ORIGINAL ARTICLE

Aligning the Haddon Matrix and combined model for a multidimensional drowning prevention strategy

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ABSTRACT

Background: Drowning is a significant global public health issue, responsible for a substantial number of injury-related fatalities each year, particularly in low- to middle-income countries. This study explored the environmental and individual risk factors of drowning and proposed a multifaceted approach to prevention.

Methodology: This study used a mixed-methods approach, integrating both theoretical frameworks and data analysis to evaluate the factors contributing to drowning incidents. Data were systematically extracted from peer-reviewed articles, focusing on health outcomes. The Haddon Matrix was applied to categorize pre-, during-, and post-event factors across human, equipment, and physical environments, while the combined model was used to map public health strategies to these phases, providing a structured evaluation of intervention effectiveness.

Results: Factors affecting drowning include a range of personal (host) risk factors, equipment-related issues, and features of the physical environment. These factors include lack of supervision, swimming skills, alcohol use, pre-existing medical conditions, cultural norms, socioeconomic status, language barriers, gender, age, disabilities, mental health conditions, overcrowding, non-use of life jackets, and poor water visibility. The study proposes a multifaceted approach to prevention, including education, enforcement, environmental modifications, economic incentives, and emergency response, with a focus on community involvement and advanced technologies.

Conclusion: This study underscores the complexity of drowning prevention and the need for a proactive and multifaceted approach. The proposed strategies, when adapted to diverse cultural and contextual factors, have the potential to significantly reduce drowning incidents, ultimately safeguarding public health and well-being.

Keywords: Drowning, prevention, Haddon Matrix, combined model, injuries.

Introduction

Globally, drowning is a significant public health issue, which accounted for an estimated 236,000 deaths in 2019, equivalent to 7% of all injury-related fatalities during that year, making drowning the third leading cause of unintentional injury death worldwide. The majority of drowning incidents occurred in low- to middle-income countries [1]. The prevalence of these incidents is not evenly distributed across the world. For example, in Southeast Asia, 70,034 deaths by drowning were reported in 2019, highlighting the disproportionate impact on this area [2]. The Eastern Mediterranean region, encompassing 22 countries with extreme income inequalities, conflict, and migration, also reported a significant number of drowning incidents. A literature review revealed a wide range of all-age fatal drowning rates in this region, from 0.48/100,000 individuals in the United Arab Emirates to 18.5/ 100,000 in Egypt [3]. In the United States, the Centers for Disease Control and Prevention (CDC) reported that between 2016 and

2020, the annual age-adjusted drowning death rate (including boating-related drowning deaths) was 1.28 deaths/100,000 individuals. Around 4,000 people drown each year in the United States, with the most vulnerable age group being children under the age of 5 years [4]. To tackle this issue effectively, it is important to note that the existing statistics likely underestimate the true scale of the problem, as many cases are unreported or attributed to other causes of death.

This study used the Haddon Matrix - a well-recognized tool in the field of injury prevention research and intervention - to identify ways to prevent drowning incidents. The Haddon Matrix, developed by Dr. William Haddon in 1968, attributes influencing factors to three categories: host, agent, and environmental (physical environment and socio-cultural environment). These factors are placed according to their influence pre-, during, or post-event. This study also used a combined framework, which is a three-dimensional framework that incorporates the concepts for the three axes of the Haddon Matrix and the methodology of the community risk reduction model. The combined model includes 1) the three epidemiologic elements compromising *host, agent,* and *environment* (physical and social); 2) the three time intervals of event occurrences classified as *pre-event, during event,* and *post-event*; and 3) a systematic science-based methodology built on *education, enforcement, engineering/environmental modification, economic incentives,* and *emergency response.* Thus, all the necessary variables for the comprehensive analysis, understanding, and management of drowning incidents were included in this three-dimensional framework (Figure 1).

Methodology

This study used a mixed-methods approach, integrating both theoretical frameworks and data analysis to evaluate the factors contributing to drowning incidents. Data were systematically extracted from peer-reviewed articles, focusing on health outcomes. The Haddon Matrix was applied to categorize pre-, during, and post-event factors across human, equipment, and physical environments, while the combined model (Figure 1) was used to map public health strategies to these phases, providing a structured evaluation of intervention effectiveness. As this study was based entirely on secondary data, it did not require ethical approval; however, it adhered to ethical standards in the use and citation of published sources. Limitations such as potential biases in the original datasets and the challenges associated with analyzing diverse data sources are acknowledged.

Key Determinants Affecting Drowning Incidents

Host

Based on the results from the Haddon Matrix (Table 1), there are many variables that determine drowning morbidity and mortality, contributing to the complexity and difficulty of prevention. Personal risk factors vary from a lack of supervision, poor swimming skills, and alcohol consumption to demographic and other health factors, such as pre-existing medical conditions. The lack of supervision is a primary risk factor, especially for young children. Young children can easily slip unnoticed into bodies of water and drown if they are not rescued promptly (5). Inadequate supervision is often correlated with distractions, such as using mobile phones, which may delay rescue efforts [5]. A lack of knowledge of local water conditions and swimming skills also
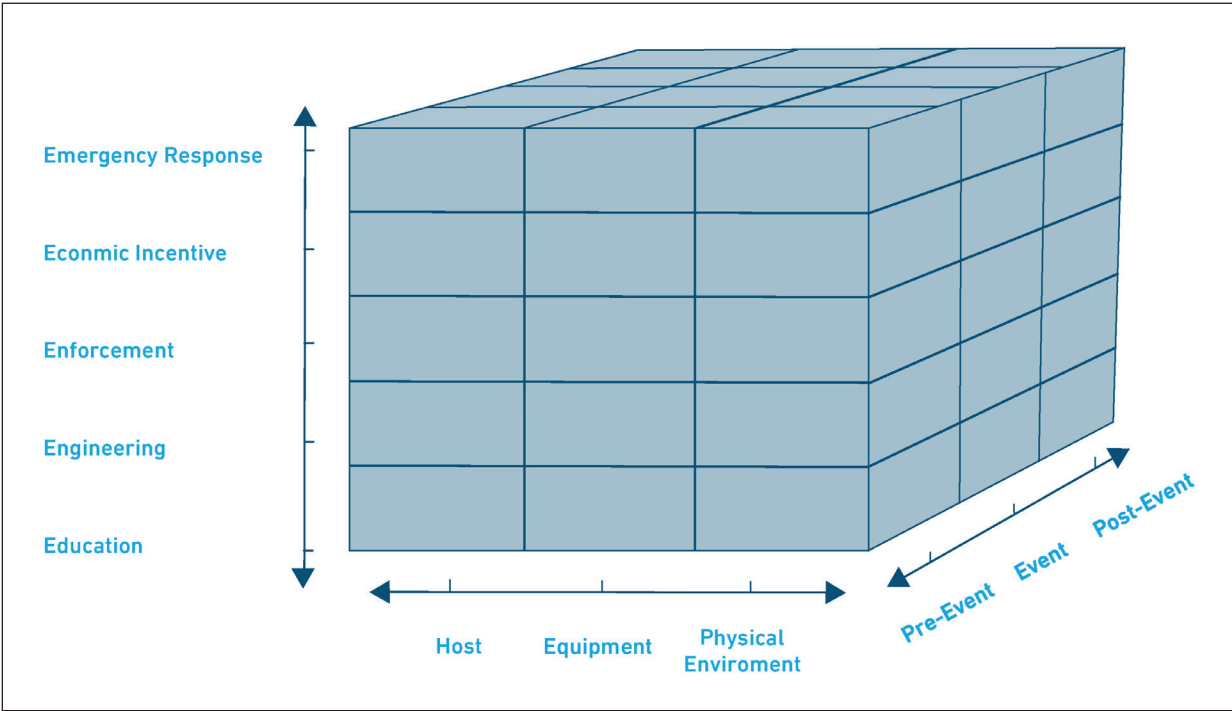

Figure 1. *3D shape for the combined model.*

Table 1 . *Using Haddon Matrix to identify drowning risk factors.*

Timeline	(Host) Personal factors	Equipment	Physical environment
Pre-event	• Age • Gender • Lack supervision • Lack of swimming skills/ or overestimation of swimming ability • Alcohol or drug use • Risky behaviors • Comorbidities • Distractions (e.g., using a mobile phone) • Lake awareness • Cultural norms • Socioeconomic status • Unfamiliarity with local water conditions	• Lack of barriers/fences • Absence of life jackets/PFDs • Unsafe/Overcrowded watercraft • Poorly maintained equipment • Absence of rescue equipment • Inaccessible safety equipment • Lake of lifeguards • Improper use of flotation devices	• Unsecured water bodies • Poor water visibility • Strong currents • Slippery surfaces • Remote or isolated locations • Absence of warning signs • Water pollution • Lack of barriers • Weather conditions • Uncovered wells • Lack of weather forecast warnings • Lack of designated swimming areas
During-event	• Poor swimming ability • Not wearing a life jacket • Rescuer's ability to swim • Panic response • Solo swimming • Inability to call for help • Inability to float • Fatigue or exhaustion • Misjudgment of water depth or distance	• Insufficient number of lifeguards on duty • Failure of life jackets/PFDs • Inaccessible rescue equipment • Improper use of safety equipment • Absence of rescue personnel trained in water emergencies	• No lifeguarded swim areas • Cold water temperatures/ sudden changes in water depth • Poor-lit swimming areas • Weather conditions (e.g., storms, heavy rain) • Wildlife hazards (e.g., sharks, crocodiles)
Post-event	• Lack of CPR skills • Emergency response time • Delayed recognition of drowning • Delay in seeking medical help • Inadequate post-drowning care	• Miscommunication between rescuers and emergency services • Lack of defibrillators • Delay in accessing rescue equipment • Inadequate training of lifeguards and rescuers	• Absence of lifeguards • Adverse weather conditions • Limited access to emergency services • Distance to medical facilities • Insufficient medical facilities or medical points around the area

increases the likelihood of drowning [6]. Furthermore, the lack of swimming education, in terms of both formal swimming lessons and general open-water education, compounds these risks [5]. Alcohol consumption is another major contributor to drowning incidents. The CDC estimates that 31% of all drownings involve blood alcohol concentration levels of 0.10% or higher [7].

A recent systematic review found that pre-existing medical conditions, such as diseases of the nervous system, mental and behavioral conditions, and circulatory system diseases, increase the risk of drowning. Specific conditions, such as epilepsy and cardiovascular disease, notably increase the risk of drowning [8]. In Canada, one-third of accidental fatal drownings involve individuals with pre-existing medical conditions [9]. Ischemic heart disease and seizure disorders are associated with an increased risk of drowning-2.7 times and 6.3 times higher, respectively [9].

Cultural norms and beliefs shape behaviors, which can affect drowning risks, for example, in some societies, swimming may not be taught for cultural or religious reasons; each culture has unique attitudes that contribute to drowning risks [10]. In addition, socioeconomic status plays a pivotal role in determining health outcomes, particularly in relation to drowning incidents. Lower socioeconomic groups are frequently exposed to elevated risks and disparities in drowning incidents [11].

Gender and age are also critical factors influencing the risk of drowning. Infants and young children face increased risks due to their limited physical strength, coordination, and cognitive abilities, which make them more vulnerable to drowning incidents. Moreover, males, particularly adolescent males, exhibit a notably higher risk of drowning, which is primarily attributed to increased engagement in water-related activities and risk-taking behaviors [5].

Finally, the impact of mental health conditions, particularly chronic depression, also affects the risk of drowning, which can sometimes be an act of self-harm or suicide. A review of the literature on suicide by drowning underscores the significance of this issue, particularly in Western countries [12].

Equipment

The use of unsafe watercraft without rescue equipment or are poorly placed can lead to drowning incidents. Such watercraft often lack essential safety measures, including life preservers, safety rails, and onboard communication devices. Additionally, overcrowding on watercraft and unsafe practices, such as not wearing life jackets or personal flotation devices (PFDs), contribute to the risk of drowning. In 2021, the US Coast Guard reported that 81% of boating deaths were due to drowning, with 83% of victims not wearing life jackets [13]. Similarly, in a 2014 report, the World Health Organization (WHO) stressed that the absence of life jackets during water-based activities contributes markedly to global drowning deaths [1]. A study analyzing US Coast Guard data concluded that the risk ratio for drowning death was lower for boaters wearing PFDs compared with not wearing them. The adjusted risk ratio was 0.51, indicating that the use of a PFD could potentially prevent one in two drowning deaths among recreational boaters [14]. However, poorly

designed or improperly used PFDs increase drowning risks.

Physical environment

The physical environment significantly influences the risk of drowning incidents. The absence of adequate physical barriers around bodies of water, including residential pools, has been recognized as a strong contributor to the risk of drowning. Installing barriers, such as pool fencing, helps prevent children from gaining unsupervised access to pool areas.

Similarly, a lack of lifeguards can also markedly raise the likelihood of drowning incidents. It is important to note that drownings can still occur in areas where lifeguards are stationed. Poor water visibility and strong rip tides greatly elevate drowning risks. Poor water visibility can prevent individuals from recognizing dangers in the water and can also decrease the likelihood of being seen and rescued if they are in distress. Rip currents are estimated to cause more than 100 deaths in the United States every year, making them a significant danger in aquatic environments [15].

Furthermore, remote locations often have natural bodies of water with varying and unpredictable conditions, such as rivers with strong currents, hidden underwater hazards, and sudden changes in depth. These natural features can increase the risk of drowning, especially among those unfamiliar with the environment [16]. A study on unintentional drowning in Australia highlighted the unique challenges in rural and remote areas, including geographical factors, such as the nature of rivers and lakes, greater distance from immediate emergency response services, and limited access to swimming and water safety education [17]. In addition, the absence of warning signs in swimming areas can lead to a deceptive sense of safety among swimmers.

This often results in people underestimating the potential dangers of swimming in areas that might be hazardous. The lack of adequate warning and subsequent unawareness can increase the risk of drowning, especially in environments where the water conditions are unpredictable or inherently dangerous.

Strategies of the Combined Model for the Enhancement of Drowning-Prevention Measures

The WHO has recommended a comprehensive set of six measures for drowning prevention, emphasizing the need for their contextual adaptation across different countries. These measures include the provision of safe places for preschool children away from bodies of water, the installation of barriers to control access to water, and the education of school-aged children in swimming and water safety skills. Additionally, the strategy encompasses building resilience to manage flood risks and other related hazards, training bystanders in safe rescue techniques and resuscitation, and establishing and enforcing stringent regulations for safe boating, shipping, and ferry operations [18]. However, the effective implementation of these measures varies based on each country's unique context, resources, and cultural considerations.

Building on that concept, this study explored the application of the combined model - encompassing *education, enforcement, environmental modification, economic incentives*, and *emergency response* - in addressing the challenges of drowning prevention (Table 2). Each domain of this multifaceted approach, which has been effective in addressing various issues from infectious disease during the COVID-19 pandemic to heat-related illnesses, was examined. Public safety in water-related activities and the prevention of drowning are greatly improved through education. Building and evaluating preventive measures, improving health outcomes, and creating a strong foundation for proactive action are all essential components of reducing drowning incidents.

Education

A Malaysian study found that the Be SAFE booklet intervention significantly improved parents' knowledge of drowning prevention and water safety among primary school children in the Hulu Langat district, Malaysia, with a 24.75% increase in knowledge after four weeks. Results indicated that the educational intervention had a large effect, with a significant difference in the knowledge scores obtained before and after the intervention within the booklet group and the booklet and seminar group [19]. It was concluded that the integration of swimming lessons into school curricula would be a significant step toward reducing the incidence of drowning. It would be advisable if this could be made mandatory by law.

Enforcement

Enhancing safety measures through the enforcement of strict penalties and fines for those who do not adhere to essential drowning-prevention practices could be highly effective. This approach would make it mandatory for both individuals engaging in water-related activities and operators providing these activities to use life-saving equipment, such as life jackets and PFDs. Additionally, it would encompass imposing fines on those found swimming in unguarded or unsafe bodies of water. A comprehensive evaluation of adult drowning-prevention initiatives indicates that socio-ecological tactics often involve long-term, economically sustainable interventions, such as environmental or regulatory changes that impact the entire population. For example, a 2014 study demonstrated that while an educational campaign increased the use of life jackets by 2%, the introduction of regulations making the use of life jackets mandatory increased their use by more than 50% [20]. Such regulatory measures, if rigorously applied, could serve as a strong deterrent against negligence and non-compliance, thereby playing a crucial role in substantially lowering the number of drowning incidences. This strategy promotes a culture of safety and responsibility among participants in water-related activities and also ensures that service providers adhere to the highest safety standards, further safeguarding public health and well-being.

Table 2. Application of the combined model for the drowning prevention strategies.

Public health approach	Timeline	Host	Mitigation strategies	
			Vehicle/equipment factors	Physical environment
Education Education influences audiences to refrain from risky or unhealthy behavior or take positive action to reduce risk.	Pre	• Swimming lessons for all age groups • Risk awareness and prevention education • Alcohol and drug awareness campaigns • Supervision training for parents/guardians • Drowning recognition and response training • Implement water safety curricula in schools • Promote use of life jackets/PFDs in advertisements and media campaigns • Encourage swimming in pairs or groups • Encourage the public to report unsafe conditions or behaviors they observe, using mobile apps or dedicated helplines	• NA	• NA
	During			
	post			
Enforcement Enforcing legislation through inspections and fines for noncompliance.	Pre	• Developing and Implementation of national drowning prevention policies • Fines for swimming in disallowed areas • Imposition of penalties on providers of water-based activities for non-compliance with established safety standards	• Check and disallow low-quality equipment from entering the country • Develop and enforce water equipment safety standards • Develop and enforce regulations for watercraft safety	• Compliance with the International Swimming Pool Code (ISPSC)
	During	NA		
	Post			
Engineering/environmental modification Engineering includes incorporating new products and technology to modify the environment to prevent or control injuries and deaths.	Pre	• NA	• Provide life jackets/PFDs at public water access points • Regular equipment inspection and maintenance • Provide accessible rescue equipment • Regular inspections of life jackets/PFDs	• Install barriers/fences around water bodies • Improve water visibility (e.g., clean water, add lighting) • Install warning signs for strong currents/rip tides • Improve walking surfaces (e.g., non-slip materials) • Mark sudden changes in water depth • Implement beach safety flag systems • Manage aquatic vegetation to reduce hazards • Promote coastal and waterway clean-up initiatives
	During			
	Post			
Economic incentives Economic incentives are typically offered to encourage better choices and changes in behavior.	Pre	• Offer mini free guides materials / pocketbooks. • Offer free courses and training sessions. • Offer wristbands for children on which parents can write their contact information.	• Offer free protective equipment (e.g. life jackets)	NA
	During			
	Post			
Emergency response Mitigate the effects of drowning and save lives.	Pre	• Establishment of surveillance system for potential drowning incidents • Implement early warning system for weather conditions (forecast) • Staff training • CPR and first aid training for the public • Establish networks of trained community first responders • Conduct periodic emergency drills that simulate drowning scenarios.	• Preparation of emergency plans vehicles, staff, and equipment • Develop smartphone apps for emergency communication and location sharing	• Expand the number of medical stations in high-risk areas. • enhance the response efficiency of organization like red cross, red crescent, and civil defense) • Ensure safe swimming zones by designating specific areas for swimming in larger bodies of water. • During peak times, increase the number of patrols around high-risk areas
	During	• Proper coordination between all involved entities		
	Post	• Adhering to the recommended protocols for managing drowning incidents.	• Availability of medical points • on-site medical care • Continuous evaluation of surge capacity plan • Stockpiles monitoring	

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Engineering/environmental modification

Implementing environmental modifications for drowning prevention involves altering physical environments to mitigate drowning risks. This encompasses establishing physical barriers around bodies of water, such as pool fencing, to prevent unsupervised access by children [4]. In 2021, a recent study highlighted the critical role that pool fencing plays in protecting young children from drowning. It found that compliance with pool fencing regulations significantly reduced drowning incidents among children [21]. Other environmental modifications include safer beach layouts with designated, lifeguard-monitored swimming areas. A 2018 study in California, US, highlighted the efficacy of lifeguards in preventing drowning at recreational beach areas, revealing that the presence and proactive measures of lifeguards significantly lowered the incidence of drownings [22]. Furthermore, the implementation of clear and visible signage in aquatic environments is a crucial safety measure. These signs act as essential alerts, notifying swimmers of potential dangers, such as strong currents or sudden changes in water depth. For those unfamiliar with the area, these signs are especially useful and can increase the understanding of potential risks [23]. Adopting this proactive approach to promote safety through awareness is an integral part of drowning prevention and effective water safety management. This strategy warns people of potential hazards and helps to foster a culture of caution and preparedness in aquatic settings.

Economic incentives

An innovative approach to drowning prevention is the use of economic incentives, which entails using financial motivations to encourage adherence to safety measures. The provision of financial rewards or benefits for engaging in safe practices around bodies of water can significantly influence behavior and reduce the risk of drowning. One effective strategy is subsidizing swimming lessons. Making swimming lessons more affordable encourages a larger segment of the population to learn essential water safety skills. Research has shown that formal swimming lessons can significantly reduce the risk of drowning, especially in children [24]. Another approach is to offer rebates or tax incentives for installing pool fencing in residential areas. Installing pool fencing is a proven method of preventing accidental drownings, especially among young children [25]. Incentivizing the use of safety equipment, such as life jackets and PFDs, is also beneficial. Programs that provide discounts or vouchers for safety gear can encourage boaters and swimmers to use these life-saving devices more consistently. Evidence suggests that the use of life jackets can drastically reduce the risk of drowning in boating incidents [26]. Moreover, economic incentives can be extended to public spaces, such as beaches or resorts. Offering financial rewards or recognition to locations maintaining high safety standards can motivate operators to prioritize water safety. This could include maintaining lifeguard services, providing adequate safety signage, and ensuring the availability of first aid equipment. To maximize the effectiveness of these incentives, it is crucial to ensure that they are well publicized and accessible to the target audience.

Public awareness campaigns can play an important role in informing the public about the incentives available and how to take advantage of them.

Emergency response

Emergency response encompasses rapid and skilled intervention to mitigate the severity of drowning incidents and improve survival rates. Collaboration and coordination among various stakeholders, including beach management, local authorities, and emergency services, are essential for an effective emergency response system. Key components include the presence of trained lifeguards, the availability of rescue equipment, and the efficiency of emergency medical services (EMS). Lifeguards play a crucial role in recognizing distress, performing rescues, and administering first aid, including cardiopulmonary resuscitation (CPR). Their training and vigilance are vital in minimizing the time between a drowning incident and the initiation of rescue efforts. Equally important is the availability of life-saving equipment, such as lifebuoys, rescue tubes, and automated external defibrillators, at swimming venues. These tools enable both lifeguards and bystanders to provide immediate assistance. One study found that early intervention in drowning situations, particularly the prompt initiation of resuscitation efforts, can significantly improve the chances of survival and reduce the likelihood of severe brain damage [27]. Furthermore, the role of EMS in drowning incidents is paramount. EMS personnel need to be competent in advanced life-support techniques and familiar with the specific challenges associated with water-related emergencies, including hypothermia, respiratory complications, and spinal injuries. Community-based emergency response training is another critical aspect of drowning prevention. Teaching the public CPR and basic water rescue skills can empower bystanders to act effectively in emergency situations, thereby improving immediate response capabilities [28]. Programs such as the American Red Cross's water safety and CPR training have been instrumental in building community resilience. Surveillance systems are also invaluable for identifying high-risk areas and times, which can inform and improve safety protocols and resource allocation. A study conducted in Thailand - which involved extensive community participation and evaluated the efficiency of the surveillance system in reducing drowning rates - demonstrated the effectiveness of a community-based surveillance system in drowning prevention, with a significant reduction in drowning incidents in the area with the surveillance system compared with a control area [29]. The integration of advanced technologies, such as drones and artificial intelligence-powered monitoring, can enhance surveillance systems, making them more efficient and effective in preventing drownings. A 2018 study investigated the potential of unmanned aerial vehicles, or drones, in strengthening drowning-prevention efforts [30]. The study evaluated the effectiveness of drones in swiftly delivering flotation devices in various sea conditions and compared the rescue times with traditional methods. The results indicated a substantial decrease in the time required to provide aid to simulated drowning victims, especially

in challenging sea conditions. These results indicate that drones accelerate the delivery of essential life-saving equipment and improve the safety and efficiency of rescue operations. Overall, a comprehensive and well-coordinated emergency response system is the cornerstone of drowning-prevention efforts. It requires a multifaceted approach combining skilled human resources, appropriate technology, community involvement, and effective collaboration among various entities involved in water safety.

Conclusion

In conclusion, the study effectively highlights the complexity and necessity of a multidimensional approach to drowning-prevention. It integrates the WHO's recommended measures with the multifaceted combined model, focusing on education, enforcement, environmental modification, economic incentives, and emergency response, tailored to fit the unique contexts of different countries. The effectiveness of these strategies, from the installation of barriers to prevent unsupervised access to water bodies to the integration of advanced technologies, such as drones, for efficient rescue operations, varies depending on each country's unique context, resources, and cultural considerations. This comprehensive approach underscores the need for proactive, well-informed strategies that involve community participation. The evidence-backed methods discussed in this study not only increase safety in aquatic environments but also encourage a culture of vigilance and readiness. This coordinated and inclusive approach is pivotal in reducing drowning incidents and reinforcing public health and safety in water-related activities.

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