How different surrounding environments influence the characteristics of flash flood-mortality: The case of the 2017 extreme flood in Mandra, Greece

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Abstract
In November 2017, a high-intensity storm caused a catastrophic flash flood that devastated the city of Mandra, in Greece, and led to the tragic loss of 24 people. The storm caused flooding in the two main tributaries of the basin, creating two very similar hydrological responses with similar flood characteristics that hit two different environments: one within the city and one outside. This work examines the fatal incidents that occurred in relation to the characteristics of the surrounding environment, to investigate the role of the latter in flood mortality. Then, the analysis carried out for the 2017 flood is expanded to a broader database of flood deaths for Greece (1960–2018) for comparison. Results show that certain mortality characteristics differ substantially depending on the setting. Outdoor incidents are more abundant in nonurban environments, in which victims exhibit mostly an active or risk-taking behaviour against the imminent risk. Urban environments are characterised by a greater diversity of victim activities, higher percentages of indoor deaths, especially for older victims and more passive behaviours. Overall, the study presents evidence on how risk situations develop differently between urban and nonurban settings. Findings are relevant in shaping policy and education programs aiming to mitigate risk.

KEYWORDS
behaviour, fatalities, flash floods, flood mortality, loss-of-life, surroundings

1 | INTRODUCTION

Flash floods are one of the most destructive natural hazards. Characterised by rapidly changing conditions, they leave little time for citizens and authorities to take protective actions. Flash floods have a shorter duration than riverine floods (typically shorter than one day) and occur in small basins (typically less than 1,000 square km), characterised by shorter concentration times. Because of their nature (rapid onset) flash floods are responsible for a large number of victims and significant economic damages on an annual basis (Barrero, 2007, 2009; Gaume et al., 2016). A large percentage of flood-related fatalities is attributed to flash floods (Barrero, 2007; Jonkman &
expressed in different ways in the existing literature. The surrounding environment or the circumstances are (Anquetin, & Gourley, 2017).

Some of these works explore the role of surroundings (Coates, 1999; FitzGerald et al., 2010; Terti, Ruin, & Villeneuve, 2004, Gaume et al., 2009, 2016) show that extreme flash floods can lead to a dramatic human toll.

Recent findings indicate that the influence of climate change (Alfiieri et al., 2015; Easterling et al., 2000) and global urbanisation trends (Antrop, 2004; Jha, Bloch, & Lamond, 2012), as well as qualitative changes in mortality (Diakakis, 2016) lead to new challenges and highlight the need to enhance efforts to protect human life from floods.

Previous works analyse the diverse effects of flooding on human health (Ahern, Kovats, Wilkinson, Few, & Matthies, 2005; Alderman, Turner, & Tong, 2012). Part of this literature examines specific variables that influence the vulnerability and risk of individuals to flooding (Bern et al., 1993; Coates, 1999; Diakakis & Deligiannakis, 2017; FitzGerald, Du, Jamal, Clark, & Hou, 2010; French, Ing, Von Allmen, & Wood, 1983; Jonkman & Kelman, 2005; Pereira, Diakakis, Deligiannakis, & Zêzere, 2017; Petrucci et al., 2018; Zhai, Fukuzono, & Ikeda, 2006), including victim demographics (Ashley & Ashley, 2008; Pradhan et al., 2007; Rappaport, 2000), their activity at the time of the incident (Drobot, Benight, & Gruntfest, 2007; Staes, Orengo, Mailay, Rullan, & Noji, 1994; Vale, Cole, Garrison, Runyan, & Riad Ruback, 2003), the use of motor vehicles (Ashley & Ashley, 2008; Diakakis & Deligiannakis, 2013; Drobot et al., 2007; Ruin, Gaillard, & Lutoff, 2007), the medical cause of death (Jonkman & Kelman, 2005) and several other variables.

Some of these works explore the role of surroundings and circumstances by studying the physical environment in which fatalities occur. For instance, Salvati et al. (2018) determine how many deaths occurred on river banks, on bridges, outdoors or indoors. Others examine the activity that the victims pursue just before the incident, such as being in a vehicle or on a boat, fording a river and others (Coates, 1999; FitzGerald et al., 2010; Jonkman & Kelman, 2005; Salvati et al., 2018).

Certain studies provide a broader view of risk situations integrating the intentions or other behavioural aspects of the victims into the study of surroundings. For instance, they refer to individuals staying indoors to secure personal property, moving to a lower floor to rescue personal goods or engaging in inappropriate behaviour (Coates, 1999; FitzGerald et al., 2010; Terti, Ruin, Anquetin, & Gourley, 2017).

The number and type of variables that describe the surrounding environment or the circumstances are expressed in different ways in the existing literature. The boundary of what is considered activity, surroundings or behaviour is not clearly drawn and adequately discussed and there is no consensus about it. For instance, in certain studies “being in a vehicle” is perceived as part of the surroundings, while in others “using a vehicle” is analysed as an activity.

In part, due to the complexity of situations and circumstances of fatal incidents, including hydro-meteorological and geomorphological parameters, situation-related and victim-related factors, it is difficult to isolate and study the influence of a single parameter or a group of similar variables on mortality. In addition, broad datasets (e.g., nationwide databases) rarely include detailed descriptions for each fatality. Thus, certain factors such as the victim’s intentions or the availability of other options that could lead to safety cannot be analysed in depth.

In this work, we examine the mortality caused by the 2017 flash flood of Mandra in Greece, the most deadly flood in the country over the last 40 years. Exploiting in-depth descriptions of the 23 fatalities of this event that occurred in the vicinity of Mandra and their circumstances, this work focuses on the role of the surrounding environment in mortality.

Due to the extensive similarities of the two main tributaries of Mandra’s river network in terms of geomorphology, rainfall accumulation, time to peak, peak discharge and timing, this event provides a unique case to examine the influence of the two contrasting settings on flood mortality. Thus, assuming that river and catchment characteristics, as well as hydro-meteorological features are fairly similar, we examine the role of the only major contrasting factor between the two tributaries, that is the setting in which the fatalities occurred.

To this end, the study examines the locations and the characteristics of the surrounding environment where the incidents took place, the timeline of the events, as well as the behaviour of the victims, as expressed by their actions, to understand their role in how fatality situations develop. Then, it compares the findings from Mandra to a broader flood-fatality dataset (1960–2018), in order to examine the statistical validity of the patterns identified. The role of Mandra flood examination in the whole analysis is crucial, as the extensive details available for each incident shed light on new behavioural and situational aspects.

2.1 | Study area

The town of Mandra is located in Attica region, central Greece, in the western part of Thrission plain at the eastern foothills of Mt. Pateras. Thrission is host to
extensive socioeconomic and an important logistical hub, adjacent to the country’s capital, Athens, dominated by large industrial units and industrial activity surrounding small towns. The local river network consists of mostly dry torrents that drain eastward from the hills around Mt. Pateras, towards the town of Mandra and into Thriassion plain near the towns of Magoula and Elefsina, eventually turning south towards the sea (Figure 1). The western part of the plain is dominated by the sharp relief of Mt. Pateras and the hills around its SE part, due to uplift caused by tectonic activity.

Mandra is situated within the basin of Soures torrent and its two main tributaries named Soures and Agia Aikaterini. The main course of Soures flows through a narrow valley formed in limestone, where a major road axis is established on top of the torrent’s older deposits. The torrent frequently crosses on the two sides of the road using small concrete bridges/culverts with rectangular cross-sections (Figure 2). Apart from this road axis, other infrastructure and buildings along this tributary are limited. Due to the relatively sharp relief of the valley slopes, and the surrounding forest, access to the valley is restricted and limited to this road axis, as well as a few dirt roads and paths that intersect with it.

Soures reaches the north edge of the town of Mandra and flows around the town on its northern, north-eastern and eventually eastern edge where it converges with Agia Aikaterini.

**FIGURE 1** (a) Location map of the study area, showing Soures and Agia Aikaterini torrents in relation to the town of Mandra. (b) Close-up Google Earth-based map of the two torrents in Mandra. Agia Aikaterini flows directly through the urban fabric into an artificial underground culvert, while Soures reaches the northern outskirts of the town.
On the other hand, Agia Aikaterini torrent flows through a wider valley, upstream of Mandra, forming a small and poorly developed alluvial fan. Its apex is situated approximately at the western edge of Mandra. Nowadays, the torrent in its natural form is discontinued and substituted with an underground culvert, which serves as the main waterway through the urban fabric. This waterway runs through the central and southern parts of the city and eventually reaches the eastern edge, where it meets Soures (Figures 1b, 2 and 3).

The two basins are very similar in terms of characteristic geomorphological measures, that is, relief ratio, upstream area and shape (as expressed by elongation ratio) (Table 1).

### 2.2 The 2017 extreme flood

The storm event that triggered the catastrophic flash flood occurred between 23:00 UTC of November 14, 2017, and 12:00 UTC of the next day (15 November), with a large part of rainfall aggregating within 6 hr (01:00 to 07:00).

The spatio-temporal distribution of rainfall was captured by the X-band polarimetric radar (XPOL) of the National Observatory of Athens (Andreadakis et al., 2018; Diakakis et al., 2019; Kalogiros et al., 2018), indicating rainfall amounts that reached up to 300 mm in the core of the event (Diakakis et al., 2019).

The basin-average rainfall, according to XPOL estimates (using algorithms produced by Kalogiros et al. [2018]),
was 153 and 194 mm total accumulation for Ag. Aikaterini and Soures catchment, respectively. The timing of peak rainfall was very similar over both sub-catchments as shown by Diakakis et al. (2019). For the above amounts, Elefsis and Mandra stations intensity-duration-frequency (IDF) curves showed a return period of over 500 years (Special Secretariat for Water, 2017), while other botanical and geological evidence point to the same direction (Diakakis et al., 2019), indicating the extremity of the event.

The ensuing discharge overflowed local torrents at approximately 4.00 a.m. UTC of the 15th of November. The debris-laden flood destroyed a large part of the towns of Mandra, Elefsina and Magoula, inducing structural damage in many buildings, washing away cars and affecting vegetation and geomorphology in the vicinity of the torrents. The transportation network was heavily affected as well both in terms of structural damages and vehicle circulation.

During the flood, Soures tributary flooded the narrow valley affecting mainly the road axis and the associated
infrastructure as well as the town’s northern edge. On the contrary, Agia Aikaterini torrent flooded a large part of the town with devastating effects. Both Agia Aikaterini and Soures flooded at the same time, and estimates of peak discharge (117–193 and 141–204 m³/s, respectively) show very similar responses, especially in relation to the basin size.

The timing of peak discharge was estimated in both basins at around 5.10 to 5.40 a.m. UTC (Diakakis et al., 2019), indicating the same level of daily activities and vehicle circulation during the disaster in the two catchments.

Regarding flood water depth in the two different environments, field surveys for high-water marks showed that Agia Aikaterini incidents occurred in shallower water (1.5–2.8 m) in comparison to Soures (2.4–4.2 m). In general, in Soures, the concentration of water flow in a narrow zone increased water depth, whereas, in Agia Aikaterini, where water flowed in a wider flood zone, smaller depths were recorded (Diakakis et al., 2019). Nevertheless, it is not clear whether fatalities occurred during peak water depth or not. In addition, in urban environments, even small water depths in the floodplain (or in the street) can lead, due to faulty designs (e.g., basements with below-ground openings) to the development of dangerous conditions. For instance, floodwater of 1 m depth at the street can lead to a 3 m water depth in a neighbouring basement.

### 3 | METHOD

Data on the fatal incidents, including a detailed description of the timeline of events and details on the setting and the surrounding environment, were collected from various sources:

1. Ground and UAV-derived aerial observations during and after the flood, in the course of post-flood field surveys (Figure 4).
2. Bulletins and press releases by the Fire Service (Hellenic Fire Service, 2017a, 2017b, 2017c, 2017d, 2017e)
3. Press releases from the Ministry of Health (Ministry of Health, 2017)
4. Bulletins and press releases issued by the General Secretariat for Civil Protection (GSCP, 2017a, 2017b, 2017c)
5. Interviews with 19 eyewitnesses and survivors
6. Press reports (aftodioikisi.gr, 2017a, 2017b; Antonopoulos, 2017; Katakouzinos, 2017)

Bulletin and press releases contained information on the victims (i.e., age, gender) and the exact location of incidents. Field surveys at the location of fatal incidents were based on ground observations, aided by aerial imagery, which was captured by an Unmanned Aerial Vehicle (UAV—DJI Phantom 4 Pro), capturing 20-megapixel photos and 4 K video. The subsequent examination of this visual material allowed an analysis of local conditions, including estimation of water stage through high watermarks, identification of the infrastructure elements at the scene of the incidents, the type of vehicles involved and other elements of the surrounding environment. The timeline and the events describing each incident as well as the activities and behaviour of each victim were extracted from interviews.

To examine the behaviour of individuals around floodwaters, we divided it into the nine categories

| Parameter | Soures torrent | Agia Aikaterini torrent |
|-----------|----------------|------------------------|
| Upstream area (km²) | 17.01 | 15.5 |
| Average rainfall accumulation from the storm of November 15, 2017 | 194 mm³ | 153 mm³ |
| Average estimated velocity of peak discharge (Diakakis et al., 2019) (m/s) | 2.6³ | 2.1³ |
| Estimated peak discharge (range) (m³/s) | 170 (range 141–204)³ | 140 (range 117–193)³ |
| Unit peak discharge (m³/s/km²) | 9.98³ | 9.03³ |
| Elongation ratio | 0.52 | 0.62 |
| Relief ratio (m/m) | 0.08 | 0.08 |

³Estimated based on X-band polarimetric radar radar data of the National Observatory of Athens, presented in previous works by Diakakis et al. (2019) and Varlas et al., 2019.

²Calculated at locations within 500 m of fatal incidents clusters, downstream in the case of Soures and upstream in the case of Agia Aikaterini.

From left to right: minimum, probable and maximum estimation, Calculated at locations within 500 m of fatal incidents clusters (Diakakis et al., 2019).

⁴Unit peak discharge is calculated by dividing probable peak discharge by the upstream area.
(Table 2) depending on the actions or intentions of the victims.

To organise the collected data, we developed a database to link information of each incident. Each entry of the database, corresponding to one fatality, consisted of several variables that provided a detailed description of the incident as well as an objective description of each setting and of the circumstances under which the fatal incident occurred.

The analysis provided an overview of the characteristics of mortality and a comparison of the findings between the two tributaries (Sohres and Agia Aikaterini), in terms of the gender and age of the victims, their activities and intentions, their behaviour around floodwaters, as well as the surroundings.

Furthermore, this study exploited a larger dataset available for Greece containing details on flood fatalities in the country between 1960 and 2018 (Diakakis & Deligiannakis, 2017). Findings and patterns from the case of Mandra were compared to this broader dataset. Chi-square tests were then used to examine the correlation between variables.

It has to be noted that one fatality that occurred in the town of Nea Peramos is not included in this analysis, as the study aimed to analyse mortality circumstances only under very similar hydrological conditions within the two catchments presented above, and therefore included only the 23 fatalities that occurred in and around the city of Mandra, along the two tributaries.

4 RESULTS

4.1 Mortality overview

The study identified 23 victims attributed to the flood around and inside the city of Mandra and 1 in the town of Nea Peramos. Out of the 23, 15 individuals died in the narrow valley of Sohres torrent, whereas eight passed away within the city of Mandra due to flooding caused by the Agia Aikaterini tributary (Figure 5).

The victims’ age ranges from 29 to 95 years old (hereafter y.o.), with an average of 65. Nine victims (or 37.5%)

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**TABLE 2** Categories of behaviour against the imminent flood threat

| Category | Description of behaviour |
|----------|--------------------------|
| Category 1: While in an initial position of safety | 1.a. Decision to travel across or enter floodwaters<br>1.b. Decision to enter floodwaters for a rescue or to retrieve something<br>1.c. Decision to enter floodwaters as passenger of vehicle<br>1.d. Decision to stand/walk/drive at the boundary of floodwaters ignoring threat (aware of risk) |
| Category 2: While in an initial position of reducing safety or where safety is compromised | 2.a. Decision to travel across floodwaters, while fleeing or evacuating a position of reducing safety (aware of risk)<br>2.b. Decision to stay temporarily to retrieve something or rescue someone (aware of risk)<br>2.c. Decision to stay at location as the most safe option (aware of risk)<br>2.d. Unaware of risk until insufficient time to evacuate<br>2.e. Aware of risk but unable to evacuate due to physical condition |
were over 80 y.o., and 12 (or 50%) over 60 y.o. This significant percentage of older individuals has been recorded before as a pattern in extreme events (Vinet, Lumbroso, Defossez, & Boissier, 2012), but also as a common trend in flood mortality literature (Alderman et al., 2012). With regard to their gender, 17 of the decedents were male, whereas six were female (Figure 6). Seven (or 30.4% of total) of the victims were using a vehicle, while eight (or 34.8%) passed away indoors and seven (or 30.4%) outdoors on foot. For one (1) case, the exact activity is not known.

The vehicles used by the victims included passenger cars (two cases) and dump, tank and container trucks (five cases), ranging from 1.5 up to 32 tons in weight.

### 4.2 | Comparison between the two settings

Comparison of mortality characteristics between the two settings (i.e., the narrow valley of Soures and the urban environment of Mandra), illustrated very different mortality characteristics.

#### 4.2.1 | Immediate surroundings

In detail, it was found that all 15 Soures victims were outdoors, either on foot (7) or using a vehicle (7). For one victim the exact activity was not reported. On the other hand, Agia Aikaterini victims were all indoors, either waiting for rescue.
(2), sleeping (1), shopping (1), trying to retrieve belongings (1) or in an unclear indoor activity (2) (Figure 6).

This disparity with regard to the immediate surroundings (indoors/outdoors) is apparent on the impact that rushing water had on the victims, as reflected by the way they were washed away. Sours victims were carried away in large distances of 0.7 to 10 km (average 3.9 km), measured from the locations in which the incidents happened to the sites where each body was eventually recovered (Figure 7). For some of these victims, it is not clear where exactly they passed away. In contrast, in the case of Agia Aikaterini victims died on location. This disparity is not attributed to differences in water stage and/or the average velocity, as in both settings they were enough to carry large vehicles and trucks and therefore capable of moving people. The difference is attributed to the fact that indoor incidents trapped individuals inside confined spaces. It is also noteworthy that some of the outdoor victims were recovered up to 12 days after the event.

4.2.2 Victims’ behaviour

With regard to their behaviour, based on the categories presented in Table 2 in Method, we assigned a classification for each victim (Figure 8), as expressed by their reported actions described below.

In the case of Agia Aikaterini, out of a total of eight (8) victims, at the time of the flood, five (5) were at their homes unaware of the emergency until there was insufficient time to evacuate (shown also in Coates, 1999). This is confirmed in all five cases by testimonies of neighbours that alerted them at a time that was impossible to evacuate on their own or be rescued by the civilians that were in the vicinity. One (1) victim decided to stay in a store as the safest option, while water level was increasing rapidly in surrounding streets and while there was still time to evacuate it, as other individuals did. Another victim living in a basement became aware of flooding at an early time, but due to a physical inability to climb the stairs and find refuge, she asked for help, but the civilians (some of which relatives) that were in the vicinity were not able to rescue her. Finally, one (1) victim became aware of flooding while at home. In the course of evacuating, while he was a few meters out of the building, he...
changed his mind and returned to the building’s basement to retrieve something and was trapped.

In the case of Soures, out of a total of 15 victims, six (6) were sitting outdoors near two small kiosks observing the situation when floodwaters reached them and washed them away. Five (5) victims were driving trucks uphill when the road started to suffer inundation. They decided, based on survivor testimonies, to continue uphill since there was limited space to turn around or park as water level was rising. All five trucks were eventually washed away and thrown into the torrent. Two (2) victims were driving their passenger cars uphill (at separate occasions) and decided to continue their drive passing through floodwaters at locations where the torrent had partially flooded the road. They were both washed away together with their cars and thrown into the torrent. Finally, one (1) victim was doing sports at the mouth of the river unaware of the flood, when water flow became too strong and carried him into the sea where he drowned.

All Agia Aikaterini victims exhibited behaviours that belong to the “passive” group, trapped in confined spaces in which safety was rapidly reducing. In the case of Soures, behaviours of victims belong both in the active and passive groups.

4.2.3 | Victim demographics in the two settings

Concerning victim demographics, indoor victims were mostly female (six out of eight), whereas in the outdoor setting all victims were males. Comparison of their age showed a noteworthy difference between Agia Aikaterini and Soures (Table 3). Victims in the urban environment of Agia Aikaterini were significantly older than in the rural, outdoor setting of Soures.

4.3 | Comparison with broader datasets

4.3.1 | Comparison between urban and rural environment fatalities

Comparison of urban-environment fatalities (hereafter UEFs) to rural-environment fatalities (hereafter REFs) in Greece, based on the flood fatality dataset (1960–2018) of Diakakis and Deligiannakis (2017) showed findings in agreement with the case of Mandra.

Examination of the activity of victims exactly before the time of death between UEFs and REFs showed a different distribution (Figure 9). Vehicle-related and other outdoor fatalities tend to record significantly higher percentages in rural environments (blue colours in Figure 9), whereas, on the contrary, indoor deaths are more abundant in urban environments (orange colours in Figure 9).

In this dataset, a Pearson’s chi-square test of independence (N = 201) showing a p-value of .000 indicates that the null hypothesis (i.e., the two variables, activity and environment, are perfectly independent) is rejected. Cramer’s V for this test shows a value of 0.621, which indicates a moderate association.

Examination of the age of victims in different environments for the 1960–2018 dataset showed that between urban and rural environments there is no significant difference, with urban environment victims showing marginally higher age on average than rural environment ones (46.5 y.o. and 46.2 y.o., respectively).

| TABLE 3 | Age distribution of victims at the two tributaries |
| River | Agia Aikaterini | Soures |
| Average age (years) | 84.5 | 52.6 |
| Range (years) | 67–95 | 29–80 |
| Standard deviation | 9.1 | 16.0 |

**FIGURE 9** Distribution of activity of victims (N = 201) at the time of the incident that occurred in urban or rural environment
However, when we isolated UEFs that occurred indoors in the 1960–2018 database (N = 221), we found a higher average age of victims than any other group of fatalities (Table 4).

Indoor fatalities exhibited higher percentages in events with a large number of fatalities. Dividing all events in the 1960–2018 dataset in high-mortality (>10 deaths) and low-mortality (<10 deaths) floods, we identified an important discrepancy (Table 5) in the indoor/outdoor ratio. A Pearson’s chi-square test of independence (N = 201), showing a p-value of .000, indicates that the null hypothesis is rejected. Cramer’s V for this test shows a value of 0.276, which indicates a weak but existing association.

### Table 4 Average age of victims in indoor and outdoor settings

| General setting | Location setting | Average age of victims (years) |
|-----------------|------------------|-------------------------------|
| Urban (N = 104) | All fatalities    | 46.52                         |
|                 | Only indoor fatalities | 57.95                     |
| Rural (N = 117) | All fatalities    | 46.22                         |
|                 | Only outdoor fatalities | 46.23                      |

### Table 5 Differences in the indoor and outdoor percentages between high-mortality (>10 deaths) and low-mortality (<10 deaths) floods, based on data deriving from the 1960–2018 dataset

|                     | High-mortality (>10 deaths) events | Low-mortality (<10 deaths) |
|---------------------|-----------------------------------|---------------------------|
| Indoor fatalities   | 26 (41.3%)                        | 22 (or 15.9%)             |
| Outdoor fatalities  | 37 (58.7%)                        | 116 (or 84.1%)            |
| Totals              | 63 (100%)                         | 138 (100%)                |

### Figure 10 Distribution of urban and rural environment fatalities (N = 57) in different categories of behaviour around floodwaters (2010–2018)

### 4.3.2 Comparison of victims’ behaviour

Comparison of the behaviour of victims around floodwaters between UEFs and REFs showed a different distribution (Figure 10). Passive behaviours (2a–2e) tend to record higher percentages in urban environments (blue colour in Figure 10), whereas, on the contrary, behaviours that belong to the risk-taking or active sphere (1a–1d) are more abundant in rural environments (orange colour in Figure 10).

In the 1960–2018 dataset (using only the years 2010–2018 for which behaviour information is available), a Pearson’s chi-square test of independence (N = 57) showing a p-value of .003 indicates that the null hypothesis (i.e., the two variables, behaviour and environment, are perfectly independent) is rejected. In addition, Cramer’s V shows a value of 0.660, which indicates a moderate to strong association.

The behaviour was found to be different between the high-mortality event of Mandra and the rest (low-mortality events) in the 2010–2018 dataset. Out of the 57 cases, for which behaviour was known, 23 were part of the high-mortality group, whereas 34 belonged to the low-mortality one. The ratio of active (Category 1) to passive (Category 2) behaviour in these two groups was found to be 0.53 (or 8 to 15) and 2.8 (or 25 to 9), respectively.

### 5 DISCUSSION

Overall, the high average age of the victims (65 years) and the increased representation of older individuals and men among them are in agreement with findings of multiple previous works on flood mortality in Greece (Diakakis & Deligiannakis, 2017) and elsewhere in the world (Alderman et al., 2012; Salvati et al., 2018). The same applies for the high percentage of vehicle-related...
fatalities that confirm respective literature-wide findings (Ashley & Ashley, 2008; Diakakis & Deliannakis, 2017; French et al., 1983; Jonkman & Kelman, 2005).

A comparison of the fatalities of the two settings reveals significant differences in the characteristics of mortality. Firstly, there is a noteworthy difference in mortality rates between the two tributaries, considering the vast disparity of population numbers found in the two flood zones. Based on survivor testimonies, the population in Soures flood zone probably did not exceed a few tens of individuals at the time of the flood and certainly did not surpass 500 people, including vehicle occupants, pedestrians and people inside a cafe and a few other buildings. On the contrary, in the case of Agia Aikaterini, approximately half of the city of 10,711 people experienced inundation at a time in which most of this population was at home. Despite this population disparity, the flood caused an uneven distribution of victims (15 in Soures, 8 in Agia Aikaterini). This is in agreement with literature findings that show a tendency for larger mortality rates in outdoor settings, apparent both in broad fatality datasets (Coates, 1999; Petrucci et al., 2018; Salvati et al., 2018; Terti et al., 2017) and in single events (Ruin, Creutin, Anquetin, & Lutoff, 2008).

The same pattern emerges regarding vehicle-related fatalities. Despite the fact that more than 300 vehicles were washed away in numerous streets of the city of Mandra and that water velocity in the streets was high enough to destroy vehicles and road infrastructure, no vehicle-related fatalities were recorded. On the contrary, numerous vehicle-related fatalities were recorded on the one and only road axis passing through the narrow valley of Soures, where not more than a few tens of vehicles were circulating at the time. Considering the difference in the number of vehicle occupants and in vehicles that were washed away in the flood zones of Agia Aikaterini and Soures, this is clearly a notable pattern.

With regard to the activity of the victims, the complete contrast found between Soures and Agia Aikaterini shows that risk situations tend to develop differently in the two environments. In rural environments, where only a small number of buildings exist, it is, of course, expected that indoor victims would be limited. However, within the town of Mandra where tens of motorists were trapped in the flooded roads, and many others were in danger outdoors, it is noteworthy that all victims died indoors. This pattern is present in the broader dataset as well. Examination of the 1960–2018 database showed that urban environments recorded a higher percentage of indoor deaths. Even though in these large datasets vehicle-related and pedestrian fatalities are present in urban environments as well, indoor incidents are still the majority.

Analysis of victims’ behaviour reveals differences as well. Most of the time in outdoor incidents, individuals try to travel across / enter floodwaters to reach a destination, retrieve something/someone or stand/walk/drive at the boundary of the flooded zone, despite the fact that they are aware of the flood.

These behaviours fall within the spectrum of a more risk-taking way of behaving around floodwaters, given that the victim became aware of the threat from an initial position of safety and nevertheless chose to come in contact with floodwaters. Active behaviours, named by some authors as “dangerous,” “hazardous” or “inappropriate” have been shown in previous works in outdoor incidents (Coates, 1999; Petrucci et al., 2018; Petrucci et al., 2019; Ruin et al., 2007; Salvati et al., 2018).

Other types of behaviours are identified as well. For example, in the case of Mandra, a part of Soures victims (truck drivers) started to experience road flooding while in the middle of an uphill section of the road with no options to avoid danger, as (a) there was a complete lack of road intersections leading out of the flood zone, and (b) it was impossible to make a U-turn for a truck of a considerable size in this narrow road. Thus, although they continued to travel through floodwaters this could be an action caused by their concern that safety at their initial position was reducing rapidly. Turning downhill or staying in their spots was not a safe option according to survivor testimonies and post-flood examination of the scene. This latter behaviour is considered to belong to the passive group.

Broader dataset findings are in agreement with the above pattern, as behaviours that belong to the active group tend to appear in risk situations in rural environments at a higher percentage than passive types, whereas passive behaviours are more abundant at urban settings.

With regard to victim demographics, a first look in the 1960–2018 database shows that a discrepancy in age, similar to the one identified in Mandra, between urban and rural fatalities is not present, as the average age of victims between the two has negligible differences. However, when considering only indoor incidents in the urban environment, then the average age of victims is much higher.

In the case of Mandra flood, the loss of older individuals at an indoor setting is attributed to: (a) becoming aware of the risk at a late stage, (b) inability to flee due to a physical condition and (c) reluctance to flee before retrieving some belongings. Although detailed information is not always available for the broad dataset, this general pattern of elderly indoor against younger outdoor victims (acknowledged also in Terti et al., 2017) may be attributed to several reasons suggested previously in the literature. These reasons include: a higher degree of
emotional attachment to their property or belongings (Gladwin & Peacock, 1997), suffering from poor physical condition and physical ability to flee as well as poor appreciation of the circumstances (Alderman et al., 2012; Brunkard, Namulanda, & Ratard, 2008; Carroll, Morbey, Balogh, & Araoz, 2009; Coates, 1999; Jonkman & Kelman, 2005; Vinet et al., 2012).

Discrepancies between high mortality (>10 deaths) and low mortality (<10 deaths) flood events found in this study (on the 1960–2018 dataset) are in agreement with findings of Vinet, Boissier, and Saint-Martin (2016) who suggest that in smaller events, outdoor fatalities and fatalities occurring due to risk-taking behaviour are more abundant. On the contrary, high-mortality events exhibit higher percentages of indoor victims and passive behaviours.

Overall, the results provide evidence which shows that the surrounding environment has an influence on certain mortality characteristics and a role on how fatal incidents happen. This fact and the statistical relationships with these characteristics have not been acknowledged in previous works. The environment’s role highlighted in this study and specifically, its correlation with the victims’ behaviour can be particularly useful in future studies. As risk mitigation measures are gradually adopted in flood-prone areas, authorities will eventually have to focus more on improving people’s behaviour around floodwaters, through educational programs designed to reduce hazardous behaviours. To this end, a better understanding of surroundings – behaviour dynamics discussed in the present study can be particularly useful to shape educational efforts. Moreover, the need for insights on incident circumstances has been acknowledged in previous works, which stress that circumstances should be the certain point of mortality studies (FitzGerald et al., 2010; Terti et al., 2017).

6 | CONCLUSIONS

This work examines flash flood mortality occurring after an extreme flash flood at Mandra in Greece, in 2017, and focuses on its characteristics in relation with the two contrasting settings where 23 fatalities of this event clustered. Then, it compares the findings with a broad mortality dataset to investigate the validity of the patterns identified. The study presents evidence which show that mortality in these two settings differs substantially in certain aspects. Results show that the setting influences to a degree how risk situations that lead to fatalities actually develop.

Outside of the urban fabric, indoor deaths are not common, as buildings are fewer. Therefore, outdoor-setting fatalities exhibit a higher percentage. In the majority of such cases, the victims come deliberately in contact with floodwaters, even though they are in an initial position of safety. Incidents, in which floodwaters trap someone, who is in a position of reducing safety, unaware of the risk or unable to move, are far less common. In plain words, in outdoor and rural settings, incidents in which individuals who move towards/engage deliberately with floodwaters are more common than incidents where floodwaters move towards and trap individuals unaware of the imminent risk. In this sense, victims exhibit a higher percentage of risk-taking behaviours around floodwaters. Incidents in which the victims show passive behaviours are less frequent but exist.

Urban areas show a lower mortality rate and fewer victims, which is an indication of a safer environment, when it comes to floods. In urban settings, indoor incidents are more common, as many people choose to take refuge or get trapped inside buildings. Outdoor and vehicle-related fatalities exist as well, but in smaller percentages. This is probably attributed to the availability of multiple alternative ways towards safety such as detours, road intersections, ways out of the floodplain and stairs to upper floors (in the case of indoor settings). Thus, despite the much larger population near floodwaters, risk situations (especially outdoors ones) tend to develop less frequently, in comparison to rural settings.

In urban environments, buildings’ upper floors can be a good place to take refuge when constructed by durable materials (e.g., reinforced concrete) (Diakakis, 2016). This is particularly true in the case of small-basin floods, during which structures are not as vulnerable as literature suggests (Ruin et al., 2008). In the case of Mandra, despite the extremity of the flood, only a handful of buildings suffered partial or complete collapse out of many hundreds that were flooded, while none of these buildings was constructed by reinforced concrete. From the visual material and from interviews it is evident that the vast majority of people in buildings moved to upper floors and were safely monitoring the situation (even capturing video in their mobile phones) from first and second-floor balconies, windows, verandas or roofs. The upper floors, therefore, became safe locations for the vast majority of the urban population with relatively easy access (through stairs).

The results presented in this study fill the existing knowledge gap in the role of the surrounding environment in flash flood fatalities, adding a piece to the complex puzzle of mortality that was not clearly present in the existing literature. The implications of the above findings are relevant to develop policies and education programs focusing on enhancing safety during flash floods.
In detail, the high percentage of vehicle-related and outdoor fatalities once more highlights that improvements are needed in the road network safety including the redesign of critical infrastructure (e.g., bridges, ford crossings) and the installation of flood warning signs or barricades at dangerous locations. In addition, execution of public awareness campaigns on flood risk and particularly on dangers inherent in driving through flooded roads and staying around floodwaters is necessary to influence the perception of individuals towards risk, especially given the risk-taking behaviours prevalence in outdoor incidents. The higher age of indoor victims indicates that special awareness programs should target the elderly and people with disabilities, as well as their close relatives. These programs should focus on the dangers of living in basements and ground floors in flood-prone areas, and the risk of entrapment in confined spaces, along with highlighting the value of self-protection measures and household emergency planning. Finally, the search and rescue personnel should be trained accordingly with drills and training material that should reflect more realistic scenarios based on the type of environment.

Overall, this study exploits a unique case of flooding in very similar catchments and hydro-meteorological conditions to provide insights on the role of the surrounding environment on mortality, identifying correlations that have not been explored in previous studies. The findings establish the surrounding environment as a factor that influences mortality characteristics, indicating that it should be included in future research and in its role should be highlighted in educational and community awareness programs aiming to reduce risk.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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