

Sarami Foroushani, Taraneh; Balali, Hamid; Movahedi, Reza; Partelow, Stefan

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Title

Using local knowledge to assess the sustainability of groundwater resources: applying the social-ecological systems framework to the Hamedan-Bahar Plain, Iran

Authors

Taraneh Sarami Foroushani¹, Hamid Balali*², Reza Movahedi³, Stefan Partelow⁴

1) College of Agriculture, Bu-Ali Sina University, Hamedan, Iran

2) College of Agriculture, Bu-Ali Sina University, Hamedan, Iran

3) College of Agriculture, Bu-Ali Sina University, Hamedan, Iran

4) Leibniz Centre for Tropical Marine Research (ZMT), Bremen, Germany

*Corresponding author: h-balali@basu.ac.ir

Abstract

Sustainable access to groundwater remains a key challenge for local users, managers and policy makers, particularly in arid agricultural regions such as Iran. Identifying and assessing the status of diverse sustainability indicators using local knowledge can act as a step in the right direction for often invisible and hard to measure resources, especially when developed through inclusive approaches that include expert stakeholder inputs. In this article, we apply Ostrom's social-ecological systems framework (SESF) to assess how the local knowledge of key informant stakeholders can be used to assess the sustainability of groundwater resources on the Hamadan-Bahar plain in Iran. We evaluate the importance of each of the SESF's first-tier variables based on 52 indicators attained from literature review and expert insights. Local knowledge is used to assess the sustainability status of each indicator through a survey of 22 key informants. For data analysis, we use the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) and the Shannon Entropy methodologies to weight and rank indicators based on the data provided on their influence on sustainability. Findings suggest that the Resource System (RS) and Resource Unit (RU) indicators have the most positive influence on sustainability. In contrast, the Governance System (GS), Actor (A) and Interaction (I) first-tier variables were evaluated as less stable, along with Outcomes (O). This suggests that social factors and diverse outcomes may need further attention in the region to ensure management and policy development that can better enable sustainable outcomes. This analysis also demonstrates the usefulness of a comprehensive science-based framework for organizing, analyzing and presenting a wide range of complex information to inform policymakers and planners.

Key words: Groundwater management, local knowledge, knowledge co-production, sustainability indicators, socio-ecological systems (SES), stakeholder inclusion, water governance, commons

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24 **Key words:** Local knowledge; knowledge co-production; Sustainability Indicators; socio-ecological
25 systems (SES); water governance; commons

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35 **1.0 Introduction**

36 Sustaining groundwater resources is essential for human wellbeing, economic development and
37 environmental protection in many water scarce regions, particularly those dependent on local agriculture.
38 However, groundwater quality and quantity is often challenged by population growth, urban sprawl,
39 agricultural expansion and economic growth in recent decades (Yan et al., 2018; Ye et al., 2018; Xu et al.,
40 2019; Liu et al., 2020). Groundwater remains a viable option because it is often cheaper, more convenient
41 and less vulnerable to pollution than surface water. Therefore, it is commonly used for public water
42 supplies (Luker, 2017). The major difference between groundwater and surface water resources is that it
43 is very difficult to monitor and measure groundwater (Esteban, 2021). As a result, sustainable
44 groundwater use is more difficult due to uncertainties in the availability and stability of water over time,
45 exacerbating the collective action challenge of governance that often lacks a feedback mechanism on the
46 effectiveness of institutional development efforts (Asprilla-Echeverria, 2021).

47
48 Today, more than half of the global urban population relies on groundwater to meet their basic needs
49 (Mishra et al., 2021), but many challenges remain for governance towards sustainability. As groundwater
50 use and dependence increase, the more challenges and problems will arise regarding the ownership, use,
51 access, protection and development of water resources, especially in border areas (Bogardi et al., 2021;
52 Eman and Meško, 2021; Katz, 2021). In many countries, water resources have been distributed without
53 clear use rights over space or time, creating challenges for human security and development when scarcity
54 arises (Bai et al., 2015; Feng et al., 2020). Governance aimed at ensuring sustainability needs to account
55 for such risks and uncertainties, and acknowledge the common-pool resource properties of water that
56 require collective action as well as forms of rights allocation (whether common property, state or private)
57 to ensure not only water access and use, but justice and equity in relation to who gets how much and
58 why.

59
60 A substantial amount of literature has examined water and groundwater sustainability issues, with more
61 recent literature focusing on integrated social-ecological factors for analysis (Elshall et al., 2020; Gleeson
62 et al., 2020; Zwarteveen et al., 2021). For example, Di et al. (2022) show that water scarcity in China is a
63 complex social, economic and ecological system whose management is influenced by various factors such
64 as climate change, geographical location, water resources, diverse users and unbalanced development
65 policies. Ndlovu et al., (2022) argue that water problems are not separate from other social and ecological

66 problems; they are related to social, economic, legal, environmental, and political issues that need to be
67 considered when establishing governance arrangements. Montenegro and Hack (2020) found that multi-
68 level water governance in Nicaragua faces challenges of investment, budget restraints, lack of collective
69 choice rules and low knowledge in resolving disputes are key problems. Lastly, Villamayor-Tomas et al.,
70 (2014) show how applying common-pool resource theory and the SESF can help unpack the factors
71 shaping governance challenges in the large Rhine river watershed.

72
73 In social-ecological systems such as groundwater, gathering data for comprehensive assessments remains
74 challenging. Developing and monitoring indicators to inform management options can be difficult, often
75 leaving a limited set of social and ecological factors to analyze (Pandey et al., 2011). Including stakeholders
76 and local knowledge can help bridge knowledge gaps and ground an analysis in the local context. Elshall
77 et al., (2020) review the literature on management perspectives, sustainability indicators and typologies
78 for groundwater sustainability, noting that closing the science-policy gap will require: (i) engaged
79 stakeholders in participatory processes; (ii) improved understanding of social-ecological interactions and
80 scenarios; and (iii) acknowledges uncertainty in scientific knowledge and the diversity of societal
81 preferences in management. Furthermore, including stakeholders in water governance has been
82 recognized and outlined by the OECD, which suggest five principles for doing so (OECD, 2015). These
83 principles include dimensions of mapping the relevant stakeholders and embedding their perspectives,
84 knowledge and participation in policy frameworks and decision-making processes. Doing so is argued as
85 critically important for broadening the knowledge base for decision making, meeting local needs, building
86 trust and therefore higher compliance likelihood as well as increasing communication and transparency
87 in the associated processes (Reed, 2008; Schneider and Buser, 2017, Wehn et al., 2018). More broadly,
88 stakeholder inclusion and the role of science in environmental governance has received substantial
89 attention over the last few decades (Bäckstrand, 2004; Reed, 2008; Newig and Fritsch, 2009).

90
91 Harnessing local knowledge is increasingly utilized as an effective methodology because it is grounded in
92 the local social-ecological context, inclusive and often the only way to conduct rapid assessments in data
93 scarce regions by drawing on local stakeholder inputs who have extensive insights over time into key
94 issues (Tengö et al., 2017; Camara-Leret and Dennehy, 2019). Furthermore, using local knowledge from,
95 for example, resource users and expert practitioners, to inform sustainability assessments and
96 governance decision-making is increasingly championed as an inclusive knowledge co-production strategy
97 to improve outcomes (Sterling et al., 2017; Tengö et al., 2017; Norström et al., 2020).

98

99 In this article, we examine the status of 52 sustainability indicators based on local knowledge from 22
100 expert key informants on local groundwater management and governance on the Hamadan-Bahar plain
101 in Iran using the Social-Ecological Systems Framework (SESF). Drawing on locally informed stakeholders
102 to indicate the status of each indicator, we provide an empirical assessment of the social and ecological
103 priorities placed on 52 groundwater sustainability indicators associated with 7 first-tier variables of the
104 SESF. Below we briefly introduce the SESF, its use in previous studies and relevance for water governance
105 and sustainability analysis before introducing the case study area and methods.

106

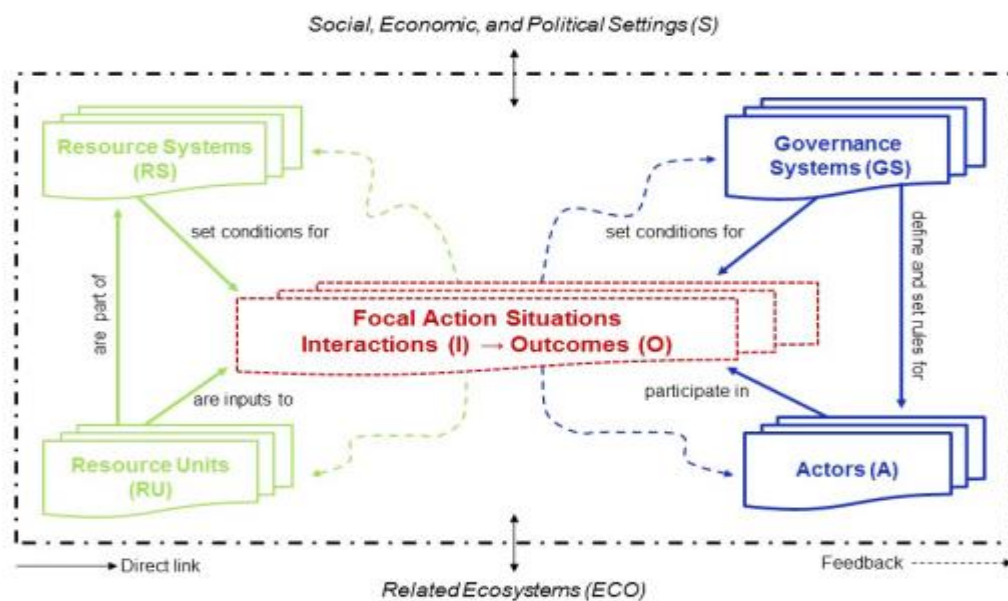
107 **1.1 Understanding groundwater sustainability with the Social-Ecological Systems Framework**
108 **(SESF)**

109 Natural resource sustainability requires an understanding of the complexity of integrated systems (i.e.,
110 social, biophysical, economic) and their interactions (Cumming et al., 2013). Historically, many natural
111 resource management approaches have failed due to fragmented, isolated or limited disciplinary
112 perspectives shaping decision-making (Holling and Meffe,1996; Holling, 2003; Bergstrom et al., 2021).
113 However, over the last few decades, substantial progress has been made in understanding the role of
114 integrated social-ecological systems (Colding and Barthel, 2019) and particularly the importance of the
115 active participation of local residents, knowledge and expectations (Carpenter et al., 2012). Furthermore,
116 work on commons governance has suggested that understanding behavior of people facing collective
117 action problems in the use of common-pool resources, and the dynamics that emerge from collective
118 action processes to govern the commons, requires knowledge of the social and ecological factors that
119 influence behaviors, intentions and the institutional development that emerge from individual and
120 collective decision-making (Ostrom, 1990; Ghorbani and Bravo, 2016; Andersson et al., 2021; Partelow et
121 al., 2022).

122

123 Various frameworks have been proposed to examine the complexity and sustainability of social-ecological
124 systems. Arguably the most widely used and cited frameworks is the Social-Ecological System Framework
125 (SESF), originally developed by Elinor Ostrom (Ostrom, 2009; McGinnis and Ostrom 2014). The
126 framework's applications and associated methodologies have been reviewed in the recent literature (Thiel
127 et al., 2015; Partelow, 2018, Nagel and Partelow, 2022). The framework is a decomposable multi-level
128 framework with 8 first-level variables or sub-systems with defined but general interactions between them

129 (Figure 1). Six of the variables are considered internal to the system boundaries, including: Resource
 130 System (RS), Resource units (RU), Governance system (GS), Actors (A), Interactions (I) and Outcomes (O).
 131 The remaining two variables are considered external to the system boundaries: Social, economic and
 132 political settings (S) and Related ecosystems (ECO). Within each of the 8 first-tier variables are second-tier
 133 variables, 52 in total, which are more specific and can be defined and measured as appreciate to the case
 134 studies of interest. The SESF has been widely used as a diagnostic tool to identify factors involved in
 135 sustainable resources management in response to the challenges posed in over a hundred case studies
 136 on human-environment interaction (Nagendra and Ostrom, 2014; Basurto et al., 2013; Thiel et al., 2015;
 137 Partelow, 2018; Villamayor-Tomas et al., 2020). However, to our knowledge, few have explicitly focused
 138 on using the framework to guide indicator review and selection with the intended purpose to analyze
 139 stakeholder preferences and perceptions of their role in local water governance sustainability (Partelow
 140 et al., 2021).



141
 142 **Figure 1.** The social- ecological systems framework (SESF), showing the first-tier variables and their conceptualized
 143 interactions. Source: McGinnis & Ostrom (2014).

144
 145 The SESF provides an important tool for examining groundwater sustainability issues, as the framework's
 146 history of development is explicitly rooted in common-pool resource management (Partelow, 2018).
 147 Ostrom first studied groundwater governance in Los Angeles during her doctoral studies in the 1950s
 148 (Ostrom 1965), later using case studies from fisheries, forestry and irrigation systems to refine theories of
 149 institutional change, collective action and rational choice theory in her study of the commons (Ostrom,

150 1990; Ostrom 1998). Common-pool resources are defined by their competition for use
151 (rivalry/extractability), meaning two fishers can't share the use of a fish, or two famers a unit of water;
152 and further defined by their difficulties in excluding people from using the resource. Groundwater typifies
153 a common-pool resource, because water is finite, and cannot be used by two people at the same time. It
154 is further difficult to exclude people from pulling water out of the aquifer, or to know how much they use
155 or how much water is left. Common-pool resource problems typically require some form of collective
156 action or cooperation among users to ensure sustainability to mitigate overexploitation. Understanding
157 how different stakeholders involved in using or managing water resources perceive what is important for
158 achieving sustainable solutions (e.g., indicators) is a critical step for finding inclusive governance paths
159 forward and identifying potential gaps.

160
161 Groundwater systems are also social-ecological systems, meaning that changes to either social and
162 biophysical features of the system have repercussive effects on the system as whole. For example, if a
163 drought occurs, it may lead to scarcity of water that lowers farming yields and income, influencing political
164 decisions over water allocation rights and monitoring. Prior studies in western Asia on groundwater
165 governance have explored such social-ecological dynamics. Vener (2007), in interviews with 30 water
166 management experts in the Kuras-Araks Basin, showed that the major obstacles to cooperation on
167 integrated water resources management in this basin are political instability, administrative and structural
168 issues and the continued ethnic conflicts that have led to mistrust (Vener, 2007). Fereshtehpour et al.,
169 (2016) examined operator exploitation laws, highlighting that laws should be defined in such a way that
170 takes into account ecosystem dynamics and the constraints that govern them to resolve the disputes
171 between operators and to motivate collective action. Furthermore, Molden et al., (2010) argue that water
172 governance relates to the range of political, social, economic and administrative systems that are in place
173 to develop and manage water resources and deliver water services at various levels. Beyond Asia, Madani
174 and Lund (2012) have shown that competition and confrontation over water rights allocations make
175 cooperative solutions difficult, suggesting the need for a senior governing body to intervene and
176 encourage collaborative solutions.

177
178 In this study, we examine the following research objectives, guided by the literature, local contextual
179 knowledge and the SESF:

- 180 (1) Examine the social and ecological aspects, and their interactions, of the groundwater resource
181 system on the Hamedan Bahar plain;

- 182 (2) Identify key variables influencing sustainability of water resources based on stakeholder inputs;
183 (3) Organize and analyze groundwater sustainability indicators with social-ecological system
184 framework (SESF) to reveal current emphases and gaps
185 (4) Reflect and discuss findings for future researchers and policymaking in the region
186

187 **2.0 Methods**

188 **2.1 Study Area**

189

190 The Hamedan-Bahar Plain, also known as Siminehrood, is one of the four plains of the Hamedan region of
191 Iran with an area of 2459 km², on the northern part of Alvand heights (Figure 2). The plain's area is 880
192 km² and the extent of the main aquifer is 468 km², with an elevation of 1579 km². This aquifer is recharged
193 directly from precipitation, surface currents, returns flow from agricultural, drinking and industrial uses
194 as well as underground inputs and is discharged through groundwater extraction for various uses as well
195 as underground output. Based on current groundwater data over the past years, there is a descending
196 trend with continuous decline and reduction of groundwater reservoirs. There is no permanent river in
197 the study area, and due to low average precipitation and its unpredictable temporal distribution, surface
198 water plays a trivial role in water supply of the agricultural sector. Thus, groundwater resources are the
199 main source for more than 80% of agricultural water. The increased cultivation, reduced precipitation,
200 overexploitation, and inadequate nutrition of the aquifer in recent years have caused the groundwater
201 level in this plain to decrease sharply and encounter the serious risk of destruction and surface subsidence.
202 During this period, the local policy-makers have attempted to control the severe depletion of
203 groundwater, although their efforts have failed due to continued illegal overexploitation causing a drop
204 of more than 11 meters in the aquifer level over the past two decades. The water crisis in the region has
205 consequences for migration, unemployment and environmental problems such as landslides, which have
206 become serious threats to farmers, concerning officials and local stakeholders.

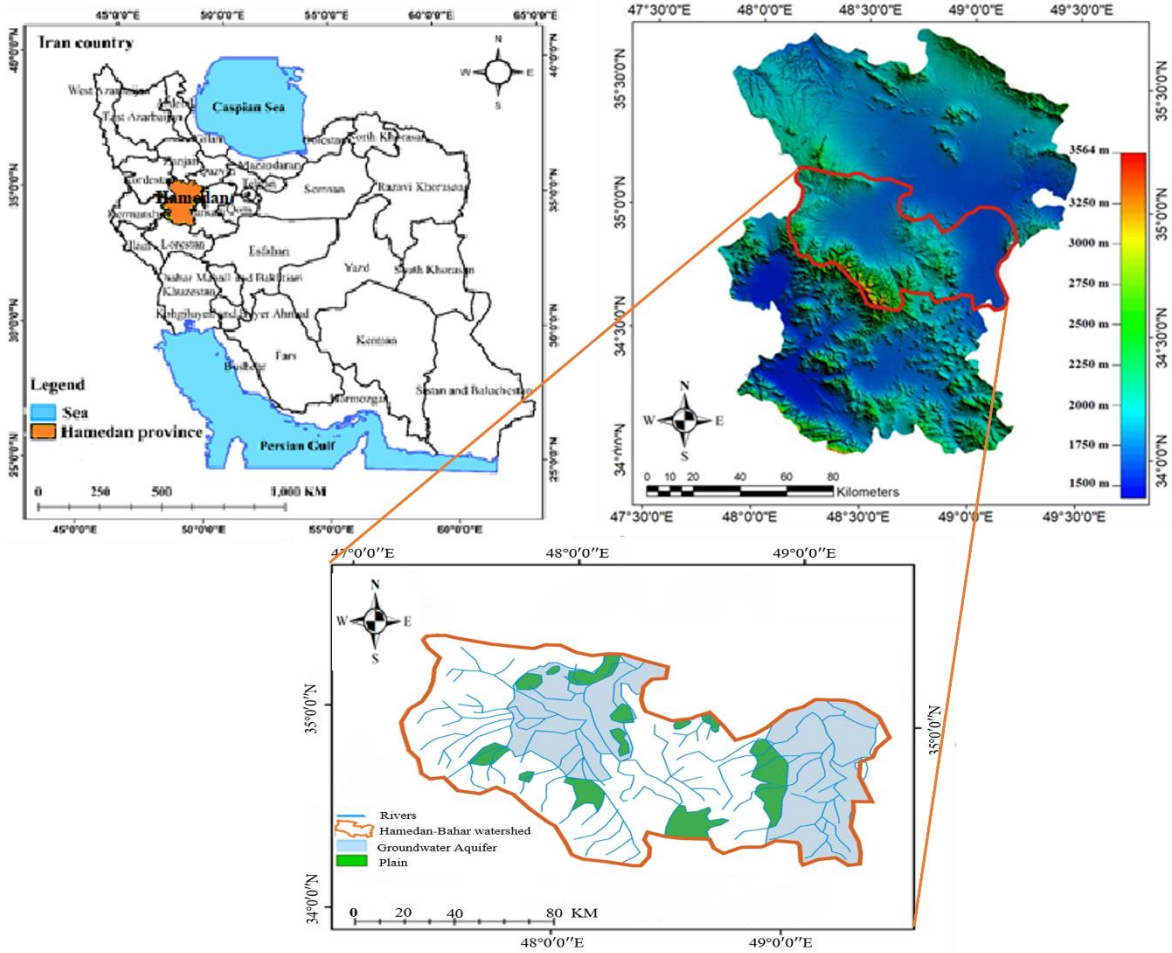


Figure 2. Study area of Hamadan–Bahar watershed in Hamadan province, Iran.

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Overall, climatic conditions and water resources in Iran set the conditions for severe limitation of water resources, leaving more than two thirds of the country in arid, semi-arid and desert areas (Arjmand et al., 2020). As noted above, national groundwater resources have reached a critical condition due to overexploitation, the increasing numbers of illegal wells and consecutive droughts (Mazaheri and Manafi, 2017). Management trends over the last two decades have neglected issues such as increasing demand, intrinsic values of water, comprehensive studies, rights allocation issues and public participation. However, the lack of adequate interaction with the private sector has also played a role. Currently, government agencies are supportive of measures to move away from the "past conditions" to the "ideal conditions" (Omranian Khorasani, 2015).

221 **2.2 Literature review and indicator selection**

222 We conducted a review of the literature applying the SESF, in tangent with consultations with local experts
 223 in the study region, to collect sets of contextually relevant indicators for groundwater sustainability. Many
 224 studies applying the SESF need to develop indicators in order to empirically measure the first- and second-
 225 tier variables of the framework, and thus there is substantial guidance in the literature for study design.
 226 The review by Partelow (2018) additionally provides a list of all the indicators used in the published SESF
 227 literature, which provided further inputs. In addition, the authors local knowledge informed the final
 228 selection of indicators specific to groundwater governance. Throughout this process we categorized the
 229 indicators into the relevant first-tier variables of the SESF to structure the social-ecological framing of the
 230 study. Furthermore, beyond direct indicator selection, support for the relevance of each first-tier variable
 231 is provided from the broader social-ecological systems and water literature: Social, Economic, and
 232 Political Settings (S) (Knüppe and Meissner, 2016; Orach and Schlüter, 2016), Resource Units (RU) (Vogt
 233 et al., 2015; Bluemling et al., 2021), Resource Systems (RS)(Ostrom, 1990; Del Mar Delgado-Serrano and
 234 Ramos, 2015; Zogheib et al., 2018), Governance Systems (GS) (McGinnis and Ostrom, 2015), Actors (A)
 235 (Cole et al., 2014; Palomo and Hernández-Flores, 2019), Interactions (I) (Villamayor-Tomas et al., 2020)
 236 and Outcomes (Thiel et al., 2015; Barnett et al., 2020; Robertson, 2021). We did not include the External
 237 Ecosystems (ECO) variable due to the large geographic scope considered already internal to the case
 238 system.

239 **Table 1.** Indicators used to measure the first tier variables. Each indicator is labeled with a number (#) for reference throughout
 240 the study.

SESF first-tier variables	Indicators
Social, Economic, and Political Settings (S)	Employment in agriculture (1), Rural per capita income (2), Income distribution (Gini coefficient)(3), Diversity of products in the region (4), Market access (5), Integration of agricultural lands (6), Farmer demand for groundwater resources (7), Population growth rate in the region (8), Farmer population density in the region (9), Age structure (10), Gender structure (11), Migration rate (12), Rural literacy rate (13), number of media (14), Number of media and educational programs in the field of water resources (15), Government policies in the field of water resources (16), Disputes and conflicts in the field of water resources (17), Installation of smart water meters (18), New irrigation equipment such as pressurized irrigation (19)
Resource Units (RU)	Rainfall (20), Potential of renewable groundwater resources (21), Economic value of groundwater in the region (22);
Resource Systems (RS)	Volume of renewable water (23), Specify hydrological boundary (24), Efficiency of transmission systems and water consumption (25), Balance between agriculture and environment (26), Watershed management projects (27)
Governance Systems (GS)	Number of governmental organizations in the field of water (28), Number of non-governmental organizations in the field of water (29), Communication and interaction of organizations in the field of water

	(30), Number of unauthorized wells (31), Number of smart meters (32), Electrification of water wells (33), Number of local water markets (34), Number of regulatory factors on groundwater abstraction control (35)
Actors (A)	Number of farmers operating in the region (36), Number of economic sectors consuming water (37), Number of social organizations operating (38), Amount of indigenous and local knowledge (39), Amount of social capital (trust, empathy and participation) of farmers (40)
Interactions (I)	The amount of information exchange between farmers (41), Farmer interaction with each other in the field of water (42), Agreements and internal regulations between farmers (43), Interaction between economic sectors (44)
Outcomes (O)	Efficiency of groundwater resources in agriculture (45), Groundwater pollution (46), Groundwater abstraction volume (47), Groundwater reservoir deficit (48), Land subsidence rate (49), Number of floods (50), Extent of agricultural empowerment programs (51), Responsibility in water resources consumption (52)

241

242 **2.3 Survey design and implementation**

243 The primary purpose of the study is to gain insights into the local stakeholder knowledge about the status of the

244 sustainability indicators above. In other words, which indicators do key informant stakeholders believe are stable or

245 unstable in relation to groundwater management, and thus shaping sustainability outcomes? Rather than collecting

246 observational data on all 52 indicators, we conducted a stakeholder survey with 22 locally informed expert key

247 informants who are affiliated with the two important agricultural and water management organizations (Appendix

248 Table S2). We asked each to indicate, to their knowledge, the status of the indicator in relation to current

249 groundwater management. Each key informant is involved in either the Agriculture Organization or the Regional

250 Water Organization of Hamedan-Bahar. For each indicator, an 11-point Likert scale was provided. Collecting local

251 expert knowledge enables drawing on local expertise while co-producing knowledge through an inclusive

252 methodology. The survey was constructed and distributed in Persian. A translated sample of the survey is provided

253 in English for reference (Appendix Table S1). The Likert rating of each indicator provided a standardized response

254 format for statistical analysis, and allowed us to identify which indicators within the 7 SESF first-tier variables are

255 perhaps most influential, stable or lacking attention in current water governance practices.

256 **2.4 Data analysis**

257 A combination of Shannon’s entropy weighting and TOPSIS methods was used to analyze the Likert survey

258 data collected. The Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) is based on

259 calculating the distance between the alternatives from the positive ideal solution (PIS) and negative ideal

260 solution (NIS) (Lin, 2010). This model was proposed by Huang and Yoon in 1981 and is often used as a

261 rigorous multi-criteria decision model. It should have the minimum distance from the PIS (best possible

262 condition) and the maximum distance from the NIS (worst possible condition). The Shannon’s entropy

263 method was used to weigh the indicator importance and the TOPSIS software was used to rank them.

264

265 Multi-criteria decision-making methods can be used to assess sustainability by ranking the factors
266 affecting a system. Collecting a full data set on all system factors to be considered is important (i.e.,
267 economic, social, and ecological dimensions) to ultimately provide a comprehensive calculation for
268 sustainability assessment. In multi-criteria decision-making problems, especially multi-indicator decision-
269 making problems, having and knowing the relative weights of the available indicators is an effective step
270 in the problem-solving process and is necessary.

271

272 Shannon's (1948) entropy theory, later put forward by Lie et al., 2010, enables the weighting calculations
273 of indicators when conducting a TOPSIS analysis, weighting the relative importance of each indicator
274 comparatively (Asgharpour, 2021.) This is done with a decision matrix, where m options are evaluated
275 based on n criteria, weighted using the concept of entropy. If we denote the decision matrix by X and each
276 of its roots by x_{ij} , first the decision matrix must be normalized. The normalized matrix is denoted by N and
277 each row is denoted by n_{ij} (Hakimi et al., 2017). In the Shannon entropy technique, according to the
278 weights obtained from the indicators in this step, indicators that have more relative dispersion, are more
279 important and their influence is greater in choosing the optimal option (Jun et al,2013).

280

281 Conducting the full analysis of the data, TOPSIS with Shannon entropy weighting, includes the following
282 steps (Asgharpour,2021). In the first step, the decision matrix of raw survey data (rows of survey inputs
283 and columns of governance indicators) was descaled (Appendix Figure S1). In the second step, the
284 "weighted scaleless" matrix was created using the formula: $V = N_D \times W_{m \times n}$ where (v) is a weighted scaleless
285 matrix, (N_D) is value of each index is unweighted, and $(W_{m \times n})$ is a weight vector. In the next step, the
286 positive ideal (A^+) and negative ideal (A^-) alternatives were determined using the following formula:
287 Positive ideal alternative $= A^+ = \{(\max V_{ij} | j \in J), (\min V_{ij} | j \in J^-) | i=1,2,\dots,m\} = \{V_1^+, V_2^+, \dots, V_i^+, \dots, V_n^+\}$; Negative
288 ideal alternative $= A^- = \{(\min V_{ij} | j \in J), (\max V_{ij} | j \in J^-) | i=1,\dots,m\} = \{V_1, V_2, \dots, V_n\}$; $j^- = \{j=1, 2,\dots,n, | j\}$ s relating to
289 the cost}; $J = \{j=1,2,\dots,n | j\}$ s relating to the profit}.

290

291

292

293 In the fourth step, the distance was calculated using the Euclidean method as follows. The i -th
294 alternative's distance from the PIS:

295

$$d_{i+} = \left\{ \sum_{j=1}^n (V_{ij} - V_j^+)^2 \right\}^{0.5}, i = 1,2,3, \dots, m$$

296

297

298

299 The i-th alternative's distance from the NIS:

300

301

$$d_{i-} = \left\{ \sum_{j=1}^n (V_{ij} - V_j^-)^2 \right\}^{0.5}, i = 1, 2, 3, \dots, m$$

302

303 In the fifth step, the ratio of the relative proximity of A_i was calculated using the following formula:

304

$$cli = \frac{d_i^-}{d_i^- + d_i^+} \quad 0 \leq cli \leq 1 \quad i = 1, 2, \dots, m$$

305 Finally, in the sixth step, cli⁺, based on the alternatives values, all were ranked and ordered.

306

307 In order to examine, compare and visually plot the relative importance for sustainability of the aggregate
 308 indicator scores in each of the first-tier variables of the SESF, the different resulting quantities were
 309 converted to relative scaleless data. To do this, the minimum and maximum values of each indicator were
 310 determined and the range of changes was obtained (rounded to the nearest 10th (i.e., 0.1)). The minimum
 311 value was then subtracted from the numerical value of each indicator and divided by the range of the
 312 fluctuations to obtain relative scaleless data between zero and one. The ranks zero to 0.2 were considered
 313 highly unsustainable; 0.2 to 0.4 unsustainable; 0.4 to 0.6 semi-sustainable; 0.6 to 0.8 sustainable, and 0.8
 314 to 1 highly sustainable. A radar plot was used for comparative visualization (Wong, 2006) .

315

316 3.0 Findings

317 3.1 TOPSIS weighting of indicators

318 The criteria were weighted in TOPSIS software using the Shannon's entropy technique and the following
 319 steps were taken. Formation of the decision matrix; the decision matrix contains information and entropy
 320 can be used as a criterion for its evaluation. Here, the decision matrix is the final scores obtained from the
 321 average score of the questionnaires. The weights of the indicators were obtained using the Shannon's
 322 entropy method in TOPSIS software. The selected results of the top 10 negative and positive weighted
 323 indicators results are presented in Table 2, with a full table in Appendix Table S3. In this matrix, the profit
 324 index has positive utility, while the cost index has negative utility. According to the results, the item "illegal

325 wells" with negative utility (cost) had the highest weight (0.066) among other indicators, followed by
 326 indicators with codes (47, 48, 1, 49, 7, 40, 9, 50, 46, 17, and 8, respectively) which related to: abstraction
 327 volume of groundwater (0.058), groundwater reservoir deficit (0.052), employment in agricultural sector
 328 (0.048), land subsidence (0.047), farmers' abstraction of groundwater resources (0.045), number of
 329 exploiting farmers (0.044), population density of farmers in the region (0.04), flood (0.038), groundwater
 330 pollution (0.037), conflicts and disputes over water (0.036) and population growth rate in the region
 331 (0.032) with negative utility. They had the greatest impact on the unsustainability of groundwater
 332 resources in Hamedan-Bahar Plain (Table 2).

333

334 **Table 2.** The 10 weighted negative (top) and positive (bottom) indicators.

Indicator	SESF	Weighted value
Illegal wells (35)	Gov	0.066 (-)
Abstraction volume of groundwater (47)	Outcome	0.058(-)
Groundwater reservoir deficit (48)	Outcome	0.052(-)
Employment in agricultural sector (1)	Soc, Eco, Pol	0.048(-)
Land subsidence (49)	Outcome	0.047(-)
Farmer demand for groundwater resources (7)	Soc, Eco, Pol	0.045(-)
empathy and participation) of farmers (40)	Actors	0.044(-)
Farmer population density in the region (9)	Soc, Eco, Pol	0.04(-)
Number of floods (50)	O	0.038(-)
Groundwater pollution (46)	Outcome	0.037(-)
↑ Negative - Positive ↓ (see Table SX for all values)		
Number of smart meters (32)	Gov	0.017(+)
Number of social organizations operating (38)	Actors	0.018(+)
Number of media and educational programs for water resources (15)	Soc, Eco, Pol	0.018(+)
Rural literacy rate (13)	Soc, Eco, Pol	0.019(+)
Gender structure (11)	Soc, Eco, Pol	0.019(+)
Electrification of water wells (33)	Gov	0.02(+)
Market access (5)	Soc, Eco, Pol	0.02(+)
The amount of information exchange between farmers (41)	Interactions	0.023(+)
Population growth rate in the region (8)	Soc, Eco, Pol	0.032(+)

335

336

337 **3.2 Positive (PIS) and negative (NIS) ideal states of each indicator with near-ideal alternative**

338 The positive and negative ideal state calculations for each indicator were calculated (Appendix Table S4),
339 which determine the distance of the i -th alternative from the ideal alternative (highest performance of
340 each indicator) with the A^+ sign and determining the distance of the i -th alternative of the minimum
341 alternative (lowest performance of each indicator) with the A^- sign. Accordingly, the near-ideal alternative
342 will have the minimum distance from the positive ideal state and the maximum distance from the NIS
343 (Cavallaro, 2010). In the next step, the difference or distance of each item is calculated using the Euclidean
344 method (Table SX). The "illegal wells" (35) and "abstraction volume of groundwater resources" (47), as a
345 negative indicator (cost), had the greatest impact on the unsustainability of groundwater resources in the
346 region, while land subsidence (49), reservoir deficit (48) and groundwater pollution (46) are the next most
347 influential indicators, respectively (Table SX).

348

349 Determining the near-ideal alternative involved taking two steps (Table 3). First, the relative proximity of
350 A_1 was calculated using the formula between zero and one, with the number one indicating the highest
351 rank and the number zero indicating the lowest rank in the set (Izadi et al., 2010). Next, the alternatives
352 were ranked in an ascending to descending order. The results of applying the weights and calculating the
353 proximity of the alternatives to the ideal solution are presented in Table 4. According to the alternative
354 of the nearest-ideal solution, the results of ranking the indicators show that monitoring agents, watershed
355 management projects, transmission efficiency, and water consumption have the greatest influence on the
356 sustainability of groundwater resources in Hamedan-Bahar Plain. In contrast, the numbers of illegal wells,
357 land subsidence, and abstraction volume of groundwater have the most negative influence on
358 groundwater resources in the region.

Table 3. Ranking of indicators affecting the sustainability of groundwater resources, calculated, ranked and ordered by the indicators with least distance from the positive ideal solution (i.e., #35) and the greatest distance from the negative ideal solution (i.e., #39). Indicator ranked 1, is interpreted as having the most positive relative influence on sustainability, while the lowest ranked indicator is interpreted as having the most negative influence. Indicator names are shortened for brevity, but each retains the same reference number throughout the paper for identification. Proximity coefficient to ideal = PCI.

Rank	1	2	3	4	5	6	7	8	9	10	11
Indicators	Regulatory factors (GS#39)	Watershed management projects (RS#27)	Efficiency and consump. (RS#25)	Hydrological boundaries (RS #24)	Number of farmers (A#36)	Rainfall (RU#20)	Balance between agri. and env. (RS#26)	Volume of renewable water (RS#23)	Number of media and education prog. (S#15)	Potential of renewable groundwater (RU#21)	Government policies (S#16)
PCI	0.812	0.807	0.802	0.779	0.771	0.766	0.761	0.758	0.753	0.752	0.746
Rank	12	13	14	15	16	17	18	19	20	21	22
Indicators	Installation of smart water meters (S#18)	Integration of agricultural lands (S#6)	Economic value of groundwater (RU#22)	Number of media (S#14)	Responsibility in water consumption (O#52)	Agriculture groundwater efficiency (O#45)	Number of governmental organizations (GS#28)	Number of NGOs in water (GS#29)	Rural literacy rate (S#13)	Migration rate (S#12)	Communication and interaction of orgs. (GS#30)
PCI	0.741	0.735	0.720	0.715	0.703	0.700	0.689	0.676	0.664	0.663	0.654
Rank	23	24	25	26	27	28	29	30	31	32	33
Indicators	Interaction between economic sectors (GS#31)	Extent of empowerment programs (O#51)	Interaction of economic sectors (I#44)	Number of sectors using water (A#37)	New irrigation equipment (S#19)	Number of local water markets (GS#34)	Regulations between farmers (I#43)	Farmer interactions (I#42)	Diversity of products (S#4)	Income distribution (S#3)	Rural per capita income (S#2)
PCI	0.649	0.642	0.631	0/6	0.594	0.568	0.566	0.553	0.519	0.494	0.493
Rank	34	35	36	37	38	39	40	41	42	43	44
Indicators	Electrification of water wells (GS#33)	Number of smart meters (GS#32)	Number of social orgs. operating (A#38)	Gender structure (S#11)	Age structure (S#10)	Farmer groundwater demand (S#7)	Integration of agricultural lands (S#5)	Employment in agriculture (S#1)	Disputes and conflicts (S#17)	Farmers' population density (S#9)	Information exchange among farmers (I#41)
PCI	0.492	0.396	0.366	0.349	0.341	0.340	0.336	0.314	0.306	0.287	0.251
Rank	45	46	47	48	49	50	51	52			
Indicators	Population growth rate (S#8)	Social capital of farmers (A#40)	Groundwater deficit (O#48)	Groundwater pollution (O#46)	Number of floods (O#50)	Groundwater use volume (O#47)	Land subsidence (O#49)	Number of illegal wells (GS#35)			
PCI	0.210	0.210	2197	192	0.184	0.155	0.113	0.088			

3.3 Comparing social and ecological sustainability with the SESF

Prescott-Allen (1996) provides a basic assessment tool for sustainability that provides a simple systematic way of measuring and combining indicators to draw conclusions about the status of social-ecological interactions. We base our aggregate indicator scores and weighting on this basic premise, dividing sustainability assessment into five levels. The weight of all indicators within each first-tier variable was averaged to get the total near-ideal alternative. The ranks zero to 0.2 were considered highly unsustainable; 0.2 to 0.4 unsustainable; 0.4 to 0.6 semi-sustainable; 0.6 to 0.8 sustainable, and 0.8 to 1 highly sustainable.

The Resource System (RS) and Resource Unit (RU) indicators have the most positive influence on sustainability based on the average weighting of indicator values from the near-ideal alternative calculations (Table 4). In contrast, the Governance System (GS), Actor (A) and Interaction (I) first-tier variables were evaluated as negatively influencing sustainability under the Prescott-Allen classification, along with Outcomes (O) being the lowest. The results are plotted for visual comparative reference in Figure 3. The RS indicators, with an average weight of 0.74, are from this analysis in a sustainable condition, with the key indicators being watershed management projects and efficiency of water transmission and consumption systems. The second rank goes to the RU indicators with an average weight of 0.7, with the key indicators being the precipitation rate and potential of renewable groundwater resources.

The third rank goes to the Interactions indicators with an average weight of 0.6, with key indicators measuring rate of information exchange between farmers, farmers’ interaction about water, farmer agreement, and internal regulations among farmers. The GS indicators, measuring the number of smart meters, electrification of water wells, and number of monitoring agents to control groundwater abstraction, are semi-sustainable with an average weight of 0.46. The Soc, Eco, Pol., indicators with an average weight of 0.45, semi-sustainable, with indicators being literacy of rural people, number of media and educational programs on water resources, government policies regarding water resources, and disputes and conflicts over water resources. The Actor indicators have an average weight of 0.4, including number of operating social organizations, level of indigenous and local knowledge, and amount of social capital. The Outcome indicators have to lowest rank, with an average weight of 0.31. Th main indicators being efficiency of groundwater resources in agriculture, the extent of farmers’ empowerment programs, and responsibility in water consumption. Overall, this analysis suggests that there are both positive and negatively influential indicators shaping the overall sustainability, but that social factors more generally rank lower. A full table of each individual indicator value within each SESF first-tier variable are shown in Appendix Table S5.

Table 4. Weighting and ranking of the SESF first-tier variables when the indicators within each are averaged. The higher rank is interpreted as having an average indicator score that more positively influences sustainability outcomes. The following sustainability influences were based on the following: 0.0 to 0.2 (highly unsustainable); 0.2 to 0.4 (unsustainable); 0.4 to 0.6 (semi-sustainable); 0.6 to 0.8 (sustainable), and 0.8 to 1 (highly sustainable).

Indicators	Resources system	Resources Unit	Interactions	Governance System	Socio-ecological Settings	Actor	Outcomes
Rank	1	2	3	4	5	6	7
Number of indicators	5	3	5	8	19	5	8
Average weight	0.74	0.7	0.6	0.46	0.45	0.4	0.31
Max.	0.8	0.7	0.6	0.8	0.7	0.6	0.7
Min.	0.7	0.7	0.6	0.3	0.2	0.2	0.2

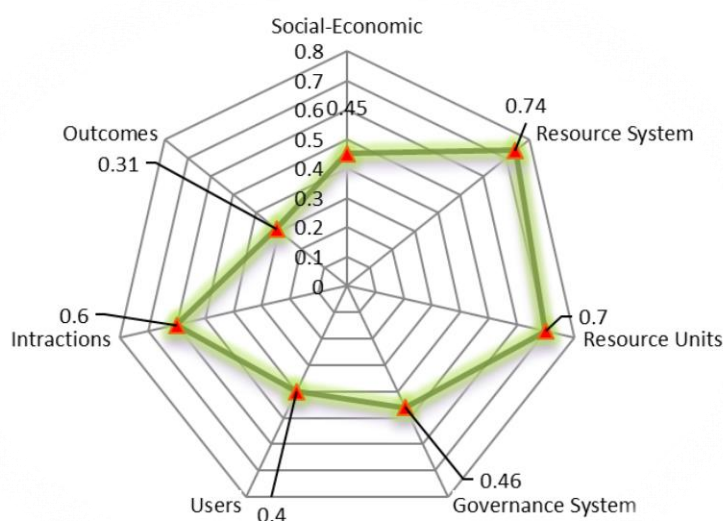


Figure 3. Radar plot of the average indicator values for each SESF first-tier variable.

4.0 Discussion

In this study we demonstrate how using local knowledge to make rapid and comprehensive assessments of social and ecological sustainability is possible and useful for gaining broad insights about a regional groundwater system to inform further studies and local decision-making. Drawing on expert knowledge and applying established analytical tools to structured data provides accessible insights into otherwise data scarce indicators in understudied regions. Integrating local knowledge into scientific assessments through SES-oriented frameworks can assist in the process of knowledge co-production and provide an inclusive methodological approach that can perhaps better link science and practice by integrating and valuing the inputs of non-science experts (Virapongse et al., 2016; Gurney et al., 2019; Partelow et al., 2019). These frameworks, with Ostrom’s SESF arguably being the most well adopted, can organize complex system information in a way that can make data aggregation and communication of results more accessible. Nonetheless, the framework will remain limited in its use without further theoretical and methodological advancements (Cumming et al., 2020), such as attempting co-production processes.

Water governance faces challenges worldwide, and our findings demonstrate that there are a broad range of potentially influential factors that can shape the importance of governance and sustainability outcomes. A main challenge is identifying potential factors and collecting data on each in a way that can provide an initial scientific basis for continued decision-making and research. A main challenge moving forward, both in science and governance, is the evaluation of connections and interdependencies between variables using diverse data (Cumming et al., 2020; Nagel and Partelow, 2022). In other words, there is a need in the current literature to move beyond generating lists of important variables, and to move towards the analysis of variable-variable and further complex system interactions (Villamayor-Tomas et al., 2020). In our analysis we demonstrate how weighting and ranking methods are useful for evaluating impact and prioritizing actions, a step beyond producing a list. Nonetheless, there is a need to develop methods to analyze how those variables interact with each other and co-shape intermediary and final outcomes (Baggio et al., 2016; Villamayor-Tomas et al., 2020).

Specific to our case, we show how social factors are consistently evaluated by local experts as the main factors hindering the sustainable use and management of groundwater. Various reviews of the literature applying the SESF have shown that social factors generally have received more attention across studies, either because most studies are conducted by social scientists interested in examining social issues, or because the social factors in most evaluated cases studies are most influential in shaping social-ecological sustainability (Thiel et al., 2015; Partelow, 2018; Nagel and Partelow, 2022). In the case of groundwater, shown in our case on the Hamedan-Bahar Plain, important RS and RU variables are difficult to change, or cannot be changed such as rainfall, hydrological boundaries or water volume. However, social factors such as illegal wells, use amounts, social capital, information exchange and regulations can be shaped through governance. Weighting and ranking enables us to show which variables have been consistently evaluated as needing attention, suggesting they could be priority areas for governance attention going forward.

As groundwater embodies the characteristics of a common-pool resource, the literature suggests potential governance strategies with many demonstrated cases. For example, establishing effective property rights arrangements such as cooperatives or private quota allocations may help address disputes and conflicts, overuse through perceived scarcity and the interactions between sectors using water (Chen et al., 2018; Jia et al., 2019; Li and Qian, 2018; Mirzaei et al., 2020; Sarami et al., 2021). Establishing monitoring and sanctioning strategies can impact the use of illegal wells or excessive use and pollution, and if done by the

water users themselves it may create accountability, trust and responsibility in the system among users while avoiding external conflicts or dependence on, for example, government agencies or NGOs (Boretti and Rosa, 2019; Loucks and van Beek, 2017; Giri and Qiu, 2016). Focusing on bringing different stakeholders together in deliberative settings to discuss challenges, needs, frustrations and potential pathways forward can foster networks of information exchange and transparency in the process of decision-making through inclusion (Meinzen-Dick et al., 2018; Rey et al., 2019; Sanchis-Ibor et al., 2017; Westerink et al., 2017; Yu et al., 2016;). However, this can also create challenges such as conflict and inefficiency, which may require effective facilitation, communication and planning.

More specifically to the Hamedan-Bahar Plain, the indicators of watershed management projects, artificial recharge and water storage are likely the most influential on sustainability. A decrease in the discharge of wells, springs and aqueducts in the plains will disturb the water and environmental equilibrium, an undesired outcome. Artificial recharge of aquifers, like the flood spreading method in the plains, is one strategy that can be used for refilling groundwater aquifers and also plays an important role in rehabilitation of degraded pastures and desertification. Moreover, using the capacity of the underground reservoir to store excess water in the cropping season will be another advantage of this method. Such approaches have been supported by an emerging literature (Floress et al., 2015; Medema et al., 2016; Reddy et al., 2017; Ali et al., 2017; Cai et al., 2018; Yang et al., 2019). An important indicator of RS is efficiency of water transmission systems. Water transmission or transportation is critical within the agricultural sector due to high demand and use. Using canals and pipes with polyethylene fittings, for example, can prevent water loss during transport and increase efficiency through mitigating leakage (Brown et al., 2015; Kotir et al., 2016; Sun et al., 2016; Fang and Chen, 2017; Cai et al., 2018). Furthermore, long-term environmental trends such as known or regularly monitored precipitation patterns and drought cycles, when considered in planning and water allocation, can help mitigate overuse and avoid crop loss (Jiang et al., 2017; Wei et al., 2017; Xie et al., 2018; Bierkens and Wada, 2019; Sulaiman et al., 2019; Hussain et al., 2019; Ahmad and Al-Ghouti, 2020; Luo et al., 2020).

Economic value is another critical factor, a political tool to increase water efficiency, reduce water demand, manage the irrigation systems and regain costs (Brown et al., 2015; Garcia and Pargament, 2015; Hering et al., 2015; Distefano and Kelly, 2017; Pires et al., 2017). The interactions (I) factors, such as the farmers' agreement and interaction on water issues and collective laws is another factor reflecting social capital and how conflicts are resolved or not. Self-organization has consistently been shown in commons literature as

a key factor in determining collective action, and thus cooperative activities to govern shared resources and resolve joint problems (Yu et al., 2016; Sanchis-Ibor et al., 2017; Westerink et al., 2017; Meinzen-Dick et al., 2018; Rey et al., 2019).

In the GS criteria, management organizations make regular and periodic inspections of wells, control the amount of water supply and operation, and sanction violators. The installation of smart water meters to measure extraction amounts have helped considerably as well as installing volume meters. Monitoring that leads to more information about the status of the resources, and thus provide a feedback loop on the impact of use can be critically important for behaviour change and governance response (Megdal et al., 2015; Giri and Qiu, 2016; Sun et al., 2016; Ashraf et al., 2017; Loucks and van Beek, 2017; Brendel et al., 2018; Boretti and Rosa, 2019; Singh and Bhakar, 2021). Broader criteria in the Social, Economic and Political Settings (S) include media communication through radio, internet and television about programs and trainings (Butler and Adamowski, 2015; Sivapalan and Blöschl, 2015; Cominola et al., 2015; Arthington et al., 2018).

6. Conclusion

Using local expert knowledge to examine and rank the factors influencing social-ecological system sustainability is an effective way to provide a broad assessment of wide ranging indicators while also valuing local knowledge. By applying multi-criteria decision making tools such as TOPSIS and Shannon entropy, we can provide a weighted and ranked list of indicators that have been locally evaluated as influential in local groundwater governance and sustainability. Our findings suggest that social factors likely require the most attention in further governance efforts to better examine how and why groundwater is used to meet sustainability goals. Nonetheless, our study has also shown that a full assessment of all potential social-ecological factors in a groundwater system, guided by Ostrom's social-ecological systems framework (SESF), is important for gaining a systems perspective that considers potentially unforeseen factors and their potential interactions. Further steps forward include reflection of findings with local managers and policy makers while also informing continued analysis of the interactions between key indicators, particularly social factors such as monitoring, social capital, regulation and overuse, to improve understandings of existing problems and potential solutions.

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APPENDIX

Table S1 - Survey distributed for indicator scoring. Below is an English translated example of the original survey for the (S) variables, with all other variables following the same format.

SESF first-tier	Indicators	Score 0 - 10 0 unstable ←→ 10 stable
	Employment in agriculture	0 1 2 3 4 5 6 7 8 9 10

Social, Economic, and Political Settings (S)	Rural per capita income	0 1 2 3 4 5 6 7 8 9 10
	Income distribution	0 1 2 3 4 5 6 7 8 9 10
	Diversity of products in the region	0 1 2 3 4 5 6 7 8 9 10
	Market access	0 1 2 3 4 5 6 7 8 9 10
	integration of agricultural lands	0 1 2 3 4 5 6 7 8 9 10
	Farmers 'demand for groundwater resources	0 1 2 3 4 5 6 7 8 9 10
	Population growth rate in the region	0 1 2 3 4 5 6 7 8 9 10
	Farmers' population density in the region	0 1 2 3 4 5 6 7 8 9 10
	Age structure	0 1 2 3 4 5 6 7 8 9 10
	Gender structure	0 1 2 3 4 5 6 7 8 9 10
	Migration rate	0 1 2 3 4 5 6 7 8 9 10
	Rural literacy rate	0 1 2 3 4 5 6 7 8 9 10
	Number of media	0 1 2 3 4 5 6 7 8 9 10
	Number of media and educational programs in water resources	0 1 2 3 4 5 6 7 8 9 10
	Disputes and conflicts in the field of water resources	0 1 2 3 4 5 6 7 8 9 10
	Government policies in the field of water resources	0 1 2 3 4 5 6 7 8 9 10
	Installation of smart water meters	0 1 2 3 4 5 6 7 8 9 10
New irrigation equipment such as pressurized irrigation	0 1 2 3 4 5 6 7 8 9 10	

Figure S1. Decision matrix. Format of raw data from survey for TOPSIS analysis.

	X_1	X_2	.	X_j	.	X_n
A_1	r_{11}	r_{12}	.	.	.	r_{1n}
A_2	r_{21}	r_{22}	.	.	.	r_{2n}
.
A_i	r_{i1}	.	.	r_{ij}	.	r_{in}
.
A_m	r_{m1}	r_{m2}	.	.	.	r_{mn}

Table S2. Key informant profiles who provided survey inputs.

Job	Level of Education	Number	Organization	Specialty
Managers	P.H.D	5	Regional Water/ Agriculture Organization	Groundwater studies Protection and exploitation
Expert staff	Masters	17	Regional Water /Agriculture Organization	Planning and economic reviews

Table S3. Weight of all 52 indicators using Entropy Shannon.

Indicators	1 (-)	2	3	4	5	6	7 (-)	8	9 (-)	10	11	12	13
Weight	<u>0.048</u>	0.006	0.009	0.006	0.02	0.01	<u>0.045</u>	<u>0.032</u>	<u>0.04</u>	0.018	0.019	0.014	0.019
Indicators	14	15	16	17 (-)	18	19	20	21	22	23	24	25	26
Weight	0.011	0.005	0.008	<u>0.036</u>	0.008	0.016	0.006	0.014	0.009	0.006	0.005	0.004	0.006
Indicators	27	28	29	30	31	32	33	34	35 (-)	36	37	38	39
Weight	0.01	0.006	0.006	0.010	0.008	0.017	0.020	0.011	<u>0.066</u>	0.007	0.002	0.018	0.008
Indicators	40 (-)	41	42	43	44	45	46 (-)	47 (-)	48 (-)	49 (-)	50 (-)	51	52
Weight	<u>0.044</u>	0.023	0.008	0.008	0.008	0.009	<u>0.037</u>	<u>0.058</u>	<u>0.052</u>	<u>0.047</u>	<u>0.038</u>	0.016	0.012

Table S4. Positive and negative ideal states of each indicator. The best option will have the least distance from the positive ideal solution and the greatest distance from the negative ideal solution.

Indicators	1	2	3	4	5	6	7	8	9	10	11	12	13
A+	0.038	0.023	0.023	0.022	0.034	0.014	0.038	0.039	0.038	0.033	0.033	0.017	0.018
A-	0.017	0.022	0.022	0.024	0.017	0.039	0.019	0.010	0.015	0.017	0.018	0.034	0.037
Indicators	14	15	16	17	18	19	20	21	22	23	24	25	26
A+	0.014	0.012	0.013	0.036	0.013	0.020	0.011	0.013	0.015	0.012	0.010	0.009	0.011
A-	0.037	0.038	0.038	0.015	0.038	0.030	0.039	0.040	0.039	0.038	0.038	0.038	0.038
Indicators	27	28	29	30	31	32	33	34	35	36	37	38	39
A+	0.009	0.014	0.014	0.016	0.017	0.028	0.025	0.020	0.042	0.011	0.018	0.033	0.009
A-	0.039	0.031	0.031	0.030	0.031	0.018	0.024	0.026	0.004	0.038	0.028	0.019	0.039
Indicators	40	41	42	43	44	45	46	47	48	49	50	51	52
A+	0.039	0.037	0.021	0.020	0.017	0.015	0.040	0.042	0.040	0.041	0.038	0.019	0.015
A-	0.01	0.012	0.026	0.026	0.030	0.036	0.009	0.007	0.01	0.005	0.008	0.035	0.037

Table S5. Individual indicator values for each SESF first-tier grouping, used to calculate the average weight.

RS	RS ₁ =0.7, RS ₂ =0.7, RS ₃ =0.8, RS ₄ =0.7, RS ₅ =0.8
RU	RU ₁ =0.7, RU ₂ =0.7, RU ₃ =0.7
I	I ₁ =0.6, I ₂ =0.6, I ₃ =0.6, I ₄ =0.6,
GS	GS ₁ =0.3, GS ₂ =0.4, GS ₃ =0.5, GS ₄ =0.08, GS ₅ =0.7, GS ₆ =0.6, GS ₇ =0.3, GS ₈ =0.8
S	S ₁ =0.3, S ₂ =0.4, S ₃ =0.4, S ₄ =0.5, S ₅ =0.3, S ₆ =0.3, S ₇ =0.7, S ₈ =0.3, S ₉ =0.2, S ₁₀ =0.2, S ₁₁ =0.3, S ₁₂ =0.3, S ₁₃ =0.6, S ₁₄ =0.6, S ₁₅ =0.7, S ₁₆ =0.7, S ₁₇ =0.7, S ₁₈ =0.3, S ₁₉ =0.5
A	A ₁ =0.2, A ₂ =0.2, A ₃ =0.5, A ₄ =0.5, A ₅ =0.6
O	O ₁ =0.7, O ₂ =0.1, O ₃ =0.1, O ₄ =0.1, O ₅ =0.1, O ₆ =0.6, O ₇ =0.7, O ₈ =0.1