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Drowning incidents in urban rivers: An underestimated issue with future challenges in need of an interdisciplinary database to characterise its epidemiology

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ABSTRACT

In recent decades, the recreational use of urban rivers has become popular, and public access to riverbanks has improved. However, in the context of global warming, the risk of drowning in urban rivers may increase. The objective of this study is to examine drownings in the Rhone and Saone rivers in Lyon (France) and to identify risk factors, hot spots and high-risk moments using an environmental database.

A total of 386 fatal and non-fatal drownings occurred in Lyon on the Rhone and Saone rivers between 2015 and 2021. The analyses identify that, universally, most drowning victims are men (68 %) and young adults (37 %). More drownings occur in the summer period (45 %). There are also hot spots near the city centre and in urban river parks. Three types of drownings are characterised by using principal component analysis (PCA) and hierarchical clustering on principal components (HCPC) methods. These groups are distinguished by hydrological and meteorological conditions, as well as by the seasonality and circumstances of the incident. The first group (G1) corresponds to drownings that occur on cold winter days, with high water flows and turbidity. The second group (G2) corresponds to drownings that resulted from bridge jumping in a festive context or a challenge between friends. These drownings occur on autumn days with interesting hydrological conditions (low flow and clear water). The last group (G3) groups together drownings that occurred while a victim is swimming in an unsupervised area. These drownings occur during the summer on very hot days. Finally, a multiple logistic regression method showed that the average daily outdoor temperature was positively correlated with the occurrence of drowning in Lyon ($p < 0.05$) and that daily rainfall was negatively correlated with the occurrence of drowning ($p < 0.05$).

1. Introduction

In large urban areas, rivers are a major asset in terms of cultural identity, sustainability, and touristic and economic attractiveness (Kondolf and Pinto, 2017). However, urban rivers are also associated with a murkier, darker side: that of drowning. The World Health Organisation (WHO) defines drowning as “Drowning is a process resulting in primary respiratory impairment from submersion/immersion in a liquid medium. [...] The victim may live or die after this process, but whatever the outcome, he or she has been involved in a drowning incident” (Idriss et al., 2003, Van Beeck et al., 2005). These tragedies are tracked in international statistics (WHO,

Global Health Estimates, 2019). Drowning is the third leading cause of unintentional injury death worldwide and accounts for 7 % of all injury deaths. Many incidents and deaths by drowning are reported each year, with approximately 650 deaths per day worldwide. According to the WHO, drowning is a major but neglected global public health problem. Of these deaths, 90 % occur in low- and middle-income countries (WHO, Global Health Estimates, 2019). Drowning in inland waterways is typically underestimated in wealthy countries, with prevention strategies largely geared towards coastal drowning and drowning in domestic settings (e.g., private swimming pools, bathtubs) (Koon et al., 2021; Peden et al., 2016a). A survey carried out by Santé Publique France referenced 1480 drownings during summer 2021 in France, 27 % of

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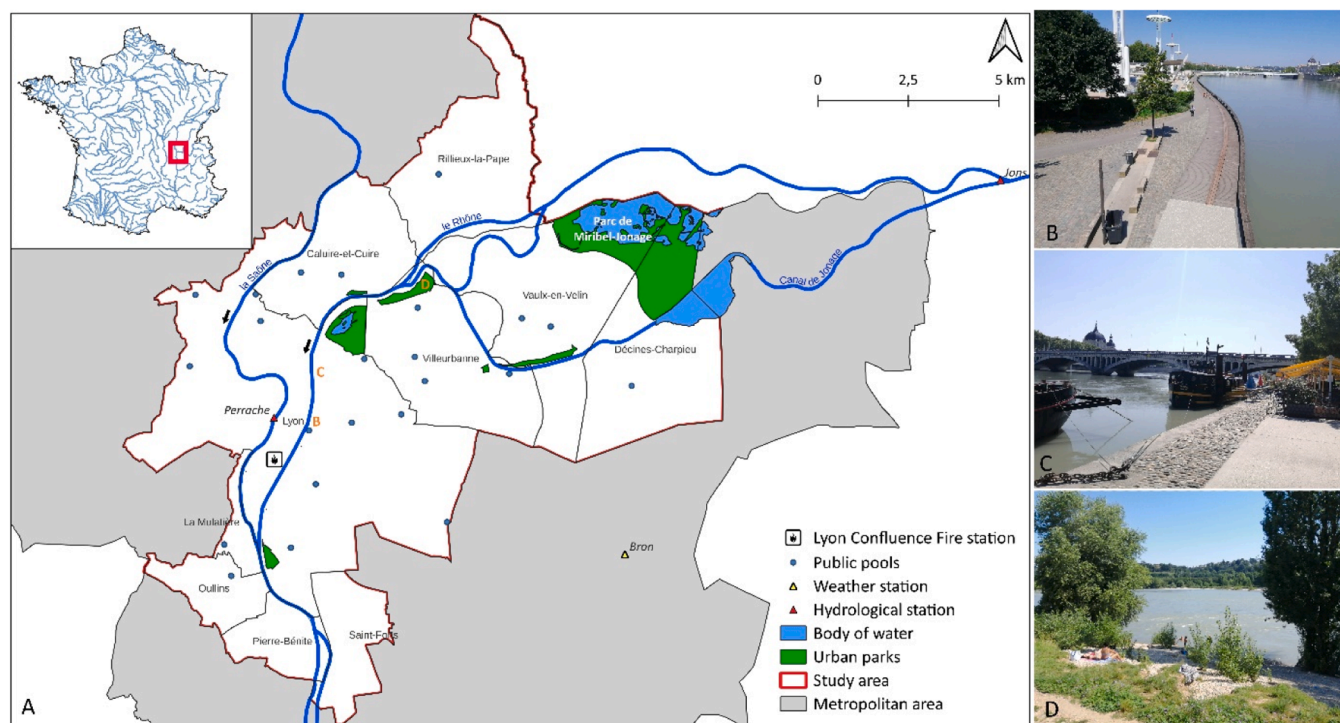


Fig. 1. Study site: (A) Study area in Lyon, France; the study location encompassing ten different municipalities of the metropolitan area. These municipalities are all crossed by the Saone River or the Rhone River, two large rivers, whose confluence is located south of the study area in Lyon. (B) Picture of the Rhone riverbank, showing an artificial landscape allows city dwellers to enjoy it. (C) Picture of the Rhone at Wilson Bridge with festive and commercial areas with restaurant barges and nightclubs. (D) Picture of the Rhone riverbank in the Feyssine park in Villeurbanne. This place is perceived as more natural. Data sources: Data Grand Lyon, Data gouv. © C.Maghakian.

which were fatal. Among these fatal and non-fatal drownings ($n = 1480$), 12 % took place in rivers and lakes. Beyond these statistics, aside from the trauma felt by the drowning victim, it represents a tragedy for the entire family, friends, rescuers, and witnesses to the fatal accident (Garshasbi, 2022).

During the 21st century, the size of cities has increased worldwide (Pacione, 2009; Masini et al., 2019), and today, more than half of the world's population lives in urban areas. Europe is the second continent (after Asia) with the largest urban population (553 million urban dwellers; World Health Organization, 2017). In France, 38 % of the population lives in the 2 % of the country's densest municipalities (INSEE, 2019), and authorised bathing areas in these municipalities include swimming pools and supervised bodies of water. Despite their presence and attractiveness, French urban waterways are forbidden for bathing. However, bathing still takes place in urban rivers. The number of unauthorised swims may be linked to the need to cool down in connection with global warming. Summer temperatures rise sharply in cities (Heaviside et al., 2017), and the intrinsic characteristics of urban environments make them vulnerable to the phenomenon of global warming (Makido et al., 2019). Hence, summer periods in cities are high-risk periods, during which the occurrence of drownings may increase (Fralick et al., 2013; Sindall et al., 2022).

Bathing in urban rivers is a long-standing practise throughout French cities, such as Paris, where the practice was widespread during the 17th and 19th centuries but banned in 1923 (Moutiez, 2021). Urban rivers were no longer perceived as places of recreation beginning in the 20th century. The perception of urban rivers is changing again in the 21st century, evolving from "production assets, used to feed industries [...] into recreational assets, places of recreation and symbols of nature" (Romain, 2010). This revaluation of urban watercourses leads to "a return to the river" (Gerardot, 2004) and the development of outdoor activities increased near and along the watercourses (e.g., walking, cycling, kayaking, rowing). The urban river landscape reference is no

longer urban but rather "nonurban" (Romain, 2010). There has been a major increase in engagement in outdoor activities in Europe (Bell et al., 2007), particularly after the COVID-19 crisis, where the use of natural spaces has proven to be essential for the well-being of city dwellers (Venter et al., 2020). In a context where urban waterways are now a symbol of nature, the practice of swimming, even if prohibited, will increase. While the need to cool off is shared by all city dwellers, exposure to the risk of drowning is uneven across the population, based on age, gender, race and socioeconomic group (Sindall et al., 2022; Wallis et al., 2015; Möller et al., 2015). The availability of a swimming infrastructure and the principle of "social exclusivity" may lead to limited access to water activities and the aquatic safety skills that mitigate the risk of death for vulnerable populations (Hastings et al., 2006).

Unauthorised bathing in urban rivers and the associated risk of drowning are therefore part of complex dynamics, including environmental (e.g., periods of heat), urban policy (e.g., reclaiming urban river frontages), cultural and social (e.g., heritage of old practices, need for "nature" in the city, rising poverty, and inequality) dynamics. However, swimming accidents are not the only causes of drowning. Suicide, falls, and homicide can, for instance, complicate the understanding of this risk.

In this study, we assume that the spatial and temporal variability of drownings provides information on social, cultural, and environmental processes that are key to understanding the risk. Creation of a structured, multidisciplinary database of drowning incidents (noted DI hereafter) is essential to integrate all these data and to test this hypothesis.

While there are epidemiological studies of drowning in watercourses incorporating sociodemographic data (e.g., victim gender, victim age, alcohol/drug use) (Brice et al., 2013; Byard, 2017; Peden et al., 2016a, Peden et al., 2016b), few incorporate local environmental data (e.g., meteorological, hydraulic, hydrological) or sociocultural data (e.g.,

social group, use of social media) that may influence the occurrence of drowning in urban waterways. Hence, this study has two main objectives: i) to examine incidents of drowning in large urban rivers in Lyon (France) and ii) to determine the principal environmental factors that might explain the occurrences of these drowning incidents. The first objective is to characterise the occurrence of drowning incidents in Lyon (France) through the presentation of an original and structured database compiling drowning incidents that occurred between January 2015 and December 2021 (e.g., nature of the drowning, date and location, victims' description) and the environmental context associated with each drowning incident. A first descriptive analysis of this database will show the spatial and temporal dynamics of these incidents for Lyon and will allow us to propose a structured database model generalisable to other cities or regions. The second objective is to explain the occurrences of drowning incidents with environmental variables. The risk of drowning is very complex to define and predict due to a very large number of factors (e.g., hydrology, hydraulics, geomorphology, landscape, social, cultural, psychological, economic). The objective of this part of the process is to identify the environmental variables that play an explanatory role in the occurrence of drowning. This step allows us to normalise the influence of environmental variables on the occurrence of drowning incidents to examine the explanatory power of sociocultural and landscape data in future studies. The final challenge will be to describe the factors that are most relevant to explaining drowning incidents occurrence.

In the long term, we believe that this work will help guide operational prevention (i.e., preventive patrols during events considered to be high-risk) and rescue efforts to reduce drowning risks in urban rivers by defining the hot spots and high-risk moments where drowning occurs in cities. Furthermore, the database model presented in this article for the city of Lyon could serve as a guideline for the collection and structuring of drowning databases in other rivers. This is an essential step in understanding the epidemiology of drowning in cities and allows for i) an intercomparison between different cities or countries and ii) an understanding of DI evolution over time (e.g., decades).

2. Study site

The study area is composed of 10 municipalities at the centre of the Lyon metropolitan area, France (Fig. 1), which cover ca. 140 km². The Rhone and the Saone rivers and the Jonage Canal cross these ten municipalities. These rivers represent a cumulative length of 51 km within the study area. The mean discharges of the Rhône and Saône Rivers over the period 2015–2020 are 560 m³.s⁻¹ and 345 m³.s⁻¹, respectively. The riverbanks are highly developed, particularly in the Lyon centre. The banks of the Rhone River were at the heart of a major rehabilitation project between 2002 and 2007 to enable inhabitants to "reclaim" the river. Today, the riverbanks are a place for relaxation and festivities, allowing residents to reconnect with places perceived as natural in the city of Lyon.

This urban area is characterised by its high population density, with an average of ca. 4700 inhabitants per square kilometre and, more precisely, a maximum density of ca. 10.9 inhabitants per square kilometre for the city of Lyon. In Lyon, an increase in minimum air temperature of 0.20 °C/decade and an increase in maximum air temperature of 0.26 °C/decade have been observed since 1921. The number of summer days, defined as days where the maximum air temperature exceeds 25 °C, has increased significantly since 2003 (Alonso and Renard, 2020).

In the study area, bathing facilities are limited to public swimming pools and one supervised site, the *Miribel Jonage* park, which offers lake bathing that is not considered in this study. There are 23 public swimming pools in the study area, which equates to approximately 3 swimming pools per 100,000 inhabitants. In addition to these paid and supervised bathing facilities, there are those that exist along the entire length of the Rhone and Saone rivers and Miribel Canal in Lyon.

Table 1

Summary of variables from rescuers' data.

Description	Name	Values	Clarification of values
Date	<i>Date</i>	Date of DI "dd/mm/yyyy"	
Hour	<i>H</i>	Time of rescue call "hh:mm"	
Time of day	<i>ToD</i>	Morning	7–12 am
		Afternoon	1–5 pm
		Evening	6–11 pm
		Night	0–6 am
Season	<i>Season</i>	Winter	December 21th - March 20th
		Spring	March 21th - June 20th
		Summer	June 21th - September 20th
		Autumn	September 21 th - 20th
River	<i>River</i>	R	Rhone River
		S	Saone River
Gender	<i>Gen</i>	M	Man
		W	Woman
Age	<i>Age</i>	victim's age "23-year-old"	
Age group	<i>Age group</i>	Children	14 years old and under
		Teenagers and young adults	15–29 years old
		Adults	30–59 years old
		Seniors	60 years old and over
Severity of DI	<i>Sev</i>	UN	Unharmd
		RE	Relative Emergency
		AE	Absolute Emergency
		DE	Dead
		MV	Missing Victim
Circumstances of the DI	<i>Cir</i>	SUI	suicide
		BJ	bridge jumping
		AFA	accidental falling and altercation
		BAT	bathing

However, bathing has remained prohibited by municipalities at those sites since 2001.

As members of the drowning rescue organisation in the study area, firefighters are members of the Fire and Rescue Department (SDMIS). The Fire and Rescue Department is responsible for firefighting, protection against other accidents, disasters and catastrophes, the assessment and prevention of technological or natural risks and emergency aid. There are several specialities within the Fire and Rescue Department, including the aquatic speciality division. This speciality is exclusively housed in the Lyon Confluence fire station (Fig. 1). Diver-rescuers are called upon for all aquatic missions. These include rescuing people who have fallen overboard, assisting boats in distress, reconnaissance, and underwater interventions. Approximately 70 % of the interventions of the Fire and Rescue Department (called hereafter the "rescuers") take place in the 10 communes that comprise the study area, which makes it a prime area to study the risk of drowning in urban waterways.

3. Materials and methods

3.1. Fatal and non-fatal drowning incident (DI) database

To build a reliable DI database, we relied on the data and intervention reports available from the rescuers for drownings in the Rhone and Saone rivers in the study area (Fig. 1) over a 7-yr period, i.e., from January 2015 to December 2021. For each DI, a rescue team intervenes at the scene to aid victims in the Rhone or Saone River (variable *river*). The database informs the date (*Date*, dd/mm/yyyy) and time (*H*, hh:mm) of intervention. Two new variables were created: *season* (i.e., winter, spring, fall and summer) and *ToD* (for time of day, i.e., morning, afternoon, evening, and night). The spatial coordinates of each intervention site (*Loc* with *X* the longitude and *Y* the latitude, in decimal) are also provided.

The DI database includes information about the victim and the context of the rescue: the age (*Age*) of the victim, the gender (*Gen*, male/female) and the severity of the accident (*Sev*). The victim's age (*Age*) is recoded as an additional variable (*Age group*) such that 14 years old and under belong to the children's group; 15–29 years old to the teenagers' / young adults' group; 30–59 years old to the adults' group and 60 years old and over to the senior group. The categories taken by the variable gender are M for men and W for women. The severity (*Sev*) is given according to the rescuers' internal classification: unharmed (UN); relative emergency (RE); absolute emergency (AE); and deceased (DE). This status is completed by the rescuers after the intervention. In addition, an open comments option allows rescuers to provide qualitative information. Based on these comments, the variable *Cir* was created and specified the circumstances of each DI. The circumstances of DI (*Cir*) are grouped into four categories: (1) suicide (SUI), (2) bridge jumping (BJ), (3) accidental fall and altercation (AFA), and (4) bathing (BAT). All variables are summarised in the following table (Table 1).

3.2. Environmental variables

To contextualise each DI, we collected environmental and social information. Environmental data were obtained from the *Observatoire des Sédiments du Rhone* database (Lepage et al., 2021) and from the *Météo France Bron station* (no 69,029,001, daily data from 01/01/2015 to 31/12/2021). We collected discharge from the Rhone and the Saone and measured their turbidity and the water temperatures for the period using the hydrometric stations of Jons for the Rhone and Perrache for the Saone. A 1D hydraulic model allowed us to add the mean flow velocity (V in m.s^{-1}).

We hypothesise that the river discharge conditions and the flow velocity will negatively influence the occurrence of swimming or bridge jumping but positively influence the risk of drowning in the case of a person entering the water (i.e., an increased risk if the discharge is high or the flow velocity strong). These factors are also important when defining the difficulties of rescue during the interventions.

The turbidity of the water defines its level of transparency. It depends on the nature and concentrations of suspended matter in the water. This parameter is directly linked to the occurrence of floods in the catchment areas, snowmelt events during the spring season (for the Rhone only), or more locally, combined sewer overflows, particularly during summer storms during low flows of the Rhone and Saone Rivers. This variable could influence the occurrence of drowning for various reasons. First, turbid water will attract fewer swimmers (or bridge jumpers), thus limiting the potential for dangerous occurrences related to drownings (Smith and David, 1992). Conversely, turbidity should not affect the occurrence of drownings by suicide. On the other hand, for bridge jumps, the danger could increase with turbidity due to low visibility of the water depth and the presence of the macrowaste deposited on the river bottom (e.g., cars, scooters or bikes). Turbidity may also affect the effectiveness of rescue efforts. Problems of reduced visibility are one of the major obstacles to the effectiveness of underwater searches.

Finally, water temperature can also influence the motivation to get into the water. We assume that cold water is not attractive. However, the water temperature is also important once you are in the water. There is a risk of hydrocution, although this risk is low, representing less than 1 % of drownings recorded during the summer of 2021 in France (NOYADES, *Santé Publique France*). Weather conditions are also essential factors to consider in our study (Castelle et al., 2019; Stokes et al., 2017). We first hypothesise that for cold air temperatures, high rainfall and significant wind speed, swimming rates are lower due to a lack of attractiveness in swimming, thus limiting incidents of drowning. However, these factors do not influence drowning by suicide or homicide.

Each DI is thus associated with the average hourly flow discharge of the Rhone or the Saone rivers (Q in m^3s^{-1}), their water turbidity (*Turb* in NTU, i.e., nephelometric turbidity units), and their average hourly water temperature (T_{water} in $^{\circ}\text{C}$). A quality code was added for each variable

Table 2

Summary of environmental variables estimated in the DI database.

Description	Name	Unit	Source
Daily mean outdoor temperature	T	$^{\circ}\text{C}$	Meteo France†
Daily maximal temperature	T_{max}	$^{\circ}\text{C}$	Meteo France Bron
Weekly mean temperature	T_{weekly}	$^{\circ}\text{C}$	calculated from T
Number of consecutive days with a maximum temperature above 25°C	No.	number of days	calculated from T_{max}
Daily mean water temperature	T_{water}	$^{\circ}\text{C}$	OSR‡
Insolation	I	min.day^{-1}	Meteo France Bron
Daily rainfall	R	mm.d^{-1}	Meteo France Bron
Daily maximal wind speed	W	m.s^{-1}	Meteo France Bron
Flow discharge	Q	m^3	OSR
Flow velocity	V	m.s^{-1}	1D hydraulic model from INRAE
Turbidity	<i>Turb</i>	NTU	OSR

†Meteo France Bron n°69,029,001, daily data from 01/01/2015 to 31/12/2021.

‡Observatoire des Sédiments du Rhone database (Lepage et al., 2021).

according to the temporal proximity between the time of data acquisition and the time of DI: if the difference in time between data acquisition and DI is less than 60 min, the data are considered of good quality (code *v* for valid); if no data exist within 60 min, then daily data are used (code *e* for estimate); finally, if no daily data are available, the data are considered missing (*m* for na.). Finally, a 1D hydraulic model of the Rhone and Saone rivers was used to determine the average flow velocity (V , in m.s^{-1}) for each time and location of the DI.

The meteorological parameters used are the daily average outdoor temperature in $^{\circ}\text{C}$ (T), the daily maximum temperature (T_{max}) and the weekly average temperature (T_{weekly}), the daily sunshine duration (I , in min.d^{-1}), the daily maximum wind speed m.s^{-1} (W_{max} , m.s^{-1}) and the daily rainfall (R , mm.d^{-1}) measured at the Météo France Bron station. The number of consecutive days during which $T_{\text{max}} > 25^{\circ}\text{C}$ was also estimated (*No. DaysT25*, in days). These data allow the estimation of the weather conditions for each incident. These environmental variables are summarised in the following table (Table 2).

3.3. Statistical analysis

3.3.1. Spatiotemporal description of drowning incidents in Lyon

A descriptive analysis of the database was carried out using spatial GIS analysis (QGIS) and a trend analysis of DI occurrences over the 2015–2021 period. Principal component analysis (PCA; R's Factoshiny package; Factoshiny function) was used i) to study the correlations between the different explicative variables and ii) to identify the relationships between DI and these variables. To preserve as much data as possible, PCA was conducted for all DI values regardless of the river. Therefore, it was necessary to normalise the flow discharge by the interannual mean discharge (noted Q_{norm} in m^3s^{-1}). Categorical variables (*River*, *Age*, *Gen*, *Cir*, *Sev*, *Season*, *ToD*) were also added in the PCA to interpret the results. Next, the hierarchical clustering on principal components method (HCPC) was used to classify all DI into smaller groups based on the principal components (PC). HCPC was used to develop a typology that more accurately describes the differences between DI to capture their variability (e.g., weather and water conditions, circumstances, seasonality).

3.3.2. Multiple logistic regression

A multiple logistic regression method was applied to test the statistical relationships between DI occurrence and the explicative variables (Riegel et al., 2020). The data were not subject to any prior transformations. To investigate the statistical relation between explicative variables and DI occurrences, the dataset was analysed at a daily time step. A binary variable "DI" reports the daily DI occurrence, with $\text{DI} = 1$ or $\text{DI} = 0$ if at least a DI took place during a day or not, respectively. The

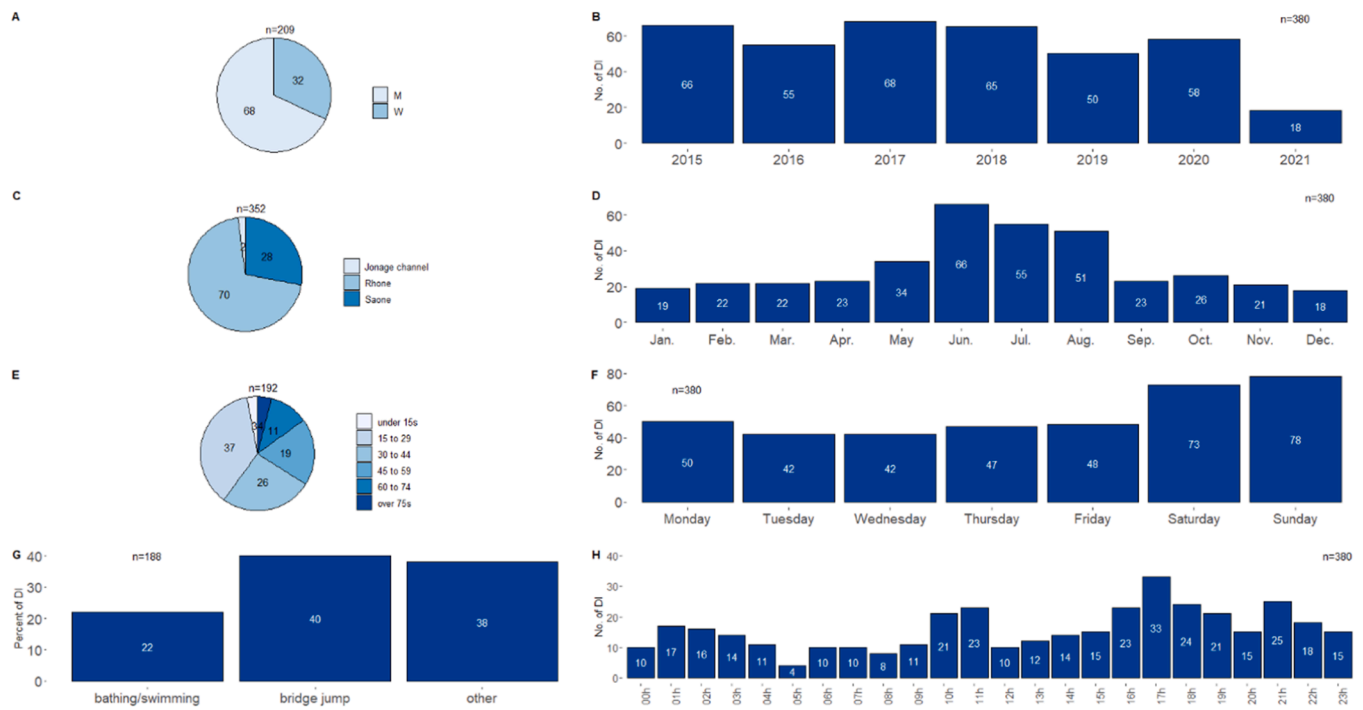


Fig. 2. Descriptive statistics of DI according to human, location and temporal factors (A) percent of drowning cases by gender; (B) number of drowning cases by year; (C) percent of drowning cases by river; (D) number of drowning cases month; (E) percent of drowning river by age; (F) number of drowning river by day; (G) percent of drowning cases by circumstances; (H) number of drowning cases by hour.

choice to use a binary variable instead of maintaining a variable representing the daily count of drownings stems from the rarity of drowning incidents. The data did not allow for the development of a viable linear regression model.

Our final objective was to highlight a very few key explicative variables explaining daily DI occurrence to compare their relevance to other cities in future research. The explanatory variables tested were i) the variables related to outdoor temperature (T , T_{max} , T_{weekly} , $No. Days T25$), ii) the other meteorological variables (R , W_{max} , and I), and iii) the hydrological and physical variables related to the watercourses (V , Q_{norm} , $Turb$ and T_{water}). Collinearity between explicative variables was estimated. If $R > 0.6$, only the most accessible, robust, and consistent variable (regarding the processes studied) was retained (Stokes et al., 2017).

To assess the model's accuracy, a test sample was set aside prior to the analysis. This sample was chosen at random from the database and represents 20 % of the data (i.e., 336 days over the period 2015–2021). The objective is therefore to compare the test sample with the model and to form a conclusion about the percentage accuracy of the forecasts.

4. Results

4.1. Descriptive statistics

The DI database includes 386 drowning incidents ($n_T = 386$, with n_T being the total number of DI) from January 2015 to December 2021, with a mean annual value of 55 DI yr^{-1} . Among the ten municipalities located in the study area, Lyon city experienced the most DI (79 % n_T , $n = 306$). DI mainly took place in the Rhone River (70 % n_T , $n = 246$). Twenty-eight percent of n_T ($n = 98$) occurred in the Saône, and only 2 % occurred in the Jonage Canal (Fig. 2c). In the database, 209 DI have gender information (with n_G for total number of DI with gender) and 192 DI with known age (with n_A for total number of DI with age). Most victims were male (68 % n_G , $n = 143$) (Fig. 2a). The age factor is also important, with the 15–29-year-old age group representing most drownings (34 % n_A , $n = 71$; Fig. 2e). The gender distribution of age

shows small differences, with a median age for men of 34 years (mean = 38) and 36 years for female victims (mean = 37). The circumstances of DI are known for $n_C = 188$ cases in the database. The main circumstance of DI (Fig. 2g) was recreational bridge jumping (40 % n_C , $n = 75$). DI after swimming represent 22 % of n_C . Finally, combining these two circumstances, we obtain DI resulting from voluntary launching (62 % n_C , $n = 117$). The remaining 38 % of n_C include accidental falls (11 %) and suicides (25 %), as well as rare cases of altercations (2 %). The distribution of circumstances according to the victim's gender shows that men are overrepresented in DI resulting from swimming, with 12 bathing accidents for which the victim's gender is known, 8 of which involve male victims (66 %). Male victims are also largely overrepresented for DI resulting from bridge jumping, with 54 bridge jumping accidents for which the victim's gender is known, 34 of which involve males (63 %).

The occurrence of DI showed no temporal trend over the study period (Fig. 2b), with a rather constant overall number of DI cases between 2015 and 2020 (max = 68, min = 50, sd = 7). On the other hand, 2021 is special, with a sharp drop in the number of DIs. While the seven years studied are comparable in terms of outdoor temperatures and insolation, 2021 stands out from the others as the wettest year in the series, with 963 mm of rainfall over the year, including 298 mm during the summer. Overall, it is 150 mm more than in 2018, the second wettest year (mean = 712 mm yr^{-1}).

The temporal distribution of DI can also be aggregated at the scale of year (Fig. 2d), week (Fig. 2f) and a typical day (Fig. 2h). The summer period is characterised by an increase in DI, with 45 % of drownings occurring between June and August (Fig. 2d). The seasonality of DI occurrences was confirmed by a statistically significant seasonal Kendall test (p value = 0.001). Except for the three summer months, the number of DI is continual but still low. The January and December winter periods show the lowest number of DI (5 %). At the scale of a typical week, the number of DI increases during the weekend: 37 % of DI occurred between Saturday and Sunday (Fig. 2f). The hourly distribution of DI is more complex, with several peaks within the day (Fig. 2h), particularly in the morning (11–12 am), the late afternoon (5 pm) and the early

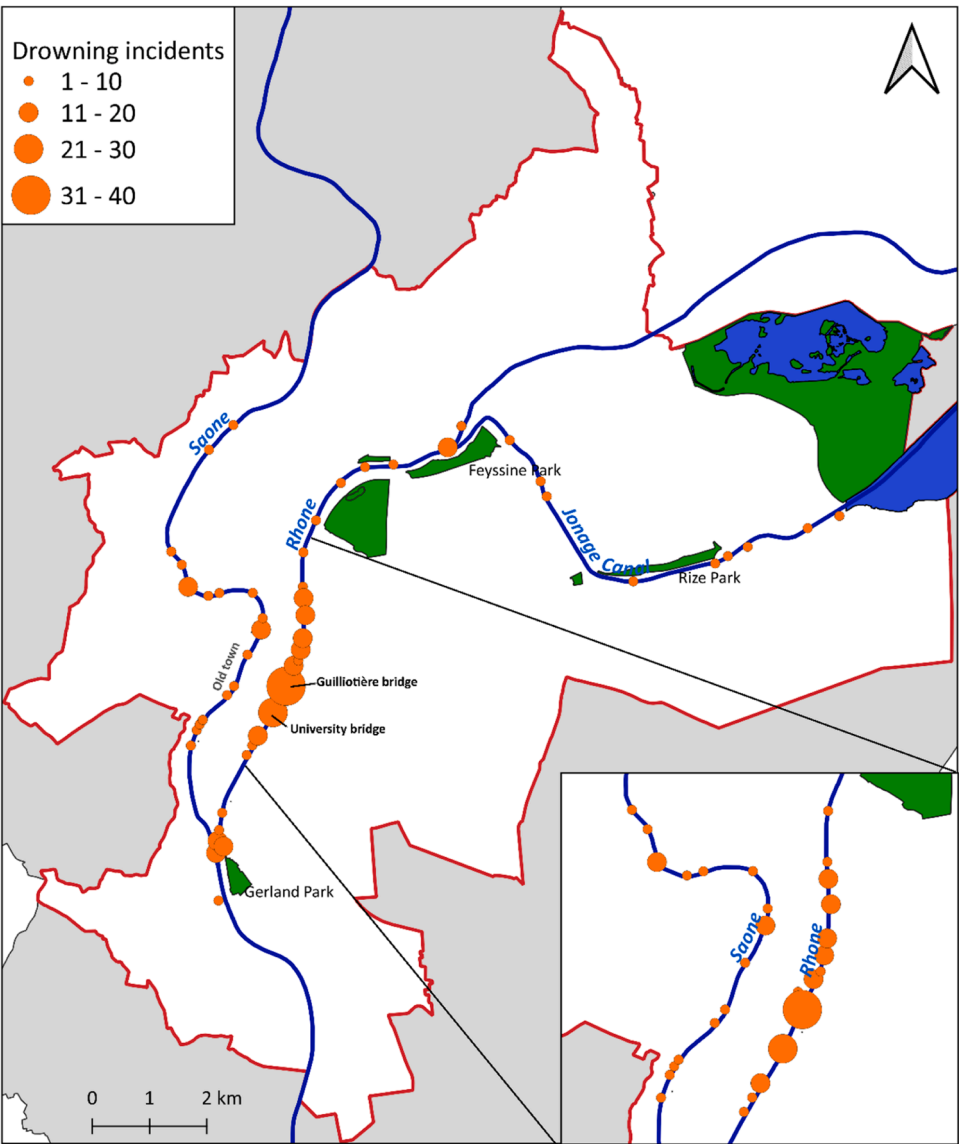


Fig. 3. Drowning location in the study area over the 2015–2021 period.

Table 3
Implications of the variables in the construction of the first three dimensions. Numbers in bold are the three variables most involved in the construction of each dimension.

	PC-1	PC-2	PC-3
Eigenvalues	4.334	1.913	1.714
Cumulative% of total variance	43.4	62.9	73.6
Axis description (cor. Threshold $p<0.05$)			
T_{water}	0.951	0.573	ns
T_{max}	0.928	0.243	ns
T	0.920	0.282	ns
T_{weekly}	0.843	ns	ns
I	0.701	ns	-0.352
No.Days T25	0.700	0.106	ns
V	-0.254	0.720	-0.108
$Turb$	-0.312	0.800	-0.125
Q_{norm}	-0.590	0.682	-0.123
W_{max}	ns	0.353	0.518
R	ns	0.130	0.856

evening (9–10 pm). Periods of lesser occurrence can also be identified; for instance, only 8 % of DI occurred in the 4-hour period from 5 to 8 am ($n = 32$), while the 5-pm period contained 9 % of DI ($n = 33$).

Most DI takes place near bridges over the Rhône and Saône Rivers in the centre of Lyon (Fig. 3). The most accident-prone locations are in the Rhône River, between the University Bridge and the Guillotière Bridge (7th district of Lyon). Some other DI also takes place upstream on the Rhône River near parks (e.g., *Parc de la Feysine* or *Parc de la Rize*). The same characteristics are found for incidents taking place on the Saône River, with most interventions occurring near the bridges in the *Vieux Lyon* district.

4.2. PCA and HCPC results

New indicators have been built via PCA that synthesise and prioritise the information of the database according to three PCs. We considered the first three PCs according to the Kaiser-Guttman criterion (Frigerio and De Amicis, 2016). PC-1, PC-2 and PC-3 gather 43, 21 and 11 % of the total information, respectively. These three PCs explain 74 % of the variability contained in the database (Table 3). The variables that contribute almost exclusively to the construction of PC-1 are T_{water} , T_{max} , and T . Among these, the river temperature T_{water} is the most relevant to

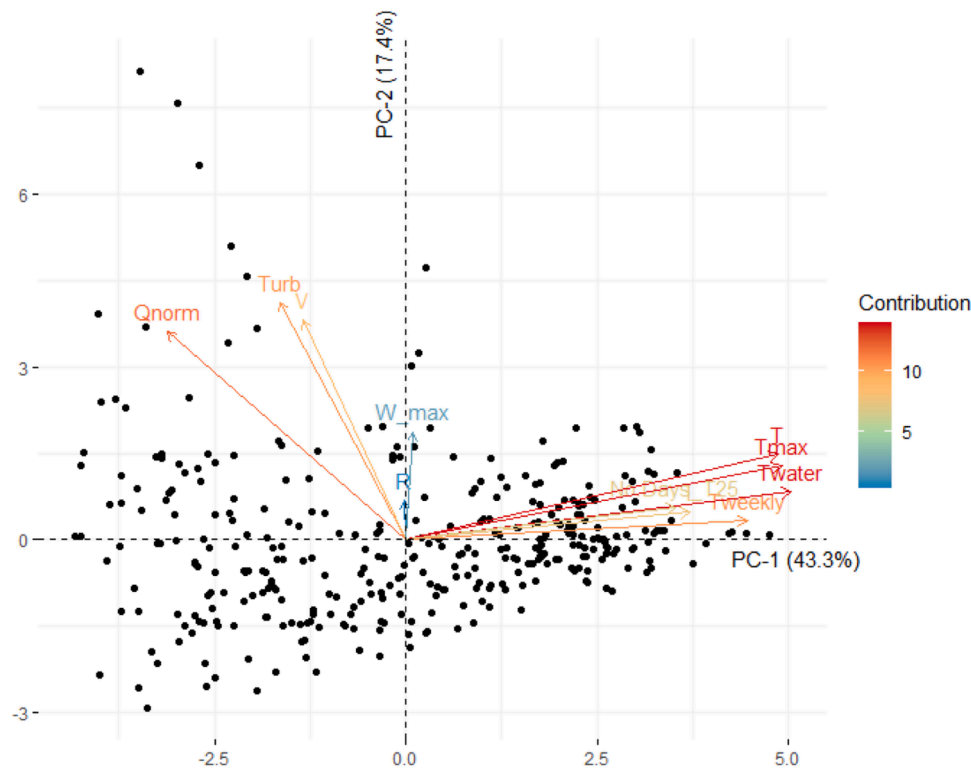


Fig. 4. Two-dimensional canonical graph of the variable factorial and individuals. PC-1 and PC-2 are the principal components, and '%' is the percentage of total variation in the sample explained. Direction (more responsible for PC1 (horizontal) or for PC2 (vertical)), length and colours (blue weaker correlation, red stronger) reflect the correlations between active variables and PCs.

explain the distribution of the data. Concerning the second dimension, the three variables *Turb*, *V* and *Qnorm* are the most important. Variables *R*, *Wmax* and *I* contribute the most to the PC-3 construction (Table 3).

DI with a high coordinate on PC-1 corresponds to DI that took place on hot, sunny days with high water temperature (Fig. 4). DI with high coordinates on the PC-2 axis occurred on days with turbid water and high flow discharge and flow velocity. DI with high coordinates on the PC-3 axis occurs during rainy, windy, and cloudy days (Table 3). The DI dataset is therefore largely structured first by the meteorological conditions and then by the hydrological conditions of the rivers.

The typology of the HCPC classified DI into three groups (Fig. 5). These groups are characterised by environmental variables but also by categorial variables added in the PCA (*River*, *Age*, *Gen*, *Cir*, *Sev*, *Season*, *ToD*). The variables that most clearly distinguish them are the flow discharge (*Qnorm*), the maximal outdoor temperature (*Tmax*), the turbidity (*Turb*), the seasonality (*Season*) and the circumstances (*Cir*) (Table 4). The DI in G1 occurred during days with high flow discharge and high turbidity. These DI occur mainly in winter, with low maximum outdoor temperatures. The DI in G2 occurred on days with favourable hydrological conditions (low flow discharge and low turbidity). These are also characterised by the fact that they arrive in autumn with low air temperatures. The main circumstance of DI in G2 is bridge jumping. DI in G3 occurs during hot summer days with low flow discharge. These DI are mainly associated with bathing accidents (Table 4).

4.3. Driving factors of drowning occurrences

A correlation matrix of the explicative variables was estimated (Fig. 6), and the first step was to determine which variables were highly correlated with each other using the $R > |0.6|$ ($p < 0.05^*$) criterion. Mean daily temperature (*T*), maximum daily temperature (*Tmax*), mean weekly temperature (*Tweekly*) and water temperature (*Twater*) are strongly correlated with each other. The insolation (*I*) is also positively correlated with the maximum daily temperature (*Tmax*). Finally, water turbidity

(*Turb*) and flow velocity (*V*) are also strongly correlated.

Highly correlated variables were removed to build the logistic regression model. The objective is to select only a few key variables to explain DI occurrence in Lyon and to test their relevance in other geographical contexts. In view of the criteria of coherence, accessibility, and robustness of the data, a choice was made to keep the daily average temperature (*T*) for the logistic regression model. Indeed, the average daily temperature is the most relevant and easily accessible data due to the numerous weather stations present in the French territory. It seems more robust than the daily maximum temperature (*Tmax*), which is strongly influenced by the environment of the station (e.g., exposure, shading, altitude). The water temperature (*Twater*) is less frequent and more difficult to access than the average daily air temperature. It is also assumed that bathers first enter the water to cool down in the heat. Moreover, similar to the daily maximum outdoor temperature, the water temperature is strongly influenced by its measurement context (e.g., water depth). Finally, the weekly average temperature (*Tweekly*) also seems consistent, since it can be assumed that after a hot period of several days, the initiative to swim may appear. However, as we do not know the comings and goings of bathers (e.g., locals, tourists passing through), it was preferable to choose the daily mean temperature.

Variable *I* was selected for the construction of the logistic regression model at the expense of *Tmax*. Turbidity (*Turb*) was also selected for the model. Indeed, turbidity can explain the occurrence of drowning, as very turbid water is not attractive in the first place to enter the water. Finally, the flow discharge (*Qnorm*) was selected, and the flow velocity (*V*) was eliminated, as flow discharge (*Qnorm*) is more robust and accessible data than flow velocity (*V*) and provides similar information. Wind speed (*Wmax*) and rainfall (*R*) were chosen because they are relevant for the construction of the model and do not show collinearity with other variables. The variables kept for the final logistic regression model are therefore *T*, *No. Days*, *T25*, *R*, *Wmax*, *I*, *Turb*, and *Qnorm*.

The logistic regression model shows a significant relationship between DI occurrence and air temperature (*T*) and rainfall (*R*) (Table 5).

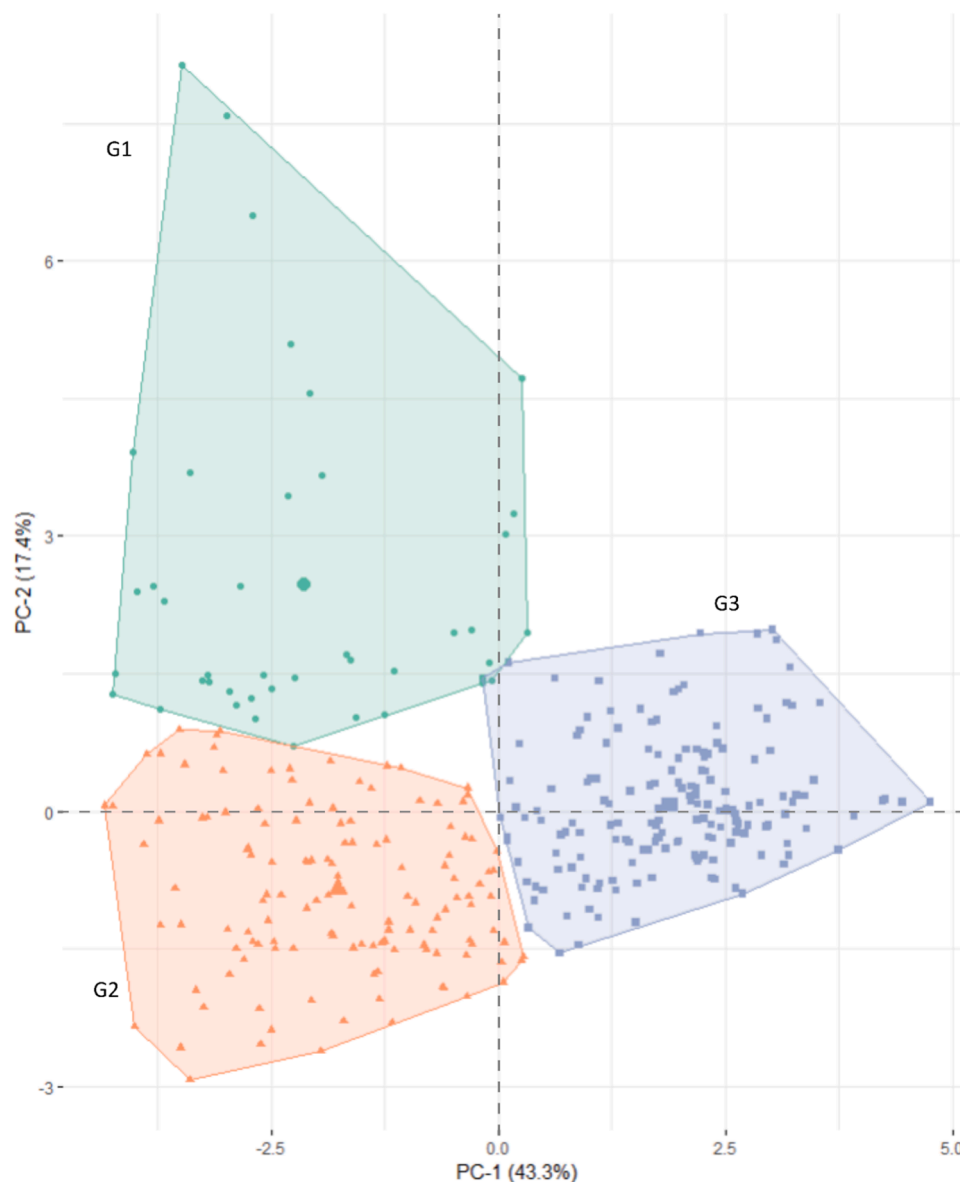


Fig. 5. Classification of DI based on PCA and hierarchical clustering on PCs. Axes represent scores on the PCs for variables included in the PCA. DI were classified into three groups.

DI is positively influenced by outdoor temperature ($p < 0.001^{***}$). Rainfall had a negative influence on the occurrence of DI ($p < 0.1$). The other explanatory variables used in the model did not show a statistically significant relationship with DI occurrence.

5. Discussion

5.1. Risk factors and spatiotemporal structure of DI in Lyon

The DI database analysis showed the presence of risk factors in the study area. The main factors are the age and gender of the victim, with the young male group being most at risk of drowning. The temporal analysis shows high-risk moments during summer periods, and on a weekly basis, during the evenings and at night. Additionally, the number of DI in 2021 is significantly lower than in the previous six years. As mentioned above, exceptional weather conditions, including a particularly wet summer, may be one possible explanation. We can also assume that the Covid-19 crisis and the successive lockdowns have had an impact on bathing practices in Lyon. However, on a national scale, the trend seems to be reversed, with a 22 % increase in the number of

accidental drownings recorded during the summer of 2021 compared to the summer of 2018 (SPF, n.d.). These risk factors are found worldwide and are highlighted in several epidemiological studies (O'Hare et al., 2002; Brice et al., 2013; Peden et al., 2016).

PCA, HCPC and logistic regression models highlight the predominant role of environmental variables in the structuring of DI and in their prediction. Air temperature, flow discharge and water turbidity allow the differentiation of three groups of DI. Some DI (G1) occurred during the least favourable days for getting into the water (e.g., high flow discharge, high turbidity, winter period). Presumably, G1 gathers DI resulting from falls, altercations, or suicides. DI in the second group (G2) occurs during low flows and low turbidity but during cold autumn days. The leading cause of DI in G2 is bridge jumping. Jumping off bridges as a challenge or during parties or other gatherings is the most frequent cause of drowning in Lyon (40 % of all DI with known circumstances). There is also a spatial pattern in bridge-jumping accidents, with incidents occurring mainly in the city centre, where bridges are highly concentrated. The hot spots for this practice are also located in the proximity of known party sites. Bridge jumping is highly represented in the database because it causes significant trauma requiring rescuers'

Table 4

Characterisation of the three DI groups according to the most discriminating variables: flow discharge (Q_{norm}), maximal outdoor temperature (T_{max}), water turbidity (Turb), seasonality (Season), and circumstances of DI (Cir). For the environmental variables, the average value for each group is given (Group Mean). The value is considered high when the group mean is higher than the general mean (in red) and low when the group mean is lower than the general mean (in red). For the categorical variables, the difference between the appearance of the modality within the group and its appearance for all the DI is given (in%). Ns means nonsignificant.

	G1	G2	G3
Q_{norm} 608 $\text{m}^3.\text{s}^{-1}$	HIGH	LOW	LOW
Group Mean ($\text{m}^3.\text{s}^{-1}$)	1116	539	480
T_{max} 21.4 °C	LOW	LOW	HIGH
Mean (°C)	15.2	17.0	30.4
Turb 33 NTU	HIGH	LOW	ns
Mean (NTU)	124	12	
Season	WINTER	AUTUMN	SUMMER
% mod	+37 %	+15 %	+45 %
Cir	ns	Bridge jumping	Bathing
% mod		+4 %	+10 %

intervention (Moran, 2014). Indeed, they are particularly dangerous due to the height of the bridges, and the presence of macrowaste in the water (e.g., electric scooters, bikes) is likely to cause serious injuries. The last

group of DI (G3) is characterised by DI occurring during hot summer days with low flow discharge. These DI are caused by bathing accidents when weather and water conditions are attractive for swimming. Unauthorised swimming is more likely to occur in urban parks than in city centres. This type of DI can be expected to increase in the context of global warming (Fralick et al., 2013). Heat waves and urban riverside renaturation policies are therefore likely to increase the risk of unauthorised bathing and drowning (Sindall et al., 2022).

Finally, only two of the seven variables tested in the logistic regression model were correlated with the occurrence of DI in Lyon: daily mean outdoor temperature (T) and rainfall (R). DI is more likely to occur on hot days with no rain. The accuracy of the model was tested on the test sample. The accuracy score is 92 %. However, for the sample of $n = 336$ days, the model predicts without error 308 days without DI but is unable to predict 28 days with DI. The model systematically generates false negatives. While outdoor temperature and rainfall are indeed linked to the occurrence of DI in Lyon, these two variables alone do not

Table 5

Regression model with binary existence of DI as the predictand.

Model term	Estimate (b)	Standardised β	p value
T	0.04780	0.01164	3.99e-05 ***
R	-0.04583	0.02308	0.0471 *

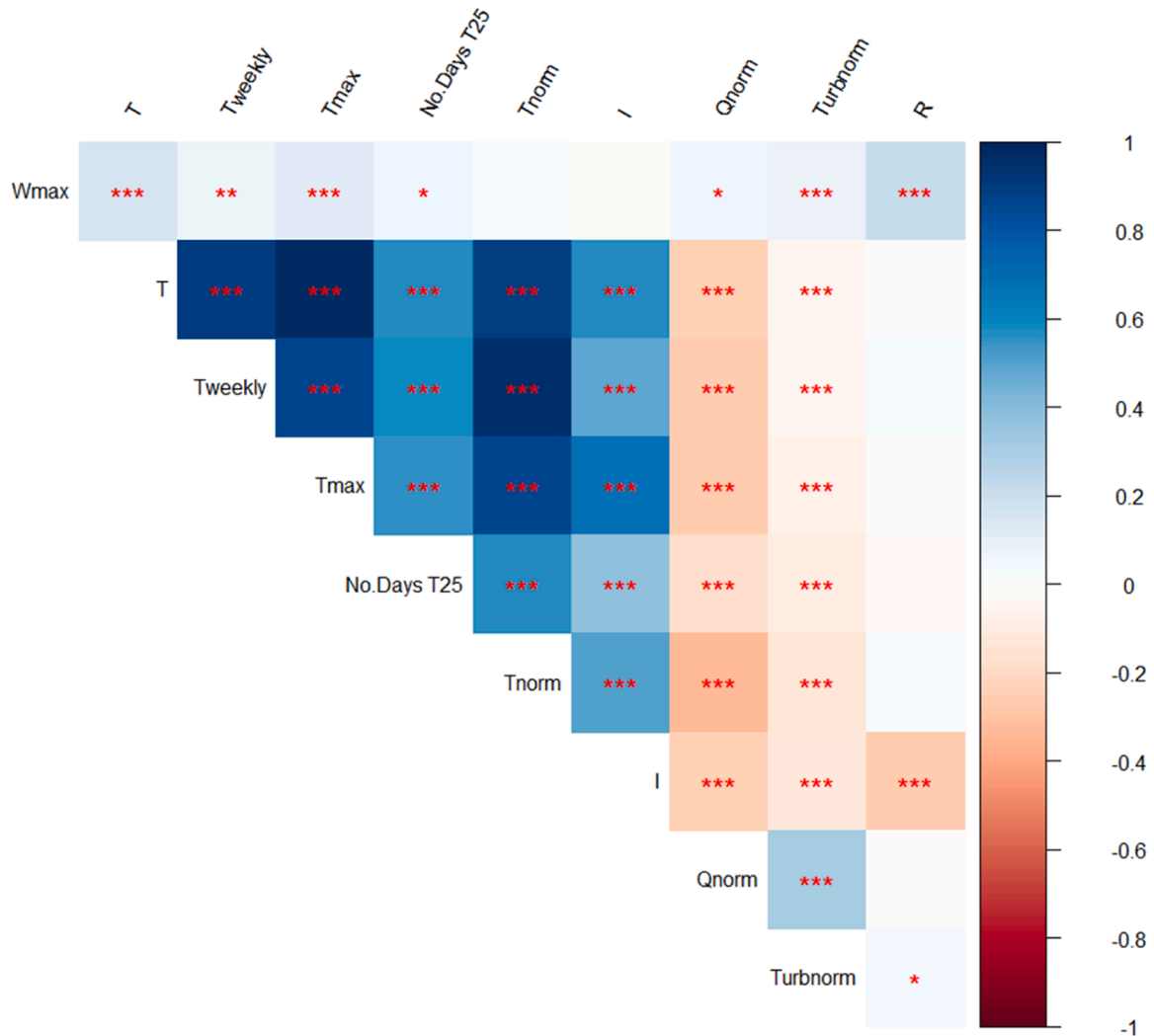


Fig. 6. Environmental variables correlogram. P value thresholds are given: * means $p \text{ value} \leq 0.05$, ** means $p \text{ value} \leq 0.01$, *** means $p \text{ value} \leq 0.001$, **** means $p \text{ value} \leq 0.0001$.

make it possible to create an effective predictive model. These results thus reflect the complexity of the drowning risk, and the environmental variables alone are not sufficient to understand and predict drownings in urban rivers.

5.2. Relevance of discharge to flow velocity

As flow rate can be used as a proxy for current speed, only one of these two environmental variables is used to create the logistic regression model. Based on the criteria of robustness, accessibility, and consistency of the data, it seemed appropriate to retain the discharge. However, the flow velocity would provide more exportable data for intercity studies since the same flow velocity is perceived in a similar way by a bather, whereas depending on the morphology and size of the river, the same flow rate will not produce similar sensations. In Lyon, only the 1D model exists, which does not seem relevant. However, with a more accurate model, it would be interesting to include this variable in the statistical analysis.

5.3. Drowning database perspectives

This study demonstrates the relevance of certain environmental variables in explaining part of the variability of the DI in Lyon. However, the complexity of drowning risk requires interdisciplinary approaches based on large datasets. Other scientific articles include different types of variables as the characteristics of the victim (e.g., standard of living, housing type, alcohol/drug use, swimming ability (Peden et al., 2019b). Landscape (e.g., the type of waterfront), cultural (e.g., risk culture and drowning prevention policies (Peden et al., 2019a), historical (e.g., past bathing and jumping practices) and psychological (e.g., transgression, mental health; Stephenson et al., 2020) data are also essential for understanding and preventing drowning. In Peden et al., 2023, more than 200 variables were identified over 20 years as useful for the epidemiological study of the risk of drowning.

The comparison of data from the Lyon area with that of other large French or European river cities would be a considerable asset to a good understanding of the risk of drowning in urban rivers. The comparison can highlight the invariants and specificities of each geographical area and identify the role of sociocultural, urban, political, and economic factors. National drowning databases exist in different countries with a developed coastal and river rescue culture (e.g., Australia, Canada, New Zealand, United Kingdom) (Peden et al., 2023). As shown in Peden et al., 2019b, a comparison of these data for Australia, Canada and New Zealand shows that they are structured in a similar way, although the choice of variables does not always match. Many demographic variables are proposed in these national databases, as well as a broad list of risk factors (particularly in relation to drug and alcohol use). To our knowledge, none of these databases includes environmental data, as we propose to do in our study. A structured interdisciplinary and international database would enable the proposal of cross-site modelling of drowning risk based on the main predictive factors.

The database is also a tool of knowledge, and its construction and discussion bring together various actors at the scale of Lyon around the issue of drowning in urban waterways: NGOs, inhabitants, firms (CNR, VNF), institutions, politics, academics, and rescuers. Therefore, the DI database represents a first step to consider this urban risk, to reveal it and to identify spatial and temporal trends (e.g., links with global warming, urban planning, social injustice). It can be used to develop drowning prevention strategies adapted to the territory, as well as to improve the organisation of rescuers (e.g., patrolling during high-risk moments, hot-spot surveillance). Finally, data collection and processing, as a key stage in prevention, must be carried out on a multi-scale basis, as recommended by WHO (WHO, 2017).

6. Conclusion

Urban riverbank restoration and landscaping policies and summer heatwaves are bringing city dwellers closer to rivers and may tend to intensify the drowning risk. Based on drowning incident (DI) reported by rescuers between 2015 and 2021, drowning epidemiology has been studied. Risk factors highlighted in the international literature have been identified in the study area (e.g., gender and age of victims, seasonality of drownings). Analyses have also highlighted the importance of weather and hydrological conditions to explain the DI temporal structure in Lyon. However, environmental variables alone are of course not sufficient to define the complexity of the drowning risk in urban rivers. A structured database incorporating environmental, sociocultural, historical, and urban planning data is essential to understand the drowning process and to propose an understanding of this risk that is generalizable to other cities and countries.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data that has been used is confidential.

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