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Trend assessment of the watershed health based on DPSIR framework

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ABSTRACT

In integrated watershed management, to identify efficient managerial responses, assessment of the status and dynamic of watershed health is crucial. This study focused on analyzing the main environmental problems for Gorganroud watershed health using the Driving force-Pressure-State-Impact-Response (DPSIR) framework. The trend of each DPSIR index was also computed using 18 quantitative indicators during the years 2004–2018. Prioritization of the watershed problems using the Friedman test ranked loss of groundwater resources, flood potential, and soil erosion rate as the most important challenges of the watershed. The results showed that except for the S index, all the other have an ascending trend during the study period. The trend slopes of D, P, S, I, and R indices were equal to 0.08, 0.05, -0.05, 0.02, and 0.04, respectively. This means the health of Gorganroud watershed becomes worse over time due to the socioeconomic activities and related pressures. Although some practical measures have been implemented as responses to balance other indices of DPSIR, however, they are neither sufficient nor integrated. The response of increasing water use efficiency has resulted in a rebound effect, causing higher consumption of water resources (Jevons Paradox). While only an integrated approach would guarantee the long-term health of watersheds, fragmented watershed governance structure has made serious challenges for the Integrated Watershed Management approach in the study area.

1. Introduction

Watersheds are social-ecological systems (SESs) where humans and other organisms interact with the physical environment and each other (Cabello et al., 2015; Gari et al., 2018). Watersheds can provide benefits for humans which defined as watershed services. Watershed services are essential to humans and range from water supply to water-risk mitigation to cultural benefits and ecological functions (Hamel et al., 2018). These hydrological response systems are the most appropriate units for analyzing water resources, land use planning and management (Wang et al., 2016). Environmental Protection Agency (EPA) of the U.S. has shifted towards integrated watershed assessments for states (Ahn and Kim, 2019). By the late twentieth century, population growth resulted in increasing constraints on the availability of watershed services. Unfortunately, watersheds are degrading or have the potential to become impaired due to anthropogenic activities and climate change (Hazbavi and Sadeghi, 2017; Mosaffaie et al., 2015). Water deficiency, land degradation, desertification, and natural hazards are creating serious long-term sustainability problems for the health of watersheds in Iran (Mosaffaie, 2015, 2016; Sadoddin et al., 2016).

The health of watershed refers to the maintenance of the "normal" state of such a complex adaptive system. Healthy watersheds play a key role in providing watershed services (Alilou et al., 2019). Watershed health evaluation has been one of the most practical approaches for assessment of the status and dynamics of watersheds (EPA, 2014). Several efforts have been done to assess watershed health, based on factors such as climate, soil erosion, flood occurrence, water quantity and quality, or a socioeconomic index (Sadeghi and Hazbavi, 2017; Sadeghi et al., 2018; Alilou et al., 2019; Ahn and Kim, 2019; Hazbavi et al., 2019). As an instance, Hazbavi et al. (2019) assessed the Shazand watershed health based on the pressure–state–response (PSR) framework during the years 1986–2014. Therefore, assessment of watershed health is crucial for watershed management and the allocation of its natural resources.

Lack of an appropriate management system and governance mechanisms is assumed to play a major role in the improper health state of Iran watersheds (Sadoddin et al., 2016; Mosaffaie and Salehpour Jam, 2018). This situation increased recognition of the importance of and need for an integrated approach to watershed management. Watershed management is an ever-evolving practice involving the management of land, water, biota, and other resources in a watershed for ecological, social, and economic purposes (Wang et al., 2016; Mosaffaie and

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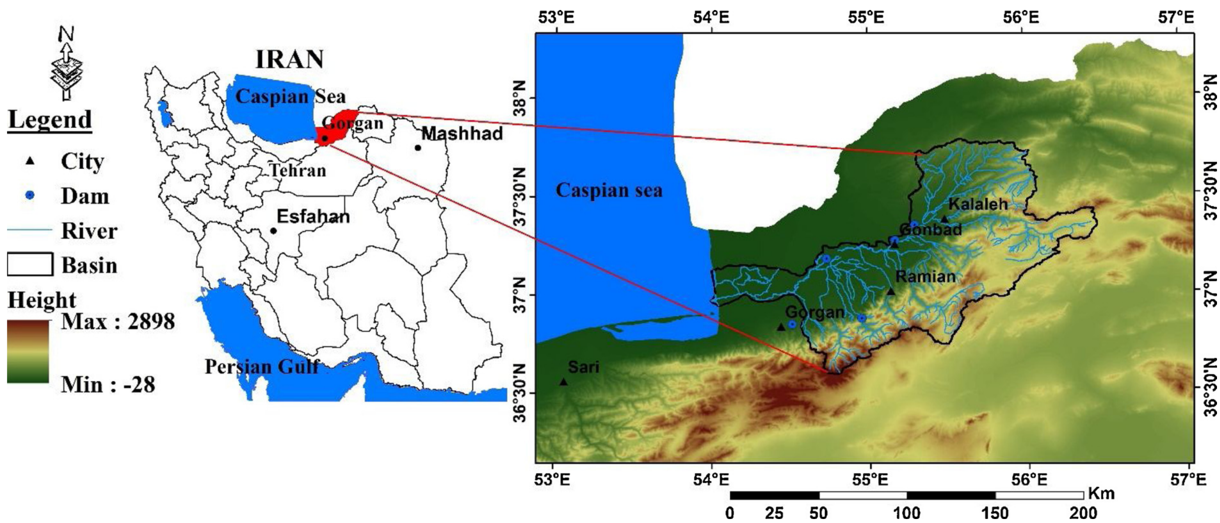

Fig. 1. Location map of Gorganroud watershed in Iran.

Salehpour Jam, 2018). Integrated watershed management grapples with the complexity of interactions between socio-economic systems and ecosystems, and aims to sustain and restore the health, biodiversity, and productivity of ecosystems through strategies that integrate the needs of the economy and the society (Einar, 2010; Qi and Altinakar, 2013). Considering the importance of IWM, a national mega-project has been approved by the High Council of Sciences, Research, and Technology of Iran to apply such an approach. Project executers developed a framework for IWM with 6 main steps. The first step is watershed system recognition which followed by outlining the conceptual model, designing solutions, choosing solutions, implementing solutions, monitoring and evaluating achievement respectively (Sadoddin et al., 2016). This framework has been implemented in Gorganroud watershed as a pilot before implementing for all over the country. According to the first step of this framework, it is essential to assess ecological problems for watershed health, which will help inform the decision-making and planning process. Since conceptual frameworks are useful to outline the watershed health (Hazbavi et al., 2019), this study was aimed to assess the health of Gorganroud watershed based on Driving force-Pressure-State-Impact-Response (DPSIR) framework.

The DPSIR framework is one of the original tools for adaptive management of SESs (Gari et al., 2015). This conceptual approach is extensively used for analyzing environmental problems by establishing cause-effect relations between anthropogenic activities and their environmental and socio-economic consequences (e.g. OECD, 1993; EEA, 1995; Bidone and Elliott, 2002; Lacerda, 2003; Borja et al., 2006; Haase and Nuissi, 2007; Svarstad et al., 2008; Bell, 2012; Kagalou et al., 2012; Tscherning et al., 2012; Namaalwa et al., 2013; Sun et al., 2016; Gari et al., 2018; Mell, 2020). The two features that have contributed to the wide use of DPSIR are, (i) it structures the indicators regarding the political objectives related to the environmental problem addressed; and (ii) it focuses on supposed causal relationships in a clear way that appeals to policy actors (Smeets and Weterings, 1999). Shao et al. (2014) present the framework as an investigative tool that analyses socio-economic and ecological issues answering the questions of what, why and how. "What happened?" which is described by S term, is what the evaluator first addresses and also is the focal point of the evaluation. After "What happened?" is clear, it is necessary to analyze why it happens because it can guarantee and guide evaluators about what happens. It is also a necessary condition to understand "how to address it". The DPSIR model depicts "why it happened" through P and D terms. After knowing why it happened, we can and should further analyze "how to deal with it". There are many ways to achieve this goal, either directly through S or I, or acting on P or D. Gari et al. (2015) concluded that DPSIR is a useful adaptive management tool for analyzing and identifying solutions to environmental problems. For adaptive management, this approach brings together natural science, social science including economics in one framework and considers human activities as an integral part of the ecosystem. Therefore the DPSIR is also a useful tool for identifying policy direction which enhances the sustainable utilization and appropriate management of watershed resources.

Noting these preliminaries, the main objectives of this paper are to identify the most important environmental problems for the health of Gorganroud watershed (What happened or S term as strong representative of watershed health), analyzing why they have happened, and to suggest appropriate responses (How to deal with them?) which enable planning of management alternatives for sustainable use of watershed services. The specific objectives consist of identification and analysis of (i) the various drivers leading to watershed problems; (ii) pressures related to the identified drivers; (iii) impacts resulting from state change; (iv) responses and policy directions which help to sustainable utilization of watershed services.

2. Material and methods

2.1. Study area

The Gorganroud is a river in northeastern Iran, flowing through Golestan province and ends to Caspian Sea. Although Iran is generally classified as arid and semi-arid, the climate of Gorganroud watershed is characterized as being semiarid in the east and wet in the western regions. The average annual precipitation ranges from 195 to 946 mm and the temperature of the basin ranges between 11–18.1 °C annually in watershed stations. Approximately 36 % of the normal precipitation falls from January to March. The maximum and minimum elevations of the watershed are 2898 and 10 m above sea level, respectively. In general, the topography of the watershed is characterized by a complex combination of mountains (46 %), hills (10 %), plateau and upper terraces (5%), piedmont plains (15 %), river alluvial plains (16 %) and low lands (8%). Major land uses include agriculture (37 %), rangeland (34 %) and forest (28 %) and the main crops are wheat, barley, sunflower, and watermelon (Fig. 1).

The Gorganroud watershed is the population center of Golestan Province in Iran, hosting approximately 1.2 million people. This watershed supports an economy based on agriculture (46 % of the population), industry and mining (20 % of the population), and contains wildlife habitats. Voshmgir dam in the watershed supports the supply of water to the public, flood control, and irrigation. The condition of Gorganroud estuary is of concern, partly as a result of upstream water use, including several dams, such as Voshmgir, Golestan, and Bostan. Currently, about 55 % of the time Gorganroud Estuary is dry without any in-stream environmental flow, causing grave environmental problems, particularly about fish habitat (Fatemi et al., 2013). Stream flow deficit volume of the watershed is lower in humid and very humid climates compared to semi-humid and semi-arid climates (Alijani et al., 2016).

2.2. Methods

Since the aim of this study is to apply the DPSIR framework for analyzing watershed health, the structure of the current research is consist of four main stages including 1) identifying the major environmental problems of the watershed and DPSIR structuring of them (conceptualization), 2) selecting the key quantitative indicators for DPSIR indices, 3) collecting and screening the data and 4) trend analysis of each DPSIR indices. In the following, each of the mentioned stages has been explained.

2.3. DPSIR conceptualization

The DPSIR framework was developed by the Organization of Economic Cooperation and Development (OECD, 1993) and the European Environment Agency (EEA, 1995). It has evolved from the S—R framework since 1979 (Friend and Rapport, 1991) through the P—S—R (OECD, 1993) to the DPSIR framework (EEA, 1995). Due to the outstanding features of the DPSIR framework, it was selected to assess the major environmental problems which have affected the health of Gorganroud watershed. To obtain a preliminary knowledge about DPSIR terms, a thorough understanding of Gorganroud watershed system was obtained through field surveys, documents, news websites, scientific articles, interviews, and books before applying the framework. The most important environmental problems for the watershed health along with their causes were first identified incorporating stakeholder's viewpoints. So, a regional experts group was first formed incorporating 24 specialists related to environmental issues (Gorgan university of agricultural sciences and natural resources, 4 experts; Golestan administration of Natural Resources And Watershed Management, 6 experts; Golestan administration of Environmental Protection, 4 experts; Golestan Regional Water Authority, 4 experts; Golestan agricultural jihad organization, 4 experts; Golestan Agricultural and Natural Resources Research and Education Center; 2 experts). Then, team members were interviewed by 3 main open-ended questions. These questions were as follows: 1) what are the major environmental problems of the watershed? (What happened?), 2) what are the causes of the problems? (Why they have happened?), and 3) what are the answers to problems? (How to deal with them?). Then, these problems were prioritized to identify the most important problems that have endangered the health of the watershed. Prioritization process was conducted using the Friedman test and based on the same expert's viewpoints and Likert's scale of 1–5, where 1 represented the most urgent problem to be tackled. The Friedman test is a non-parametric statistical test that aims to detect significant differences between the two or more problems. In this test, the null hypothesis states that all problems are similar (their ranks are equal) and the Friedman statistic which is distributed according to a χ^2 distribution is computed with $k-1$ degrees of freedom (Derrac et al., 2011). Eventually, it ranks the problems separately; the most performing problem should have the rank of 1, the second most rank 2, etc.

In the next step, the three most important problems were analyzed using the DPSIR framework. Due to the presence of multiple problems (S) that have interactions with each other, multiple DPSIR cycles were used. Regarding the definitional discrepancies, EEA definitions with the recent modifications on term of state and impact were considered in this work. Based on this modification the impact refers only to human welfare, and the impact on the environment has been moved to the state term (Gari et al., 2015). To make better use of the framework, valuable recommendations of previous studies (EEA, 1995; Elliott, 2002; Bidone and Lacerda, 2003; Borja et al., 2006; Haase and Nuissi, 2007; Bell, 2012; Kagalou et al., 2012; Namaalwa et al., 2013; Sun et al., 2016; Gari et al., 2015, 2018) was also tried to be get used.

2.4. Selecting key indicators

Indicators are values derived from parameters that provide information about a phenomenon. Developing indicators depends on the definition of what one wants to indicate (Gari et al., 2015). The choice of key indicators can make a critical difference in the results of an evaluation. Finding indicators that will be both valid and feasible is often the most challenging design issue in a monitoring system or evaluation. Good indicators are simple, variable, valid, clearly defined, measurable, reliable, and quantifiable (Gari et al., 2015, 2018). Indicators should neither be too numerous, to avoid cluttering the overview, nor too few to provide sufficient information (OECD, 1993). The OECD (1993) further elaborates that the selection of indicators depends on policy relevance, measurability, and analytical soundness.

Accordingly, after analyzing the economic, societal, and environmental characteristics of Gorganroud watershed, some indicators were selected to assess each DPSIR index quantitatively. Due to the lack of available and sufficient related data, in this study, the process of indicator selection has been concentrated on the available but key indicators. The selected indicators are useful to qualitatively assess the magnitude of pressures, the extent of state change, and the severity of impacts. Moreover, they help to assess the effectiveness of responses made by measuring the degree of progress towards management targets (OECD, 1993). This can be achieved by comparing the frequency and type of responses and the change in the every DPSIR indices. Last but not least, indicators highlight the technological level and type of drivers. It should be noted that the magnitude of an activity can be determined considering the extent of the object on which the activity takes place, what type of tool or technology they are using and how many actors are involved in the activity (Gari et al., 2018). So in this study, the process of indicator selection was based on the principle that the magnitude of activities is a function of the action availability (e.g. agricultural land, industry, and rangeland), actors (e.g. farmer, rancher) and technology (e.g. equipment).

2.5. Collecting and preparing data

Broad different types of data mainly including environmental, social, economic, industrial, agricultural, meteorological, and hydrological data were used in this study. However, as in many other countries, data and information are usually collected and presented based on the political boundaries of Iran. Therefore, most of the data used in this research was obtained from statistical yearbooks and studies by governmental agencies at the provincial and national levels. The hydrological data were obtained from the studies conducted by the Regional Water Company of Golestan Province (RWCGP, 2017) (http://www.gsrw.ir/?l=EN) and Iran Water Resources Management Company (IWRMC, 2016) (http://www.wrm.ir/index.php?l=EN). The socio-economic data were extracted from the statistical yearbooks published by the Management and Planning Organization of Golestan Province (MPOGP, 2020) (http://www.en.golestanmporg.ir/) and analysis done by the Planning and Budget Organization of Iran (PBO, 2020) (https://www.mporg.ir/en). Agricultural and industrial data were obtained from agricultural statistics data published by the Ministry of Agriculture-Jahad (MAJ, 2020) (https://www.maj.ir/index.aspx?tempname=NewEnMain&lang=2&sub=0). Other data regarding the watershed problems were also extracted from previous researches and studies conducted in Gorganroud watershed (Mohammadi et al., 2007;

Saadat et al., 2008; Sharifi et al., 2011; Fatemi et al., 2013; Alijani et al., 2016; Azari et al., 2016 & 2017).

Because of the complex types of evaluation indicators in the evaluation process, the dimensions of the coefficients are not necessarily identical. Therefore, the indicators were often not comparable. So, the maximum difference normalization method (Eq. 1) was used to standardize data and eliminate the dimension impact caused by different ranges and units of indicators.

$$Z = \frac{X - \min(X)}{\max(X) - \min(X)} \tag{1}$$

Since indicators such as sediment production and flood numbers have reverse relationship with watershed health, Eq. 2 was also used for negative contributions of such indicators in the standardization process.

$$Z = \frac{\max(X) - X}{\max(X) - \min(X)} \tag{2}$$

After this standardization, the maximum value is normalized to 1, the minimum value is normalized to zero, and the rest of the values are between zero and one.

Then, quantification of each DPSIR indices were performed using assigned weights and the standardized indicators (Eq. 3).

$$W = \sum_{i=1}^{n} I_i * X_i \tag{3}$$

Where, W is the each DPSIR index, I_i is the importance (weight) of each indicator and X_i is normalized values of indicators. The W value ranges in [0,1] and the greater its value, the higher the degree of index.

2.6. Trend analysis

Because of several indicators with different importance, Analytic Hierarchy Process (AHP) was used to quantify the contribution (weight) of each indicator on each DPSIR index. The AHP is a structured technique for analyzing complicated problems. It has particular application in group decision making and weighing factors based on multiple criteria and pairwise comparisons (Saaty, 2008). The process of AHP used in this study can be summarized in four steps: set up a matrix to compare indicators; rate the relative importance of indicators using pairwise comparisons and the scale of 1–9 (pairwise comparisons conducted by viewpoints of 10 regional environmental specialists); determine the relative importance (weight) of indicators, and eventually check the consistency of the evaluations.

The trend analysis is simulation exercises based on the law of history (Shao et al., 2014). Other studies have assessed the trend of similar ecological phenomena during a period of 5 or 10 (Shao et al., 2014; Sun et al., 2015; Mosaffaie and Salehpour Jam, 2018) years, however, this study used longer years (2004–2018) as research period due to available data. Then, trend analysis were performed using the each DPSIR index (W) which include the annual change during the research period (Eq. 3).

3. Results & discussion

3.1. Casual analysis of the main important environmental problems

The focal point of DPSIR analysis is the S (state) index. According to field studies, literature reviews, and also interviews with the stakeholders, firstly, 10 environmental problems were identified in Gorganroud watershed. These problems have led to adverse impacts on watershed health and consequently, reducing in watershed services. The prioritization results of the Friedman test have been presented in Table 1. This showed the loss of groundwater resources, flood and soil erosion rate are the main challenges (state), which affect the health of Gorganroud watershed. Fig. 2 shows the causal relations among DPSIR indices in the study area. The population of Gorganroud watershed has increased over the last decades. Population growth has caused an expansion in the watershed's economic activities such as agricultural, industrial, and ranching activities. These demands have caused dramatic pressures on watershed resources. By increasing water demand, the allocated water to the environment has decreased which has affected watershed health and stability (Zare et al., 2019).

Furthermore, limited watershed resources including soil and water along with the lack of sufficient occupations, have also exacerbated poverty in the region. Increasing poverty and declining welfare in the mountainous areas have led villagers to increase the number of their livestock. Therefore, the slope of the mountains are relatively bare due to livestock overgrazing. Consequently, overgrazing has caused compaction of the soil and widespread different types of erosions including splash, sheet, rill, and gully ones. The declining welfare has also caused forests and pastures to be changed into rainfed agricultural lands by the villagers. Because of land use and soil characteristics changes, the watershed's Curve Number (CN) has been increased, and consequently, the retention coefficient has been decreased (Kousari et al., 2010; Hashemi et al., 2014). Runoff is affected by the maximum potential retention coefficient, so low numbers show a high runoff potential especially for short return periods of storms. Conversion of natural land uses has adversely affected the hydrology of the watershed. This has provoked floods, an increasing runoff coefficient, and reducing groundwater recharge. In other words, the hydrological alteration resulting from land use changes have severely affected the infiltration rate, the volume of runoff, and maximum flood discharge as well as its frequency. As an instance, the flash flood in 2001, notably in the Madarsoo sub-catchment upstream of Golestan Dam killed at least 300 persons. Factors such as bare soils, movable materials, steep slopes, high rainfall intensity, deterioration of pasture and forests, and inappropriate agriculture and development practices as well as climate change have been cited as the main causes of this event (Sharifi et al., 2011). The maximum amounts of runoff and sediment yield are largely produced in steep areas of the watershed, where dry farming is practiced (Mahzari et al., 2016). Saghafian et al. (2008) concluded that land use change in the watershed is one of the most important reasons for the increase in flood events. The soil characteristics and linear cultivation facilitate conditions for the high rate of runoff generation and soil erosion. Flooding will increase sediment delivery to the reservoirs; therefore, it will reduce the capacity of the flood control and water supply. It is concluded that land use changes in erodible soils of the region have accelerated the amount of runoff and soil erosion (Lar Consulting Engineering, 2007). The soil erosion has reduced the productivity of agriculture and rangelands that has consequently declined the income of the farmers and ranchers of the watershed.

In general, in addition to groundwater deficit, Gorganroud watershed suffers from accelerated soil erosion, flash floods, and high sediment yield (Saadat et al., 2008).

Nested DPSIR analysis of the main problems identified the population, agriculture, ranching, industry, and human welfare as the main socio-economic drivers of the watershed. The pressure reflects the factors which caused by drivers and affects watershed health negatively. In this research, these pressures include the excessive use of various watershed resources such as water consumption (agricultural, industrial, and household), vegetation consumption, and land resources consumption. Based on EEA definitions and recent modifications, flood damages, the decline in rural people's incomes, and difficulties of rural life conditions are considered as indirect impacts of D and P. DPSIR process detected several responses that some have been implemented but others have not been implemented in the watershed. Implemented responses include items such as reduction of population growth, reduction of watershed resource consumption, soil and water conservation in waterways, restoration of forests and rangeland cover, and alternative occupations with less dependency on watershed resources. Unimplemented responses include items such as creating and strengthening insurance services, developing water harvesting systems,

Table 1
Prioritization results of Friedman test based on 24 expert viewpoints.

Problem (state)	Mean rank	Rank	Deg. of freedom	χ^2	Asymp. Sig.
Loss of groundwater resources	8.57	1	9	73.788	0.00
Flood potential	7.2	2			
Soil erosion rate	6.9	3			
Loss of soil fertility	6.17	4			
Decrease grazing capacity of rangelands	6.13	5			
Deteriorating water quality	6.03	6			
Contamination of soil resources	5.07	7			
Cold stress	4.43	8			
Drop in sea level	2.83	9			
Decreasing tourism capacity	1.67	10			

increasing agricultural productivity, assessment of ecological capability and land use planning, optimization of water allocation for different sectors, creating flood warning systems.

3.2. Trend analysis of DPSIR indices

After selecting the indicators and collecting related data, each DPSIR index was calculated using Eq.1 for the years 2004–2018 (Table 2). The variation in the values of overall index over the study period and their trends has been presented in Fig. 3. The trend slopes of D, P, S, I, and R indices were equal to 0.08, 0.05, -0.05, 0.02, and 0.04 respectively. The results show that except for the S index, all the other indices have an ascending trend in the mentioned period. The negative trend of S index means that the health of Gorganroud watershed becomes worse during the study period. It should be noted that the responses provided in the DPSIR framework include both implemented and unimplemented ones. Since there was no indicator or measurement data for unimplemented responses, R index was computed solely for implemented ones.

The declining trend of watershed health indicates that the expected services will not be achieved. While the implemented responses index has an ascending trend, the state of the watershed has not been improved. This happens due to some reasons. As an instance, despite the ascending trend of well blockage, the total water consumption has also increased during the study period. It has happened due to rural people have drilled considerable unauthorized wells, which pumped more water than the blocked ones.

The other response which has not improved the state of the watershed is the expansion of lands under novel irrigation systems. The goal of these types of irrigation is to reduce water consumption. However, this technology has expanded the lands under irrigated agriculture through surplus stored water. In other words, although the implemented response has improved the water use efficiency during the agricultural production process, a rise in water consumption has been resulted. This specific case of the rebound effect is known as the "Jevons paradox". The Jevons paradox occurs when technological progress promotes the efficiency by which a resource is used, but the rate of consumption of that resource rises due to increasing demand. According to previous studies, the efficiency gains in water use will not be adequate to offset the water use due to the effects of the expansion in the production scale (Perry et al., 2009; Sun et al., 2015). Similar to the mentioned studies, the current study also showed that the improvement in water use efficiency has not guaranteed to save water but to increase the agricultural production scale. Therefore, the improvement of water use efficiency is a tool to achieve sustainable use of water resources, but it also must be coupled with measures that increase the yield of products, not the scale expansion. Thus, only an integrated program would guarantee the long-term health and profitability of the watershed resources. This program, which called IWM, grapples with the complex interactions between socio-economic systems and ecosystems. The IWM aims to sustain and restore the biodiversity, productivity, and health of watershed ecosystem through strategies that integrate the needs of the economy and society (Einar, 2010; Mosaffaie et al., 2019). To succeed, it must be experimental, adaptive, and participatory and involve all pertinent stakeholders. Also, it must identify an appropriate balance between protection and development, and integrate all data about the social, economic, and environmental processes affecting natural resources (VanHouten, 2014).

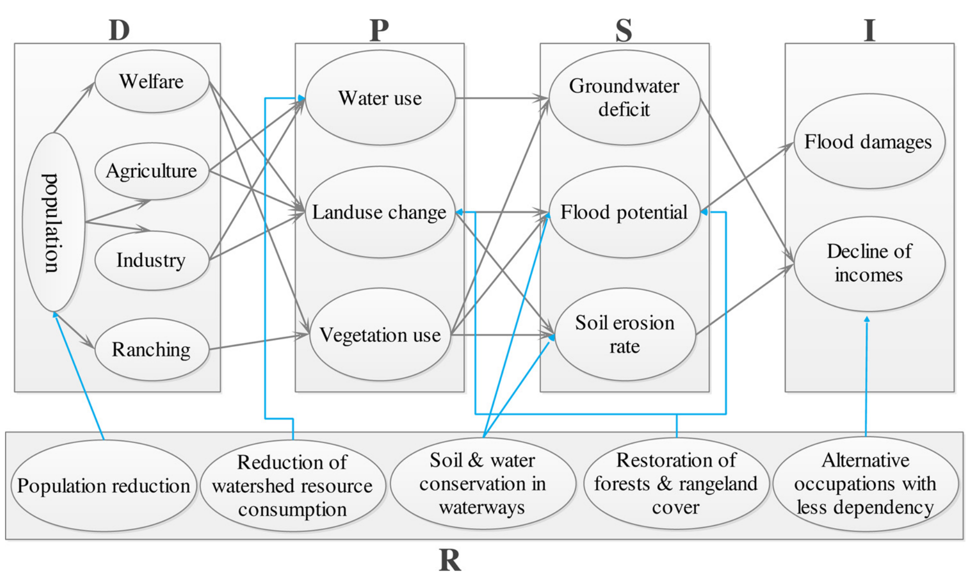

Fig. 2. Casual relations among the DPSIR indices in Gorganroud watershed.

Table 2
The values and weights of different indicators for each DPSIR indices during 2004-2018.

DPSIR indices		Indicator				Year												
		name	unit	source	weight	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
D	population	population	10^3 person	MPOGP[1], PBO[2]	0.31	1.617	1.634	1.651	1.669	1.687	1.777	1.794	1.822	1.843	1.856	1.869	1.873	1.887
	welfare	Engle coefficient	–	MPOGP	0.05	0.372	0.415	0.396	0.386	0.431	0.418	0.440	0.413	0.452	0.463	0.472	0.464	0.452
	agriculture	real GDP	10^6 rials	MPOGP, MAJ[3]	0.39	70,992	93,775	101,960	114,993	131,239	144,408	233,243	296,759	346,987	419,278	493,567	549,267	672,459
	industry	real GDP	10^6 rials	MPOGP	0.09	17,426	23,583	30,230	28,535	35,562	52,585	75,078	85,279	102,678	126,728	143,567	168,257	193,278
	ranching	grazing livestock	10^3 animal unit	MAJ	0.16	3.502	3.601	3.703	3.811	3.811	3.830	4.135	3.826	3.717	3.783	3.873	3.927	3.896
P	water use	total water use	MCM	RWCGP[4], IWRMC[5]	0.35	980	976	978	982	971	971	971	990	1029	1029	1024	1031	1038
	land use change	cultivation area	10^3 ha	MAJ	0.39	641.3	671.4	646.5	658.8	668.4	673.7	642.6	678.2	681.4	676.2	689.6	692.5	703.6
	vegetation use	total consumption of forage	10^3 ton	MAJ	0.26	560.4	576.1	592.5	609.7	609.7	612.8	661.6	612.1	594.7	605.3	619.7	628.3	623.3
S	groundwater deficit	plain unit hydrograph	m	RWCGP, IWRMC	0.38	24.60	24.19	23.35	22.16	23.29	21.70	22.38	24.10	21.73	19.86	20.93	20.09	18.26
	flood potential	number of floods	count	RWCGP, MAJ	0.34	4	5	6	4	8	5	4	13	5	6	5	9	7
	soil erosion rate	total sediment production	10^6 ton	RWCGP, MAJ	0.28	15.49	16.59	15.79	14.99	17.30	14.93	16.78	21.68	18.65	22.68	15.90	21.88	19.87
I	flood damages	flood damages	10^6 rials	RWCGP, MAJ	0.42	1.99	502.73	80.01	202.84	90.54	300.94	596.34	869.04	1412.61	1593.60	1449.25	1648.63	2142.36
	decline of incomes	rangeland forage production	10^3 ton	MAJ	0.36	168.27	165.34	159.58	153.49	154.38	157.64	149.67	146.72	145.48	142.37	144.32	144.31	142.27
		benefit/cost for water pumping	–	RWCGP, MAJ	0.22	2.73	2.68	2.59	2.46	2.58	2.41	2.48	2.67	2.41	2.20	2.32	2.23	2.03
R	population reduction	population growth rate	%	MPOGP, PBO	0.13	2.13	1.91	1.74	1.59	1.47	1.38	1.24	1.21	1.15	1.17	1.05	1.03	1.03
	reduction of watershed resource consumption	Lands under pressure irrigation	%	MAJ	0.20	11.9	12.1	12.3	12.9	13.5	14.5	16.3	17.2	17.8	19.1	19.5	22.8	23.6
		well blockage	count	MPOGP	0.16	80	118	281	222	162	140	141	118	123	204	362	508	201
	soil & water conservation in waterways	volume of check-dams	m^3	MAJ	0.12	207.7	140.9	121.7	32.8	51.5	47.6	72.5	277.1	352.1	310.2	569.2	1006.1	623.1
		The total length of river training	km	MPOGP	0.16	10.21	11.45	13.57	14.32	14.89	15.24	15.78	16.21	16.72	17.31	17.78	17.96	18.64
	restoration of forests & rangeland cover	area of biological practices	ha	MAJ	0.15	5518	4932	4578	1744	3020	4615	1267	1803	2934	1334	6920	6504	6184
	alternative occupations with less dependency on watershed resources	industrial/traditional meat production	–	MAJ	0.08	1.721	1.754	1.794	1.823	1.834	1.856	1.872	1.893	1.906	1.912	1.923	1.927	1.931

* Consistency ratios of the AHP method for D, P, S, I, and R indices are equal to 0.07, 0.07, 0.06, 0.05, and 0.9 respectively.
Management and Planning Organization of Golestan Province (MPOGP).
Planning and Budget Organization of Iran (PBO).
Ministry of Agriculture-Jahad (MAJ).
Regional Water Company of Golestan Province (RWCGP).
Iran Water Resources Management Company (IWRMC).

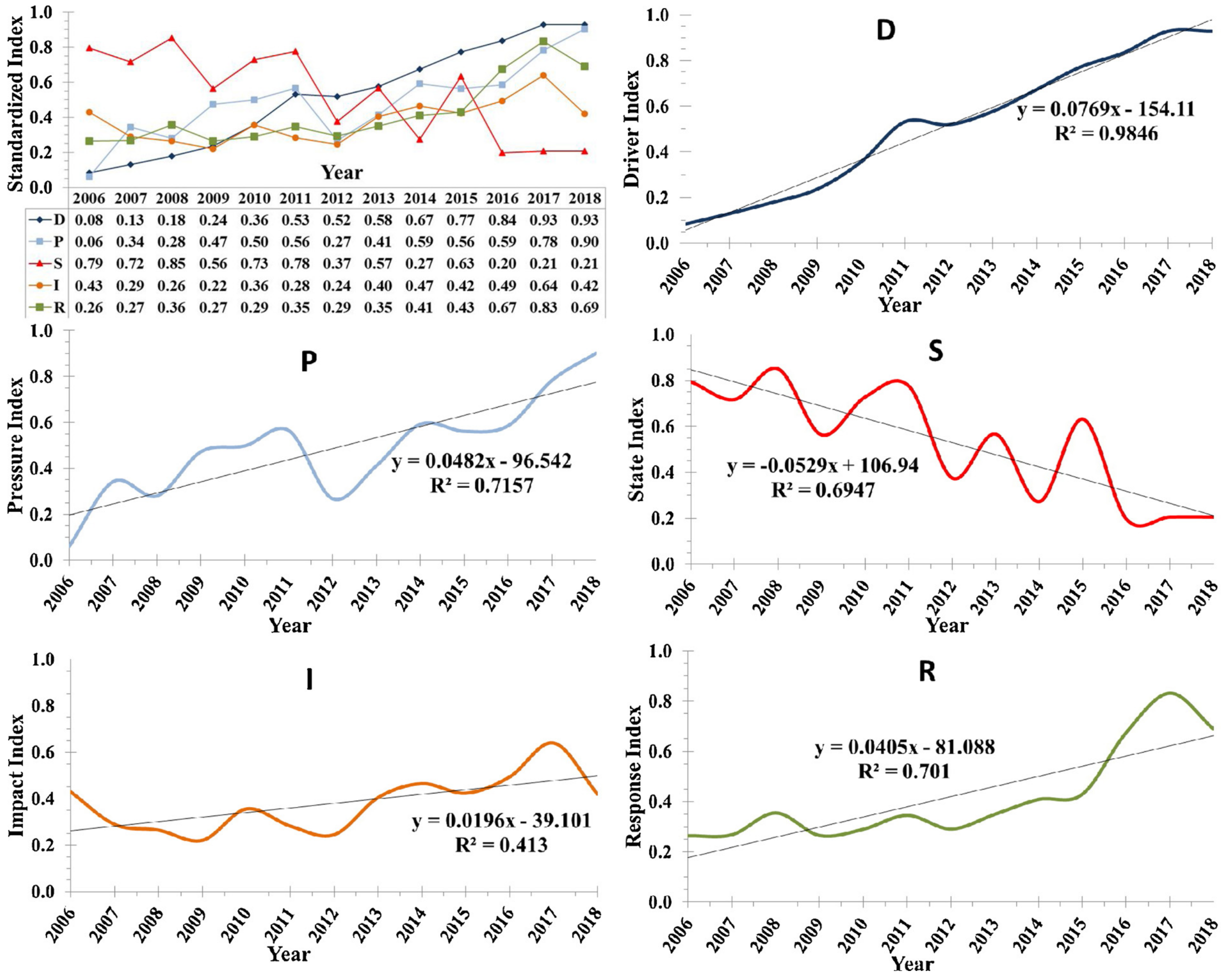

Fig. 3. Trend chart for different DPSIR index values during 2004-2018.

The main problem to accomplish IWM in Iran and particularly in Gorganroud watershed is fragmented watershed governance structure. The Ministry of Energy is responsible for setting policy for water and water provision for domestic, agricultural, and industrial sectors, generating hydropower, treating wastewater, and collecting data on water resources. Iran Meteorological Organization is in charge of collecting climatic data. The Department of the Environment is responsible for protecting the environment, both plants and animals especially wild ones. The Ministry of Agricultural Jihad is responsible to provide food security for the country through self-sufficiency within the agricultural sector. Watershed management including soil and water conservation is also among the tasks of the Forests, Range, and Watershed Management Organization. These fragmented organizations have made IWM a complex task in Iran. This indicates that improving the current organizational structure and establishing a unitary organizational structure is crucial for watershed participatory governance. This structure which could be called as "watershed council" should include all various stakeholders (different organizations, people, NGOs …) of the watershed.

Incomplete implementation of all responses derived from DPSIR analysis is other reason for the declining trend of Gorganroud watershed state. This watershed has great potentials in terms of beekeeping, sericulture, medicinal plants, sturgeon extraction, agricultural processing and packaging industries. Natural attractions such as numerous waterfalls and beautiful landscapes, cultural attractions (rural and nomadic), climatic and ecological diversity, located on the route of numerous pilgrims to holy Mashhad also cause this watershed to have a great potential in terms of tourism attraction. Despite these capabilities, most of the economic activities of this watershed are focused on agriculture, ranching as well as industries which put a lot of pressure on different watershed resources including soil, water, and vegetation. Therefore, developing the appropriate infrastructure for the mentioned capabilities which put less relative pressure on watershed resources could promote the income and welfare of the people. This shift in the type of people's livelihood can reduce the pressure on the watershed resources by decreasing activities such as agriculture and ranching.

These outcomes show that the DPSIR approach is a useful framework to present a general picture of watershed health.

This framework successfully relates the cause-effect chains for the major watershed problems. However, there are some limitations presented in this study. The bias and incompleteness of the selected indicators, data uncertainty, and data unavailability will cause uncertainty of the results of the study. As an instance, due to limited data, the current study used the Engel coefficient as indicator of watershed resident's welfare. However, the Engel coefficient usually is used as the living standard of the people life. Based on Engel's law the proportion of income spent on food falls as income rises, even if absolute expenditure on food rises. The other problem facing this study was the disagreement between the watershed boundaries and political boundaries. In Iran and most countries, data and particularly agricultural censuses are usually collected and presented on the basis political units. Watershed boundaries such as Gorganroud, which are the best units for the management of the natural resource, usually do not conform to these political boundaries. Despite such limitations, this study could provide an effective approach for analyzing watershed problems and their interrelationships with the socioeconomic system. Other studies have also indicated that despite data limitations, the DPSIR framework is capable to describe cause-effect relationships of environmental problems to the extent that data were available (Gari et al., 2018). To fill the data gap among the DPSIR indices chain and to create a brighter connection between them, more empirical research is needed on the different indices of the DPSIR approach.

4. Conclusions

This study was aimed to analyze the main environmental problems for the health of Gorganroud watershed based on the DPSIR framework. Among the study variables, the loss of groundwater resources, flood potential, and soil erosion rate are the main problems for watershed health. The trend of each DPSIR index was also shown according to 18 quantitative indicators during the years 2004–2018. This study indicated that the health of Gorganroud watershed becomes worse over time due to the socioeconomic activities and related pressures. Trend analysis of various DPSIR indices revealed that although some executive measures as responses have been implemented to enhance the status of Gorganroud watershed, they are not sufficiently integrated and stronger measures are needed. While the fragmented watershed governance structure and overlapping responsibilities of different organizations have made the IWM a complex task in Iran, this research suggests that only an integrated approach would guarantee the long-term health of watersheds. Therefore, establishing a unitary organizational structure involving all stakeholders' representatives is crucial for watershed participatory governance. Finally, this study indicated that in order to obtain IWM, despite data limitations, the DPSIR approach provide a robust framework for brightening the cause-effect relationships.

Declaration of Competing Interest

The author declares no conflict of interest

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.landusepol.2020.104911.

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