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SHORT COMMUNICATION

The cascading failure of check dam systems during the 28 July 2022 Emamzadeh Davood flood in Iran

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Abstract
On July 18, 2022, an unexpected rainfall and flash flood struck the Emamzadeh Davood village in northwestern Tehran, the capital city of Iran, claiming the life of at least 23 people. In this brief communication, we report results from a recent investigation carried out by field surveys and remote sensing data, highlighting the role of anthropogenic factors and catastrophic failures in a series of check dams in intensifying the impacts of the 2022 Emamzadeh Davood event.

Keywords Flood · Check dam · Emamzadeh Davood

1 Introduction

For centuries humans have developed a variety of torrent and erosion control networks to limit the negative impact of floods and sediment hazards to exposed elements in mountainous regions. Check dams are typical torrent structures constructed across a stream channel to diminish longitudinal slopes and curtail sediments, thereby reducing the flow speed and energy of torrential processes (Lucas-Borja et al. 2021). However, if such structures are collapsed or partially damaged due to extreme events, poor maintenance, and/or their improper localization, the released torrent sediments from these structures can exacerbate the hydrological impact of the flood and sediment-related disasters in downstream areas (Wang 2013), resulting in a catastrophic phenomenon similar to the failure of a landslide dam. Several studies have already documented the effect of check dam failures in triggering catastrophic floods and debris flow (Benito et al. 1998; Zhang et al. 2019). In this

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study, we report on field surveys and remote sensing data analysis to investigate the role of flood-control structures in aggravating the impact of the 28 July 2022 Emamzadeh Davood flood in Iran. A post-flood expedition was carried out immediately after the event to document the actual conditions of check dams in the region. Furthermore, optical and radar satellite images were analysed to obtain flood map and assess topography changes along the main stream.

2 The 2022 Emamzadeh Davood flood disaster

A catastrophic flash flood occurred on 28 July 2022 in Emamzadeh Davood village in northwestern Tehran, Iran. The flood was triggered by a rainfall of approx. 26.6 mm for 20 min, average intensity of 79.8 mm/h, according to records taken at a meteorological station near the village (source: Prof. Bohluly, personal communication); the maximum intensity being 134.4 mm/h at 00:55 h (Fig. 1). Analysis of high-resolution (3 m) satellite optical imagery from Planet Labs suggests that the flood started mainly from several streams north of the region at an altitude of approximately 3200 m (Fig. 1). The flash floods in the upstream channels were then merged and formed a torrential water along a single channel stream 1.5 km long at the lower part of the valley before entering and sweeping Emamzadeh Davood village with debris-filled water. Emamzadeh Davood, a religious shrine, and other surrounding houses and shops in the village suffered flood damage with at least 23 people being killed and many more injured (source: https://www.thmporg.ir/news/6196).

With an area of approx. 200 km^2, Emamzadeh Davood (Fig. 2) is a subbasin within a larger basin called 'Kan' in the Alborz Mountains of northwestern Tehran (Hooshyaripor et al. 2020). The watershed area above the Emamzadeh Davood village, where the 2022 flood was initiated, has an area of 6.5 km^2 ranging in altitude from approx. 2600 m at the village to approx. 3800 m at the highest peak. The local geology from the top to downstream consists of several layers of shale and tuffs which are associated with tuffaceous siltstone at the top to sandstone towards the lower altitudes (Fig. 1b). The outcrops are highly eroded due to natural glaciations, steep slopes, and human impacts. The area is highly vulnerable to flooding and landslides; a flash flood and mudslides in 2015 stranded approx. 2000 of cars in the road leading to the Emamzadeh Davood village and killed at least 14 people (source: https://roozno.com/fa/news/145383). The 1954 flood that hit northwestern valleys of Tehran including Emamzadeh Davood was even deadlier with death toll of ca. 2000 people across the affected areas (source: https://www.hamshahrionline.ir/news/694060).

For the 2022 flood event, analysis suggests that there were anthropogenic interventions in the main stream channel in region. The most significant one was a culvert constructed just in the northern entrance of the village to allow water to pass below the village (Fig. 3a). The culvert was reportedly blocked during the event by a falling car and debris brought by the flash flood, causing unexpected flow diversion out of the normal stream channel into the village. More than 45 check dams were already constructed by authorities as flood-control structures in the region (Fig. 2a). Inspection of the main flooded waterways after the event clearly revealed a cascading failure of check dam systems in the study area; except for a few ones (blue circles in Fig. 2a), most of the check dams in the main stream (red circles in Fig. 2a) were completely destroyed in the 2022 flood (See Fig. 3 for exemplary ground photos). Analysis of satellite data using Google Earth images also showed evidence of the destruction of 4 check dams in the upper part

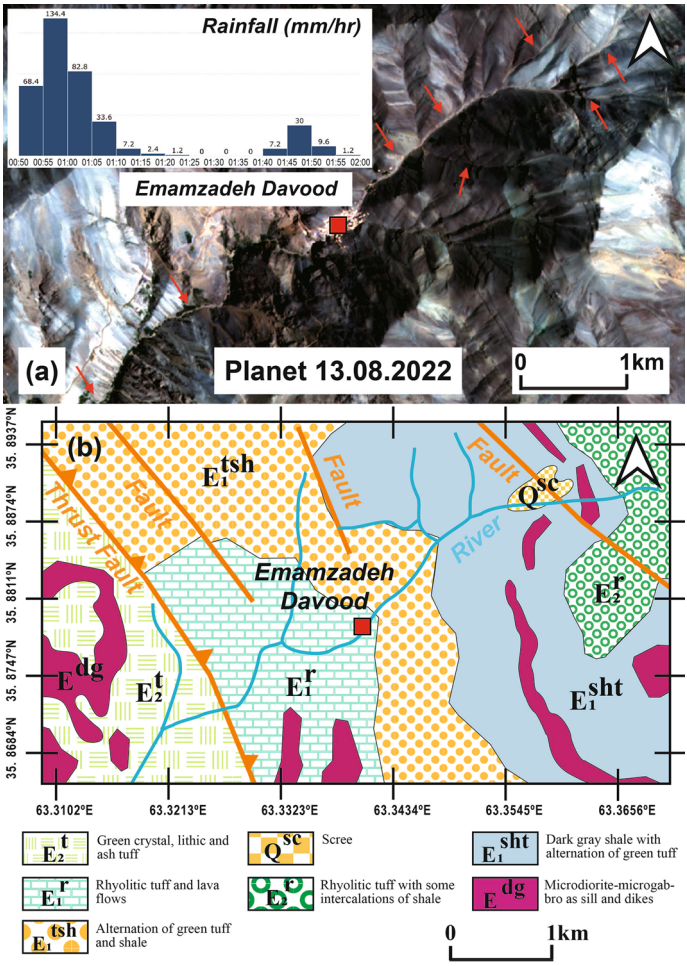

Fig. 1 **a** A Planet Labs (Planet) imagery from the Emamzadeh Davood region on 13.08.2022 (Planet Team 2017). The red arrows show the flood (brown) in the main stream and tributaries. The inset shows precipitation intensity on July 28, 2022 recorded at a meteorological station in Emamzadeh Davood. **b** Geology map of the study area (Emami et al. 1993)

of the main stream channel already in 2021 (yellow circles in Fig. 2a). Own documentation and many photos taken by independent journalists illustrated remnant of metal nets of destructed check dams in destroyed buildings of the village (Fig. 4b–c). Topography analysis along a longitudinal profile using a 12-m TanDEM-X digital elevation model (DEM) shows a relation between channel gradient and the extent and pattern of the damage to check dams. As shown in Fig. 2b, check dams Nos. 9–22 which are located in the higher gradient segment of the channel (slope ~ 19°) were all destroyed either in the 2022 flood or previous floods. Here, two types of check dams were constructed; Nos. 9–11 are masonry check dams while Nos. 12–22 are gabion check dams. Check dams Nos. 1–8 which are located in the lower gradient part (slope ~ 15°) are all masonry; with

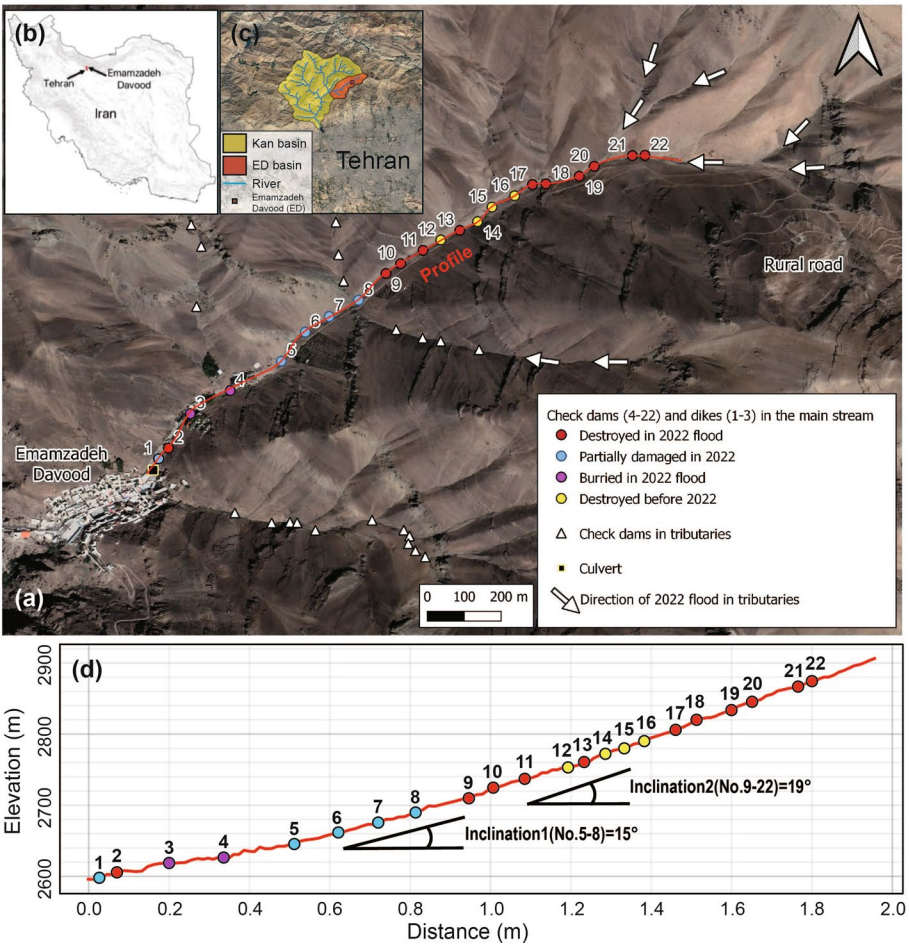

Fig. 2 **a** Distribution of check dams and other constructions in Emamzadeh Davood. The arrows indicate the direction of the 2022 flood in tributaries, inferred from high-resolution Planet imagery on 13.08.2022 (Fig. 1). The background image is from Google Earth. The insets in the upper left show the location of the study area in (**b**) Iran and in (**c**) northwestern Tehran. **d** Topography profile along the main channel extracted from TanDEM-X 12 m DEM

the exception of No. 2 which was completely destroyed, the rest of the check dams in this part of the channel were either buried or partially damaged.

In our field surveys, we also documented intensive erosion of upstream slopes due to over-grazing in a geologically degradable shale and tuff substrate (Fig. 4a). There were also several dikes and retaining walls in the river bed. The dike marked as No. 1 in Fig. 2 is located approximately 40 m before the main culvert. It was already filled with sediments before the 2022 flood so that the river bed was raised almost to the level of its surrounding (< 40 cm difference in height compared to its surrounding, see Fig. 3b). This paved the way for the lateral debris transfer of the 2022 event to both sides of the main stream channel, which then entered into the built-up areas, causing considerable damage to property and loss of life (Fig. 4).

Fig. 3 **a**–**h** Exemplary ground photos of check dams and other construction. Photos taken on August 18, 2022. For the location of objects please refer to Fig. 2a (Photos credit H. Akhani)

3 Discussion and conclusion

The disastrous consequences of Emamzadeh Davood flood is a clear result of a combined interaction between complex natural process and anthropogenic factors in terms of watershed mismanagement due to human intervention in the river course and inadequate design of protective structures. Although there is no inventory for the number of check dams and dikes in Iran, reports by the news agencies quoting of the respective authorities, suggest the numbers exceed 60,000 just in 8 provinces, 5000 only in the southern slopes of Alborz Mountains, north of the capital city of Tehran (source: http://hamshahrionline.ir/x7VPw). However, in contrast to big hydraulic dams, no proper hazard and risk assessment exists for these structures (Emadali et al. 2017). The check dams are often designed for small floods (1-in-20–50 years). Climate change in the last decades, however, has increased the likelihood of the severity and frequency of extreme

Fig. 4 **a** Degraded vegetation and intensive slope erosion in an altitude of 2900 m of Emamzadeh Davood upstream. **b**–**e** Examples of destruction to infrastructure in Emamzadeh Davood due to the 2022 flood. The remaining of metal nets from gabion check dams around columns of destroyed buildings has been marked with a red arrow in (**b**) and (**c**) (Photos credit H. Akhani)

floods and landslides (Pall et al. 2011; Ozturk et al. 2022). The real risk evaluation of a series of check dams in particular in close proximity of urban settlements, and in facing sediment hazards should be seriously revised (Xiong et al. 2016) as they are more vulnerable to failure than water storage dams (Rico et al. 2008).

Reducing flood risk in mountainous areas in North of Tehran with an elevational gradient of 3000 m and its diverse vegetation (Akhani et al. 2013) cannot be achieved by only civil engineering measures, rather it requires comprehensive watershed management for habitat restoration program to strictly control overgrazing and reduce human impacts such as road construction, off-road activities and urbanization development (villas, restaurants, hotels, ski places and agriculture) in steep slopes and along the rivers and streams. Decision-makers and disaster risk reduction experts should learn from the 2022 Emamzadeh Davood flood disaster and take into account the poor performance of check dams in aggravating the impacts of large events. The consequence of check dam failure increases the risk of sediment-related disasters for downstream communities with impacts that can easily even spread toward low-risk regions (Baggio and D'Agostino 2022).

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Declarations

Conflict of interest The authors have no conflicts of interest.

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