected area	Po5	Ha

2.2.1. Data collection and processing

2.2.1.1. Social dimensions. In order to investigate the role of the social dimension in Shazand sustainability, the most determinant and accessible criteria, viz. population density, population growth, literacy rate, and access to safe water, were selected. The entire original raw data were obtained from the Statistical Center of Iran (https://www.amar.org.ir/english). Table 1 shows the summary of different criteria used for the present study. The Statistical Center of Iran is the only authorized center that provides these data at the national level. Although, it was accredited through interviews with local administrations and field surveys.

Considering population growth leads to more human resources (Zhou et al., 2013), identified as an effective indicator. Another impressive indicator was population density which was calculated as a person per km^2. Furthermore, as other studies proved the effect of literacy for participating in initiating soil and water conservation on-farm (Habtamu, 2011), this indicator was also selected in this study. So, the number of educated and literate people in villages and towns of sub-watersheds was extracted from the data obtained from the Statistical Center of Iran. Additionally, safe water as the basic service of water to humanity (Sood and William, 2011) was considered, which directly affects the social dimension. So, water access in villages and towns was obtained from data from the Statistical Center of Iran.

2.2.1.2. Economic dimension. The economic dimension, employment rate, crop production, and crop diversity indices were considered influential factors. However, some other indicators, such as gross domestic products (GDP), were firstly considered, while they were removed from the predecessor analysis due to the unavailability of the associated data in the watershed. The related required data were also obtained from the Statistical Center of Iran (https://www.amar.org.ir/english) and the Organization of Jihad-e-Agriculture of Markazi Province.

Considering most of the Shazand inhabitants were supported by farming in past decades (Davudirad et al., 2016), crop production directly affects the economic condition. In addition, the employment rate links directly with family income. Furthermore, some phenomena or watershed characteristics such as drought or soil properties, temperature stress, and nutrient availability directly affect crop yield. Therefore, crop diversity could promote resistance and resilience to these stresses and contribute to economic activity (Elsalahy et al., 2020). So, this criterion was calculated using the Shannon-Wiener diversity index as Eq. (1):

$$H = -\sum_{i=1}^{s} p_i \, ln \, p_i$$

where p_i is the proportion of the area of a particular crop (n) divided by the total area of crop production (N) (Lazíková et al., 2019).

2.2.1.3. Policy dimension. As mentioned before, the political dimension as another influential dimension on watershed sustainability was also considered in the present study. In this vein, the number of legal materials related to natural resources and environment extracted from the Law of Economic, Social, and Cultural Development Program of the Islamic Republic of Iran. Furthermore, the percentage of the rural cooperative company as another effective criterion was obtained from the Statistical Center of Iran. Furthermore, some other criteria, such as allocated budget to the environmental projects and the associated extent of the implemented projects, protection of destroyed areas, and the area of cultivated crops with low virtual water content (VWC), were further considered. Finally, the necessary data were collected from the Organization of Jihad-e-Agriculture of Markazi Province and the General Office for Natural Resources and Watershed Management of Markazi Province.

To calculate crops with low/high VWC, the major cultivated crops were identified in different node years. Sugarcane was considered as the main cultivated crop that had low VWC in the two first node years. It means that it consumes less water for producing one kg of sugarcane. On the other hand, the bean was the primary crop with the highest VWC in the last two-node years. It should be noted that bean was the main crop in last years which it was gradually replaced by sugarcane in the first years.

2.2.1.4. Environmental/physical dimension. To consider the effects of the environmental criteria on watershed sustainability, some criteria including mean annual precipitation, evapotranspiration (ET), drought, normalized difference vegetation index (NDVI), soil erosion, groundwater level were processed and applied.

The mean annual precipitation and evapotranspiration data were obtained from the Ministry of Energy for four-node years of 1986, 1998, 2008, and 2016. The spatial variations were mapped using the Inverse Distance Weighted (IDW) method of interpolation. Drought has a detrimental impact on different conditions of social, economic, policy, and agriculture of watersheds (Yue et al., 2018), which precipitation plays a role in its persistence. Therefore, the Standardized Precipitation Index (SPI) was designated to quantify the precipitation shortage in the Shazand Watershed. Hence, the monthly precipitation data for eight meteorological stations were used to calculate 3-month SPI by the Drought Indices Package (DIP) Software to analyze the short-term drought and agricultural drought (Okpara et al., 2017).

Land use/cover map and some remote-sensing-based criteria such as NDVI were created using satellite images. These images were obtained from the United States Geological Survey (https://earthexplorer.usgs.gov) in a path of 165 and rows of 36 and 37. The land use maps of the Shazand Watershed for 1986, 1998, and 2008 were obtained from existing records (e.g., Davudirad et al., 2016), and the land use map of 2016 was generated by supervised classification and maximum likelihood algorithm. Different land uses/covers viz. bareland, dry farming, forest, irrigation farming, orchard, rangeland, residential, and outcrops were identified. In this vein, the area of rangeland was considered as another influential factor on the Shazand Watershed sustainability due to the high rate of rangeland conversion to other land uses during recent decades (Davudirad et al., 2016).

The most intensively used empirical model at different spatial scales, flexible, time-effective, and cost-efficient of the Revised Universal Soil Loss Equation (RUSLE) (Martínez-Murillo et al., 2020) was applied to estimate soil erosion in the Shazand Watershed. Furthermore, it also benefited model integration with GIS and remote sensing for better analysis (Ganasri and Ramesh, 2016).

The annual data on groundwater level of piezometric wells were obtained from the Regional Water Company of Markazi Province. The areas of crops with high and low virtual water contents were also determined for two representative crops of sugarcane and bean under the irrigation condition for the study watershed (Sadeghi et al., 2020). They were accordingly considered as the main crops with the highest and lowest virtual water content (Chapagain and Hoekstra, 2003) in two first (i.e., 1986 and 1998) and two last (i.e., 2008 and 2016) node years, respectively.

After selection, the appropriate criteria for each dimension, the statistical approach of correlation (i.e., Spearman correlation) was conducted among different criteria for choosing the variables with fewer correlations to reduce redundancy (Mazziotta and Pareto, 2013).

2.2.2. Standardization of the input variables

All criteria were standardized to remove the differences in units and magnitudes and make them consistent. So, the indicators were standardized to range from zero to one, and Eqs. (1) and (2) were used for positively (S^{+ive}) and negatively (S^{-ive}) affected indices, respectively (Pollesch and Dale, 2016).

$$S^{+ive} = \frac{X - X_{min}}{X_{max} - X_{min}} \quad (1)$$

$$S^{-ive} = \frac{X_{max} - X}{X_{max} - X_{min}} \tag{2}$$

where X, X_{min}, and X_{max} denote main, minimum, and maximum values for the study variables, respectively.

2.2.3. Weighting of the input variables

There are two kinds of subjective and objective techniques used to weigh study variables/indicators (Yao et al., 2013). An objective method was applied in the current study to overcome the limitations of human factor intervention in the subjective technique. Some objective methods, such as principal component analysis (PCA), were used as a weighted method, but it did not work for this study because of Kaiser-Meyer-Olkin (KMO) values. In addition, the successful application of the applied method in recent researches has led the authors to use it for the present study. So, the coefficient of variation method was applied as an objective weighting method as proposed by Wang et al. (2019) and followed in Eqs. (3) to (6).

$$\overline{C_j} = \frac{1}{n} \sum\nolimits_{i=1}^{n} c_{ij} \tag{3}$$

$$S_j = \sqrt{\frac{\sum\nolimits_{i=1}^{n} \left(C_{ij} - \overline{C_j}\right)^2}{n-1}} \tag{4}$$

$$V_j = \frac{s_j}{\overline{C_j}} \tag{5}$$

$$W_j = \frac{V_j}{\sum\nolimits_{j=1}^{n} V_j} \tag{6}$$

where $\overline{C}_j$ is the mean value of criteria j, S_j is the standard deviation of j, V_j is the coefficient of variation, and W_j is the weight of each indicator j.

2.2.4. Assessment of dimensions of sustainability

The combination of different criteria was designed to help policy-makers better understand the situation and gain access to different information to make the right decisions. Accordingly, the existing criteria were combined using the following linear function method (Eq. (7)):

$$Y_c = \sum\nolimits_{q=1}^{Q} I_q W_q \tag{7}$$

where Y_c is the value of the environmental, social, economic, and policy sustainability, I_q and W_q are standardized value and weight of the i^{th} indicator, respectively.

2.2.5. Development of barometer of sustainability

The barometer of sustainability as a tool for understanding and evaluating the system communications and human-ecosystem interactions might use various indicators and criteria. So that, they might also have different performances in the sound evaluation of the sustainability. Accordingly, a new barometer was developed in the present study to remove the impossibility of separate evaluation and identification of the comprehensively studied dimensions in watershed sustainability seen in existing methods like IUCN.

3. Results

The present study was formulated to assess the sustainability of the Shazand Watershed using different criteria representing various affective dimensions. Among all study variables, SPI and ET in environmental dimensions, the extent of the implemented projects in policy dimension were deleted from further calculations since they had high inter-correlation with other study criteria. The active population also correlated with other criteria in the social dimension and was removed from successor calculations. The preliminary results of criteria analyses for different dimensions are summarized in Table 2. The importance of each selected criterion in different dimensions for the study years is also given in Table 3.

The main influential factors in the social dimension (Table 3) come from population density and access to safe water in 1986, 1998. In the last two-node years (2008 and 2016), almost all sub-watersheds have access to safe water, and this criterion has lost its importance. Population density and population growth were the most critical factors in 2008 and 2016. This result is along with other researches which found population density as one of the critical factors in the socio-economic dimension (Boggia et al., 2018). This finding also agreed with Davudirad et al. (2016) and Hazbavi et al. (2019), who assessed the land degradation and watershed health in the Shazand Watershed, and notified the impact of the population during similar periods.

Table 2
Descriptive statistics of selected criteria in Social (So), Economic (Ec), Environmental (En), and Policy (Po) dimensions in study years.

Node year	Descriptive statistics	So1	So2	So3	So4	Ec1	Ec2	Ec3	En	En2	En3	En4	En5	Po1	Po2	Po3	Po4	Po5
1986	Minimum	2.30	0.50	0.00	0.00	18.50	0.02	1821.17	380.89	0.25	787.63	1845.67	10.78	0.00	0.00	0.00	0.00	0.00
	Maximum	194.51	0.28	100.00	0.03	30.76	0.04	2469.99	576.68	0.12	10,522.88	1960.03	39.23	0.00	100.00	859.70	176.47	0.00
	Mean	54.99	0.42	36.48	0.10	21.69	0.03	2132.19	476.75	0.19	3763.29	1898.07	22.98	0.00	30.27	115.04	41.66	0.00
	Standardized deviation	45.77	0.04	32.01	−0.12	2.71	0.00	175.70	65.13	0.03	2343.16	40.91	7.60	0.00	34.80	218.59	42.75	0.00
1998	Minimum	0.00	0.00	0.00	0.09	0.00	0.02	1875.02	364.13	0.24	643.29	1845.68	10.60	2.74	0.00	0.00	0.00	0.00
	Maximum	188.16	0.91	100.00	−0.04	39.99	0.05	2569.79	561.93	0.12	8279.15	1957.86	33.89	22.18	100.00	853.80	248.60	0.00
	Mean	54.31	0.66	64.88	0.00	25.71	0.03	2262.20	444.16	0.19	1888.18	1896.31	19.39	9.050	28.95	125.90	37.50	0.00
	Standardized deviation	51.38	0.15	36.32	0.03	8.36	0.00	189.91	57.66	0.03	0.64	41.99	6.12	4.61	34.31	218.42	53.19	0.00
2008	Minimum	0.00	0.00	0.00	−0.05	0.00	0.02	1713.59	344.24	0.03	505.28	1843.31	6.42	4.36	0.00	0.00	0.00	0.00
	Maximum	207.74	0.92	100.00	0.03	40.63	0.05	2254.78	491.02	0.18	8122.29	1958.32	20.75	35.27	100.00	1772.05	242.77	210.00
	Mean	106.80	0.72	95.65	−0.01	28.42	0.03	1993.78	395.16	0.24	2850.07	1893.69	12.43	14.40	24.84	278.90	25.00	8.75
	Standardized deviation	60.02	0.16	20.85	0.02	8.35	0.00	163.31	41.98	0.12	1858.01	43.75	4.30	7.34	23.78	508.08	48.01	42.86
2016	Minimum	0.00	0.00	0.00	0.00	0.00	0.02	1302.43	317.75	0.12	336.39	1843.91	10.60	1.58	0.00	0.00	0.00	0.00
	Maximum	327.95	0.84	100.00	100.00	0.35	0.05	1669.65	454.78	0.22	8162.84	1958.56	37.13	12.83	100.00	985.84	733.36	210.0
	Mean	107.89	0.61	95.83	−0.01	0.28	0.03	1518.16	382.23	0.17	2776.53	1891.14	22.03	5.24	22.28	116.19	66.66	8.75
	Standardized deviation	75.63	0.16	20.41	0.02	0.07	0.00	99.48	39.99	0.03	1924.74	44.69	7.42	2.67	24.53	279.33	144.79	42.86

Table 3
The importance of each selected criterion in different dimensions for study years.

Dimensions	Indicator	1986	1998	2008	2016
Social	Population density (S1)	0.26	0.28	0.28	0.27
	Literacy (S2)	0.17	0.16	0.15	0.26
	Access to safe water (S3)	0.36	0.36	0.26	0.21
	Annual population growth (S5)	0.21	0.20	0.30	0.27
Economic	Percentage of employment (E1)	0.33	0.24	0.22	0.22
	Agricultural crop diversity index (E2)	0.32	0.39	0.35	0.41
	Production of crops (E3)	0.36	0.37	0.43	0.37
Environmental	Mean annual rainfall (En1)	0.17	0.16	0.17	0.16
	NDVI (En3)	0.15	0.12	0.12	0.15
	Rangeland area (En4)	0.21	0.20	0.18	0.22
	Groundwater (En5)	0.20	0.29	0.29	0.24
	Soil erosion (En6)	0.10	0.09	0.11	0.13
	PD (En7)	0.15	0.11	0.13	0.10
Policy	Legal materials related to soil resources, and the environment	0.00	0.08	0.06	0.18
	Rural cooperative company	0.21	0.18	0.11	0.11
	Allocated budget to the environmental projects (P1)	0.35	0.31	0.21	0.17
	VWC (P3)	0.44	0.43	0.07	0.17
	Protected area	0.00	0.00	0.55	0.37

The economic dimension, agricultural crop diversity index, and crop production area are the most influential factors in all study years. This is because the agriculture sector was the most vulnerable sector to climate variability and drought, whose effects on various crops with different intensities were proved by previous scholars (e.g., Ray et al., 2018). So that, the high value of the crop diversity index would be of great help to indigenous people for their economic livelihood in improper climatic conditions.

In the environmental dimension, the level of groundwater and rangeland area had a significant impact with respect values of 0.20 and 0.21 in 1986; 0.29 and 0.20 in 1998; 0.29 and 0.18 in 2008; 0.24 and 0.22 in 2016, among other criteria in all studied years. Previous researchers also reported the groundwater level to decrease due to agricultural development and industrial activities (Mokhtari et al., 2011; Davudirad et al., 2016). In addition, the rangeland area also highly decreased because of the population density and population growth, urbanization, and agricultural land extension during the study periods. Rainfall was the impressive low factor among environmental dimensions due to lacking significant changes in rainfall during the study period (Davudirad et al., 2016; Hazbavi et al., 2018).

In the policy dimension, the area under cultivation of crops with high and low virtual water content (VWC) in 1986 and 1998. While the protection of destroyed areas in 2008 and 2016 was the most impressive factor in the policy dimension. However, there is no protected area in the two first node years (i.e., 1986 and 1998), so the impact of the criterion was non-significant.

3.1. Spatial and temporal variations of studied dimension across sub-watersheds

As per the procedure explained in the former sections, the results of spatiotemporal variability of the sustainability for the Shazand Watershed are depicted in Fig. 3. In addition, the inter-variability of different dimensions under consideration has been explained as follows.

3.1.1. Social dimension

As Fig. 2 showed, some 50 and 75% of the Shazand sub-watershed was classified as the moderately sustainable condition in 1986, 1998 in the viewpoint of the social dimension, respectively. However, the distribution of social dimension was changed in the last two-node years so

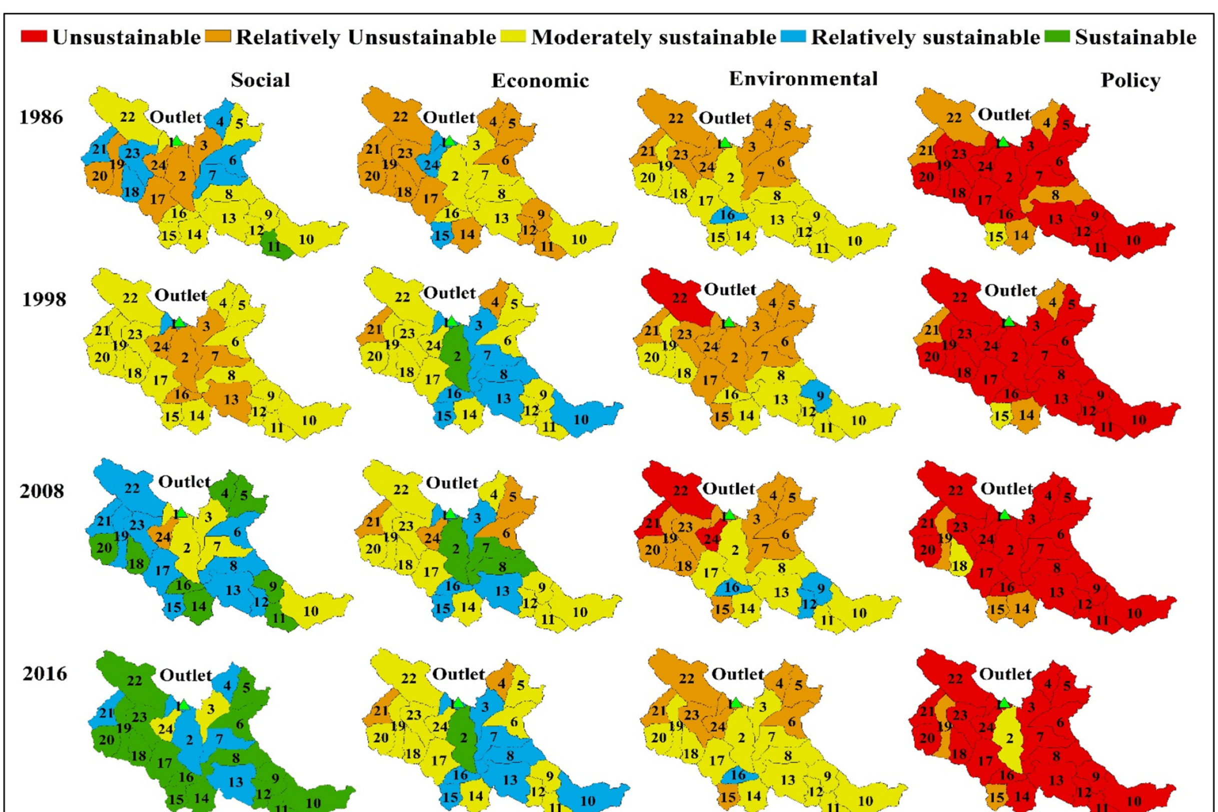

Fig. 2. Spatial and temporal variations of different dimensions of sustainability for the Shazand watershed, Iran.

that moderately sustainable conditions covered 25 and 12.5% of the sub-watersheds. Sub-watersheds 2, 3, and 24 had a worse condition among other sub-watersheds during most study years. In addition, sub-watershed 11 had the best condition compared to others in terms of the social dimension.

3.1.2. Economic dimension

The regions with relatively unsustainable conditions comprised 58% of the total sub-watersheds were mainly located in western and north-east of the Shazand Watershed in 1986. However, the condition was little improved in the second study year (1998), and the sub-watersheds with intermediate class reached 54% of the total sub-watersheds.

However, some sub-watersheds slightly improved in the third study year (2008), the condition of other sub-watersheds of 5, 6, 10, and 24 had declined. In the last study node year (2016), the condition was worsened in sub-watersheds such as sub-watersheds 7 and 8.

3.1.3. Environmental dimension

The environmental dimension of the Shazand Watershed was unstable and unevenly distributed over the sub-watersheds, as shown in Fig. 4. The northern and northwestern sub-watersheds had a constant and undesirable condition among other sub-watersheds during all study years. On the contrary, the southern and southeastern sub-watersheds had more favorable conditions in the whole study years. So that, some 54, 41, 29, and 58% of the Shazand Watershed allocated to a moderately sustainable condition in 1986, 1998, 2008, and 2016.

3.1.4. Policy dimension

The condition of the policy dimension was distinguished worse compared to other dimensions in all study node years (Fig. 3). Accordingly, appropriate policies and measures would be necessary to designate to each sub-watershed specifically. All sub-watersheds except 4, 8, 14, 15, 21, and 22 were classified as unsustainable and moderately sustainable conditions in the first two study node years. In addition, the sub-watersheds 8 and 22 were changed to unsustainable conditions, and 83% of the sub-watersheds were allocated to unsustainable conditions in terms of policy dimension. In the third node year, the relatively unsustainable and moderately sustainable conditions were limited to sub-watersheds 14, 15, 18, and 19. The Shazand sub-watersheds in 2016 gained a minor deterioration in comparison with previous years, and the sub-watersheds with the unsustainable condition in the fourth study year increased and reached the tune of some 87%.

3.1.5. Comprehensive sustainability index

The sustainability assessment results (Fig. 3) also showed that 75% of the sub-watersheds located in western, central, and northeastern of the watershed were categorized as a relatively unsustainable class in 1986. In the second node year of 1998, the sub-watershed with moderate, sustainable condition decreased, and the area of relatively unsustainable category increased and reached the level of some 83%. In 2008, the moderate, sustainable class covered three sub-watersheds of 2, 14, and 24. Furthermore, 79% of the sub-watersheds were in relatively unsustainable conditions. In the last study year, some 75% of sub-watersheds were relatively unsustainable, and sub-watersheds 2, 12, 15, 17, and 19 were moderate. Thus, none of the sub-watersheds was classified as a sustainable condition in the study years, consistent with Sadeghi et al. (2019) and Hazbavi et al. (2019), who reported similar evaluation conditions the health of the same watershed.

3.2. Development of a new barometer for sustainability evaluation

A new barometer for sustainability evaluation was developed in the current study to comprehensively indicate the sustainability condition of the watershed using all environmental, social, economic, and policy dimensions, as shown in Fig. 4. The barometer (Fig. 4) is a quadrilateral in which each side indicates the level of sustainability of each study dimension. The sustainability of each study dimension ranged between zero and one. A relative area obtained as the result of inter-connecting the allotted values to each dimension indicates the level of sustainability. In this barometer, the greater the enclosed area resulted from the

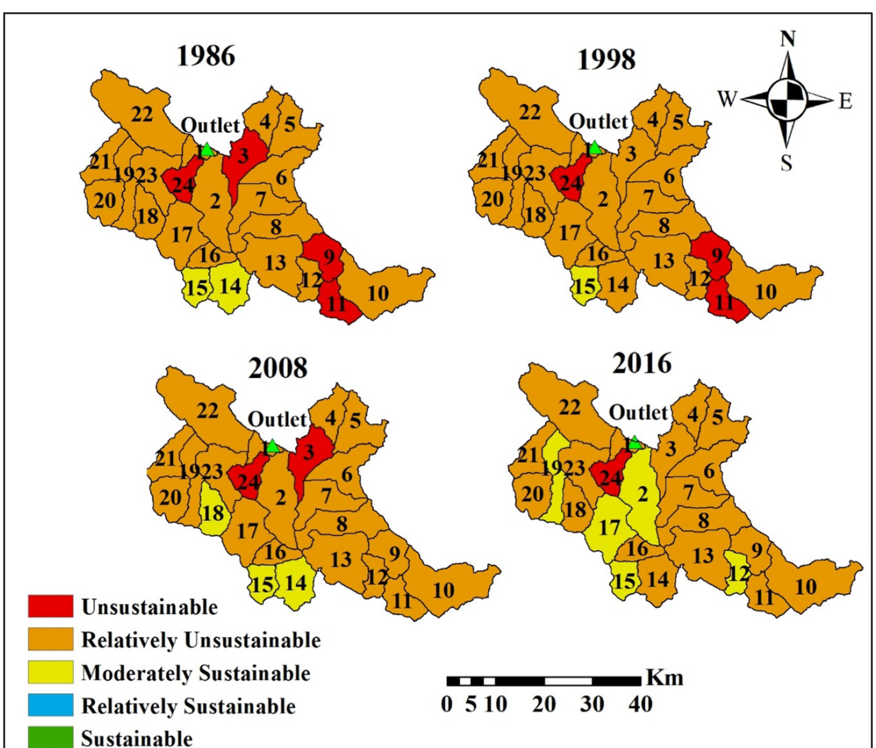

Fig. 3. Spatial and temporal variations of a comprehensive sustainability index for the Shazand Watershed, Iran.

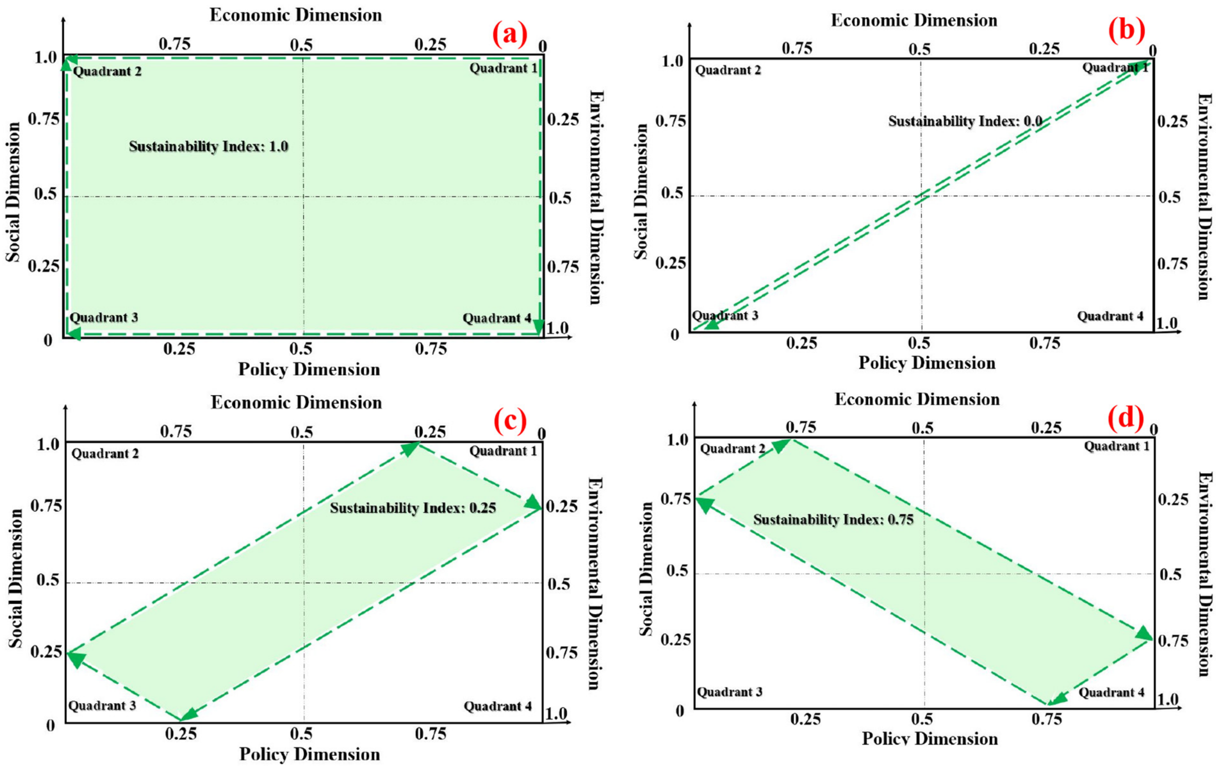

Fig. 4. Some examples of the application of the developed barometer for imaginary values of study dimensions for sustainability assessment.

intersection of these dimensions, the greater the sustainability. In addition, the more regular created quadrilateral and the more inclined to the center, the closer the values of the studied dimensions are to each other. Some examples of applying the developed barometer in which the different states are shown for imaginary values of study dimensions. When all dimensions are sustainable, and the sustainability index equals 1 (Fig. 4a), the enclosed area is at the maximum level and covers the whole area of the principal figure.

In contrast, the enclosed area tends to a line extending from the corner of quadrant 1 to the corner of quadrant 3 when all dimensions are fully non-sustainable, and the sustainability index declines to zero (Fig. 4b). In addition, the barometer was sub-divided into four quadrants for better understanding. Accordingly, the more occupation of quadrants 1 and 3 by a left downward elongated confined area, the more unsustainable it is (Fig. 4c). Adversely, the more occupation of quadrants 2 and 4 by a right downward elongated confined region, the more sustainable it is (Fig. 4d).

4. Discussion

4.1. Variation of social dimension

The spatial mapping of social dimension shows that most sub-watersheds (75%) were moderately sustainable in 1998. However, after that, its distribution was decreasing across sub-watersheds. It means 66.6% of the sub-watersheds performing relatively well with a sustainable condition in terms of social dimension during the studied years. This finding of the better condition of social dimension and importance of social dimension on sustainability was along with other researches such as Graymore et al. (2009) and Nevado-Peña et al. (2015).

In addition, the investigation of influential data indicated the undesirable condition of sub-watershed 24 also had an unpleasant condition resulted primarily from lacking access to safe water and literacy in all study node years. In this way, accessible supplies of safe water are necessary to support human health and socio-economic benefits, which other researchers mentioned (Jordan and Benson, 2015). Furthermore, the level of literacy is associated with adopting and success in improved conservation programs. In other words, literacy and educated humans are negatively associated with land degradation, which previous studies proved (Qasim et al., 2011).

4.2. Variation of economic dimension

More than half of sub-watershed (58%) were classified as a relatively unsustainable condition in 1986, which was improved in 1998. The periods of 1986–1998 coincided with the beginning and expansion of industrial activities in the watershed. Hence, employment increased due to the expansion of industrial areas. In addition, land-use change from rangeland to the agricultural area occurred in this period, which led to an increase in agricultural production and improved economic dimension in 1998. The overall economic condition in 2008 was further improved except in some sub-watersheds (i.e., 5, 6, 10, and 24) where agricultural crop diversity index and production of crops were responsible for decreasing economic dimension. In 2016, the condition of most sub-watershed was improved. In sub-watersheds 4, 7, and 8, which experienced deteriorating conditions, agricultural crop diversity index and production were identified as the principal influential factors. In all studied years, the economic dimension had significant spatial variation across sub-watersheds, which disagrees with Graymore et al. (2009), who concluded less variation and good performance of this dimension at the regional level.

4.3. Variation of the environmental dimension

Generally, the northwestern and southeastern sub-watershed had respective undesirable and desirable conditions in all studied years. However, some sub-watersheds, especially 1, 4, 5, 6, 22, 23, and 24, had unfavorable which different indicators play a significant role in that situation. For example, in sub-watershed 5, rainfall and NDVI were identified as indicators that negatively impacted this dimensional sustainability. In adverse, the groundwater level had the highest contribution rate in sub-watershed 10 with the pleasant condition. The spatial variation of the environmental dimension was also reported by other studies (Boggia et al., 2018).

Some sub-watersheds of 3 and 7 had also relatively unsustainable in three first node years (i.e., 1986, 1998, and 2008) due to intensive land-use change and impact of rangeland area criteria. This result was also verified by Davudirad et al. (2016) and Hazbavi et al. (2018), who evaluated land-use change and watershed health for the same study watershed, respectively. The results further revealed that sub-watershed 16 had the best condition in the viewpoint of the environmental dimension. This is primarily due to the favorable situation of NDVI and the rangeland area having a significant effect on relatively and moderately sustainable conditions in all study years. Graymore et al. (2009) also proved that land-use had a significant impact on environmental conditions and sustainability for Victoria Region, USA. In addition, these results agree with Munda et al., 2009 who showed the undesirable condition of an indicator could be moderate by other indicators in the same dimension.

4.4. Variation of policy dimension

The investigation of the policy criteria revealed that in 1986 and 1998, lacking the legal articles related to soil resources, environment, water resources conservation, and protection of destroyed areas significantly contributed to the unsustainable condition of the policy dimension, moreover, in the last two years (2008 and 2016), insufficient and shortage of allocated budget to environmental projects negatively impacted sustainability in most sub-watersheds.

Sub-watershed 15 had a better condition in terms of policy dimension due to allocating appropriate budget to the environmental projects and Rural Cooperative Company in the whole study period. The moderate condition of the policy dimension in sub-watersheds 18 and 2 in 2008 and 2016 was, on the other hand, linked to the desired state of the environmental budget.

4.5. Variation of comprehensive sustainability index

The analysis of the sustainability index (Fig. 3) indicated that the sub-watersheds located in the northwestern and southeastern had lower values where are classified with the highest priority for managerial and rehabilitation measurements. These findings agreed with Sadeghi et al. (2018), who reported the fragile conditions of land degradation in central parts of the watershed in two first study nodes (i.e., 1986 and 1998).

Most sub-watersheds (75%) were categorized as relatively unsustainable conditions in 1986, in which social and environmental dimensions were identified to have a significant impact on the condition of sustainability. These results agreed with Boggia et al. (2018), who concluded the great importance of the social dimension in Malta. In 1998, the sustainability conditions of 11 sub-watersheds were getting a bit deteriorating, which economic dimension was responsible for that. In this way, 83% of the watershed has been categorized in a relatively unsustainable status. Overall, the economic dimension was the most influential factor among all study dimensions in 14 sub-watersheds. After that, the social dimension was the most influential in six sub-watersheds.

Similarly, in 2008, more than half of the entire watershed was located in the relatively unsustainable condition class. Sub-watershed 3 gets a bit deteriorated with a comprehensive sustainability index of 0.18 due to the influence of the environmental dimension. In addition, the improvement in terms of social and environmental dimensions in 2008 caused sub-watersheds 14 and 18 to have a more favorable situation. Ultimately, in 2016, the sub-watersheds located in the south and center of the Shazand Watershed, especially sub-watersheds 2, 9, 10, 11, 12, 16, and 17, were recovering over time. Because of a better condition in social, economic, and policy dimensions, sub-watershed 19 had recovered and reached a moderate level of sustainability. In addition, sub-watershed 24 had an unsustainable condition in all studied years due to environmental and policy dimensions. So, it requires the immediate adoption of management measures. The results agreed with Nevado-Peña et al. (2015), who indicated the social dimension moved to sustainability in some European cities.

4.6. Evaluation of barometer of sustainability

In this study, a new barometer of sustainability was proposed, which overcame the existing barometer limitation.

For example, the values obtained for social, economic, environmental, and policy dimensions for sub-watershed 1 and the whole watershed for the node year of 1986 were 0.46, 0.60, 0.32, and 0.06; and 0.51, 0.40, 0.40, and 0.12, respectively as shown in Figs. 4 and 5. The overall sustainability of sub-watershed 1 and the entire Shazand Watershed was calculated as 0.28 and 0.32, respectively, classified as relatively unsustainable.

Similarly, the social, economic, environmental, and policy dimensions for sub-watershed 1 in 1998 were calculated as 0.60, 0.65, 0.31, and 0.05 with an overall sustainability index of 0.29, which verified relatively unsustainable conditions. At the same time, these dimensions obtained the respective values of 0.46, 0.55, 0.39, and 0.11 for the Shazand Watershed with an overall sustainability index of 0.32 and relatively unsustainable conditions. In the third node year (2008), the sustainability dimensions of social, economic, environmental, and policy for sub-watershed 1 were 0.55, 0.73, 0.26, and 0.07, and for the Shazand Watershed were calculated as 0.71, 0.56, 0.38, and 0.09. Correspondingly, the overall sustainability for the sub-watershed 1 and the Shazand Watershed was found 0.29 and 0.35, respectively. Finally, in the last node year, the sustainability dimensions of society, economy, environment, and policy for sub-watershed 1 were 0.79, 0.83, 0.36, and 0.04, and for the Shazand Watershed were 0.80, 0.59, 0.41, and 0.08, respectively. Accordingly, the sustainability indices for sub-watershed 1 and the entire watershed were 0.31 and 0.35, respectively, categorized as relatively unsustainable. The details have been demonstrated in Fig. 6.

In addition, the watershed sustainability was calculated using the IUCN barometer for the Shazand Watershed in the study years. In this way, to calculate human wellbeing, social and economic indicators were applied. First, the reference values were used to define thresholds of performance scale intervals that correspond to values from 0 to 100 in the barometer of the sustainability scale. Then, the values of indicators were transposed to the barometer of sustainability scale using the associated formula, and arithmetic means were applied to calculate hierarchy levels. This calculation was also performed for an environmental subsystem. The results showed that the human wellbeing and ecosystem wellbeing for the first node year were 25 and 40. Then, the human wellbeing and ecosystem wellbeing were calculated as respective values of 17 and 39 for 1998, 21 and 38 for 2008, and 19 and 41 for 2016. So the sustainability condition was classified as relatively unsustainable, unsustainable, relatively unsustainable, and unsustainable in 1986, 1998, 2008, and 2016, respectively. These conditions are close to the proposed barometer of sustainability in the present study.

5. Conclusion

The present study considered the impact of the policy in addition to social, economic, and environmental dimensions for the assessment of watershed sustainability, which has been rarely used in previous studies. Moreover, a new barometer of sustainability was also developed using four dimensions to bridge the gaps of the existing barometer. To this aim, the newly developed multi-dimensional barometer was established as a sustainability framework using some 17 different criteria and eventually exemplified for the Shazand Watershed, Iran.

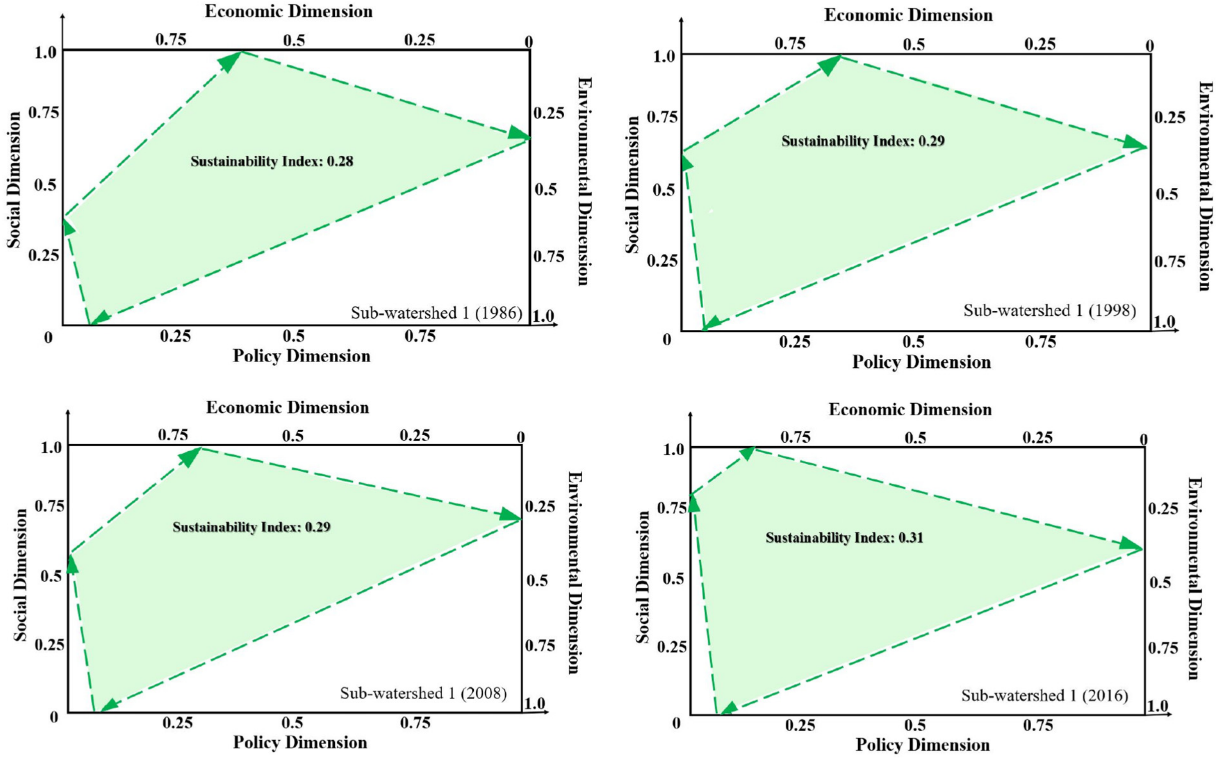

Fig. 5. Proposed barometer of sustainability for sub-watershed 1 in the Shazand watershed, Iran.

The spatial and temporal dynamics of study dimensions were also well-conducted for the study watershed. It was found that the policy dimension had an undesirable condition in all study years. Most parts of the watershed, especially western and southeastern sub-watersheds, were subjected to a high status of the social dimension, particularly in 2008 and 2016. The sub-watersheds were mainly classified as relatively unsustainable at 75, 83, 79, and 75% of the sub-watersheds in respective node years. In addition, no sub-watersheds were in the sustainable

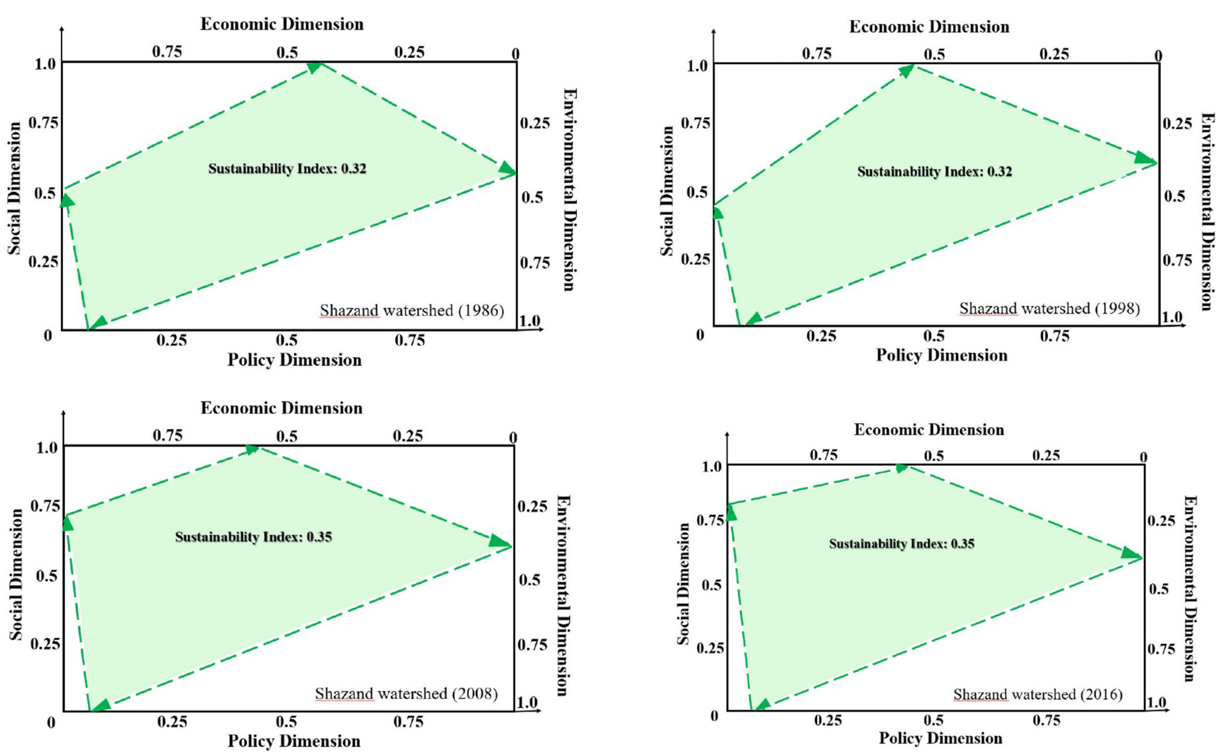

Fig. 6. Proposed barometer of sustainability for the Shazand watershed, Iran.

condition in all study years of 1986, 1998, 2008, and 2016. The results also indicated that sub-watershed 24 was classified as an unsustainable area in the last study year. So, this sub-watershed could be considered the primary priority for restoration activities and needs more attention from managers and decision-makers. Moreover, the sub-watersheds situated in the northwestern and southeastern had lower values where have a critical condition, were categorized as the highest priority for managerial measurements.

The results of the comprehensive sustainability index are a simple understanding index for regional managers and policy-makers to explicitly identify areas most in need of initiatives to progress sustainability. So, it can help prioritize sub-watersheds to implement effective mitigation strategies and revitalization measures and develop the planning. In addition, the proposed barometer of sustainability facilitated understanding the dimensional sustainability and comprehensive watershed sustainability.

The main limitation of this work is the unavailability of data and criteria such as GDP, which could influence the results of this study. So, this research suggested some further studies with more accessible criteria and longer data set facilitating a more comprehensive conclusion.

CRediT authorship contribution statement

F Mirchooli: Conceptualization, Methodology, Validation, Investigation, Data curation, Resources, Data collection and field inventory, Formal analysis, Validation, Writing- Original draft preparation, Software

SHR Sadeghi: Conceptualization, Methodology, Validation, Investigation, Data curation, Writing - Review & Editing, Supervision, Project administration, Funding acquisition

A Khaledi Darvishan: Methodology, Software, Supervision

Josef Strobl: Methodology, Software, Supervision, Project administration, Funding acquisition

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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