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Integrating community perception, CVI, and DPSIR approaches for climate risk assessment of the Persepolis world heritage site

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Abstract

Climate change is a global phenomenon that has significant impacts on cultural heritage sites, including World Heritage Sites. This article explores the vulnerability of the Persepolis World Heritage Site (WHS) in Iran to the impacts of climate change, using an integrated approach that combines community perception, the Climate Vulnerability Index (CVI), and the Driver-Pressure-State-Impact-Response (DPSIR) framework. The study identifies the interdependence between the vulnerability of WHSs and the local communities through stakeholders' perception and CVI. It also highlights the indirect impacts of climate change on the site's authenticity and integrity and the livelihoods of local communities. The DPSIR framework is used to understand drivers and pressures that contribute to vulnerability and the complex relationships between environmental factors and human activities and to suggest a range of responses, including the development of more efficient irrigation practices, the implementation of groundwater management plans, and efforts to adapt traditional water management systems to modern needs. We suggest that a multidisciplinary and integrated approach is necessary for effective vulnerability assessment and management of WHSs facing climate change.

1. Introduction

WHSs are essential components of our shared human history and represent the irreplaceable cultural and historical heritage of past civilizations (UNESCO, 1972; Khalaf, 2021). These sites have been recognized and protected as a collective human endeavor, as they symbolize the common heritage of humanity and possess an Outstanding Universal Value (OUV). However, climate change poses an increasing threat to WHSs, which are particularly vulnerable to its effects (Nakhaei and Correia, 2021; Heron et al., 2022; Jones et al., 2022). Using high-resolution climate models, expert elicitation, and literature, scholars, estimated that human-induced climate change could result in a 3- to 4-fold increase in annual damage to cultural properties by the end of the 21st century (O'Neill et al., 2022). In the IPCC Sixth Assessment Report (AR6), climate risk is defined as the potential for adverse impacts arising from the interaction of hazards (climate-related events or trends), exposure (the presence of people, ecosystems, infrastructure, or heritage assets in harm-prone locations), and vulnerability, which refers to the physical, social, economic, and environmental conditions that determine a system's susceptibility and limited capacity to cope or adapt. AR6 emphasizes that climate change does not create risk in isolation; rather, risk emerges when intensifying climate hazards coincide with highly exposed and vulnerable systems. For cultural and natural heritage, this means that climate-change risk is shaped not only by the severity of climatic threats but also by material sensitivities, site conditions, ecological fragility, management limitations, and institutional capacities, making the assessment of vulnerability a critical component of understanding and addressing climate impacts (IPCC, 2022). According to Woodside, vulnerability assessment is an appropriate and effective means of assessing the risk of climate change to WHSs (Woodside, 2006) and it is possible to use vulnerability assessments to identify and monitor the effectiveness of interventions that can protect and strengthen the resilience of WHSs to climate change (Sesana et al., 2020, Daly 2025). However, the vulnerability assessment of WHSs is a multifaceted and intricate process that requires a comprehensive, integrated, and multidisciplinary

approach. Various studies have proposed diverse methodologies for evaluating the vulnerability of these sites to environmental instability, including climate change, geomorphological hazards, and alteration factors (Dupont and Van Eetvelde, 2013; Daly, 2014; Shirvani Dastgerdi and Sargolini, 2019; Fatorić and Egberts, 2020; Lafrenz Samuels and Platts, 2020; Garzia, 2021; Andra-Topârceanu et al., 2023; Chen et al., 2023). Although there have been improvements in vulnerability assessment, implementation remains a challenge due to concerns about data reliability, a lack of necessary information, resource constraints, and a need for more specialized skills and guidance (Phillips, 2014). While there have been several vulnerability assessment methodologies suggested, there has been limited research conducted to explore the mutually dependent connection between the vulnerability of WHSs and the communities living around them. Furthermore, including local communities with traditional knowledge and historical experience in conversations regarding climate change vulnerability is critical (Abdalhaleem et al., 2024) as scientific literature frequently lacks this valuable information. The lack of this research gap highlights the urgent need for a comprehensive understanding of the complex relationship between local communities and WHSs, particularly in terms of vulnerability to external risks. To achieve this objective, a systematic approach to risk assessment is necessary. Using different tools and frameworks, this study will provide insights into how the vulnerability of the local communities can exacerbate the impact of climate change on WHSs. We agree with recent studies that policies and practices that neglect the local communities surrounding heritage sites are ineffective and unfeasible. To address this issue, the aim of our research is to employ a combination of community perception, CVI and DPSIR frameworks to assess the climate risk of Persepolis WHS and facilitate the practical creation of resilient places.

2. Material and method

2.1. Material

2.1.1. Study area

Persepolis, an exceptional historical site located on the Marvdasht plain in Iran, stands as a remarkable representation of the Achaemenid Persian Empire. The remains of the acropolis in Parse, the capital of the Achaemenid Persian kings from 550 to 330 BC, are situated on a man-made platform approximately 10 meters above ground level (Mousavi, 2012), which overlooks a vast and fertile landscape (Fig. 1). In recognition of its historical and cultural significance, UNESCO designated Persepolis as a WHS in 1979 (Naderi et al., 2014). Several archaeological sites, agricultural fields, a city, and permanent villages surround the site and agriculture, and animal husbandry are the primary sources of income of locals (Golian et al., 2021). The plain is also home to a diverse range of flora and fauna and has a growing agricultural sector that is heavily reliant on water from the Kor and Pulvar Rivers (Hosseini et al., 2023).

2.2. Methodology

The assessment of climate change risk at the Persepolis WHS and the interrelationship between local community vulnerability and world heritage vulnerability was achieved through a combination of inSIGHT

game, CVI and DPSIR framework (Fig. 2). Firstly, the inSIGHT game is utilized as a participatory tool that encourages active engagement among diverse stakeholders. This innovative game fosters a shared understanding of how both cultural and natural heritage can play pivotal roles in disaster risk reduction and sustainable development. Through inSIGHT, traditional knowledge and sustainable resource management practices are recognized, enabling the mitigation and adaptation to climate change risks (ICCROM, 2020). Complementing the inSIGHT game, the Climate Vulnerability Index (CVI) approach is employed as a robust assessment tool widely acknowledged for evaluating the impact of climate change on World Heritage Sites (WHSs) and their associated communities (Day et al., 2019, 2020; Heron et al., 2022; Jones et al., 2022). Nonetheless, limitations arise in cases of data scarcity and the potential exclusion of cultural and social factors. To address these shortcomings, the DPSIR framework is integrated into the assessment. The DPSIR framework, a versatile tool employed in various fields, facilitates the understanding of the intricate relationships between human activities, environmental pressures, and their consequences on ecosystems, cultural heritage, and societies (Gari et al., 2015; Afroz, 2022; Jiao et al., 2023; Castronuovo, 2023; Zhao et al., 2023). Comprising five interconnected components—Driving Force, Pressure, State, Impact, and Response, it offers a holistic perspective (Smeets and Weterings, 1999; Zhao et al., 2023). This integrated approach allows for the identification of underlying drivers and pressures contributing to vulnerability, enabling the formulation of effective strategies to address climate-related challenges and safeguard the cultural and historical significance of the Persepolis World Heritage Site.

3. Result

Community engagement

The objective of this action is to enhance the involvement of the local community in evaluating climate change-related risks at the Persepolis WHS. This was achieved through the application of the inSIGHT game approach. The inclusion of a diverse range of stakeholders (30 participants) in the game allowed for the incorporation of various perspectives from different stakeholder groups (Fig. 3). The first step was to examine the needs of the local community, including their awareness, mentality, and cultural identity. Through a series of questions, the participants were asked to reflect on their relationship with the WHS and the impact it has on their lives. They were also asked to provide feedback on the actions taken by cultural heritage officials to improve their quality of life and suggest solutions to address the challenges they face (Table 1).

Table 1
Assessment of Local Perception Using inSIGHT Game

Components	Factors	Score
Cultural Values/ features	Unique agriculture	Very significant
	Culture and heritage centers	Moderately significant
	Variety of handicrafts	Moderately significant
	Industrial environment	Moderately significant
	Cultural and ethnic diversity	Moderately significant
	Human resources	Very significant
Most significant and vulnerable	Agriculture	Highly significant and vulnerable
	Human resources	Highly significant and vulnerable
	Cultural heritage properties	Highly significant and vulnerable
	Industries	Moderately significant and vulnerable
Hazard/Threats	Drought	Very significant and high risk
	Water crisis and decrease in underground water	Very significant and high risk
	Subsidence	Moderately significant and moderate risk
	Saltwater intrusion, increasing salinity in groundwater, converting lands to salt marshes	Moderately significant and moderate risk
	Agricultural dependent economy	Moderately significant and moderate risk
Strengths and Capacities	Tourism-related activities	Moderately significant and high adaptation capacity
	Youth experts among locals	Moderately significant and high adaptation capacity
Solutions	Development of the tourism industry and handicrafts.	Moderately significant and high potential for mitigation and adaptation
	Community-Based climate risk management and Sustainable Development Coordinator	Moderately significant and high potential for mitigation and adaptation

During the game, the participants identified the unique agriculture, cultural and ethnic diversity, and cultural heritage properties as the most significant and vulnerable aspects of the area. They also

highlighted the threats to the area, including drought, water crisis, subsidence, and agricultural dependence. To manage these risks, the participants suggested leveraging the strengths of the local community, such as tourism-related activities, youth experts, traditional knowledge, and risk management skills. The game also highlighted the need for increased collaboration between the local community and cultural heritage officials. Participants expressed a desire for greater involvement in decision-making processes and suggested that their traditional knowledge could be harnessed to protect the WHS. By empowering the local community and involving them in risk assessment and management, the game aimed to create a sense of ownership and responsibility towards the Persepolis WHS. The outcomes derived from this program were integrated into both the CVI and DPSIR Framework.

3.4. Assessment of Climate Risk

Persepolis WHS faces a range of climate-related hazards, including drought, groundwater depletion, land subsidence, saltwater intrusion, flash floods, and desertification (Naderi et al., 2014; Arıkan and Olsvig-Whittaker, 2023; Masoudi et al., 2023). To assess the level of vulnerability of Persepolis and the surrounding communities to these hazards, an approach modelled on the CVI was used (Table 2, Fig. 4). The CVI is a structured, rapid-assessment framework designed to evaluate the vulnerability of World Heritage properties to climate change. It assesses vulnerability through three core components: exposure, sensitivity, and adaptive capacity. Together, these components provide an integrated understanding of how climate change may affect a site's OUV and its associated communities (Day et al., 2022). In this study, we employ a CVI-informed approach, drawing on the conceptual structure of the CVI, while acknowledging that the full official CVI tool, its proprietary spreadsheets, and protocols are not applied here. In the CVI dataset, data were compiled from a diverse array of sources, encompassing stakeholder insights garnered through the Insight Game, references, as well as assessments conducted by experts in the field.

Table 2
Assessment of CVI for the Persepolis and its surrounding communities

	Components	Indicators	Data	Impact
World Heritage Site	Climate Hazard	Temperature	Increase in temperature by up to 1 degree Celsius by 2040 (Ashraf et al., 2021; Motamedi et al., 2023).	Physical/chemical damage to structures.
		Precipitation	Decrease in total rainfall by 9% by 2040 (Ashraf et al., 2021).	May result in land subsidence and formation of sinkholes.
			Increase in heavy and flood-inducing rainfalls by up to 40% (Naderi, 2014).	May increase the risk of flash floods/ severe erosion of ancient structures.
		Extreme weather events	Increase in the number of hot days and decrease in freezing days (Motamedi et al., 2023).	This can lead to cracks and other forms of damage.
			Increase in the number of dry days in most parts of the region (Motamedi et al., 2023).	It may exacerbate groundwater depletion and subsidence indirectly.
		Groundwater depletion	Significant reduction in groundwater (Golian et al., 2021) .	May result in land subsidence, formation of sinkholes, and damage to heritage buildings and infrastructure.
			Overexploitation and lack of replenishment by rainfall (Golian et al., 2021) .	This may lead to land subsidence, the creation of sinkholes, and harm to historic structures and infrastructure. Additionally, it can cause an increase in the level of

Components	Indicators	Data	Impact
			saltiness in groundwater.
	Surface water depletion	Drying up of nearby rivers and streams (Motamedi et al., 2023).	Increase in the risk of flash floods during heavy rainfall events.
		Significant reductions in the flow of Kor and Pulvar Rivers (Motamedi et al., 2023).	Leading to a decline in biodiversity of the region. Negative impact on the landscape of the site.
Exposure	Increase in temperature	Increasing diurnal temperature variation (Motamedi et al., 2023).	Ancient structures may become damaged in various ways, such as developing cracks and crumbling into powder.
	land use change	The number of newly constructed buildings has been on the rise in recent years (Golian et al., 2021).	Negative impact on the landscape of the site.
Sensitivity	Landscape of the site	Residential buildings have increased in recent years (Golian et al., 2021).	Removal from the World Heritage List.
	Traditional knowledge	Traditional knowledge of living in harmony with nature in the region.	Traditional knowledge will be lost because of migration.
	Ecosystems	It is home to several species of flora and fauna adapted to the semi-arid climate (Hosseini et al., 2023).	Increasing water stress on vegetation, which can affect plant growth and survival, land degradation and desertification.

	Components	Indicators	Data	Impact
	Adaptive Capacity	Low adaptive capacity due to limited financial resources, lack of effective governance, and limited public awareness.		
	Overall Risk for World Heirtage (OUV)		High climate risk and potential for significant impacts.	
Local Community	Climate Hazard	Temperature	Increase in temperature by up to 1 degree Celsius by 2040 (Ashraf et al., 2021).	May result in health impacts, such as heat-related illnesses.
		Precipitation	Decrease in total rainfall by 9% by 2040 (Ashraf et al., 2021).	May result in decreased agricultural productivity and water scarcity.
		Extreme weather events	Increase in frequency and intensity of heat waves, droughts, and flash floods (Ashraf et al., 2021)	May result in loss of life, displacement, and damage to infrastructure.
		Groundwater depletion	Groundwater levels have been declining at an average of 1.8 meters per year between 2003 and 2016 (Golian et al., 2021).	May result in water scarcity and decline in agricultural productivity.
		Surface water depletion	The Kor and Pulvar Rivers has experienced significant reductions in their flow due to decreased precipitation and increased evaporation rates (Motamedi et al., 2023)..	May result in water scarcity.
				Socio-economic impact.
	Exposure	Water resources	Semi-arid region with limited water resources (Motamedi et al., 2023)..	Water scarcity can lead to a decrease in livelihoods and an increase in migration, as it can affect both agricultural water

Components	Indicators	Data	Impact
			use and access to domestic water.
	Agriculture	Agriculture is a significant source of livelihood in the region (Khalili et al., 2021).	Crop failures, reduced yields, and loss of income of farmers.
	Public health	The presence of vulnerable populations, as well as a lack of adequate health facilities and awareness-raising efforts in the region (Khalili et al., 2021).	Drought can lead to the spread of diseases and infections as well as mental health disorders.
Sensitivity	Dependency on groundwater resources	Limited access to modern methods and technologies to improve efficiency of water use (Khalili et al., 2021).	Loss of income of farmers.
	Agriculture	Agriculture is the most important occupation of the locals (Khalili et al., 2021)..	Decline in agricultural productivity and decreasing livelihood.
	Ecosystems	It is home to several species of flora and fauna adapted to the semi-arid climate (Hosseini et al., 2023)..	Increasing water stress on vegetation, which can affect plant growth and survival. Loss of natural habitats.
Adaptive Capacity	Efficient irrigation practices and implement groundwater management plans (source: local reports)	Groundwater management plans	Ability to plan and implement potential adaptation measures.
	Traditional knowledge and practices for water management/Traditional Qanat system (source: local reports).	Ability to withstand and recover from climate hazards, Equitable and sustainable	Development of alternative water sources as a potential measure for adapting to

Components	Indicators	Data	Impact
		water sharing and distribution.	changing conditions.
Overall Risk for Community		Moderate risk to climate hazards but it still has the possibility of being significantly affected by them.	

3.5. Assessment of DPSIR

The DPSIR framework, originally developed by the European Environment Agency for environmental assessment and policy support, is widely used across sectors such as environmental management, ecosystem monitoring, water and land-use planning, coastal zone management, and climate adaptation, where it helps identify causal relationships between human activities, ecological change, and policy responses. Although not created specifically for cultural heritage, DPSIR has increasingly been applied in heritage studies to analyze urbanization impacts on historic landscapes, environmental pressures on archaeological sites, risks to cultural landscapes, and climate-related degradation processes (Wei et al., 2007; Castronuovo, 2023). Its structured cause-and-effect logic is particularly valuable for heritage research seeking to integrate natural, social, and cultural dimensions. In this study, the DPSIR framework is used to provide a comprehensive understanding of the drivers, pressures, state changes, impacts, and responses associated with climate change. Drivers such as population growth or socio-economic activities generate pressures that alter the state of heritage sites and their surrounding environment. These state changes lead to impacts on site integrity and community well-being, while responses encompass actions or strategies aimed at mitigating adverse effects and enhancing resilience (Zhao et al., 2023).

This amalgamation of data, in conjunction with the information acquired in antecedent sections, serves as a pivotal catalyst for fostering a heightened situational awareness, thereby facilitating the formulation of more efficacious adaptive strategies. This systematic approach considers the interplay between natural processes, human activities, and external forces to gauge the effect of climate change in the Marvdasht area. The data obtained in this section were also gathered through the input of stakeholders and experts.

Table 3
The DPSIR-based analytical framework at place level

Component	Description
Driving Forces	a. Climate change: Increasing temperatures, reduced precipitation, and increased evaporation rates have led to a decline in surface water availability and groundwater levels in the region. b. Unsustainable water management practices: The unbridled exploitation of groundwater resources through various sources, including wells and springs, has led to a significant decline in the water table. c. Increasing water demand: The economy's focus on agriculture has resulted in an increase in the number of water wells, which has led to land subsidence, among other hazards.
Pressures	a. Decline in groundwater levels: The Marvdasht plain is experiencing an alarming rate of groundwater level decline, with levels dropping by an average of 1.8 meters annually between 2003 and 2016. b. Land subsidence: Due to the depletion of groundwater resources, the land in the region has subsided, causing damage to heritage buildings and infrastructure. c. Geological hazards: The depletion of groundwater can trigger geological hazards such as soil liquefaction, erosion, sedimentation, landslides, and saltwater intrusion.
State	a. Drought: The ongoing drought has worsened the arid conditions in the region, resulting in a decrease in surface water availability. b. Land subsidence: The region's heritage buildings and infrastructure are threatened because of the land subsidence caused by the depletion of groundwater resources. c. Reduced agricultural productivity: The decline in groundwater levels and surface water availability has led to a decline in agricultural productivity in the region.
Impacts	a. Cultural heritage damage: The depletion of groundwater resources has caused damage to heritage buildings and infrastructure due to land subsidence. b. Environmental degradation: The depletion of groundwater resources can lead to land degradation, soil erosion, and the expansion of desert areas. c. Social conflicts: The impact of climate change on the local economy and livelihood has led to conflicts with the residents, particularly regarding water management.
Responses	a. Sustainable groundwater management plans: Efforts are underway to address the issue of declining groundwater levels, including the adoption of more efficient irrigation practices and the implementation of groundwater management plans. b. Promote water conservation practices, such as using drought-resistant crops, drip irrigation, and precision agriculture technologies, to reduce water demand and maintain agricultural productivity. c. Promote public awareness campaigns to educate the local population on the importance of groundwater conservation, sustainable water use, and the potential hazards of over-pumping. d. Explore alternative water sources, such as desalination, wastewater reuse, and rainwater harvesting, to diversify the water supply and reduce the reliance on groundwater.

Component	Description
	e. Develop and implement climate change adaptation plans that integrate traditional groundwater management and conservation strategies, such as the use of Qanats, drought-resistant crops and the promotion of water-efficient technologies.

Based on Table 3 and Fig. 5, the key drivers of vulnerability at the Persepolis WHS are climate change, unsustainable water management practices, and increasing water demands. These drivers lead to various pressures, including the decline in groundwater levels, land subsidence, and geological hazards. These pressures ultimately have resulted in negative impacts such as cultural heritage damage, environmental degradation, and social conflicts. The interconnections between these drivers and pressures are complex. Unsustainable water management practices and increasing water demands contribute to the decline in groundwater levels, which in turn cause land subsidence and geological hazards. These hazards can further exacerbate the impact of climate change by triggering soil erosion and the expansion of desert areas. To address these interrelated issues, varieties of responses are necessary. These responses include sustainable groundwater management plans, water conservation practices, public awareness campaigns, exploration of alternative water sources, and the development of climate change adaptation plans.

Discussion

The Marvdasht plain is facing a rise in extreme weather patterns and climate variability. This area is naturally arid, with high temperatures and low rainfall (Ashraf et al., 2021). In recent years, this has worsened due to an ongoing drought, resulting in a decrease in surface water availability (Motamedi et al., 2023; Naderi, 2020). The region is heavily reliant on groundwater for both agricultural and domestic purposes, with the hydrogeology of the area comprising unconfined aquifers made up of alluvial deposits (Ashraf et al., 2021). These aquifers receive recharge from precipitation, surface water, and irrigation activities (Norouzi Nazar et al., 2023). However, the combined effects of climate change and increasing water demands have resulted in a decline in groundwater levels over time. A 2019 study revealed an alarming rate of groundwater level decline in the regions, with levels dropping by an average of 1.8 meters annually between 2003 and 2016. This has led to land subsidence in several cities and regions of the province (Khalili et al., 2021), including the Marvdasht plain, with ground fissures attributed to high population density, increased agriculture activities, farmers' reliance on groundwater as rivers dry up, and preference for high water consumption crops (Golian et al., 2021). The average land subsidence rate is 0.76 meters per 10 meters, and if the current usage trend continues, it is estimated that the groundwater level will decrease by 15 meters by 2029. By comparing the amplitude and subsidence patterns obtained from the radar interferometry technique with the location, density of wells, and groundwater abstraction in the area, it can be observed that subsidence has taken place in the areas where the density of wells and extraction of groundwater resources are high (Alesheikh et al., 2022). The researchers attributed this decline to a combination of factors, including climate change, growing water demands, and unsustainable agricultural practices (Hematian et al., 2019). Moreover, the amount of

water extracted from the aquifer was twice the amount being replenished by rainfall, further exacerbating the problem (Hematian et al., 2019). To irrigate their crops, many farmers have been compelled to dig deeper wells due to the scarcity of water. The Kor River, which used to supply water to agricultural lands and settlements in the area, has also been significantly impacted by the drought. The river's flow has been reduced due to decreased precipitation and increased evaporation rates, and it has dried up in many places (Mozafari, 2022). This, along with the decline in groundwater levels, has led to a decline in agricultural productivity, loss of natural habitats, conflicts among user groups, and increased migration from the region (Khalili et al., 2021). To address the issue of declining groundwater levels in the region, several proactive actions have been outlined. These plans include filling and sealing unauthorized wells, installing meters on licensed wells for water usage regulation, utilizing treated wastewater from the city's sewage treatment plant for urban green spaces, and equipping all agricultural wells with smart meters to facilitate efficient water management. Additionally, farmers are encouraged to adopt more sustainable practices such as optimizing cropping patterns, implementing modern irrigation systems, changing planting dates, and using seedlings instead of seeds. However, climate change and increasing water demands continue to pose significant challenges to the sustainability of groundwater resources in the region.

To effectively address the issues related to vulnerability, it is crucial to develop a deeper understanding of the problem and establish robust methodologies and tools for assessing it. This study takes a comprehensive, integrated, and multidisciplinary approach to vulnerability assessment, utilizing community perspectives, the CVI and the DPSIR framework.

It's crucial to highlight that there are limitations to the CVI approach. One major limitation is the availability of data. The CVI approach relies on accurate and up-to-date data to provide an accurate assessment of vulnerability. In areas with limited data availability, the CVI may not accurately capture the level of vulnerability. Another limitation is that the CVI approach may not fully account for cultural and social factors that contribute to vulnerability. Cultural and social factors, such as local's experiences and community-based adaptation strategies, can significantly affect a community's vulnerability to climate change impacts. Therefore, it is essential to incorporate community perspectives and priorities in the assessment of vulnerability. To address these limitations, the DPSIR framework can be used in conjunction with the CVI approach. The DPSIR framework allows for the identification of underlying Drivers and Pressures that contribute to vulnerability, State of the issue, Impact and Response to the hazard. By combining these methods, we can gain a more comprehensive understanding of vulnerability to climate change impacts and identify effective strategies to address these challenges. The inSIGHT game provided a platform for the local community to voice their concerns and perceptions for addressing the challenges faced by the Persepolis WHS. The game involved a diverse group of stakeholders, who reflected on their relationship with the WHS and the impact it has on their lives. The participants identified the unique agriculture, cultural and ethnic diversity, and cultural heritage properties as the most significant and vulnerable aspects of the area, and highlighted the threats to the area, including drought, water crisis, subsidence, and agricultural dependence. The game also

highlighted the need for increased collaboration between the local community and cultural heritage officials, and participants expressed a desire for greater involvement in decision-making processes.

Using CVI The study found that climate change has significant impacts on the Persepolis WHS and the local communities. The most significant impacts include an increased frequency and severity of extreme weather events, such as droughts and floods, which can damage the site's physical structures and has affected the livelihoods of local communities. Rising temperatures and heightened levels of moisture can potentially result in the erosion and deterioration of the stone structures, ultimately leading to the deterioration of the physical infrastructure of the Persepolis site. Population growth and climate change have increased the pressure on local resources such as water and land. Local communities in this region are vulnerable to climate change also due to their reliance on traditional agricultural practices and limited access to resources and infrastructure. The study highlights the conflicts that have emerged between the site custodians and the local community due to climate impacts, such as drought and reliance on traditional agricultural practices. It is also clear that climate change impacts are a threat to the OUV of the WHS, and the usual regulation and management methods are not adequate to address the threat. While the CVI approach is a useful tool, it is essential to recognize its limitations, particularly in areas with limited data availability and in accounting for cultural and social factors that contribute to vulnerability.

The DPSIR framework is used for understanding the complex relationships between environmental factors and human activities. In the case of climate change risks to the Marvdasht Plain, the framework highlights the driving forces of climate change, increasing demands for water, and unsustainable agricultural practices. These forces result in a range of pressures, including declining water availability, decreasing groundwater levels, and land subsidence, which can ultimately lead to a variety of impacts such as a decline in agricultural productivity, loss of natural habitats, and increased migration. To address these issues, the framework suggests a range of responses, including the development of more efficient irrigation practices, the implementation of groundwater management plans, and efforts to adapt ancient water management systems to modern needs. These measures are crucial for mitigating the impacts of climate change and increasing demand for water on the sustainability of groundwater resources in the region. Implementing these responses, however, is not without its challenges. The development of more efficient irrigation practices may require significant investment in infrastructure and technology, while the implementation of groundwater management plans may face opposition from different user groups with conflicting interests. Additionally, efforts to adapt traditional water management systems to modern needs may require more research and development. Despite these challenges, the DPSIR framework provides a useful starting point for understanding the complex relationships between environmental factors and human activities in the Marvdasht Plain.

Conclusion

Climate change poses a significant threat to the Persepolis WHS and its local community. The assessment of vulnerability was carried out using a multidisciplinary approach, utilizing community

perspectives, the CVI, and the DPSIR framework. The study identified the vulnerability of the Persepolis site and its local community to climate change. This region's inherent aridity, compounded by a prolonged drought and excessive groundwater usage, has led to a significant drop in groundwater levels and land subsidence, triggering detrimental consequences for cultural heritage, agriculture, ecosystems, and local communities. Analyses recommend a range of actions, including improving local infrastructure, promoting sustainable agricultural practices, and a comprehensive monitoring and adaptation plan for the Persepolis WHS that considers the impacts of climate change. The research underscores the need for public awareness and education about the impacts of climate change on cultural heritage sites and the importance of adaptation.

Declarations

Conflict of interest

The authors declare no competing financial or non-financial interests.

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declaration

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Author Contribution

Masoud Nakhaei: Conceptualization; Methodology; Data curation; Formal analysis; Investigation; Writing - original draft; Visualization.Cathy Daly: Conceptualization; Methodology; Supervision; Validation; Writing-review & editing.All authors contributed to the interpretation of results and approved the final manuscript.

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Figures



Figure 1

Aerial photo of the site (Archive of Persepolis WHS)

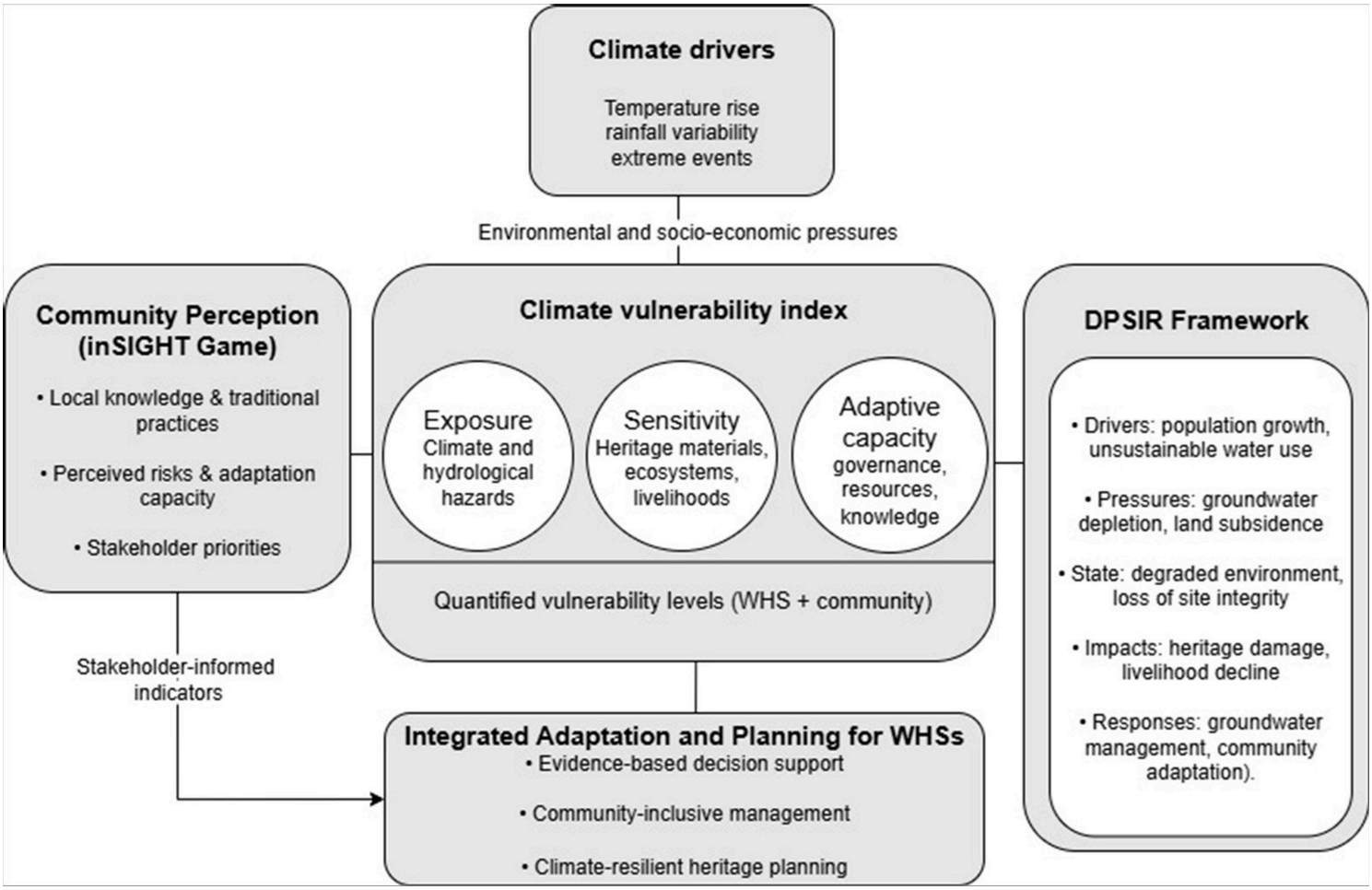


Figure 2

Integrated framework for assessing climate change risk at the Persepolis World Heritage Site

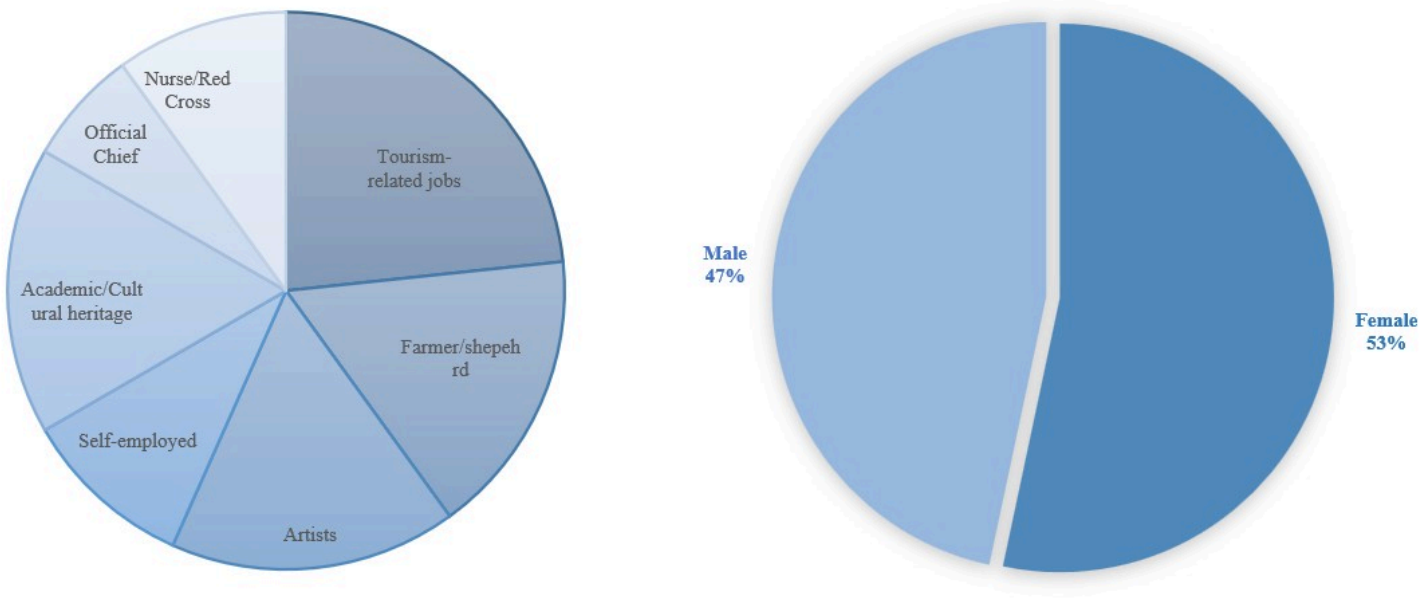


Figure 3

Participants of various genders and occupations

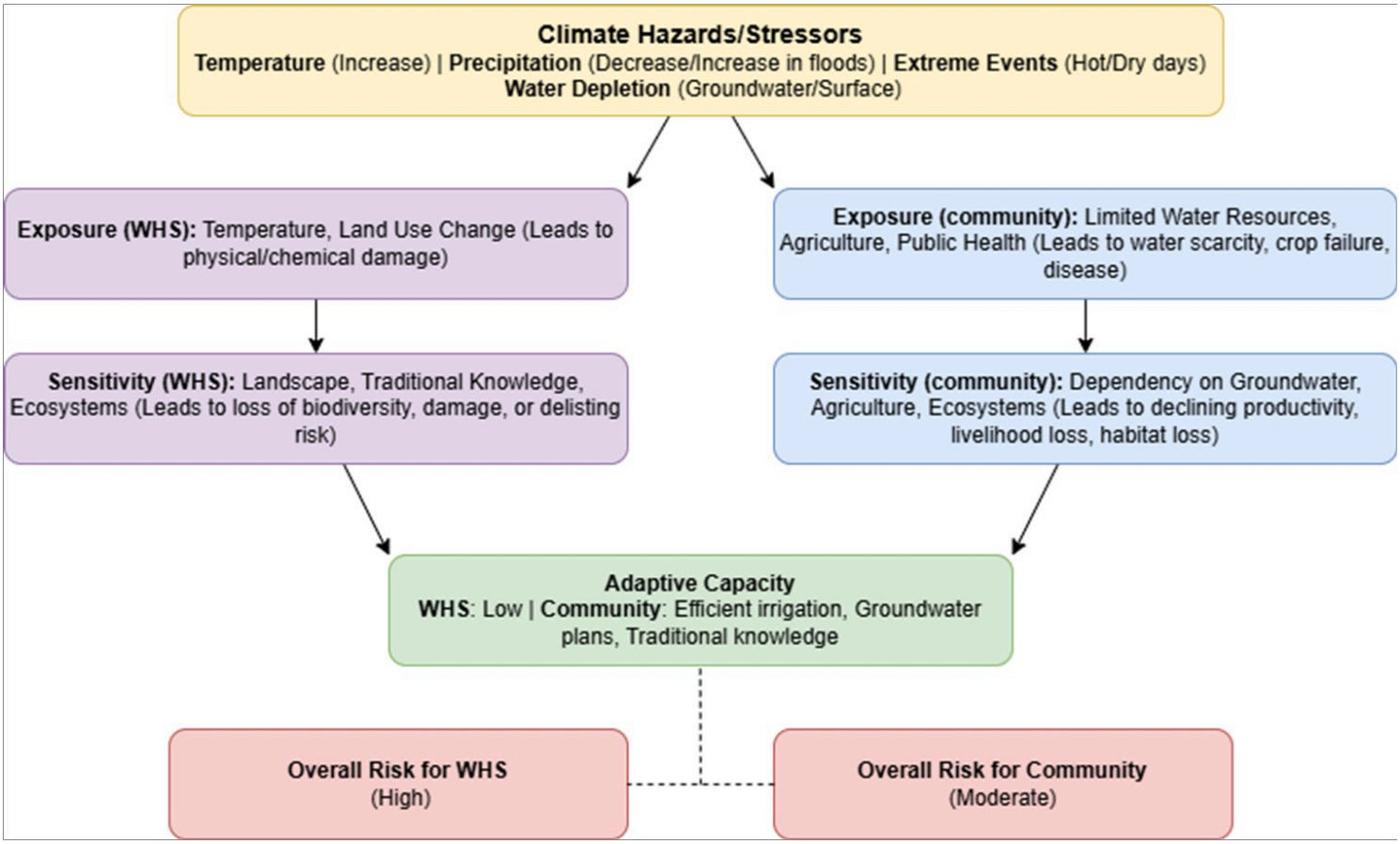


Figure 4

Conceptual flowchart for CVI assessment of Persepolis and its surrounding communities

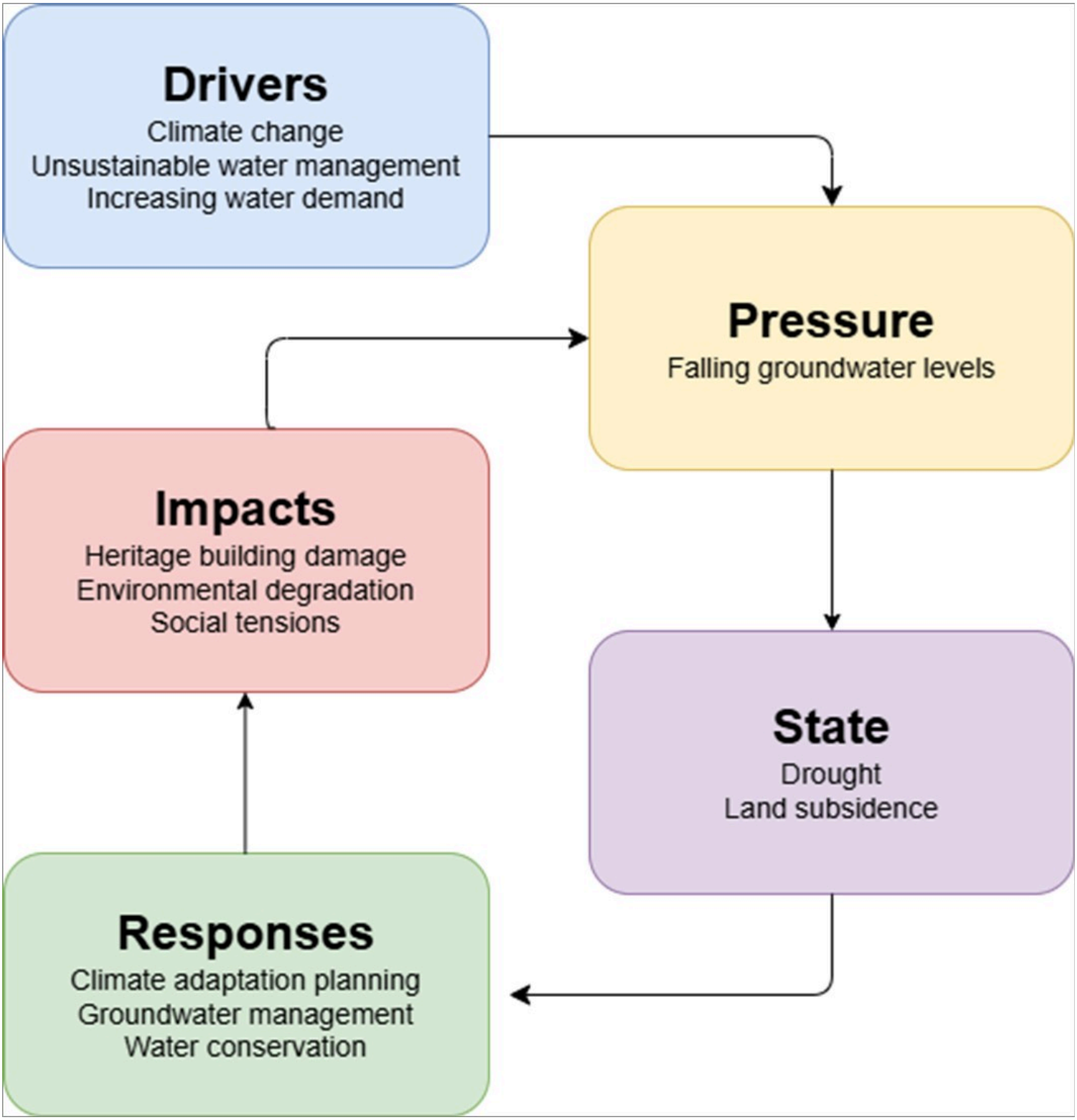


Figure 5

Causal interactions among Drivers, Pressures, State, Impacts, and Responses at the Persepolis WHS