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Assessment of flash flood hotspots through local knowledge and capacity for flood crowdsourcing

Parvaneh Hatami Golmakani[1], Vahedberdi Sheikh[*2], Arash Zare Garizi[3], Abdolreza Bahremand[4]

1. Ph.D. Student of Watershed Management, Faculty of Range and Watershed Management, Gorgan University of Agricultural Sciences and Natural Resources, Gorgan, Iran. Email: p.hatami@gau.ac.ir
2. Corresponding Author, Professor, Dept. of Watershed Management, Faculty of Range and Watershed Management, Gorgan University of Agricultural Sciences and Natural Resources, Gorgan, Iran. Email: sheikh@gau.ac.ir
3. Assistant Prof., Dept. of Watershed Management, Faculty of Range and Watershed Management, Gorgan University of Agricultural Sciences and Natural Resources, Gorgan, Iran. Email: arash.zare@gau.ac.ir
4. Professor, Dept. of Watershed Management, Faculty of Range and Watershed Management, Gorgan University of Agricultural Sciences and Natural Resources, Gorgan, Iran. Email: bahremand@gau.ac.ir

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ABSTRACT

Background and Objectives: The complex knowledge of local communities on the full cycle of disaster risk management has been proven valuable in various researches. However, the scientific literature still lacks studies that examine how to use Local Knowledge (LK) and the local people's capabilities for crowdsourcing in Flash Flood Early Warning Systems (FFEWS) studies. Hence the main target of this research is the investigation of the capacity of crowdsourcing for FFEWS and the identification of Flash Flood Hotspots (FFHs) by LK across a flood-prone area in northeast of Iran.

Materials and Methods: In this study, a questionnaire with three different themes was designed. The first theme was related to the individual characteristics as independent variables, and the second theme addressed the residents' LK in determining the FFHs, the type and the predominant time of the flood occurrence in the region, by asking open-ended questions with short answers. The last theme addressed the assessment of people's capacity in Flash Flood Crowdsourcing (FFC), through asking questions with a Likert scale of 0-5. The face-to-face questionnaire administration mode was used for public surveys through conducting oral interviews and live discussions.

Results: The results showed that there was no significant correlation between the individuals' characteristics and their willingness and motivation to participate in FFC. Comparing residents' LK with the 31-year flood report and literature review showed that the residents' LK about the flood occurrence location, time and type on a local scale was very promising. The research results indicated that the respondents showed the highest level of willingness to participate in the release of flood warning messages with an average score of 4.23 and the most important motivating factor for their willingness to participate was introducing saving relatives, fellow villagers, and human being from flood hazards with an average score of 4.84.

Conclusion: In the most of the previous studies that have focused on the development of FFEWS, very little attention has been paid to understanding the needs of citizens and promoting their participation. There is a research gap regarding the method of citizen's participation and their potential support for FFEWS. Hence in this research, an attempt was made to take a small step towards filling this gap by investigating LK, motivation and willingness of local residents to participate in various aspects and steps of FFEWS. Our findings indicate that involving local people in FFEWS has various unknown aspects that should be explored through more extensive and detailed studies.

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ارزیابی نقاط داغ سیل ناگهانی از طریق دانش محلی و ظرفیت جمع‌سپاری سیل

پروانه حاتمی گل‌مکانی[۱]، واحدبردی شیخ*[۲]، آرش زارع گاریزی[۳]، عبدالرضا بهره‌مند[۴]

۱. دانشجوی دکتری آبخیزداری، دانشکده مرتع و آبخیزداری، دانشگاه علوم کشاورزی و منابع طبیعی، گرگان، ایران.
رایانامه: p.hatami@gau.ac.ir

۲. نویسنده مسئول، استاد گروه آبخیزداری، دانشکده مرتع و آبخیزداری، دانشگاه علوم کشاورزی و منابع طبیعی، گرگان، ایران.
رایانامه: sheikh@gau.ac.ir

۳. استادیار گروه آبخیزداری، دانشکده مرتع و آبخیزداری، دانشگاه علوم کشاورزی و منابع طبیعی، گرگان، ایران.
رایانامه: arash.zare@gau.ac.ir

۴. استاد گروه آبخیزداری، دانشکده مرتع و آبخیزداری، دانشگاه علوم کشاورزی و منابع طبیعی، گرگان، ایران.
رایانامه: bahremand@gau.ac.ir

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چکیده

سابقه و هدف: دانش پیچیده جوامع محلی در مورد چرخه کامل مدیریت ریسک بلایا در پژوهش‌های مختلف به اثبات رسیده است. بااین‌حال، ادبیات علمی هنوز فاقد مطالعاتی است که چگونگی استفاده از دانش محلی (LK) و قابلیت‌های مردم محلی را برای جمع‌سپاری در مطالعات سیستم‌های هشدار زودهنگام سیل (FFEWS) موردبررسی قرار دهد. ازاین‌رو هدف اصلی این پژوهش بررسی ظرفیت جمع‌سپاری ساکنان محلی برای FFEWS و شناسایی نقاط داغ سیل‌های ناگهانی (FFHs) با استفاده از LK در یک منطقه مستعد سیل در شمال شرق ایران است.

مواد و روش‌ها: در این پژوهش پرسشنامه‌ای با سه بخش مختلف طراحی شد. بخش اول مربوط به ویژگی‌های فردی به‌عنوان متغیرهای مستقل بود، بخش دوم مرتبط با به LK ساکنان در تعیین FFH ها، نوع و زمان غالب وقوع سیل در منطقه بود که از طریق پرسیدن سؤالات باز با پاسخ کوتاه صورت گرفت. بخش آخر نیز مربوط به ارزیابی ظرفیت ساکنان محلی برای جمع‌سپاری سیل ناگهانی (FFC) بود که از طریق پرسیدن سؤالات با طیف لیکرت ۰-۵ انجام شد. نظرسنجی‌های عمومی پرسشنامه به‌صورت حضوری و از طریق مصاحبه شفاهی و بحث زنده تکمیل شد.

یافته‌ها: نتایج نشان داد که بین ویژگی‌های فردی و تمایل و انگیزه افراد برای مشارکت در FFC رابطه معناداری وجود ندارد. مقایسه LK ساکنان با گزارش سیل ۳۱ ساله و مرور منابع نشان داد

که LK ساکنان در مورد مکان، نوع و زمان وقوع سیل، در مقیاس محلی بسیار امیدوارکننده بود. نتایج پژوهش بیانگر آن است که پاسخگویان با میانگین امتیاز ٤/٢٣ بالاترین میزان تمایل برای مشارکت در انتشار پیام‌های هشدار سیل را نشان می‌دهند و مهم‌ترین عامل انگیزشی آن‌ها به مشارکت با میانگین امتیاز ٤/٨٤، نجات اقوام، آشنایان و انسان‌ها بود.

نتیجه‌گیری: در اکثر مطالعات قبل که بر توسعه FFEWS متمرکز شده‌اند، توجه بسیار کمی به درک نیازهای شهروندان و ارتقای مشارکت آن‌ها شده است. درواقع، یک شکاف تحقیقاتی در مورد روش مشارکت شهروندان و حمایت بالقوه آن‌ها از FFEWS وجود دارد. ازاین‌رو در این پژوهش سعی شد با بررسی LK، انگیزه و تمایل ساکنان محلی به مشارکت در جنبه‌ها و مراحل مختلف FFEWS، گامی کوچک در جهت پرکردن این شکاف برداشته شود. یافته‌های ما نشان می‌دهد که مشارکت افراد محلی در FFEWS جنبه‌های ناشناخته مختلفی دارد که باید از طریق مطالعات گسترده‌تر و دقیق‌تر موردبررسی قرار گیرد.

استناد: حاتمی گل‌مکانی، پروانه، شیخ، واحدبردی، زارع گاریزی، آرش، بهره‌مند، عبدالرضا (۱۴۰۲). ارزیابی نقاط داغ سیل ناگهانی از طریق دانش محلی و ظرفیت جمع‌سپاری سیل. *پژوهش‌های حفاظت آب و خاک*، ۳۰ (۴)، ۱۴۵-۱۲۵.
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Introduction

Social impacts of flash floods can be alleviated by development of more efficient tools and frameworks to discern Flash Flood Hotspots (FFHs) (1). FFHs are the areas that the flash flood hazards are more frequent and severe. In fact, flood hazard is a momentous component of flood risk and means the occurrence of a flood event with a certain eventuality (2) that generally can be appraised through qualitative, semi-quantitative or quantitative methods for all flood types (3 and 4). Additionally, flash floods are prompt response of small to medium-scale hydrologic systems to high-intensity rainfalls or the release of stored water behind dams (5). Inundation of this flood type, over dry land happens within a few minutes or hours of the rainfall (5) and leave little time for residents to take actions to reduce damage to properties and the risk to life (6 and 7). The small spatial and temporal scales of flash floods (8) make their forecasting a challenging issue, especially in regions with sparse data and without high-resolution (9) weather models (10). Crowdsourcing or citizen science (11) is a conceivably useful approach to complete the existing observation networks to fill this data scarcity and gap (12). Local communities have been proven to have a complex knowledge of the cycle of disaster risk management (13). Integration of both Local Knowledge (LK) and capabilities for crowdsourcing with scientific knowledge is recommended in all steps of flood risk management (10 and 14).

Crowdsourcing is a form of citizen science, involving non-scientific citizens in scientific research (15, 16 and 17). The design and successful implementation of citizen science-based monitoring systems requires appraisal of the willingness, motivation and needs of participants (18). Being motivated means to make a move to perform something (19). Motivations of volunteers can vary depending on individual characteristics, attitudes, socio-cultural norms, experiences, and expectations (20 and 21). With the rise of citizen science, various researches on the determination of participants' motivation to collaborate in crowdsourcing projects have been conducted (22, 23, 24, 25, 26 and 27). In different studies, various aspects such as, social and physical enthusiasm (27), progressing in literacy level (28), contributing to scientific knowledge (23) competition, rewarding and the feeling of belonging to a larger social community can be the salient motivations for the participants (29 and 30). The literature review in this subject, indicates that a limited research has been done on exploring motivation and willingness for participating in flood related, particularly flash flood related, citizen science projects, particularly in non-developed and developing countries. Also practice and research still lack studies that investigate how to use LK and local people capabilities for crowdsourcing in flood risk management. Although, efforts have been made in this regard, but still do not fill the gap between citizen knowledge and flood risk management. Because these efforts only focus on the development of systems, methods and approaches and do not consider the needs of citizens or better ways to interact with them (31). To this end, the main target of this research is the investigation of the crowdsourcing capacity for Flash Flood Early Warning Systems (FFEWS) in a most flood-prone area in northeast Iran, particularly in upstream zones which suffers from hydroclimatic monitoring stations and enough formally recorded data which are the prerequisites for flood risk management.

Materials and methods

Study area

This study investigated the capacity of LK and willingness to implement Flash Flood Crowdsourcing (FFC) to discern FFHs in the most flood-prone area in the eastern part of Golestan province in northeast Iran. Two main river basins of Atrak and Gorganrood are located in this area. The General information related to these watersheds has been summarized in Table 2. The study area is characterized by undulating mountains intersected by U-shaped valleys and mainly covered with deep fertile loess deposits, making it attractive for agriculture and herding and consequently rural settlements (32). The climate is semi-arid with temperate autumn and winter and relatively hot and dry spring and summer. Although the majority of annual precipitation falls during the wet period (from mid-autumn to mid-spring), the majority of devastating flash floods occur during the dry period (from mid-spring to mid-autumn), particularly in summers (33).

شکل ۱- برخی از رایج‌ترین خسارات سیل در منطقه مورد مطالعه، **A**: به زیر آب رفتن اراضی کشاورزی، **B**: آبگرفتگی معابر، **C**: تخریب زیرساخت‌ها و **D**: تخریب املاک خصوصی (منبع: ٣٤).

Figure 1. Some of the most common flood damages in the study area are, A: Inundation of agricultural farms, B: Inundation of streets, C: Damage to infrastructures, D: Damage to private properties (Source: 34).

Identifying FFHs on a regional scale was the first step in determining FFHs, which was done based on research studies. According to the official grey documents and research studies, the frequency of floods in this area is higher than in other areas of the province (35 and 34). Due to the susceptible geological formation of this area, most of the flood events are accompanied by landslides and high sediment loads resulting in large damages including the destruction of public infrastructures and private properties. Some types of the most common flood damage in these areas are illustrated in Figure 1. The worst flood of the region which damaged eighty light and heavy vehicles and destroyed 15 hectares of the national Golestan Park, occurred in August 2001. The economic losses of this flood event were estimated at ca. 750 thousand million Iranian Rials. This flood killed 500 people and ranked as one of the highest human casualties in the world (36). The history of the number of annual flood events in the two watersheds of the study area during the last 30 years is given in Table 1.

جدول ۱- سیل‌های ثبت شده در منطقه مورد مطالعه از تاریخ ۱۳۷۰ تا ۱٤۰۱ (منبع: ۳٦).

Table 1. The flood records in the study area from 1991-2022 (Source: 36).

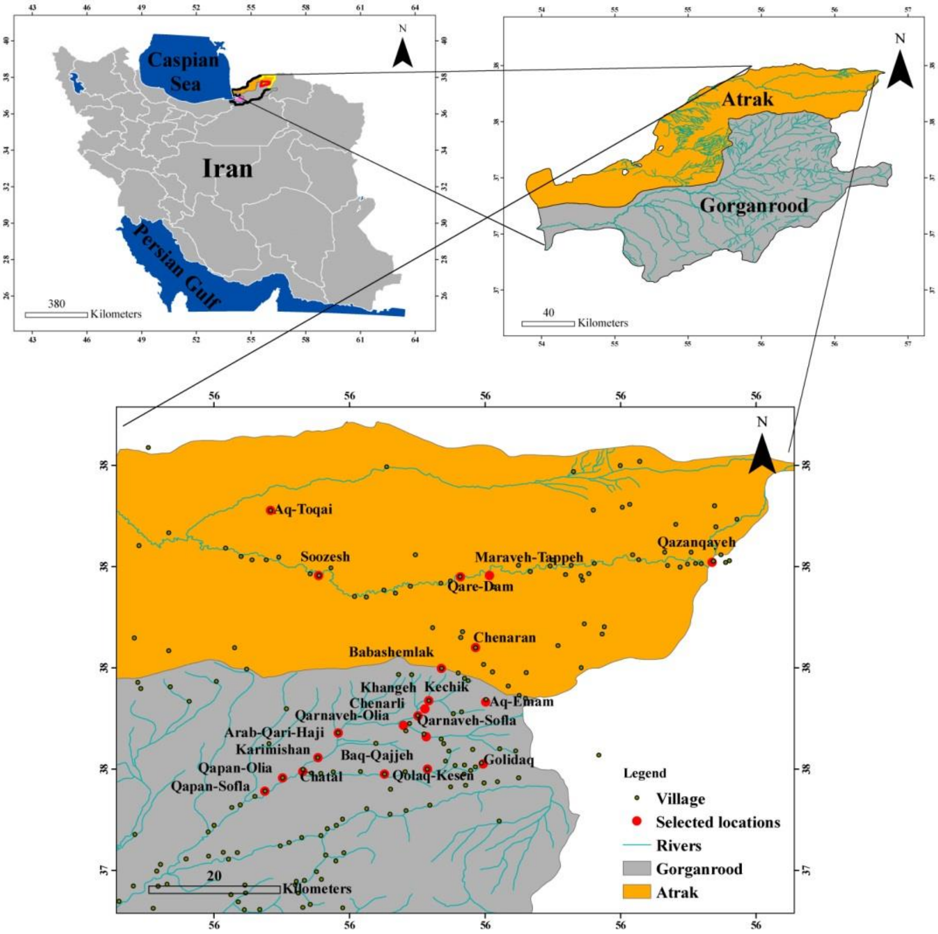
Year	Flood events in Gorganrood watershed	Flood events in Atrak watershed	Flood events in Golestan province	Year	Flood events in Gorganrood watershed	Flood events in Atrak watershed	Flood events in Golestan province
1991-1992	3	-	4	2007-2008	5	2	6
1992-1993	3	-	6	2008-2009	2	-	4
1994-1995	1	-	3	2009-2010	8	2	8
1995-1996	2	-	3	2010-2011	5	4	5
1996-1997	9	3	10	2011-2012	2	2	3
1997-1998	6	3	6	2012-2013	-	-	-
1998-1999	5	-	6	2013-2014	13	6	13
1999-2000	2	-	3	2014-2015	5	2	6
2000-2001	3	2	6	2015-2016	5	3	5
2001-2002	2	1	4	2016-2017	6	4	6
2002-2003	2	1	2	2017-2018	3	2	4
2003-2004	3	2	4	2018-2019	8	7	9
2004-2005	4	2	4	2019-2020	1	-	1
2005-2006	3	1	4	2020-2021	2	1	2
2006-2007	3	2	5	2021-2022	4	3	4

Following that devastating flood, the government has decided to relocate many flood-affected sparse villages on the valley beds of the study area to a few newly designed small towns on higher-elevation plains. However, due to various socio-cultural backgrounds and conflicts and also economic issues, recently, most of the families have returned to their home villages, despite being aware of flood hazards. Therefore, it is of utmost importance to look for alternative solutions to reduce the risk of flash floods in these communities at peril.

جدول ۲- اطلاعات کلی دو حوضه اصلی که منطقه مورد مطالعه بخش محدودی از آن‌ها را در شاخه‌های بالادست خود تشکیل می‌دهد (منبع: ۳٤).

Table 2. General information of two main watersheds where the study area makes up a limited part of them in their upstream tributaries (Source: 34).

Watershed Name	Area (km^2)	Slope (Percent)	Annual precipitation (mm)	Number of hydrometric stations	Number of rain gauge stations	Number of population centers
Gorganrood	11414.8	17.4	615	35	72	689
Atrak	7665.2	5	220-550	10	23	135



شکل ۲- موقعیت جغرافیایی دو حوزه آبخیز اصلی در منطقه مورد مطالعه و سکونتگاه‌های روستایی انتخاب شده برای بررسی اجتماعی.

Figure 2. The geographic location of two main watersheds in the study area and the selected rural settlements for social survey.

Research Methodology

To discover the FFHs in sub-watershed scale, prior to the commencement of field survey, three experienced official experts from the provincial authorities and administrative organizations responsible for watershed management and water resources management were consulted regarding the study area selection in the loess lands of the eastern of Golestan province. They unanimously suggested the upstream sub-watersheds of the Atrak and Gorganrood river basins in the vicinity of the Marave-Tappeh County in the eastern part of the Golestan province (Fig. 2). They indicated this region as the most affected area by frequent flash floods resulting to high human losses and properties damages. Therefore, delving was done into the villages in the vicinity of Marave-Tappeh County through the latest thematic maps and Google Earth data as preliminary work before to entry to the study area. Although initially 824 population centers were identified as target locations, but according to experts' opinions, the final set of target communities became smaller and limited. Conducting field visits and unstructured conversations with local residents addressed us to the FFHs. As a result, questionnaires were filled in 14 villages and finally, the most hazardous population centers were identified and ranked.

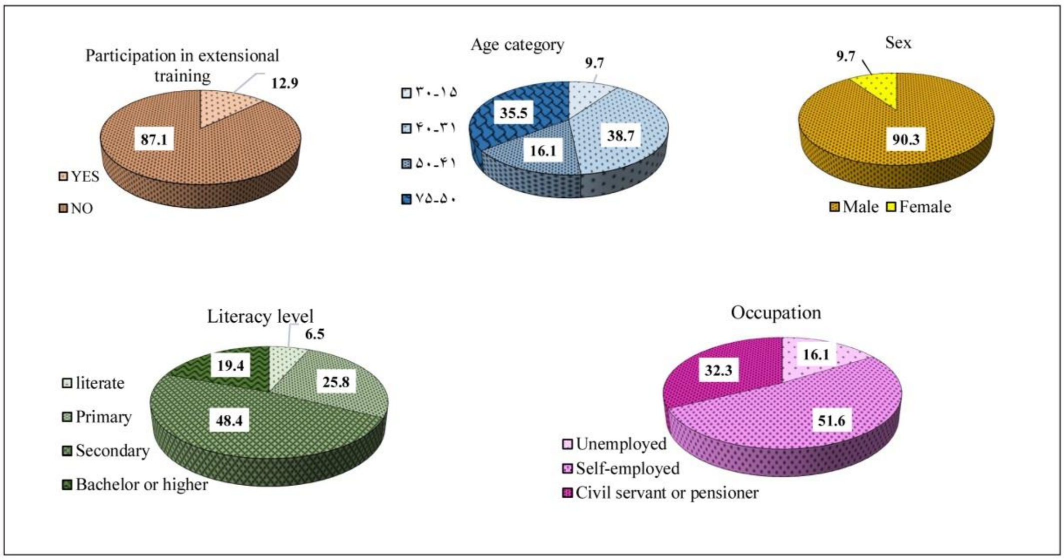
Current study presented a questionnaire-based, consequential data collection strategy for acquiring information about flash floods. Therefore, a structured questionnaire with three main sections including, 1-personal attributes, 2-open-ended questions and 3- questions based on the Likert scale was developed. The face-to-face questionnaire administration mode was used for public surveys through conducting oral interviews and live discussions with each respondent. The confidentiality of responses and anonymity of respondents were assured at the onset of the interview with the local participants. To better know the study area and select the proper distribution of villages for the survey, a preliminary 1-day reconnaissance field visit across the study area was organized. After visiting and making general inquiries from the local communities, 14 villages were selected to carry out social survey through questionnaire interview. A total number of 51 respondents were face-to-face interviewed. It should be noteworthy that in the study area, the majority of people speak the local Turkmen dialect. The interviews were intentionally held in public places such as supermarkets, bakeries, repair shops, mosques and health centers. Hence, our research was restricted to a limited number of interviewees, consisting mainly of males.

To cross-check and assess the quality of the explored LK on FFHs perception and recognition, an official report documenting 31 years (21/03/1991 to 22/12/2022) statistics of the recorded flood incidences and their casualties and damages across the Golestan province was consulted. Moreover, the willingness and motivation of the local inhabitants to participate as a citizen scientist in FFEWS, as well as the effect of individuals' features on their willingness and motivation were analyzed using IBM SPSS Statistical software version 27.

Results and discussions

The Characteristics of Individuals and their effects on Willingness and Motivation

The demographic characteristics of the respondents, such as age, gender, education, occupation, and participation in flood-related extensional training, have been depicted in Figure 3.



شکل ۳- ویژگی‌های جمعیت‌شناختی جوامع مورد مطالعه.

Figure 3. The demographic characteristcs of the survey communities.

Also, Table 3, summarizes the results of correlation analysis between individuals' characteristics and the level of willingness and motivation of local residents to play the role of citizen scientist in FFEWS. As can be seen, there is no significant (at the 95% confidence level) correlations between the demographic characteristics and their willingness and motivation. Therefore, it can be concluded with high certainty that the findings of the questionnaire survey are not biased due to the demographic characteristics of the selected survey sample.

جدول ۳- تحلیل رابطه بین ویژگی‌های جمعیت‌شناختی و میزان تمایل و انگیزه.

Table 3. Exploratory analysis of the relationship between demographic characteristics and the level of willingness and motivation.

Individual variable (independent variable)	Variable type	Analysis method	Dependent variable	Correlation	Significance level
Age	Ordinal	Pearson	Willingness	0.321	0.078
			Motivation	-0.113	0.544
Sex	Nominal	Independent T-test	Willingness	-	0.307
			Motivation	-	0.106
Literacy level	Ordinal	Pearson	Willingness	0.089	0.633
			Motivation	0.206	0.266
Occupation	Nominal	ANOVA	Willingness	-	0.483
			Motivation	-	0.322
Received training related to floods	Nominal	Independent T-test	Willingness	-	0.574
			Motivation	-	0.743

The findings of current research ascertained that individual characteristics were not significantly associated with people's willingness and motivation in FFC. These findings were in line with the findings of Alender (2016) who found that there is no significant correlation between individual characteristics, such as gender with the participation motives in citizen science-based projects (37). Contradictorily, Richter et al. (2021) stated that gender was one of the strongest influencing factors on participation motivation (18). In another study, Prager and Posthumus (2010) clarified that education and employment are the most important factors in farmers' participation in sustainable soil management (38). Mendoza and Parabhau (2006) revealed in their research that age and income have a positive and significant relationship with the people's participation in environmental protection programs (39). Huntsinger and Fortman (1990) remarked that literacy level, age, and income have the highest effect on the people's contribution to Oak Forest Management (40). Koehler and Koontz (2008) showed in their study that there is a significant relationship between people's age and literacy level and their participation in watershed management projects (41). Similarly, in the study conducted by Elyasi et al. (2017) on people's participation in watershed management projects, they depicted that there is a significant relationship between participation and age as well as literacy level (42).

A brief overview of the above-mentioned studies shows that public participation motivation has been studied in various fields of environmental studies but not specifically on the participation of local grassroots people in FFEWS. One likely explanation for the absence of statistically significant correlations between individual characteristics and willingness and motivation to participate in FFEWS is the prevalence of a dominant category of characteristics for the majority of the studied attributes (e.g. dominance of male against female for the sex attribute), which could introduce bias into the sample data. Additionally, the limited number of respondents may also contribute to this lack of significance. The apparent biases in the sample statistics may be attributed to our selection of a sampling method, because our samples were selected from public places. It is recommended to carry out additional research using larger and more diverse sample sizes in similar studies. Furthermore, due to the unique characteristics of floods, including the extent of damage, casualties, and the need for local residents to be involved in emergencies, it is essential to incorporate inquiries about these factors. These factors may include the frequency of floods in the residence areas, past experiences with flood-related hardships and financial losses, the extent of property or assets exposed to floods, prior exposure to flood events, and any other factors that could impact residents' willingness and motivation to FFC.

The local knowledge on flash floods

So far, LK has been used in the recognition and studies of many natural phenomena such as climate changes (43), droughts (44), storms (45), brushfires (46), soil erosions (47) and floods (48) which have not only been successful in conceiving and promoting the concept of these phenomena by the general public (49 and 45), but also are used in locating and participatory mapping of these phenomena and various natural hazards (50, 51 and 52). The research conducted by Brandt et al. (2020), has specifically addressed utilizing local knowledge about community perceptions of flooding in a data-scarce context at a village scale through participatory preparation of sketch maps of flood-affected zones (48). However, in the current research, the capacity of LK was assessed for the first time in conceptualizing and identifying FFHs at a relatively large scale. To address this target, three open-ended questions, were asked from residents, then their responses were evaluated and discussed as follows:

A) Perception of flash floods by upstream rural communities

To confirm whether the flood events of the study area are possibly flash floods or not, the individuals were requested to provide descriptions of the flood events occurred in their local environments. The used expressions are listed in Table 4. Furthermore, the characteristics of flash floods were extracted from literature review and summarized in Table 3. Later on, the descriptive statements from the respondents and literature review were compared.

Based on the similarity of features such as high-intensity rainfalls, sudden occurrence, short-term duration of a few minutes or hours, causing loss of lives and tremendous damage enumerated by the local residents for description of the occurred flood events in the study area with features of flash floods enumerated within the scientific literature, we can certainly conclude that most of the floods occurred across the study area of the flash flood type.

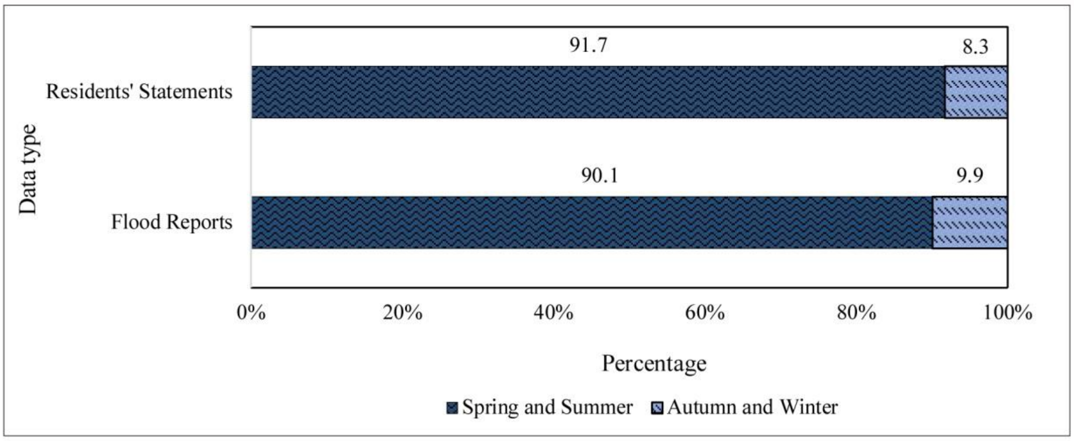
جدول ٤- توصیف سیل‌های ناگهانی بر اساس اظهارات ساکنان و مرور منابع.

Table 4. Flash flood description based on residents' statements and literature review.

Category	1. Descriptive expressions stated by local residents	2. Descriptive expressions based on literature review	Overlapping between 1 and 2
Signs and symptoms before the flash flood events	• Occurrence in a day with a calm weather • Seeing a huge black cloud over the mountain and upstream villages and after a few minutes or hours the flood reaches to other villages along the river • A sudden onset of high-intensity rainfall for a short time	• Severe thunder storms in limited areal extent (53) • Thunder storms over the inland watersheds ranging in area from few kilometers to several hundred square km (54) • Occur within minutes or hours of excessive rainfall, a dam or levee failure, or a sudden discharge of water previously held upstream by an ice jam (55) • Short time and high-intensity rainfall rates, mainly of convective origin that occur locally (56 and 5) • Cloud bursts or stationary rainfall, heavy rainfall and rapid snow melt in high mountain areas, glacial lake outbursts, failure of dams built up by landslides, rock falls or debris flows, and overspill following the failure of water power reservoir dams" has been introduced as the main cause of flash floods (57)	High-intensity rainfalls, sudden occurrence, short term duration, after a few minutes or hours in locally
Signs and symptoms During and after the flash flood events	• Sudden increase in volume, height, speed and strength of water flow • Water flowing out of the channel and the inundating the roads and home yards • destroying main or local access road to the villages • Sweeping away a few people, animals and vehicles by flood water • Inundating and the entry of flood water and sediments into residential houses and agricultural lands • Flow of mud, landslide, collapse of some residential houses • Short duration of flood rise and fall within a few hours	• Rapid generated flows or sudden floods with high peak discharges (53) • Can carry large debris, rip out trees, destroy buildings and bridges, trigger catastrophic mudslides, and scrape out new channels, rapidly rising floodwaters (55) • The sudden rise and rapid fall of water levels, as well as the high flow velocities combined with large sediment transport (57) • loss of a great number of lives as well as tremendous damage (55 and 57)	Sudden rise and rapid fall of water levels, the high flow velocities, sediment transport, destroy buildings, road and channel, loss of lives and tremendous damage

B) People's perception of the predominant time of flood occurrence

The respondents were inquired about the dominant time of flood occurrences in their neighborhood environments. The majority of respondents declared that the majority of flash floods in the region occur in the hot and dry period (mid-spring to mid-autumn) (Fig. 4).



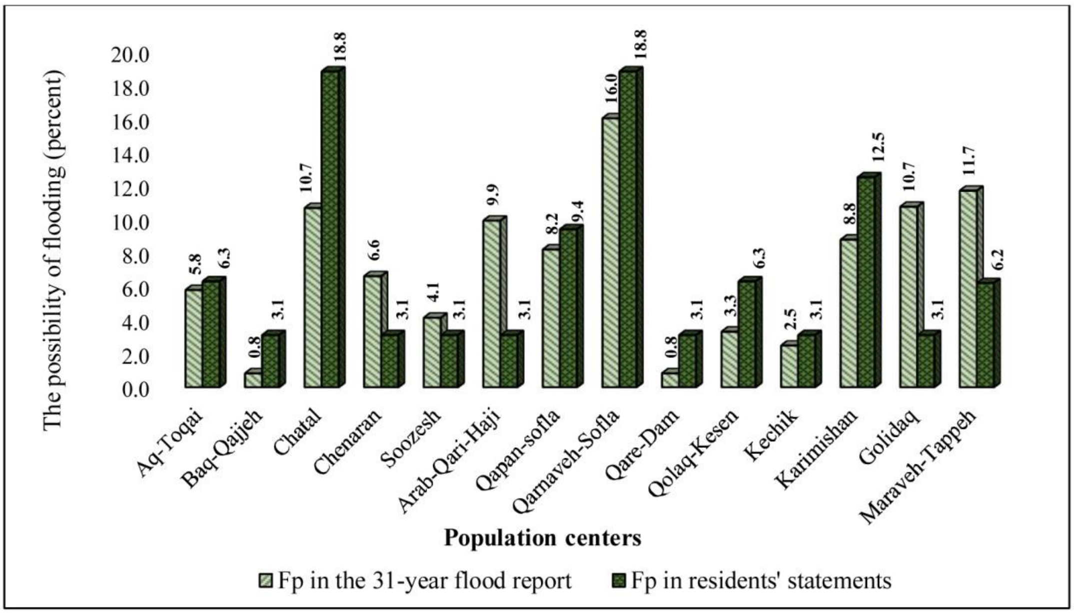
شکل ٤- مقایسه اظهارات ساکنان و گزارش سیل ۳۱ ساله در مورد زمان وقوع رخدادهای سیل در منطقه مورد مطالعه.

Figure 4. The comparison of residents' statements and 31-year flood reports about the occurrence time of flood events in the study area.

According to Fig. 1, the number of hydrometric stations in the study area is very limited (only two stations, and both of them in the downstream area across the main drainage channel). Therefore, there is not enough accurate observed data for local small-scale flash flood events per upstream tributaries where villages and population centers were located in their vicinity. The only reliable document for appraisal of flood events statistics was the 31-year flood damage report prepared by the local administrative authorities. In this report, general information about the date and location of flood occurrence and the losses and damages per rural and urban population centers has been gathered per each flood event. Therefore, to compare and validate the respondents' answers about the occurrence season of floods, this official document was used and the results are indicated in Figure 4. As seen in Fig. 4, the percentage of flood events during spring and summer seasons based on residents' statements and the 31-year flood damage report was calculated 91.7 and 90.5, respectively. The percentages of flood events during the 2nd half of the year were estimated at 8.3 and 9.9, respectively based on the residents' statements and the 31-year flood damage report. Interestingly, it was shown that the grassroots public provided qualitatively correct information about the dominant time of flash flood occurrence in the study area.

C) Locality of flood occurrence

The literature review showed that Gorganrood river basin has been introduced as the most flood prone river basin in the Golestan province (58 and 59), but so far, no formal information has been reported to signify the most flood prone sub-watershed or the residential areas across this river basin. Hence, due to the very low density of the hydrological observation network across this river basin, particularly in upstream areas, the LK resorted to discern the most flood-prone area or flood hotspots in the study area by reaching the local residents. Again, the province's 31-year flood report was consulted to validate the quality of LK in this regard. The comparison of the results of public opinions about FFHs and the 31-year flood report statistics is depicted in Figure 5.



شکل ۵- درصد فراوانی (Fp) روستاهای معرفی شده توسط ساکنان به عنوان سیل‌خیزترین منطقه و درصد فراوانی رخداد سیل برای این روستاها در گزارش سیل ۳۱ ساله.

Figure 5. The frequency percentage (Fp) of villages introduced by residents as the most flood prone area and the frequency percentage of flood incidence reported for these villages in the 31-year flood report.

In response to the query about the most flood prone areas, Chatal, Gharnaveh-Sofla, Karimishan and Qapan-Sofla villages (Fig. 5) with the frequency percentages of 18.8, 18.8, 12.6 and 9.4, have respectively been introduced as the most FFHs by the majority of respondents. Also, these villages with frequency percentage of 16, 10.7, 8.8 and 8.2, were respectively listed as the areas with the highest probability of flooding in the 31-year flood report. Interestingly, there is a very good conformity between the results of the social survey and the officially documented report (Fig. 5). These results, on one hand, support the rationale of the research problem statement and study area selection and on the other hand, they highlight the importance and credibility of local information and knowledge extracted by the social survey.

In situations that are not possible to fill the data gap through formal and routine instrumental methods, using LK can be a helpful alternative (60). According to the aim of the current research to determine FFHs on the small scale of villages and upstream tributaries and the lack of formally observed data and information, the LK capacity was used and the promising results of this method have proved its competency.

In the present research, taking into account the frequency of floods reported by official grey documents and elicited through the local residents' points of view the sub-watershed of Qarnaveh within the Gorganrood watershed was indicated as the most flood-prone and impacted area in Golestan province. However, in the study of Rahmati et al. (2016), the Madarsu sub-watershed located in the southeast of Qarnaveh was introduced as the most dangerous sub-watershed of the Gorganrood watershed (59). They included a combination of natural and human factors to prepare the flood hazard map of the Golestan province. The results of the current research are in line with the findings of Hajibigloo et al. (2017) in introducing the Qarnaveh sub-watershed as the most hazardous area concerning flood occurrence (58). They used the method of hierarchical analysis of experts' opinions to prepare the flood hazard map and assigned the most scores to the factor of proximity to the river, and this factor is abundantly visible in the placement of rural areas around Marave-Tappeh County.

Although merely relying on the findings from LK to assert the FFHs is not enough, it will be qualitatively helpful in decision-making regarding flood hazards and risk management in data-scarce areas. Nowadays, the application of process-driven hydrological models with extensive use of remotely sensed and easily and freely accessed data and global climate data is considered very helpful approach to quantify and prioritize flood prone zones in data scarce areas. However, a cogent evidence of their validity should be provided through comparing with sufficient counterpart observed data which are not available in data scarce areas. In such situations, qualitative validation of the models' results using the LK can be an alternative and helpful solution. Since, rural communities are most often present in the nature, they observe and eye-witness the flood events and remember their features.

This research aimed to explore the capacity of LK for identification of prioritization of FFHs. The majority of previous studies on this topic have predominantly relied on the experts' knowledge elicitation (3). As hydrometric stations are typically installed at the outlets of large enough watersheds, information about flood occurrences in the upstream tributaries is often unavailable. Consequently, the utilization of LK can be beneficial and effective acquiring such information. This is of utmost importance for flash flood hazard and risk management that usually occur at local and small scales, particularly in remote upstream zones.

Capacity of local residents for flash flood crowdsourcing

To investigate capacity of local residents for FFC, the willingness and motivation of the local people to participate in FFC programs have been inquired and assessed. Regarding the willingness to participate in the FFC program mainly focused on FFEWS, four proxy attributes were assessed as indicators of willingness. To assess the respondents' motivation to participate in FFC, seven proxy indicators were defined and inquired by local inhabitants. The Likert scale (0-5) was applied to score the indicators by the respondents.

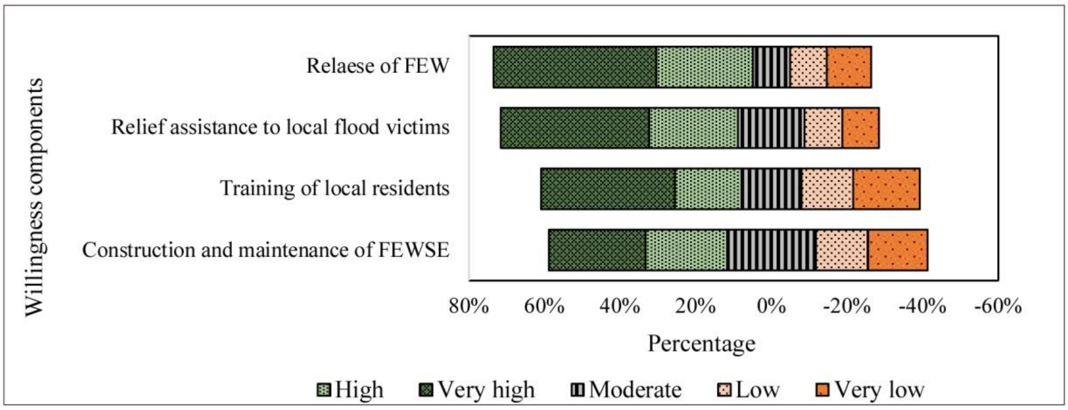
جدول ۵- ارزیابی شاخص‌های تمایل و انگیزه برای مشارکت در طرح هشدار زودهنگام سیل.

Table 5. Assessment of willingness and motivation indicators to participate in flood early warning initiative.

Survey component	Proxy indicator	Average score	SD[1]	CV[2]	Rank
Willingness to participate in flood warning initiatives	Participation in training courses	3.42	1.82	0.53	3
	Contribution in the release of warning messages	4.23	1.28	0.30	1
	Provision of emergency relief assistance to flood victims	4.10	1.3	0.32	2
	Participation in construction and maintenance of flood monitoring systems	3.32	1.57	0.47	4
Motivational drivers to participate in flood warning initiatives	Saving family members and personal belongings from flood hazards	4.48	0.67	0.15	2
	Saving relatives, fellow villagers, and human being from flood hazards	4.84	0.37	0.08	1
	Financial incentive	1.77	1.6	0.90	7
	Sense of human and social responsibility	4.42	0.61	0.14	3
	Participation in science and knowledge production	3.29	1.3	0.40	4
	Interest in nature and its phenomena	2.32	1.35	0.58	6
	Personal hobby and sense of curiosity	2.52	1.46	0.58	5

1- Standard Deviation
2- Coefficient of variation

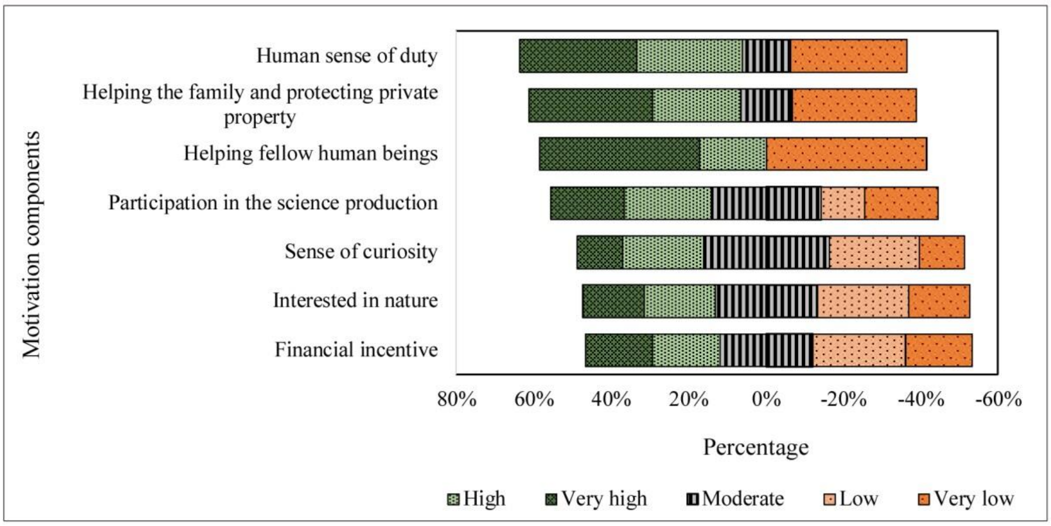
The results of inquiries on the upstream communities' willingness and motivation in FFC have been summarized in Table 5 and shown in Figs. 6 and 7. Generally speaking, more than 60 percent of all respondents, showed a moderate or higher willingness to participate in flood warning initiatives. Particularly, the indicators, "Contribution in the release of warning messages" and "Provision of emergency relief assistance to flood victims" scored 4.2 and 4.1, respectively. However, a less interest in training courses and flood monitoring systems has been shown by the respondents with mean scores of 3.4 and 3.3, respectively (Table 5 and Fig. 6). This indicates that upstream communities are most inclined toward activities related to preparedness and response phases of a flood management plan and a lesser degree to the activities concerned with the mitigation phase.



شکل ٦- ارزیابی شاخص‌های تمایل به ایفای نقش شهروند دانشمند توسط ساکنان محلی.

Figure 6. Assessment of indicators of willingness to play the role of citizen scientist by local inhabitants.

Regarding the motivations to participate in FFEWS, as seen in Fig. 7, generally more than 50% of the respondents opted for a higher score to four components of "Human sense of duty", "Helping the family", "Helping fellow human beings" and "Participation in the scientific production". However, about 40% of the respondents gave higher scores to the three components of "Interested in nature", "Financial incentive" and "Sense of curiosity". Furthermore, as detailed in Table 5, the respondents appraised the sense of humanity (saving humankind from flood hazard), saving personal belongings, and social responsibility with average scores of 4.8, 4.5 and 4.2, as very important driving forces, respectively. While financial incentives with an average score of 1.8 have been considered as the least important deriver (Table 5 and Fig. 7). Interest in nature and natural phenomena as well as a personal hobby and curiosity with average scores of 2.3 and 2.5, respectively showed low priority as a motivational cause to participate in flood warning initiatives. This is not an unexpected result as the majority of upstream rural communities are suffering from limited socio-economic progress and are predominantly struggling for their livelihoods.



شکل ۷- ارزیابی محرک‌های انگیزشی برای ایفای نقش شهروند دانشمند توسط ساکنان محلی.

Figure 7. Assessment of the motivational driving forces to play the role of citizen scientist by local inhabitants.

In the present research, humanitarian factors such as helping fellow beings, helping the family and sense of human duty as the most important motivating factors, as well as financial incentives as the least important motives were introduced for residents' participation in FFEWS. This part of the research results corresponds with the surveys of Richter et al. (2021) and Kragh (2016); while some other researchers introduced learning and gaining social experience (61) and interest and enjoyment (62) as the most momentous motivations for people's participation. Due to the poor and sporadic studies on the willingness and motivation of local residents to participate in FFEWS, and also because the selected and related items to the willingness and motivation were chosen from the review of different fields of studies, it is necessary to use open-ended questions in such similar researches for this section. Also, regarding the fact that flood-related information and training in this area is only local and not done on behalf of specific organizations, it is necessary to carry out various awareness programs before the implementation of any related-flood kinds of crowdsourcing initiative to increase the local residents' willingness and motivation primitively for participation in FFEWS, and to accomplish the target projects in the next step.

Conclusions

In general, this study presented a questionnaire-based, consequential data collection strategy for achieving information about flash floods. In this regard, the local knowledge of residents about the type of floods, time and place of predominant flood occurrence were evaluated and the results were very promising. Therefore, regarding the results obtained in this section, it is suggested to use the LK in order to obtain information about the areas with scarce and sparse data. Especially LK can be used in determining flood hotspots and qualitative maps of flood hazard on a local scale. However there is no precise understanding of using LK in the FFHs determining that in what spatial scale it can be efficient, so more detailed research needed in this field. In the other section, the residents' motivation and willingness participated in FFC and FFEWS and the related components were investigated. However, discovering the reasons for residents' willingness to participate in different parts of FFEWS and participation barriers in FFC are important issues that have not been addressed in this research and it is proposed to address in next similar researches.

Data availability

The data of this research is related to the doctoral thesis of the first author, which can be accessed by correspondence with the corresponding author.

Declaration of competing interest

The authors declare that they have no competing or conflict of interests that could have appeared to influence the work reported in this paper.

Author contributions

The authors confirm their contribution to the paper as follows: PHG and VSH: conceived the study and led the writing of the manuscript, PHG collected data and ran analyses under the supervision of VSH. All authors contributed critically to the writing process and approved the final version of the manuscript.

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Ethics

The authors have considered the ethical principles in carrying out and publishing this research and this issue is approved by all of them.

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