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Providing basic information for integrated management and restoration of rivers through assessing the human pressures at different scales (Case study: Talar river catchment)

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ABSTRACT

River ecosystems face numerous human pressures that can lead to certain impacts on the environment. However, there is limited information available regarding the prevalence, spatial patterns, mutual impacts, and simultaneous occurrences of these pressures. In this pilot study, we aimed to identify and assess various types of human pressures at different scales within the Talar River catchment. In this regard, a total of 43 sites within the Talar River catchment were selected for investigation. We employed a comprehensive approach by selecting 30 key indicators that represent major human pressures on river ecosystems. These indicators were combined to create a pressure index, enabling us to showcase the synergistic effects of these pressures. The findings revealed that 93% of the studied sites experienced land use pressure, indicating significant human modification in those areas. Additionally, 69% of the sites were subjected to connectivity pressure, 88% to morphological pressure, 86% to water quality pressure, and 41% finally exhibited hydrological pressure. Importantly, our analysis also revealed complex interactions between multiple human pressures. Approximately 8.4% of the sites were affected by two distinct human pressures, while 2.3% experienced three overlapping pressures. Moreover, an overwhelming majority (92%) of the sites were impacted by combinations of more than three human pressures, emphasizing the cumulative impacts of all pressures. These findings underscore the need for comprehensive and systematic consideration of multiple factors when undertaking integrated river basin management and restoration efforts. In other words, effective management and restoration strategies should account for the different scales within the catchment and address the specific combinations of human pressures present.

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1. Introduction

Rivers have long captivated human interest, offering a diverse range of ecosystem services. However, these vital ecosystems are now facing significant threats worldwide, primarily due to human activities and their impact on river systems. The sustainable development of human communities in the 21st century is at stake (Vörösmarty et al., 2010).

Human pressures extend across almost all catchments/basins globally, highlighting the extensive impacts of our actions (Schinegger et al., 2012). Unregulated human activities in river ecosystems pose considerable risks to water security, affecting both human well-being and biodiversity (Kummu et al., 2016; Falkenmark, 2013).

Land use changes, water pollution, water abstraction, channelization, and dam construction are among the major stressors that rivers endure (Mostafavi et al., 2021; Gergel et al., 2002). To address these challenges, river managers have conducted numerous studies focused on managing and restoring river ecosystems. However, traditional approaches often prioritize water pollution reduction and tend to be localized in scale. Practical measures frequently encounter obstacles such as financial constraints, time limitations, system complexity, and a lack of comprehensive ecological assessments, leading to potential failures post-implementation (Nardini and Conte, 2021). Recognizing the need for effective river system management and restoration, developed countries have recently adopted various criteria to assess and guide changes within river systems (Pont et al., 2006; Schmutz et al., 2007; Schinegger et al., 2012). These criteria emphasize comprehensive watershed-based measures that analyze different human pressures—such as land-use changes, hydro-morphological factors, water quality, connectivity, and biological aspects—at multiple scales (Schinegger et al., 2012; Lemm et al., 2020; Mostafavi et al., 2015, 2019, 2021). This approach enables river specialists and stakeholders to undertake multidisciplinary projects aimed at understanding river ecological performance, assessing the ecological impacts of human activities, and providing guidelines for effective river management and restoration. In line with these efforts, the European Water Framework Directive (WFD) has sought to improve and protect the ecological status of water bodies by addressing the diverse pressures that impact aquatic systems through an integrated approach (European Commission, 2000). A key aspect of this strategy is establishing clear communication between water status and driving pressures as a foundation for designing effective measures. Given the aforementioned reasons, there is an urgent need to analyze the multitude of human pressures exerted on rivers across different scales to enable comprehensive management and restoration. In Iran, insufficient information and understanding of human pressures, combined with inadequate guidelines, have resulted in escalating damage to rivers on a daily basis. Many catchments within the country face the consequences of unsustainable development driven by intense human activities (Mostafavi et al., 2022). Current studies and actions predominantly address local pollution, necessitating a shift towards a more holistic approach that assesses various dimensions of human pressures, including land use changes, connectivity, hydro-morphological factors, water quality, and ecological considerations, across different scales (Mostafavi et al., 2021). Assessing interventions throughout the catchment based on the spatial distribution of human pressures allows for the identification, comparison, and prioritization of high-risk areas (Kummu et al., 2012; Meybeck et al., 2013). Understanding the spatial patterns of human pressures on river ecosystems is crucial for developing and implementing targeted strategies. To exemplify how different human pressures can inform the management and restoration of rivers, the Talar River catchment has been selected as a pilot study area. This research aims to identify and analyze various human pressures across different scales, producing maps to illustrate the spatial patterns of these pressures. By doing so, it aims to provide indispensable information for the effective management and restoration of the Talar River catchment and potentially serve as a model for broader application.

2. Material and Methods

2.1. Case study and Selecting stations

The Talar River, situated within the geographical boundaries of Mazandaran province and spanning the cities of Savadkouh, Ghaemshahr, and Joybar, meanders through the northern region of the Alborz Mountains and the southern part of the Mazandaran Caspian Sea (Figure 1). Its coordinates range from 35°30' to 36°45' north latitude and 52°30' to 53°25' east longitude. With a permanent flow, the river extends for approximately 147 kilometers. It originates at an elevation of 2,500 meters above sea level and maintains a gradient of 1.7 percent. The Shirgah station reports an average annual discharge of 260 million cubic meters, while the river's drop height measures 25 meters. To facilitate a comprehensive assessment, the study area was divided into two distinct regions: mountainous and hilly areas, utilizing ArcGIS software to analyze elevation, topography, geology, and land use patterns. The mountainous regions exhibit elevations surpassing 800 meters above sea level and are characterized by steep terrain. In contrast, the hills encompass relatively soft and erodible rock formations, accompanied by gentle slopes. The predominant elevations in this region range from 200 to 800 meters. An extensive examination of all available sources of information pertaining to the target catchment was conducted as an initial step. Subsequently, in conjunction with field visits and information obtained from the Environmental Protection Agency of Mazandaran Province regarding the diverse human pressures affecting the Talar River catchment, a total of 43 evaluation sites were carefully selected. The locations of these sites are depicted in Figure 1.

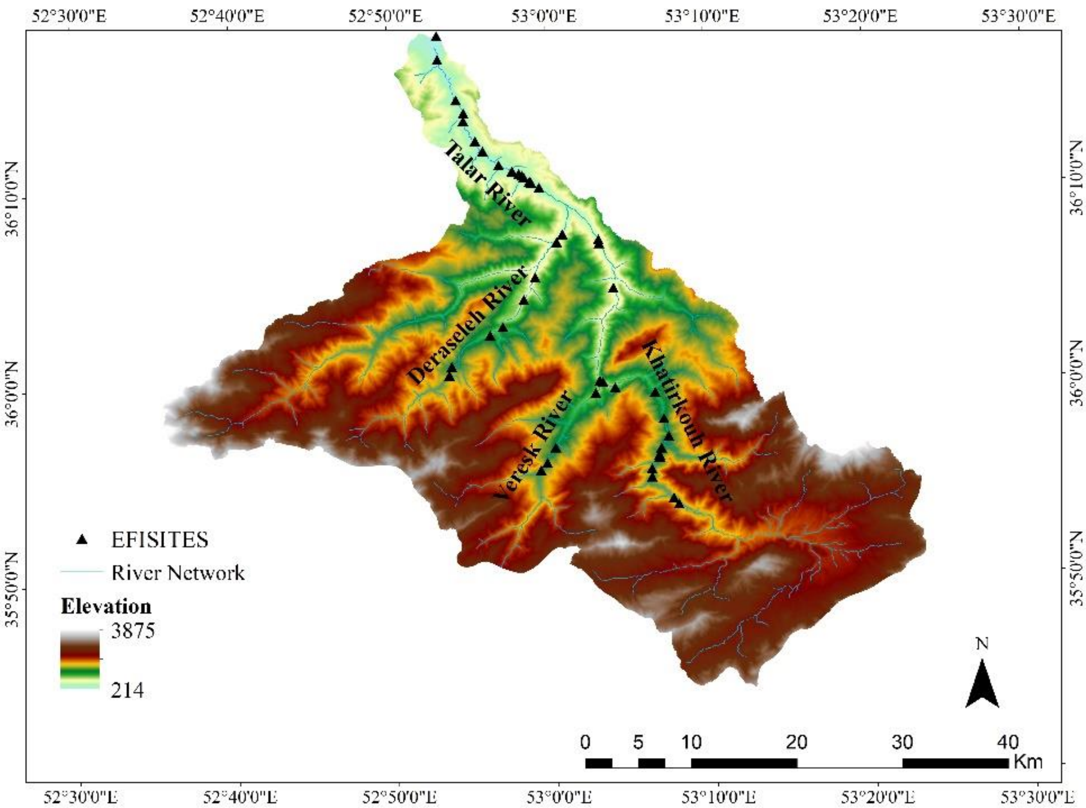

Fig. 1. Talar River catchment and selected sites for investigation of multiple human pressures.

2.2. Selecting human pressures, their measurement and appropriate

To assess and weigh the human pressures on the Talar River catchment, the study utilized the EFI$^+$ index (2007), modified by Mostafavi et al. (2015, 2019) (Table 2). Thirty variables associated with human pressure were categorized into five groups: land-use pressure, hydrological pressure, morphological pressure, water quality pressure, and connectivity pressure. These variables were selected based on their recognized ecological impacts on river ecosystems. The weighting process was conducted primarily at four scales: upper catchment, sub-catchment, reach, and site (Table 1). The intensity of each pressure was determined through expert assessment and available resources, utilizing the EFI$^+$ index (2007) modified by Mostafavi et al. (2015, 2019). Each pressure was assigned a weight ranging from 1 (indicating minimal impact) to 5 (representing severe impact), depending on the presence/absence or the degree of changes observed in different variables. The four scales used for assessment are defined as follows:

1. Upper catchment: Encompasses all areas or upstream catchments that contribute to the drainage of the study site in some manner.

2. Sub-catchment: Refers to all areas associated with the specific sub-catchment where the site under consideration is located.

3. Reach: Represents the region comprising 500 meters upstream and 500 meters downstream from the targeted site.

4. Site: Denotes a location directly affected by at least one type of pressure.

This comprehensive approach enables the assessment and weighting of anthropogenic pressures across multiple scales, providing a nuanced understanding of their impacts on the Talar River catchment.

Table 1. Characteristics of human pressure variables based on EFI+ (2007); (modified by Mostafavi et al., 2015, 2019), their classification and weighting for estimating the intensity of pressure on riverine ecosystems (LUP: Land Use Pressure, CP: Connectivity Pressure, MP: Morphological Pressure, HP: Hydrological Pressure, WQP: Water Quality Pressure).

Human pressure variable	Type	Code	Classification
Agriculture	LUP	LU agri sit	Range: 50 m from stream; 1 = none, 3 = along one side, 5 = along both sides
Urbanisation	LUP	LU urb sit	Range: 100 m from stream; 1 = <5%, 3 = ≥5% and <10%, 5 = ≥10%
Agriculture	LUP	LU agri pc	Extent and pressure of agriculture and silviculture; 1 = <10%, 3 = ≥10% and <40%, 5 = ≥40%
Urbanisation	LUP	LU urb pc	Extent and pressure of urban areas; 1 = <1%, 3 = ≥1% and <15%, 5 = ≥15%
Agriculture	LUP	LU agri dr	Extent and pressure of agriculture and silviculture; 1 = <10%, 3 = ≥10% and <40%, 5 = ≥40%
Urbanisation	LUP	LU urb dr	Extent and pressure of urban areas; 1 = <1%, 3 = ≥1% and <15%, 5 = ≥15%
Migration barrier upstream	CP	C B s up	Barriers on the segment level upstream; 1 = no, 3 = partial, 3 = yes
Migration barrier downstream	CP	C B s do	Barriers on the segment level downstream; 1 = no, 4 = partial, 4 = yes
Channelisation	MP	M channel	Alteration of natural morphological channel plan form; 1 = no, 3 = intermediate, 5 = straightened
Channelisation	MP	M crosssec	Alteration of cross-section; 1 = no, 3 = intermediate, 5 = technical cross-section/U-profile
Channelisation	MP	M instrhab	Alteration of in-stream habitat condition; 1 = no, 3 = intermediate, 5 = high
Channelisation	MP	M embankm	Artificial embankment; 1 = no (natural status), 2 = slight (local presence of artificial material for embankment), 3 = intermediate (continuous embankment but permeable), 5 = high (continuous, no permeability)
Channelisation	MP	M ripveg	Alteration of riparian vegetation close to shoreline; 1 = no, 2 = slight, 3 = intermediate, 5 = high (no vegetation)
Flood protection	MP	M floodpr	Presence of dykes for flood protection; 1 = no, 3 = yes
Flood protection	MP	M remfloodpl	If the river has a former floodplain, proportion of connected floodplain still remaining. Floodplain = area connected during the flood; 1 = >50%, 2 = 10–50%, 3 = <10%, 5 = some water bodies remaining or no
Sedimentation	MP	M sediment	Input of fine sediment (mainly mineral input; bank erosion, erosion from agricultural land); 1 = no, 3 = yes
Flow velocity increase	HP	H veloincr	Pressure on flow conditions (mean velocity) due to channelisation, flood protection, etc.; 1 = no, 3 = yes
Impoundment	HP	H imp	Natural flow velocity reduction on site because of impoundment; 1 = no (no impoundment), 3 = intermediate, 5 = strong
Hydropeaking	HP	H hydrop	Site affected by hydropeaking; 1 = no (no hydropeaking), 3 = partial, 3 = yes
Water abstraction	HP	H waterabstr	Site affected by water flow alteration/minimum flow; 1 = no (no water abstraction), 3 = intermediate (less than half of the mean annual flow), 5 = strong (more than half of mean annual flow)
Reservoir flushing	HP	H reflush	Fish fauna affected by flushing of reservoir upstream of site; 1 = no, 3 = yes
Temperature pressure	HP	H tempimp	Water temperature pressure; 1 = no, 3 = yes
Eutrophication	WQP	W eutroph	Artificial eutrophication; 1 = no, 3 = low, 4 = intermediate (occurrence of green algae), 5 = extreme (oxygen depletion)
Acidification	WQP	W aci	Acidification; 1 = no, 3 = yes
Organic siltation	WQP	W osilt	Siltation; 1 = no, 3 = yes
Organic pollution	WQP	W opoll	Is organic pollution observed; 1 = no, 3 = intermediate, 5 = strong
Toxicity	WQP	W toxic	Toxic priority substances (organic and nutrient appearance); 1 = no or very minor, 3 = weak (important risk, link to particular substance), 5 = high concentration (a clearly known input)

$$\text{M\_morph\_instr} = \frac{\text{M\_channel}+\text{M\_instrhab\_}+\text{M\_crossec}}{3} \quad (1)$$

$$\text{MPI} = \frac{\text{M\_morph\_instr}+\text{M\_embankm}+\text{M\_floodpr}}{3} \quad (2)$$

$$\text{HPI} = \frac{\text{H\_imp}+\text{H\_hydrop}+\text{H\_waterabstr}+\text{H\_resflush}+\text{H\_hydromod}}{5} \quad (3)$$

$$\text{WQPI} = \frac{\text{W\_aci}+\text{W\_osilt}+\text{W\_opoll}+\text{W\_toxic}}{4} \quad (4)$$

$$\text{CPI} = \frac{\text{C\_B\_up}+\text{C\_B\_do}}{2} \quad (5)$$

$$\text{LUPI} = \frac{LU\_agrisit+LU\_agripc+LU\_agridr+LU\_urbsit+LU\_urbpc+LU\_urbdr}{6} \quad (6)$$

Then, the Global Pressure Index (GPI) was calculated based on equation (7):

$$\text{GPI} = \frac{LUI+HPI+MPI+WQPI+CPI}{5} * affected\_groups \quad (7)$$

Class 0 or no human pressure class: This class includes sites with GPI values less than 3, indicating minimal to no human pressure. These sites are considered un-impacted or slightly impacted. **Class 1** or single-pressure class: Sites with GPI values ranging from 3 to 5 fall into this class. These sites experience a moderate level of pressure from one specific factor. The specific pressure source could be related to connectivity, land use, or morphological changes. **Class 2** or double-pressure class: GPI values in the range of 6 to 8 would classify sites into this class. These sites experience pressures from two simultaneous factors, indicating a higher level of cumulative impact. **Class 3** or triple-pressure class: this class includes sites with GPI values between 9 and 11. These sites face pressures from three different factors, suggesting a significant level of cumulative impact. **Class 4** or multiple-pressure class: GPI values greater than 11 classify sites into this class. These sites endure pressures from multiple factors, indicating a high level of cumulative impact and vulnerability to various stressors. The GPI classification provides a simplified way to assess the intensity of pressure and vulnerability of each site based on the cumulative effects of different factors. Finally, all analyses were performed using Google Earth, ArcGIS 9.3, and Excel software.

3. Results and discussion

3.1. Evaluation and analysis of human pressures

As shown in Table 2, the status of sites in relation to each human pressure variable is presented separately and proportionate to the degree of degradation with color coding.

Table 2. Weighting of human pressure variables for 43 study sites (good condition with blue color for variables with a score of less than 3, medium condition with yellow color for variables with a score of 3, bad condition with orange color for variables with a score of 4, and very bad condition with red color for variables with a score of 5).

Site	Agriculture			Urbanization			Migration barrier upstream	Migration barrier downstream	Channelization					Flood protection		Sedimentation	Flow velocity increase	Impoundment	Hydropeaking	Water abstraction	Reservoir flushing	Temperature pressure	Eutrophication	Acidification	Organic siltation	Organic pollution	Toxicity
	LU agri sit	LU agri pc	LU agri dr	LU urb sit	LU urb pc	LU urb dr	C B up	C B do	M channel	M crosssec	M insthab	M embankm	M ripveg	M floodpr	M remfloodpl	M sediment	H veloincr	H imp	H hydrop	H waterabstr	H reflush	H tempimp	W eutroph	W aci	W osilt	W opoll	W toxic
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	1	1	1	1	1	1	1	1	1	1	3	3	5	1	1	1	1	1	1	1	1	1	1	1	1	1	1
3	1	1	1	5	1	1	1	4	1	1	1	1	1	3	1	1	1	1	1	1	1	1	1	1	1	1	1
4	3	1	1	1	1	3	3	4	3	3	3	2	3	3	1	1	3	1	1	1	1	1	1	1	1	3	1
5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3	3	1
6	1	1	1	1	1	1	1	1	3	3	3	5	5	3	2	3	3	1	1	1	1	1	1	1	3	3	1
7	1	1	1	1	1	1	3	4	3	3	5	2	1	3	1	3	3	1	1	1	1	1	1	1	3	3	1
8	3	1	1	1	1	1	1	1	1	1	5	1	1	1	1	3	1	1	1	1	1	1	1	1	3	3	1
9	1	1	1	1	1	1	1	1	1	1	5	1	1	1	1	3	1	1	1	1	1	1	1	1	3	3	1
10	1	1	1	1	1	1	1	1	1	1	5	1	1	1	1	3	1	1	1	1	1	1	1	1	3	3	1
11	3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3	1	1	1	1	1	1	1	1	3	3	1
12	3	1	1	1	1	1	1	1	1	1	1	2	5	3	1	3	1	1	1	1	1	1	1	1	3	3	1
13	1	1	1	1	1	1	3	4	1	1	5	2	1	1	1	3	1	1	1	1	1	1	1	1	3	3	1
14	3	1	1	1	1	1	1	4	3	1	5	2	5	3	2	3	1	1	1	1	1	1	1	1	3	3	1
15	1	1	1	1	3	1	3	4	3	3	5	2	5	1	1	3	3	1	1	1	1	1	1	1	3	3	1
16	1	1	1	1	3	1	3	1	3	3	5	2	1	3	1	3	3	1	1	1	1	1	1	1	3	3	1

17	1	1	1	1	5	1	1	1	3	3	5	2	1	3	1	3	3	1	1	1	1	1	1	1	3	3	1
18	1	1	1	5	1	1	3	4	3	3	5	2	1	3	1	3	3	1	1	1	1	1	1	1	3	3	1
19	1	3	1	5	3	1	3	4	5	3	3	3	5	3	5	3	3	1	1	1	1	1	1	1	3	3	1
20	3	3	1	5	3	1	3	4	5	3	3	3	5	3	5	3	3	1	1	1	1	1	1	1	3	3	1
21	1	1	1	1	1	1	3	4	5	5	5	5	5	3	5	1	3	1	1	1	1	1	1	1	3	3	1
22	3	1	1	1	1	1	1	4	1	1	1	2	1	3	1	3	1	1	1	1	1	1	1	1	3	3	1
23	5	1	1	5	1	1	1	4	1	1	1	1	1	3	1	3	1	1	1	1	1	1	1	1	3	3	1
24	5	3	1	1	1	3	3	1	3	1	2	2	1	3	1	3	1	1	1	1	1	1	1	1	3	3	1
25	1	3	1	1	1	3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3	3	1
26	3	3	1	1	1	3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3	3	1
27	1	1	1	5	1	1	1	1	1	1	1	1	1	1	1	3	1	1	1	1	1	1	1	1	3	3	1
28	1	1	1	5	1	1	3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3	3	1
29	5	3	1	5	5	1	3	4	3	3	5	2	3	5	5	3	3	1	1	1	1	1	1	1	3	3	1
30	1	3	1	5	5	1	3	4	3	3	5	2	3	5	5	3	3	1	1	1	1	1	1	1	3	3	1
31	1	3	1	5	5	1	3	4	5	5	5	5	5	5	5	3	3	1	1	1	1	1	1	1	3	3	1
32	1	3	1	5	5	1	3	4	5	5	5	5	5	5	5	3	3	1	1	1	1	1	1	1	3	3	1
33	1	3	1	5	5	1	3	4	5	5	5	5	5	5	5	3	3	1	1	1	1	1	1	1	3	3	1
34	1	3	1	5	5	1	3	4	5	5	5	5	5	5	5	3	3	1	1	1	1	1	1	1	3	3	1
35	5	3	1	5	5	1	3	4	5	5	5	5	5	5	5	3	3	1	1	1	1	1	1	1	3	3	1
36	5	1	1	1	1	1	3	4	1	1	5	3	5	5	5	3	1	1	1	1	1	1	1	1	3	3	1
37	3	3	1	1	1	3	3	4	1	1	5	3	5	5	1	3	1	1	1	1	1	1	1	1	3	3	1
38	3	3	1	1	1	3	3	4	3	3	5	5	5	5	1	3	3	1	1	1	1	1	1	1	3	3	1
39	5	3	1	1	1	3	3	4	1	1	1	1	1	1	1	3	1	1	1	1	1	1	1	1	3	3	1
40	1	1	1	1	1	3	3	4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3	3	1
41	1	1	1	1	1	3	3	4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3	3	1
42	1	1	1	5	5	3	3	4	1	1	1	1	1	1	1	3	1	1	1	1	1	1	1	1	3	3	1
43	1	1	1	5	5	3	3	4	3	3	5	3	1	1	1	3	3	1	1	1	1	1	1	1	3	3	1

Based on the information provided, here is a summary of the key findings from the Table 2:

Land use pressures (including agriculture and urbanization): 30 sites are experiencing very bad and bad pressure status due to urbanization and land use changes. Most impacted sites located in the urbanization are under very bad status than sites located in the agriculture areas. Moreover, upstream land use impacts were nothing in these studied sites.

Connectivity pressure: The connectivity pressure, both upstream and downstream of the studied sites, is reported to be high (34 for upstream barriers and 43 for downstream barriers). This actually refers to barriers specially weirs that hinder the movement of organisms or water flow within the catchment.

Morphological pressures: Among 43 sites, 31 ones are under morphological pressures which are related to channelization because of land use change, gravel mining and flood protection.

Hydrological pressure: The table suggests that hydrological pressure in the catchment is negligible. This means that there are no significant pressures related to water flow in the studied sites except "Flow velocity" increase which is attributed to various factors such as channelization or alterations in land use patterns.

Water Quality pressure: Water quality in the catchment is under specifically from organic pollutants and sediment pressures. These pollutants and sediments can originate from various sources such as agricultural runoff, urban discharges or aquaculture.

Table 3. Calculating various pressure indices and the Global Pressure Index (GPI) for 43 studied sites (good condition with blue color for variables with a score of less than 3, medium condition with yellow color for variables with a score of 3, bad condition with orange color for variables with a score of 4, and very bad condition with red color for variables with a score of 5).

Site	Land use Pressure (LUP)	Connectivity Pressure (CP)	Morphological Pressure (MP)	Water Quality Pressure (WQP)	Hydrological Pressure (HP)	GPI score	Site	Landuse Pressure (LUP)	Connectivity Pressure (CP)	Morphological Pressure (MP)	Water Quality Pressure (WQP)	Hydrological Pressure (HP)	GPI score
1	3	1	3	2	1	8	23	4	4	3	3	1	14
2	3	1	3	2	1	8	24	4	3	3	3	1	12.7
3	4	4	3	2	1	13	25	3	1	2.7	3	1	8.7
4	3	3.5	3	2	3	14.5	26	3	1	2.5	3	1	8.5
5	5	1	5	3	1	13	27	3	1	2.5	2.5	1	8
6	4	1	3	3	3	13	28	1	3	3	2.5	1	8.5
7	1	3.5	3.7	3	3	13.2	29	4	3.5	3.2	4.25	3	17.6
8	5	1	4.3	3	1	12.3	30	4	3.5	3.3	4.25	3	18
9	3	1	4.5	3	1	10.5	31	4	3.5	4.3	4.25	3	19
10	4	1	3.6	3	1	10.6	32	4	3.5	4.3	4.25	3	19
11	4	1	4	3	1	11.0	33	4	3.5	4.3	4.25	3	19
12	3	1	3.6	3	1	9.6	34	4	3.5	4.3	4.25	3	19
13	1	3.5	4	3	1	10.5	35	4	3.5	4.3	4.25	3	18.7
14	3	4	3.8	3	1	13.8	36	4	3.5	2.8	4.25	1	14.6
15	3	3.5	3.8	3	3	16.3	37	6	3.5	3.6	4.25	1	16.8
16	3	3	3.6	3	3	15.6	38	4	3.5	4	4.25	3	18.4
17	3	1	4.3	3	3	13.3	39	4	3.5	3	4.25	1	14.4
18	4	3.5	3.1	3.5	3	17.1	40	3	3.5	2.5	4.25	1	13.3
19	4	3.5	4	3.5	3	17.7	41	3	3.5	3	4.25	1	13.8
20	4	3.5	3.8	3.5	3	17.4	42	3	3.5	3	4.25	1	13.8
21	3	3.5	4.7	3.25	3	17.5	43	3	3.5	3.3	4.25	3	17.1
22	3	4	3.8	3.25	1	14							

Based on the information provided in Table 3, it can be seen that most sites experience moderate to high cumulative pressure due to the combined impacts of connectivity, land use, and hydro-morphological changes. Sites 1, 2, 6, and 13 have relatively lower scores regarding Land use pressure (LUP) compared to other sites, indicating less pressure from land use changes. Connectivity pressure (CP) scores remain consistent across most sites, with values ranging between 3.5 and 4, except for site 28 which has a CP score of 1. Morphological pressure (MP) is generally in the range of 3.0 to 4.7 across different sites, indicating moderate to high pressure related to morphological changes. Water Quality pressure (WQP) scores range from 2.5 to 4.3, with most sites falling within the 3 to 4, suggesting varying levels of pressure from pollutants and sediment affecting water quality. Hydrological pressure (HP) scores are mostly 1, indicating negligible pressure related to water flow or availability. The Global Pressure Index (GPI) varies between 10 and 19, with higher values indicating higher overall pressure on the studied sites. According to Figure 3, the results of GPI for different pressure classes range from 2 to 4. Class 2: Comprised 4.8% of the total. Class 3:

Comprised 2.3% of the total. Class 4: Comprised 92% of the total. This suggests that a significant majority of the visited sites fell into class 4, which had the highest-pressure rating. Class 2 and class 3 represented smaller proportions of the total sites visited.

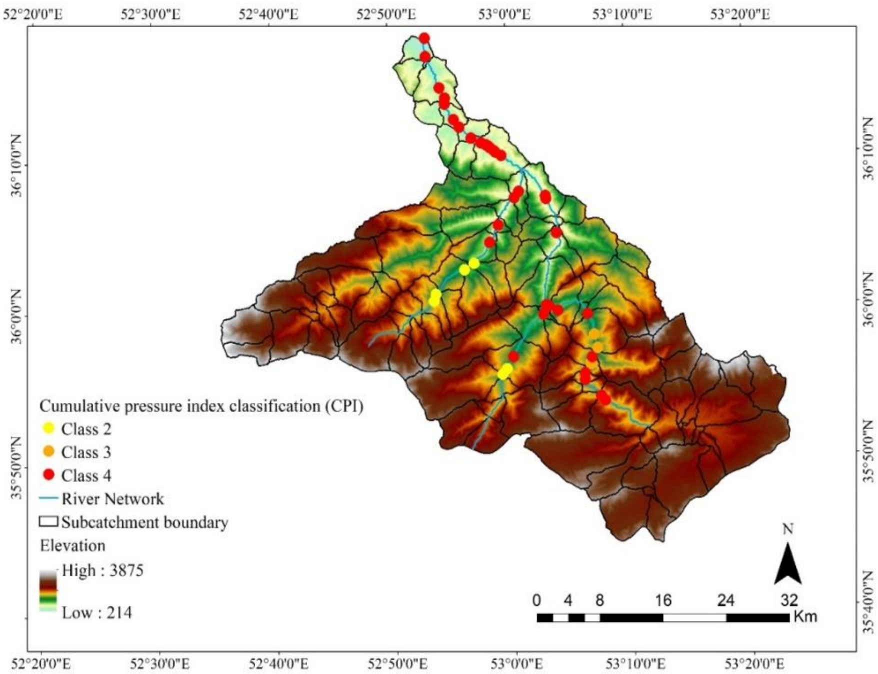

Fig. 2. Distribution of Global Pressure Index (GPI) in the studied sites.

Based on the information provided in Tables 4 and 5, the GPI results for landscape units and main tributaries have been compared with each other.

Table 4. GPI results for each landscape unit.

Landscape Units	GPI			
	Max	Min	Ave.	Median
Hill	19	13.2	16.5	17.3
Mountainous	18	9.5	13.8	13.3

According to Table 4, it can be concluded that the pressure status is worse in the hill landscape unit (average GPI is 16.5) compared to the mountainous landscape unit (average GPI is 13.8).

Table 5. GPI results for each main tributary.

Main tributary	GPI			
	Max	Min	Ave.	Median
Talar	19	13.3	16.9	17.4
Veresk	14.5	12	12.8	12.5
Khatikouh	18	12.5	18	14.3
Deraseleh	17.5	9.5	13	12.8

According to Table 5, the overall pressure status among different main tributaries has been compared. It can be seen that the most impacted tributary is Talar River followed by Khatikouh River.

3.2. Discussion

To our knowledge, this research is actually the first study on the identification and analysis of all types of human pressures in an integrated way at different scales in Iran, which has been done in a catchment area of a river like Talar as a pilot. Although Mostafavi and Teimori (2018) and Mostafavi et al. (2015, 2019, 2021) studied the anthropogenic pressures in the southern basin of the Caspian Sea or Schinegger et al. 2012 investigated in a similar way on the European rivers to describe and analyze the land use, hydrological, morphological, water quality and connectivity pressures on the riverine ecosystems but all of them didn't focus on the catchment of a river specifically with more details for a better understanding regarding river restoration and management. Generally, for developing countries like Iran focusing on a river specific is more successful due to a lack of enough budget, time, or even ecological experts. According to our findings, most sites are impacted by multiple pressures. Moreover, all pressure types influence on the rivers of Talar catchment in a way (Figure 3).

Fig. 3. Pictures related to pressure drivers in Talar river; A: Gravel mining pressure, B: Agricultural pressure, C: Water quality pressure, D: Connectivity Pressure, E: Urban Development, F: Channelisation.

In the following, the discussion related to different pressures and their impacts will be discussed.

3.2.1. Agriculture impacts

Agriculture usually disturbs rivers by increasing nonpoint inputs of pollutants, impacting riparian and stream channel habitats, and altering flows (Osborne and Wiley, 1988). According to our findings, generally, this activity extends to the Talar River margin and natural riparian forest has been removed in some sections. Therefore, it is expected warmer conditions during summer, receiving fewer energy inputs such as leaf litter, and increasing primary production which all is in line with Quinn (2000). Moreover, it is observed that bank stability decreases in some reaches, although the establishment of deep-rooting grasses can stabilize banks, this is also confirmed by Lyons et al. (2000).

3.2.2. Urbanization impacts

Major changes that are expected to be related to increased urban land area include rises in the amounts and variety of pollutants in runoff, more irregular hydrology due to increased impervious surface area and runoff conveyance, increased water temperatures because of the loss of riparian vegetation, and warming of surface runoff on exposed surfaces, and reduction in channel and habitat structure due to sediment inputs, bank destabilization, channelization, and restricted interactions between the river and its land margin (Paul and Meyer, 2001; Mostafavi et al., 2022). All the above-mentioned changes have been observed in the Talar River.

3.2.3. Connectivity impact

The longitudinal river connectivity is interrupted by dams, ground sills, and weirs. In the studied area, there is no dam but particularly affected by ground sills and weirs representing a physical barrier to the migration of fish. Due to these barriers, no long-distance migratory species (e.g. Acipenser sp., C. wagneri; R. caspicus; R. rutilus) move up-stream in Iran, while these species have been reported in many up-streams the past (Mostafavi, 2007). Dams block their migration upstream to spawning areas, threatening to decrease reproduction numbers and reduce the species population, they have led to changes in upstream and downstream species composition. Almost no fish-ways or fish ladders are considered for them in Iran. The majority of the natural habitats have recently been fragmented downstream which is very prevalent in Iran (Mostafavi et al., 2022).

3.2.4. Water quality impact

Water quality pressures in the studied area are typically related to untreated sewage of cities and agriculture as well as aquaculture and gravel mining. Although all increases are concomitant either with increased land-use change or human development, elucidating precisely which factors are responsible for these trends is problematic, as there may be multiple underlying causes. The runoff of agriculture and some livestock, slaughterhouses, hospitals, restaurants etc. is directly discharged into rivers without any treatment. In addition, gravel mining, is one of the main reasons for polluting the rivers within the catchment, in fact, around 10 mentioned industries are dramatically located beside of Khatirkoh River (one of the upstream rivers that influence downstream especially the Talar river). Mining and dredging activities, poorly planned stockpiling and uncontrolled dumping of overburden, turbidity, and electro-conductivity are the main parameters that change violently in the location of incidence plus chemical/fuel spills will cause reduced water quality for downstream users, increased cost for downstream water treatment plants and poisoning of aquatic life. Sand and gravel mining sediment is mechanically removed from river channels, extraction of sand and gravel for construction aggregate is one of the largest mining industries in most parts of Iran, and similar to dams are dramatically increasing along the river network (Padamal et al., 2008; Paukert et al., 2011; Mostafavi et al., 2022). The negative environmental impacts aquaculture has had are nuanced. Nutrient buildup happens when there is a high density of fish in one area. Fish produce waste, and their waste has the potential to build up in the surrounding area. This can deplete the water of oxygen, creating algal blooms and dead zones (Hejazi et al., 2023).

3.2.5. Morphological impacts

Channelization is defined here as a reach where a river is restricted to the main channel and is disconnected from the surrounding riparian zone. The reasons for channelization in this area as well as other areas in Iran/world are generally linked to farmland acquisition, construction of bridges or roads, flood prevention as well as river bed and bank erosion control. Moreover, gravel mining and sand extraction are other main drivers for morphological pressures, changing the stream's physical habitat characteristics and leading to e.g. siltation, clogging of the riverbed, turbidity, and degradation of the riparian vegetation (Lau et al., 2006; Paukert et al., 2011; Mostafavi et al., 2022).

3.2.6. Hydrological impacts

Natural hydrological cycles and hydraulic conditions are intrinsically important to the physical and ecological processes in lotic ecosystems, with alterations to the natural flow regime now widely recognized as a serious threat to their ecological integrity (Poff et al., 1997). In the studied area, hydrological pressures have not been significantly observed because of the topography of the catchment. Moreover, water abstraction due to agriculture generally at the end of the studied catchment happens where it is plain and extensive agriculture (mostly for rice) has been developed. As above mentioned, hydrological pressures are usually observed in canalization reaches and areas impacted by gravel mining.

4. Conclusion

These impacts may have ecological effects on the direct and indirect loss of stream reserve habitat, disturbances of species attached to streambed deposits, reduced light penetration, reduced primary production, and reduced feeding opportunities. Taking into account different dimensions allows for a more comprehensive approach to river restoration and management. By recognizing the interplay between local and catchment pressures, it becomes possible to develop effective strategies that address the root causes of ecological degradation. We see that for an integrated river basin management and restoration, assessment of different scales and study of human pressure types are essential.

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