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Search and Rescue on Frozen Rivers

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ABSTRACT: Rescuing people and objects on frozen rivers is a complex activity that involves intervention in unpredictable and often extreme conditions. In this regard, every country with river waterways must to some extent think about ice during the winter months, about the impact of ice on river navigation, and about possible accidents that occur during that period. Frozen rivers, as a natural phenomenon, are often places where accidents occur due to ice breakage, collapse of objects, or traps for people who find themselves in inadequate conditions. In such situations, timely reaction and well-organized rescue teams are required. The topic is important for the entire social community due to the increasing frequency of water accidents during the winter period and the inclusion of all segments of society, especially the military and police, in search and rescue operations, which would be the primary response force during water accidents or as support for civilian structures that are threatened by the appearance of ice on the water. Civil-military cooperation in these cases involves pooling resources, knowledge and capabilities in order to increase the efficiency of rescue operations. The aim of this paper is to analyze the challenges and techniques of rescue on frozen rivers and highlight the importance of civil-military cooperation in these activities. It will be investigated how coordination between different structures (military, civilian and volunteer) can contribute to greater population safety, reduction of losses and more efficient use of all resources.

1 INTRODUCTION

The aim of this paper is to analyze the specific characteristics of search and rescue operations on frozen rivers, with a particular emphasis on the application of rescue techniques and the importance of civil-military cooperation. The research will cover the natural features of frozen rivers, typical accidents, intervention methods, the organization of rescue teams, as well as practical examples, with the ultimate goal of proposing measures to improve existing capacities and protocols.

2 NATURAL CHARACTERISTICS OF FROZEN RIVERS

Formation of ice on rivers represents a complex hydrological and climatic phenomenon that affects not only human safety but also river traffic, infrastructure, and the environment. Unlike still waters, river ice is unstable, asymmetrical, and highly unpredictable due to the dynamics of the water flow beneath the surface.

2.1 *Phases of ice formation and types of river ice*

The formation of ice on rivers takes place through several phases, the course of which depends on the air

temperature, the speed of the water flow, heat exchange with the atmosphere, and the characteristics of the riverbed. Recognizing these phases is of key importance for predicting risky phenomena and assessing the safety of navigation.

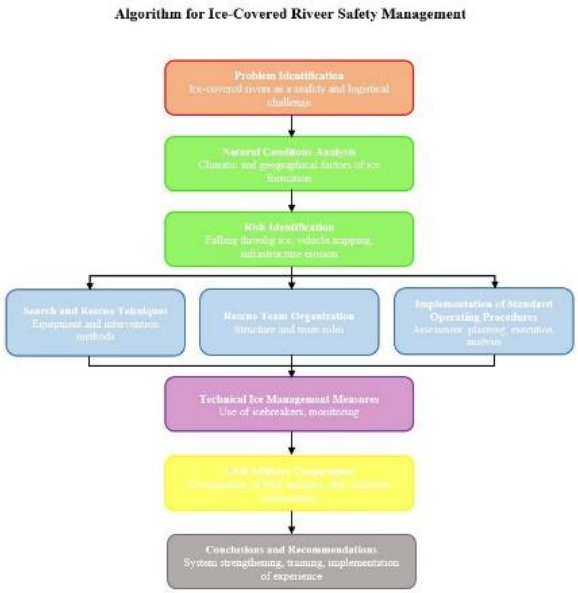

Figure 1.

1. Initial crystallization – With the drop of temperature below 0 °C, the formation of ice needles begins in the coastal and calm parts of the flow. This phenomenon represents the first phase of icing, still mechanically insignificant.
2. Formation of frazil ice – With further cooling, ice needles join into flocs that form a loose surface layer – frazil ice. It is visually noticeable but has insufficient load-bearing capacity.
3. Appearance of anchor ice – Under conditions of strong cooling and low turbulence, ice can form below the water surface. Such ice, known as anchor ice, is not visible but can endanger the operation of underwater infrastructure.
4. Formation of congelation ice – With stable temperatures and continuous heat loss, a solid, transparent ice layer forms – congelation ice, which evenly covers the river surface and has the greatest load-bearing capacity, although it may contain hidden cracks.
5. Ice floes and ice drift – Under unstable conditions, ice breaks and forms floes that move downstream (ice drift). Floes can damage vessels and infrastructure, and their accumulation can lead to ice jams and the need for intervention.

Table 1.

Phase	Name od the phase	Description	Place on the river	Risks and impact
1	initial crystallization	ice needles in cold, still water	coastal zones	safe phase
2	Formation of snow ice	Crystals form a floating layer	Slow currents	Low load-bearing capacity
3	Formation of anchor ice	Ice beneath the surface, invisible	Shallow areas, riverbed	Hazardous to infrastructure
4	Solid, stable ice cover	Strong, stable ice	Entire river surface	Potential cracks
5	Ice floes and ice drift	Ice breaking and movement	Middle and lower river course	High risk

2.2 *Basic Definitions and Types of River Ice*

The occurrence of ice on rivers holds significant importance in hydrological, navigational, and safety contexts. Therefore, the terms describing the dynamics, condition, and shape of ice formations are clearly defined in professional and scientific literature. Proper understanding of these terms forms the basis for effective risk management, protection of infrastructure and vessels, as well as the organization of rescue and technical intervention operations.

2.2.1 *Basic Definitions of Ice Phenomena*

- Ice Drift – a dynamic phenomenon in which ice formations (ice floes, ice sheets, fragments of solid ice cover) move downstream along the river. It occurs at the beginning of the freezing process and during the thawing phase. Ice drift can cause mechanical damage to hydraulic structures, bridges, and vessels, as well as blockages of the river channel.
- Ice Drift Period – the time interval during which ice is actively moving along the watercourse. During this period, ice jams may form, leading to water accumulation and potential upstream flooding.
- Ice Cover – a phenomenon in which the surface of the river is partially or completely covered with static, immobile ice. Unlike ice drift, ice during this phase remains still, but it still poses a mechanical obstacle and a threat to the stability of structures and the safety of people.
- Ice Cover Period – the time interval in which the ice on the water surface remains stationary, without significant changes in position or structure.
- Ice Jam – a localized accumulation of ice floes and fragments in a narrow section of the river channel, obstructing the free flow of water. The formation of an ice jam often requires intervention by icebreakers or controlled blasting of the ice.

2.3 *Climate Conditions and Ice Cover Phenomena in Serbia*

The occurrence of ice on rivers in Serbia is influenced by a combination of climatic factors, hydrological characteristics of river flows, and local geographical conditions. River freezing most commonly occurs during the winter months, from December to February, during prolonged periods of low temperatures [7]. According to data from the Republic Hydrometeorological Institute, stable ice usually forms after at least 7 consecutive days with an average air temperature below –5°C, under conditions of weak water currents and absence of wind.

2.3.1 *Historical and Statistical Data*

Analysis of the period from 1991 to 2004, based on observations from the water gauge stations in Novi Sad and Zemun, shows the following:

Table 2.

Location	Average Onset of Ice Cover	Average Duration of Ice Cover	Maximum Duration of Ice Cover
Novi Sad	Beginning of January	7–10 days	Up to 20 days
Zemun	Mid-January	5–8 days	Up to 15 days

During the specified period, ice cover was in most cases of short duration and limited to narrow sections

of the river. It was most commonly recorded in areas with reduced flow and where the river channel is narrower [11].

2.3.2 *Example: Winter of 2011/2012.*

The winter of 2011/2012 was one of the most extreme ice periods in recent Serbian history. The Danube near Belgrade and Smederevo was covered with ice across more than 90% of its width, temperatures ranged from –10°C to –20°C, and the snow cover exceeded 30 cm. Navigation was suspended, and an emergency ice congestion defense was declared.

This event illustrates the impact of climate extremes on river traffic and the need for rapid intervention.

2.4 *Historical Examples of Extreme Winters in Serbia*

Historical data show that extremely harsh winter periods have occasionally been recorded in the territory of Serbia, during which rivers were completely frozen, ice cover persisted for extended periods, navigation was suspended, and serious consequences occurred for river infrastructure and public safety [11].

These events serve as an important basis for modeling emergency situations caused by climate extremes.

- Winter 1928/29 – The Danube was frozen for more than 60 days, ice thickness exceeded 40 cm; complete traffic suspension and major damages. It is considered a reference case in extreme event analyses.
- Winter 1956 – Temperatures dropped below –25°C, the Danube and Sava rivers were frozen; ice thickness over 50 cm, bridges and river ports were damaged.
- Winter 1984/85 – Ice jams on the Ibar, Tisa, and Danube rivers; interventions included blasting and the use of icebreakers.

These examples highlight the need for risk management plans to be based on extreme scenarios, not just average climatic values.

2.5 *Impact of Ice on Navigation and Infrastructure*

Freezing of rivers has significant consequences for river traffic, hydraulic structures, and public safety, requiring a systematic approach to monitoring and risk management.

1. Suspension of Navigation
   The formation of ice cover and ice drift leads to complete or partial suspension of river traffic, causing economic losses and supply interruptions.
2. Ice Jams
   The accumulation of ice sheets in narrow river sections causes blockages, water level rises, and flood risks. Emergency measures are taken when over 60% of the surface is covered by ice.
3. Infrastructure Damage
   Moving ice masses, especially during ice drift, can damage bridges, pontoons, docks, and other structures, as well as cause erosion of the riverbed.
4. Controlled Blasting
   To clear the river channel, controlled ice blasting is carried out according to a professional plan and under the supervision of specialized teams.
5. Use of Icebreakers
   Icebreakers break the ice to allow water flow and vessel movement. In Serbia, due to limited resources, private vessels and capacities from neighboring countries are often engaged in cooperation with the Water Directorate.
6. Preventive Measures and Monitoring
   - Installation of shoreline barriers to slow ice movement
   - Monitoring using radar systems and drones
   - Timely issuance of warnings and forecasts

Effective management of winter risks requires coordination of all relevant services and consistent application of preventive and intervention measures.

Table 3.

Consequence / Phenomenon	Description	Protection Measures / Response
Suspension of Navigation	Interruptions in river traffic due to ice.	Temporary suspension of navigation; organization of alternative transport.
Ice Jams	Blockage of the river channel and flood risk.	cebreakers, controlled blasting, water level monitoring.
Infrastructure Damage	Impact of ice on bridges, pontoons, docks.	nhanced maintenance and protective structures.
Controlled Blasting	Removal of ice masses in critical sectors	Carried out by expert teams according to a plan and in coordination with authorities.
Use of Icebreakers	Breaking ice to prevent blockages and allow water flow.	Engagement of domestic and regional capacities.
Preventive Measures	Risk reduction before critical situations arise	Shoreline barriers, radar and visual monitoring, warning systems

3 HAZARDS AND TYPICAL ACCIDENTS ON FROZEN RIVERS

Frozen rivers represent a high-risk environment for the movement of people and vehicles, as well as for rescue service interventions. The most significant hazards are presented below:

Table 4.

Type of Hazard	Brief Description
Falling Through Ice	Caused by thin or unstable ice. Results in falling into the water and rapid hypothermia, with a high risk of drowning. Most commonly affects fishermen and recreational users.
Vehicle Breakthrough	Insufficient ice load-bearing capacity leads to cracking under the weight of vehicles. Consequences include rapid sinking and difficult rescue.
Ice Jams (Barricades)	Ice floes get stuck in narrow river sections, causing blockages and flood risks. Requires emergency measures, including controlled blasting.
Isolation on Ice Floe	Mechanical separation of an ice sheet from the shore creates a dangerous situation for people on the ice. Immediate rescue intervention is necessary.
„Ice Dams“ and Ice Gates	A mixture of snow and submerged ice forms a mass that blocks flow and causes ice floods. Historically extremely dangerous, especially in gorges.

Professional assessment of these hazards forms the basis for planning effective search, rescue, and population protection measures.

4 SEARCH AND RESCUE TECHNIQUES ON FROZEN RIVERS

Conducting search and rescue operations on frozen river surfaces requires a multidisciplinary approach that includes precise risk assessment, use of specialized equipment, and strict adherence to operational procedures [2]/[3]. Below is the rescue operation algorithm on a frozen river:

1. Preparation
   - Activation of the rescue team.
   - Checking the condition of equipment (ropes, sleds, thermal suits, boats, probes).
   - Deployment of drones for reconnaissance (if available).
2. Situation Assessment
   - Visual inspection of the ice (color, cracks, structure).
   - Measuring ice thickness at multiple points:
     - Less than 12 cm – entry prohibited.
     - 30 cm – vehicle movement permitted.
   - Checking underwater currents and heat sources.
   - Analyzing access routes and safety zones.
3. Approaching the Endangered Person
   - Choosing the approach method (lying position on sleds or using ropes and specialized equipment).
   - Communication with the shore team.
   - Maintaining rope tension and movement control.
4. Extraction and First Aid
   - Securing the endangered person with a safety harness.
   - Coordinated extraction by the shore team.
   - Removing wet clothing, putting on dry thermal suits, gradual warming, and monitoring vital signs.

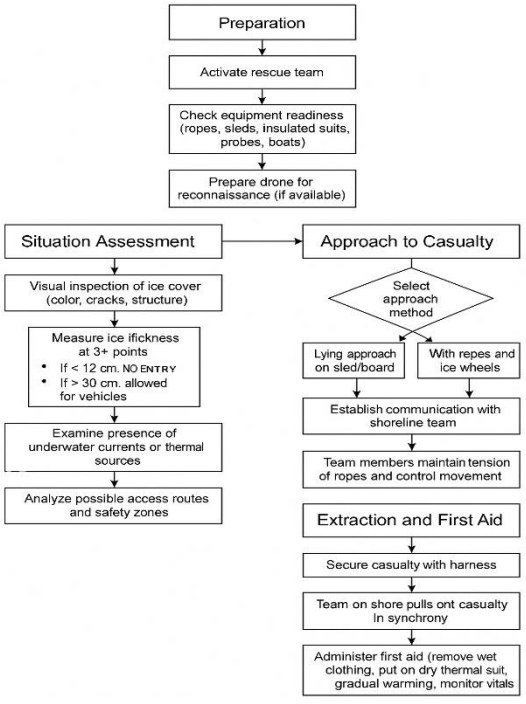

Figure 2. River rescue operation algorithm

5 ORGANIZATION OF RESCUE TEAMS

The success of search and rescue operations on frozen rivers largely depends on a precisely defined organization, clearly assigned roles, and effective coordination among participants [6]. Below is an algorithm for organizing and conducting a rescue operation on frozen rivers.

Figure 3. Algorithm: Organization and execution of rescue operations on frozen rivers

The algorithm for organizing and conducting rescue operations on frozen rivers consists of seven phases.

- In the first phase, the rescue team is formed with clearly defined roles: incident commander, ice rescue team, shore support, and medical team.
- The second phase involves operational preparation, including assessment of field conditions, definition of safety corridors, and identification of risk zones.
- The third phase covers intervention planning, which includes developing an approach and communication plan, as well as an alternative scenario.
- The fourth phase is the execution of the rescue operation, during which the rescue team approaches the victim, and the medical team provides first aid.
- The fifth phase involves evacuation and medical treatment, including thermal protection and transport to a healthcare facility.
- The sixth phase is the operation analysis, which includes a debriefing, identification of shortcomings, and updating of operational procedures.
- The final phase consists of training and drills outside emergency situations, aimed at improving readiness and adapting existing procedures.

6 STANDARD OPERATING PROCEDURES (SOP) FOR SEARCH AND RESCUE ON FROZEN RIVERS

Standard Operating Procedures (SOP) provide a key framework for planning, coordinating, and executing rescue operations on frozen river surfaces [2]/[3]. Below is the algorithm for a rescue operation on a frozen river.

Figure 4. Algorithm: Standard operating procedures for ice river rescue operations

The algorithm of standard operating procedures for rescue on frozen rivers consists of four main phases.

- The first phase involves situation assessment, including gathering hydrological and meteorological data, visual inspection of the ice, and measuring its thickness.
- The second phase covers approach planning and organization, which includes marking safe corridors, assigning team roles, preparing backup equipment, and establishing communication protocols.
- The third phase relates to executing the rescue operation, during which the shore team secures ropes and monitors the ice, while the rescue team approaches the victim and provides first aid.
- The fourth phase includes evacuation and provision of first aid, involving protection against hypothermia, assessment of vital signs, and possible transport.
- After the operation, a performance analysis is conducted, along with internal documentation and collection of feedback to improve procedures and training.

7 CIVIL-MILITARY COOPERATION IN RESCUE OPERATIONS

In cases of search and rescue on frozen rivers, civil-military cooperation represents a key element of successful intervention. The conditions under which these operations are conducted require the deployment of significant resources, expert personnel, and rapid coordination among multiple different entities [5]/[10].

7.1 *Role of Civilian Structures*

Civilian structures, such as rescue services, fire units, emergency medical services, and specialized volunteer teams, usually play the primary role in responding to water-related accidents. Their role includes:

- rapid receipt of notifications and assessment of intervention priorities,
- direct execution of rescue operations within their capacities,
- providing first medical aid,
- securing the accident site and requesting additional support if their own capacities are insufficient.

7.2 *Role of the Military and Police*

The military and police represent extremely important support segments in operations on frozen rivers. Their engagement includes:

- Providing technical equipment (amphibious vehicles, specialized sleds, helicopters),
- Supplying human resources with a high level of training for operating in extreme conditions,
- Organizing the transport of endangered persons in inaccessible areas,
- Securing the intervention area to prevent additional incidents.

Police forces also take on the role of regulating access to the accident site, managing the civilian population, and supporting the coordination of activities.

7.3 *Key elements of successful cooperation*

Successful civil-military cooperation involves:

- Clear command structure: establishing unified command with clearly defined responsibilities.
- Joint training and exercises: regular joint drills of rescue and military units to align procedures and build mutual trust.
- Communication coordination: using shared communication channels for timely information transfer.
- Optimal resource use: coordinating available equipment, specialized teams, and transportation means.
- Rapid decision-making: establishing mechanisms for urgent decision-making in crisis situations.

7.4 *The importance of civil-military cooperation*

Civil-military cooperation enables:

- faster response in critical situations,
- greater safety and protection of endangered lives,
- more efficient use of all available resources,
- strengthening society's resilience to emergencies.

The integration of efforts between civilian and military structures forms the basis for establishing an effective risk management system on rivers during the winter period.

8 EXAMPLES AND PRACTICES

To better understand the challenges and successful implementations of rescue procedures on frozen rivers, two significant practical examples are presented below.

8.1 *Rescue of an Animal from the Frozen Sava River in Belgrade (January 2017) [6]*

In January 2017, due to extremely low temperatures, a dog became trapped on the frozen Sava River in Belgrade. The intervention was carried out by members of the Emergency Situations Sector, using specialized equipment for moving on ice. Following established procedures, the rescuer safely approached and evacuated the animal, which was then cared for by the veterinary service.

This incident illustrates the capability and preparedness of rescue services in Serbia to respond effectively under challenging conditions on frozen water surfaces.

8.2 *Rescue Operation on the Danube near Novi Sad (Serbia, 2021) [6]*

In February 2021, due to a sudden onset of weak ice, several pedestrians found themselves in danger on the frozen surface of the Danube near Novi Sad. The local fire and rescue unit, in cooperation with members of the Gendarmerie and River Police, organized a rescue operation:

- a rescue line was established with ropes and special ice carriers,
- amphibious vehicles were used for safe access,
- all those at risk were rescued, without serious consequences.

This example shows the effectiveness of local civil-military cooperation, but also the importance of regular training and readiness of teams for work in winter conditions.

8.3 *Rescue operation on the frozen Lake Palić (February 2021) [6]*

In February 2021, an incident occurred on Lake Palić when a sailor became trapped on the frozen surface. During the rescue operation, due to the insufficient stability of the ice, members of the fire and rescue unit also found themselves in danger. Thanks to the coordinated intervention with members of the Sailing Club, the person was successfully rescued and treated for frostbite.

This event highlights the complexity of rescue procedures under unstable ice conditions and the necessity of specialized training and equipment.

9 CONCLUSION

Search and rescue on frozen rivers is an exceptionally demanding activity that involves numerous risks both for the endangered individuals and the rescue teams. The specific natural conditions, unpredictable behavior of the ice, and weather circumstances require well-planned, coordinated, and technically equipped interventions.

The implementation of standard operating procedures enables more efficient situation assessment, safe approach to the endangered, and rapid evacuation. In this context, a key factor of success is civil-military cooperation, which unites resources, knowledge, and capabilities of various structures to achieve a common goal – saving human lives.

Experience from practice so far shows that regular joint training, establishment of clear communication channels, and unified command significantly increase efficiency in emergency situations on frozen rivers. In the future, it is necessary to continue developing integrated response systems and investing in specialized equipment and training to further enhance society's ability to respond to the challenges posed by the winter period on rivers.

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