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Prioritizing the causes of desertification and its control strategies using the DPSIR. Case study: Ivanki, Semnan Province

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Abstract

The most important step in assessing and controlling desertification is identifying relevant indicators and determining their significance. This study applied the DPSIR framework—comprising the components of Driving forces, Pressures, State, Impacts, and Responses—in the study area. The results from 180 questionnaires were analyzed using SPSS software and prioritized with the Friedman test. The analysis identified 6 driving forces, 13 pressures, 3 state factors, 9 impacts, and 32 responses. A Cronbach's alpha coefficient of 0.87 for the expert-completed questionnaire confirmed satisfactory levels of validity and reliability. According to the results, the most significant response for controlling desertification was "reviewing population growth policies in land use planning," while the least important was "desilting operations in dams." The most important driving force was identified as "population growth," and the least important was "industrial development." For pressures, the most and least significant were "improper land use change" and "fires," respectively. Implementing various reactive and preventive responses based on these priorities is crucial for enhancing ecosystem health and preventing the spread of desertification in the region.

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Introduction

Desertification has a profound and widespread impact on arid lands around the world and is considered a serious challenge for human societies (Akbari et al., 2024; Sarbazi et al., 2022). This phenomenon is often accompanied by changes that can last for years, leading to permanent and irreversible consequences (Gray et al., 2018; Talebanfard et al., 2022;). The factors influencing desertification include both environmental (climatic and geological) and human activities, with human factors being the most significant (Akbari et al., 2020a). There are numerous strategies for controlling and managing desertification, but their effective implementation requires planning and coordination between relevant government agencies, research sectors, and executive units. However, the selection of the most appropriate strategy depends on identifying the factors and assessing the status and severity of desertification in each region (Memarian & Akbari, 2020b; Mofaei et al., 2021; Sarbazi et al., 2022; Akbari et al., 2024). Therefore, accurate assessment of the desertification status and trend using related indices, along with a more detailed evaluation of their significance, and proper prioritization using multi-criteria decision-making models, is an effective tool for implementing proper management strategies (Jazi et al., 2018). One of these model is the DPSIR approach, which includes five components: driving forces, pressures, state, impacts, and responses. Each of these components is continuously related to the others. This model has been comprehensively endorsed by the European Environment Agency and not only considers environmental impacts but also the socio-economic effects resulting from ecosystem changes. Experts and policymakers use the output data from this framework to develop potential responses (Shao et al., 2014; Karaskosa, 2018; Soleimanpour, 2019; Elliott, 2011; Karimi Sangchini et al., 2022; Tavakolnia et al., 2018; Mahdikarbalai, 2016).

Soltani et al. (2021) identified the factors influencing dust generation in the Hendijan County using the DPSIR approach and presented management strategies using expert questionnaires, Likert scale, and Friedman tests. Their research concluded that population growth, agricultural activities, livestock and industrial development, and climate change were the primary driving forces in the region. Amin Fank et al. (2022) found that factors related to the crisis in the Urmia Lake watershed were categorized into 45 different indices, among which climate change (as a driver for the Urmia Lake crisis), inappropriate policies, and weak water management (as pressures on the spread of the crisis) had the highest priority. The study also revealed that the most significant responses to the Urmia Lake crisis and its sustainable management included forming new organizations, implementing groundwater balancing programs, enhancing the capacity of non-governmental organizations, enforcing water protection laws, and increasing promotional and educational activities for farmers in water conservation.

Malek Mohammadi et al. (2021), in their study of the prioritization of factors affecting rangeland degradation in Shahrud County, using the DPSIR conceptual model, showed that the primary driving force was the need for employment and food, directly causing pressure factors such as economic problems in local communities, increased erosion, and reduced rangeland areas. The ecosystem services affected by these conditions include provisioning (fodder and water production with a score of 0.7), regulating (soil conservation with a score of 0.63), and cultural (landscape beauty with a score of 0.5). Soleimani Sardoo et al. (2021) demonstrated that the DPSIR causal framework and the system dynamics approach were effective in evaluating and simulating various policies in the study area. Additionally, in the "business-as-usual" scenario, the water sufficiency ratio for agriculture decreased from 0.55 in 2006 to 0.2 by 2021, but in the "increase water supply" scenario, this ratio increased to 0.9 by 2021. The research by Sheikh et al. (2020) in the Hablehroud watershed revealed that "land planning and management" strategies were prioritized in all decision-making approaches. "Preparing and developing comprehensive watershed and water resources management programs," "preparing and developing land use planning at various scales," and "identifying and educating new and alternative occupations" were ranked first to third, respectively. Thus, for better watershed management and achieving sustainable development, more attention should be given to land planning and management strategies. Soleimanpour et al. (2023) examined the risks of land subsidence in the Seydan-Farouq, Marvdasht plain in Fars Province using the DPSIR framework. The findings indicated that in this plain, driving forces such as population growth, agricultural and horticultural and industrial development, and climate change had created pressures on the watershed resources. The main pressures included "over-extraction from the groundwater table for agriculture" and "failure to respect the environmental water rights of the aquifer," which contributed to the unsustainable lowering of the water table. This situation resulted in adverse impacts such as "land and aquifer degradation." Key management responses suggested for improving the situation were "increasing irrigation efficiency" and "changing crop patterns." Ningal et al. (2008) applied the DPSIR model in the "Mirobe" region and identified land use as the primary factor influencing the area. With the projected population increase, land cover changed, leading to higher groundwater usage, which accelerated and exacerbated land subsidence. The study by Dzonga et al. (2020) indicated that the main drivers of desertification in the Ngomeni and Kipini fishing regions on Kenya’s northern coast were the high population growth rate (3.7%) and the heavy dependence on natural resources (74%). The study by Navid Ahmad and Schneider (2020) showed that the DPSIR study provided an overall perspective on the multiple pressures and status changes in the Mekong River region in Vietnam, along with potential responses for forming systematic and sustainable approaches to reduce and adapt to the effects of widespread river sand and gravel extraction. Ku et al. (2020) demonstrated the influence of land use demand in the urban developement and land use policy, which showed an increasing trend. The findings suggested that land use policies should consider the complexity of urban land expansion in urban land management. Overall, the framework, methods, and findings of this study could contribute to improving the effectiveness of land use policies, not only in China but also in other developing countries. The study by Duan et al. (2021) in the Chaohu watershed in China showed that the water quality in the watershed decreased with the socio-economic development and associated pressures, and the main response strategy was to reduce the pressure from socio-economic development on water quality in the watershed. The method proposed in this study improves the understanding of the impact of watershed management performance and provides solutions for future management actions.

This research was conducted with the aim of identifying and prioritizing the main drivers and pressures affecting desertification in the study area, as well as determining and prioritizing appropriate management responses to control or mitigate desertification and its adverse effects.

Materials and Methods

Study Area

Ivanki, located in the westernmost region of Semnan Province, has earned the nickname "the province’s forehead." This city, with a population of 12,462 (according to the 2022 census), is situated 55 kilometers east of Tehran. Geographically, Ivanki is located at a longitude of 52°06'31" East and a latitude of 35°34'53" North. It experiences a cold and dry winter climate, in contrast to its very hot summers. Ivanki is situated at an approximate altitude of 1,200 meters above sea level and covers an area of 826 square kilometers (8.7% of the total area of Garmsar). The city comprises 11 villages, with the villages of Chahdab, Cheshmeh Nadi, Kark, Ahmadabad, and Hosseinabad being included in this study.

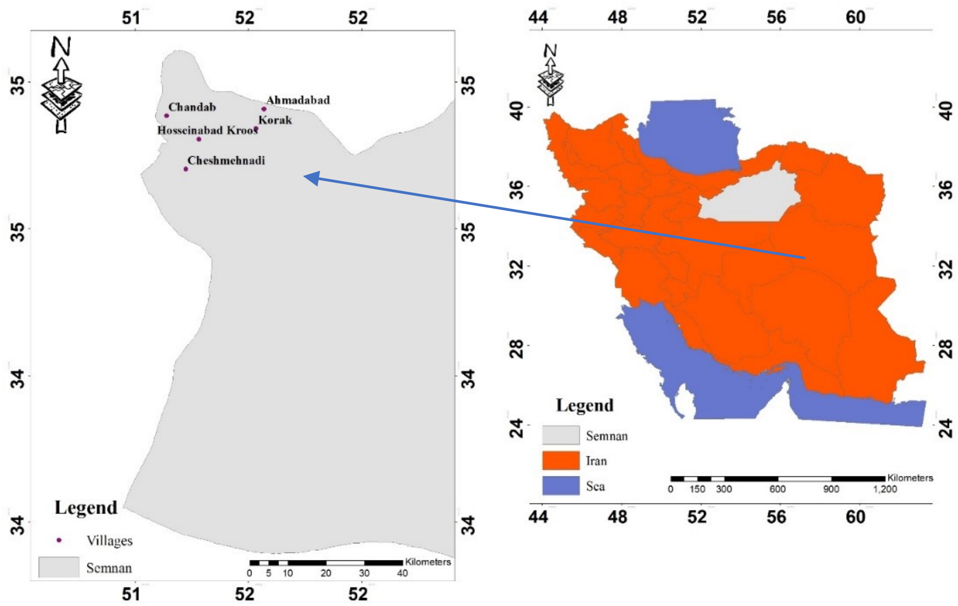


Figure 1. Location map of the study area

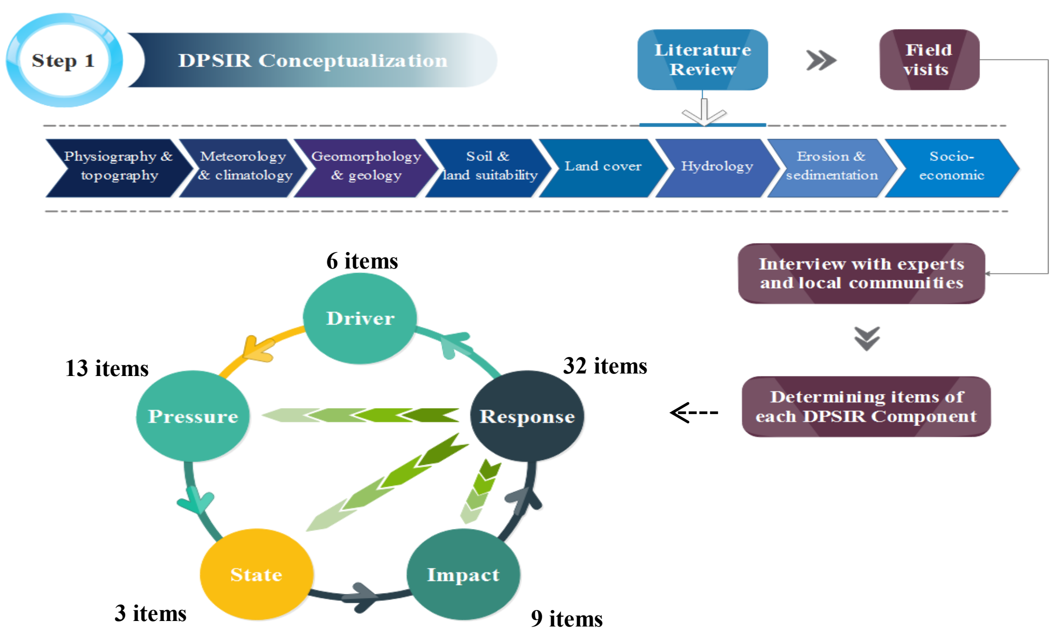
Methodology

In this study, the initial phase involved structuring the topic by examining the cause-and-effect relationships between the elements of the DPSIR model. This model follows a logical sequence, beginning with identifying the current status (including environmental issues and challenges). Then, by analyzing the direct (pressures) and indirect (driving forces) factors contributing to the adverse state, cause-and-effect relationships are created. To illustrate the different components of DPSIR (Table 1), a multi-stage approach was adopted (Figure 2). This included reports from different organisations (hydrology, climate, phsiography, soil and lands cover, erosion, socio-economic), examining environmental issues, conducting site visits, and interviewing experts in various fields such as natural resources, environmental management, regional water, and agricultural organisation, as well as academic faculty members, local community representatives, and other knowledgeable stakeholders regarding the area. A Participatory Rural Appraisal (PRA) was conducted to refine and complete the components of DPSIR, focusing on key issues in the region. Subsequently, the viewpoints of the residents were discussed and compiled during the final working group session. The working group consisted of 26 experts with over a decade of experience and a comprehensive understanding of the region's challenges (Figure 2).

Table 1. Indicators of the five components of the DPSIR

Response (R)	Response (R)	Impact (I)	Status(S)	Pressure (P)	Driving Force (D)
Monitoring mining activities in the region (R20) Implementation of watershed management and groundwater conservation operations (R21) Insurance services for damages (R22) Support packages for damage compensation (R23) Design of drought monitoring and early warning systems (R24)	Revision of Population Growth Policies in Land Use Planning (R1) Reform of land tenure laws (R2) Revision of self-sufficiency policies in agricultural and horticultural products (R3) Revision of self-sufficiency policies in livestock production (R4) Review of industrial development policies in the region (R5)	Increased production costs (I1) Damage to land and infrastructure (I2) Decreased food security (I3) Reduced forage production	Increased Erosion (S1) Susceptibility Decreased Soil Fertility (S2) Land Subsidence (S3)	Extreme Temperature Variations (p1) Reduced Precipitation (P2) Changes in Precipitation Timing Distribution (P3)	Climate Change (D1) Population Growth (D2) Land Affairs Laws (D3) Self-sufficiency in Agricultural

Response (R)	Response (R)	Impact (I)	Status(S)	Pressure (P)	Driving Force (D)
Identification and Planting of Species Resistant to Temperature Changes and Suitable for the Region (R25) Implementation of rangeland management programs (R26) Development of rainwater harvesting systems (R27) Sediment removal operations in dams (R28) Formation of NGOs Based on Integrated Watershed Management Plans, Programs, and Objectives (R29) Establishment of a coordination committee for integrated watershed management (watershed council) (R30) Prioritizing and addressing factors affecting public participation in implementing rangeland management, desertification control, and watershed management programs (R31) Implementation of All Natural Resource Projects in the Framework of Integrated Watershed Management Programs (R32)	Awareness-raising to reduce risks (R6) Design of early warning and fire extinguishing systems (R7) Improvement of living standards for residents, both economically and socially (R8) Revision of grazing permits (R9) Job creation and alternative livelihoods (R10) Strengthening the natural resources protection units (R11) Ecological capacity assessment and incorporating it into land use planning (R12) Water and soil conservation activities (R13) Agricultural education and promotion (R14) Development of volumetric controls in the region (R15) Increasing productivity in agricultural production (R16) Adaptation to water scarcity (improvement of irrigation patterns, crop patterns, and water consumption patterns) (R17) Increasing the Supervision Unit for Proper Groundwater Extraction (R18) Revision and allocation of environmental water rights (R19)	and grazing capacity (I4) Decreased income for local residents (I5) Reduced lifespan of downstream dams (I6) Increased migration from rural areas to cities (I7) Lower success of water and soil conservation projects (I8) Loss of biodiversity (I9)		Wildfires (P4) Shrub Cutting (P5) Excessive Livestock (P6) Improper Land Use Change (P7) Uncontrolled Expansion of Orchards in Sloped Lands (P8) Plowing Along the Slope (P9) Cultivation in Sloped Lands without Agricultural Potential (P10) Over-extraction of Groundwater (P11) Neglecting Environmental Water Rights of the Aquifer (P12) Uncontrolled Mining Activities (P13)	Products (D4) Self-sufficiency in Animal Products (D5) Industrial Development (D6)



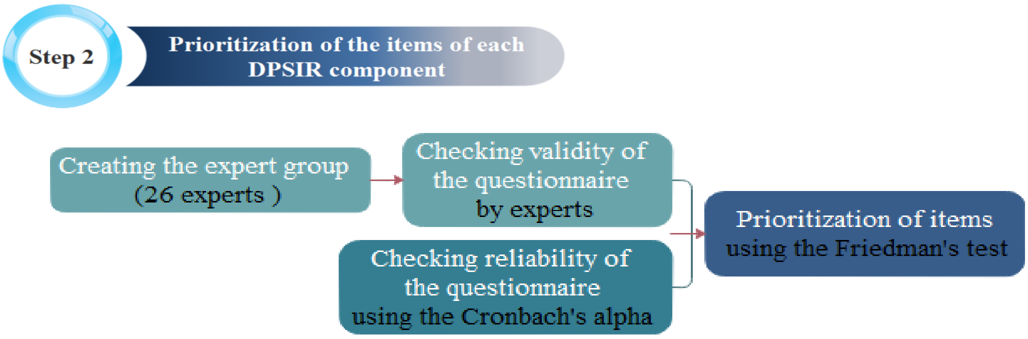


Figure 2. The study flowchart for structuring the DPSIR framework and prioritization of different items of each DPSIR component

A matrix was designed to document the existing driving forces, pressures, status, impacts, and corresponding management responses. This matrix helps decision-makers visually understand the complex interactions in the DPSIR model. To assess the importance of each categorized indicator, a Likert scale questionnaire was used, with a ranking from 1 (very low) to 5 (very high) for the importance of each indicator. The validity of the questionnaire was confirmed by experts. For reliability assessment, Cronbach's alpha method with a threshold of 0.7 was used, indicating consistency (Equation 1) (Mansourfar, 2006).

Equation (1): $$\alpha = \frac{k}{k-1}\left(1-\frac{\sum_{i=1}^{k} S_i^2}{S_t^2}\right)$$

K, The number of items

S_i^2 , The variance of the scores for item number j

S_t^2 ‹The variance of the total scores for each respondent (the total variance of the items)

The Friedman test in SPSS software was used to rank the indicators within each group based on their importance (Equation 2). A significance level smaller than 0.01 or 0.05 indicates differing priorities among the indicators. Finally, the Friedman test was applied for hierarchical analysis of the importance of indicators for each component through ranking and comparing the averages.

quation (2):

$$\chi^2 = \frac{12}{Nk(k+1)}\sum_{j=1}^{k} R_j^2 - 3N(k+1)$$

In this relation:
Where:

K is the number of columns or questions,

N is the number of rows,

Rj is the sum of the ranks in column j.

In this case, the degrees of freedom are calculated as k−1 (Mansourfar, 2006).

Results and Discussion

Validity and Reliability of the Questionnaire: The validity of the indicators was confirmedby experts, and to assess reliability, Cronbach's alpha coefficient was calculated. The Cronbach's alpha for the questionnaire completed by the experts was 0.87. These results indicate that the questionnaire has satisfactory levels of validity and reliability. In Tables 2 and 3, the rankings of the driving forces and pressures based on the experts' views are presented.

The most important driving force in the region, according to experts, is population growth (D2) (4.96), while the least important is industrial development (D6) (2.46). The most significant pressure, according to experts, is improper land use change (P7) (10.25), and the least significant is wildfire (P4) (3.08) (table 2).

Table 2. Ranking of Driving Forces from the Experts' Perspective

Priority	Indicator	Mean Rank	Sample Size	Chi-Square	Degrees of Freedom	Significance Level
1	Population Growth (D2)	4.96	26	927.82	12	0.000
2	Self-sufficiency in Agricultural and Horticultural Products (D4)	4.72				
3	Self-sufficiency in Animal Production (D5)	4.20				
4	Land Affairs Laws (D3)	3.21				
5	Climate Change (D1)	2.89				
6	Industrial Development (D6)	2.46				

Table 3. Ranking of Pressure Factors from the Experts' Perspective

Priority	Indicator	Mean Rank	Sample Size	Chi-Square	Degrees of Freedom	Significance Level
1	Improper Land Use Change (P7)	10.25	26	654.32	5	0.000
2	Excessive Livestock (P6)	9.43				
3	Over-extraction of Groundwater (P11)	9.12				
4	Uncontrolled Expansion of Orchards in Sloped Lands (P8)	8.74				
5	Shrub Cutting (P5)	7.82				
6	Cultivation in Sloped Lands without Agricultural Potential (P10)	7.69				
7	Uncontrolled Mining Activities (P13)	5.28				
8	Neglecting Environmental Water Rights of the Aquifer (P12)	4.86				
9	Plowing Along the Slope (P9)	4.45				
10	Reduced Precipitation (P2)	3.79				
11	Changes in Precipitation Timing Distribution (P3)	3.26				
12	Extreme Temperature Variations (P1)	3.14				
13	Wildfires (P4)	3.08				

Expert Responses Using Friedman Test in Villages of Garmsar County

The results of the analysis of Likert-scale questionnaires by 26 experts and the use of Friedman test to prioritize the indicators and determine their relative importance regarding community participation in watershed management projects are presented in Table 4. The mean rank values vary from 22.43 to 9.73. Furthermore, the significance level in the Friedman test is less than 0.00 (Sig = 0), indicating a significant difference in the relative importance of the indicators in the response component.

From the experts' perspective, the indicator " Revision of Population Growth Policies in Land Use Planning (R1)" has the highest relative priority with a mean rank of 22.43, while the indicator " Sediment removal operations in dams (R28)" has the lowest relative priority with a mean rank of 9.73.

Table 4. Ranking of Effective Responses for Desertification Control from Experts' Perspective

Priority	Indicator	Average Rank	Sample Size	Chi-Square	Degrees of Freedom	Significance Level
1	Revision of Population Growth Policies in Land Use Planning (R1)	22.43	26	325.632	31	0.000
2	Revision of Self-Sufficiency Policies in Agricultural and Horticultural Products (R3)	21.20				
3	Ecological capacity assessment and incorporating it into land use planning (R12)	21.00				
4	Implementation of All Natural Resource Projects in the Framework of Integrated Watershed Management Programs (R32)	20.47				
5	Revision of self-sufficiency policies in livestock production (R4)	19.77				
6	Revision of grazing permits (R9)	19.57				
7	Reform of land tenure laws (R2)	18.90				
8	Job Creation and Alternative Livelihoods (R10)	18.83				
9	Rangeland Management Projects in the Region (R26)	18.57				
10	Increasing the Supervision Unit for Proper Groundwater Extraction (R18)	18.40				
11	Strengthening the Natural Resources Protection Units (R11)	17.53				
12	Implementation of watershed management and groundwater conservation operations (R21)	17.40				
13	Water and soil conservation activities (R13)	17.37				
14	Improvement of living standards for residents, both economically and socially (R8)	17.20				
15	Establishment of a coordination committee for integrated watershed management (watershed council) (R30)	17.03				
16	Awareness-raising to reduce risks (R6)	16.73				
17	Design of drought monitoring and early warning systems (R24)	16.50				
18	Development of rainwater harvesting systems (R27)	15.43				
19	Increasing productivity in agricultural production (R16)	15.40				

Priority	Indicator	Average Rank	Sample Size	Chi-Square	Degrees of Freedom	Significance Level
20	Adaptation to water scarcity (improvement of irrigation patterns, crop patterns, and water consumption patterns) (R17)	15.37				
21	Formation of NGOs Based on Integrated Watershed Management Plans, Programs, and Objectives (R29)	15.23				
22	Revision and allocation of environmental water rights (R19)	15.17				
23	Development of volumetric controls in the region (R15)	15.03				
24	Prioritizing and addressing factors affecting public participation in implementing rangeland management, desertification control, and watershed management programs (R31)	14.90				
25	Review of industrial development policies in the region (R5)	14.90				
26	Agricultural education and promotion (R14)	14.57				
27	Identification and Planting of Species Resistant to Temperature Changes and Suitable for the Region (R25)	14.27				
28	Monitoring proper mining activities in the region (R20)	13.47				
29	Design of early warning and fire extinguishing systems (R7)	12.80				
30	Support packages for damage compensation (R23)	12.27				
31	Insurance services for damages (R22)	10.57				
32	Sediment removal operations in dams (R28)	9.73				

Desertification is a multifaceted process influenced by various human and natural factors. These factors interact with each other, exacerbating the progression of desertification. Understanding these factors and their impacts on the region is crucial for implementing effective strategies to combat desertification and prevent its further advancement. This study aimed to identify and prioritize the causes of desertification and strategies for its mitigation using the DPSIR framework in five villages of Garmsar County.

According to experts, the most decisive indicator (response) for controlling desertification is Revision of Population Growth Policies in Land Use Planning (R1) (22.43). This is because population growth leads to increased exploitation of land. Changes in land use are the most significant effect of population growth in the region, which, in turn, leads to changes in land cover and increased extraction of groundwater resources, accelerating and intensifying land subsidence. Furthermore, population growth results in pressures such as overgrazing and the associated negative consequences (Salehpourjam et al., 2021b; Akbari et al., 2024)). The findings of Ningal et al. (2008) in Guinea, Akbari et al. (2020a), and Salehpourjam et al. (2021) also confirm that population growth leads to significant changes in land use, agricultural land expansion, and the destruction of natural environments. In fact, responses refer to policies and programs that can be implemented to control the driving forces, pressures, or their effects. These responses can help improve the system's state (Sarbazi et al., 2022; Memarian & Akbari, 2020b; Talebanfard et al., 2022). In other words, responses are corrective measures for the situation and the related effects, as well as mitigation or adjustment measures for driving forces and pressures, which are provided for all components of the DPSIR approach. In the research by Borji et al. (2018), the ranking of response component statements based on the Friedman test revealed significant differences in the statements within the DPSIR framework. Integrated watershed management and the establishment and strengthening of support funds were ranked first and twenty-sixth in importance from the experts' perspective. In contrast, the integrated watershed management approach, assessing ecological capacity, land use planning, and developing an appropriate model for comprehensive watershed management were the top three priorities. However, in this study, experts identified revising population growth policies in land use planning as the most decisive response to control desertification.

The experts in this study introduced various executive policies to control desertification. The proposed response policies included increasing irrigation efficiency, changing crop patterns, watershed operations, controlling legal well extraction, blocking illegal wells, point recharge of water, and cultural actions in the plains.

The ranking of driving forces, according to experts, prioritized population growth (D2) (4.96), Self-sufficiency in Agricultural and Horticultural Products (D4) (4.72), Self-sufficiency in Animal Production (D5) (4.20), Land Affairs Laws (D3) (3.21), Climate Change (D1) (2.89), and Industrial Development (D6) (2.46). It should be noted that controlling driving forces is not always feasible, as population growth is one of the national policies, and climate change is a global issue beyond managerial control. Therefore, the expansion of agricultural, horticultural, and industrial lands, i.e., changes in land use, is inevitable and will ultimately strengthen the driving forces. In the study by Mosaferi et al. (2019), four factors (climate change, population growth, management structure, and laws) were identified as the main driving forces in the DPSIR framework based on expert opinions and the review of resources and data. The ranking of driving force statements showed significant differences in the DPSIR framework, where management structure and climate change were ranked first and fourth in importance from the experts' perspective, with climate change being a key driver, consistent with the findings of this research. In the present study, population growth ranked first in the driving forces ranking, while industrial development ranked last.

Additionally, the ranking of pressures according to experts included, in order of priority, Improper Land Use Change (P7) (10.25), Excessive Livestock (P6) (9.43), Over-extraction of Groundwater (P11) (9.12), Uncontrolled Expansion of Orchards in Sloped Lands (P8) (8.74), Shrub Cutting (P5) (7.82), Cultivation in Sloped Lands without Agricultural Potential (P10) (7.69), Uncontrolled Mining Activities (P13) (5.28), Neglecting Environmental Water Rights of the Aquifer (P12) (4.86), Plowing Along the Slope (P9) (4.45), Reduced Precipitation (P2) (3.79), Changes in Precipitation Timing Distribution (P3) (3.26), Extreme Temperature Variations (P1) (3.14), and Wildfires (P4) (3.08). Agricultural activities, in addition to the overexploitation of water resources, have led to excessive use of agricultural inputs. Inadequate management structures and ineffective laws have created pressures such as sectoral thinking and parallel work. In the study by Borji et al. (2018), the ranking of pressure component statements also revealed significant differences in the DPSIR framework, with sectoral thinking and neglecting the sustainability of resources being ranked first and twenty-second in importance, and the expansion of unsustainable agriculture and overexploitation of water resources being the top three priorities. This is aligned with the findings of the current study. Mosaferi et al. (2019) also emphasized the importance of forming a unified and powerful organization and creating watershed councils for proper watershed management. Sheikh et al. (2020), in the Hablehroud watershed, considered land management and planning strategies such as developing integrated watershed and water resource management programs, creating land use planning programs at various scales, and identifying and training new and alternative occupations as the most important revitalization strategies for watersheds, which closely align with the findings of this study.

Although identifying and prioritizing the various components of the DPSIR framework plays an important role in planning to improve watershed health (Karimi Sangchini et al. 2022), assessing the trends in changes in its components also plays an important role in good watershed management (Mosaffaie et al. 2021). Therefore, assessing the trends in changes in DPSIR components is recommended for future studies. Also, examining the comprehensiveness of management actions and responses to improve watershed health is one of the functions of the DPSIR framework (Salehpour Jam et al. 2022), which can be considered for the purpose of evaluating projects in future studies.

Conclusion

Overall, this research demonstrates that the DPSIR approach provides a suitable intellectual infrastructure for integrated watershed management by generating corrective responses for each of its structural components. Furthermore, it serves as a key entry point for developing executive watershed plans, which can be structured around the strategic headings derived from its own response framework. Therefore, creating a watershed action plan with the participation and approval of all stakeholders is a fundamental step. To improve watershed management, it is recommended to reform the current organizational structure, assess trends in environmental changes, establish watershed councils, promote participatory governance, and involve all stakeholders in the policy-making process.

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Data availability statement

All relevant data are included within this article.

Conflict of Interest

The authors declare that they have no conflict of interest.

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