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The use of explosives as a means of securing criminal control of rivers in *the Legal Amazon.*

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Summary

Public security in the Legal Amazon is facing a paradigm shift with the evolution of the "New Cangaço" (a term referring to organized crime groups) into "River Control," a phenomenon characterized by the territorial control of strategic waterways by transnational criminal factions. This article investigates the adaptation of irregular warfare tactics to the river environment, with an emphasis on the use of explosive devices. The research adopts a multidisciplinary perspective, integrating the chemistry of energetic materials, the physics of underwater explosions, and operational logistics. The results demonstrate that the high humidity of the Amazon renders ammonium nitrate (ANFO)-based explosives obsolete, leading organized crime to adopt explosive emulsions and detonating cords resistant to water. From a physiopathological point of view, the amplified lethality of shock waves in liquid media and the risks of severe internal injuries (blast injury) underwater are discussed. The study adopts a qualitative, exploratory, and descriptive approach, based on bibliographic review and document analysis. The data were collected from primary sources (legislation, police manuals) and secondary sources (technical literature in engineering and medicine). The analysis compared the doctrines of "New Cangaço" and "River Control," focusing on explosives and the propagation of shock waves. It concludes that a detailed understanding of the Bubble Pulse phenomenon and its associated injury mechanisms is a fundamental pillar for safety in hazardous underwater environments.
Keywords: Public Security. Drug Trafficking. Military Police. New-Cangaço.

Abstract

Public security in the Legal Amazon is facing a paradigm shift with the evolution of the "New Cangaço" to the "Domination of Rivers," a phenomenon characterized by the territorial control of strategic waterways by transnational criminal factions. This article investigates the adaptation of irregular warfare tactics to the riverine environment, with an emphasis on the use of explosive devices. The research adopts a multidisciplinary perspective, integrating the chemistry of energetic materials, the physics of underwater explosions, and operational logistics. The results demonstrate that the high humidity of the Amazon renders ammonium nitrate (ANFO)-based explosives obsolete, leading organized crime to adopt explosive emulsions and detonating cords resistant to water. From

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a physiopathological point of view, the amplified lethality of shock waves in a liquid medium and the risks of severe internal injuries (blast injury) underwater are discussed. The study adopts a qualitative, exploratory, and descriptive approach, based on bibliographic review and document analysis. The data were collected from primary sources (legislation, police manuals) and secondary sources (technical literature in engineering and medicine). The analysis compared the doctrines of "New Cangaço" and "River Control," focusing on explosives and the propagation of shock waves. It concludes that a detailed understanding of the Bubble Pulse phenomenon and its associated injury mechanisms is a fundamental pillar for safety in hazardous underwater environments.

Keywords: *Public Security. Drug Trafficking. Military Police. Neo-Cangaço.*

1. Introduction

The use of explosive devices, from their military and industrial origins to their appropriation. by non-state actors, represents a qualitative leap in the capacity to project force and establish the Terror. Historically associated with conventional conflicts and mining and construction activities. In the contemporary criminal landscape, explosives have become an instrument of power. Asymmetrical, used not only to cause material destruction, but also to destabilize institutions. to control territories and coerce populations.

In the Legal Amazon, this logic takes on particular contours: the combination between the availability of precursor materials (through illegal mining, construction waste or (of border smuggling), the rudimentary expertise disseminated in clandestine networks, and the conditions Environmental factors that challenge the chemical stability of compounds result in a scenario where artifacts improvised, but no less lethal, they are employed both as a logistical tool (for opening) of routes and clearing of waterways) as well as a tactical weapon, in attacks on vessels, posts security and rival communities (Costa, 2016)

Thus, explosives cease to be an exceptional resource and become an essential element. The structuring nature of violence in the "Domain of Rivers" requires a deep understanding of its... composition, physical behavior and effects, lest we underestimate its ability to transform The dynamics of conflict in the region.

Public security in the Federative Republic of Brazil, historically strained by complex dynamics of urban violence in large metropolitan centers and agrarian conflicts in The rural area is currently facing a paradigm shift in operational, criminological, and... Unprecedented geopolitical situation in the Legal Amazon region. The criminal phenomenon, previously categorized under the sociological and journalistic moniker of "New Cangaço," a historical reference. directly addressing the endemic social banditry of northeastern Brazil in the first decades of the 20th century, but modernized by city siege tactics, the "siege" and robberies of financial institutions employing From weaponry of war, it underwent a profound adaptive mutation upon encountering geography. labyrinthine, monumental and hydrologically intricate Amazon river basin (Costa, 2016).

This evolution resulted in what is now the most advanced public security doctrine and intelligence.

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Police began to call it "River Domain." This is not merely an amphibious variant of
"City Control" refers to a multifaceted criminal modality, characterized by...
due to the strict territorial control of strategic waterways by transnational criminal factions, which
They utilize geographic isolation as a force multiplier (Queiroz, 2024).

Public safety in Brazil has traditionally been challenged by urban violence.
Driven by metropolitan and agrarian conflicts, it faces a paradigmatic transformation of a nature...
Operational, criminological, and geopolitical aspects of the Legal Amazon. The phenomenon known as "New
"Cangaço" – a 21st-century criminal activity that adapted historical tactics of siege and assault.
with weaponry of war – it underwent a profound transformation upon establishing itself in the complex geography
from the Amazon basin (COSTA, 2016). From this adaptation emerged a new and more sophisticated one.
A type of territorial control, which specialized doctrine refers to as "River Control".
Unlike a simple transposition of urban crimes to the river environment, this is a
A multifaceted criminal model in which transnational factions exercise sovereignty over waterways.
strategically, using geographic isolation as a force multiplier and a shield against
state action (QUEIROZ, 2024).

Given this scenario, this article seeks to answer the following central question: How does the
strategic and tactical use of explosive devices (industrial, military and improvised) by
Criminal organizations are consolidating "River Control" in the Legal Amazon, and what are the challenges?
What are the technical, scientific, and operational challenges imposed by this new reality for public safety?

The overall objective of this research is to analyze the transition of the criminal phenomenon to the paradigm.
of the "Domain of Rivers" in the Legal Amazon, with a specific focus on the use of explosives such as
Asymmetrical force vector, investigating its technical, operational, and impact dimensions.

To meet the overall objective, this work is structured around the following specific objectives:
each corresponding to an axis of analysis in development: Contextualizing evolution
criminological analysis of the "New Cangaço" to the "Domínio de Rios," examining the geopolitical dynamics and
The hegemonic dispute between factions (CV and PCC) in the region. To examine the technical and scientific aspects.
of explosive devices in the Amazonian environment, including the chemistry of energetic materials
In the face of high humidity, the physics of shock wave propagation in aquatic environments and the pathophysiology
Regarding blast injury trauma: Assess the logistical, tactical, and response challenges posed.
through the Amazonian operational ecosystem to public security agencies, with emphasis on the limitations
for the disarmament of explosive devices (EOD) and in providing assistance to victims.

The relevance of this study is highlighted by the violent escalation in the region, driven by
War between Comando Vermelho (CV) and Primeiro Comando da Capital (PCC). These organizations
They transformed major rivers, such as the Solimões, Negro, and Madeira, into global logistics corridors.
employing irregular warfare tactics that include improvised river mines and attacks with

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Explosives against vessels and installations (SIQUEIRA; PAIVA, 2019). Understanding the interaction between the chemistry of explosives and ambient humidity, as well as the amplified physics of the wave of Shock in the water transcends academicism: it is an imperative for survival. security agents and for the formulation of effective state responses to a hybrid threat and high lethality.

2. Methodology

This research is characterized as an exploratory and descriptive study, with an approach... Qualitative, based on literature review and document analysis.

For data collection, primary and secondary sources were consulted, including: (i) current legislation and technical manuals of Standard Operating Procedures (SOPs) of corporations police officers (PMAM, PMSC); (ii) specialized technical literature in the areas of Mining Engineering (Explosives chemistry) and Combat Medicine *(blast injury).*

The data verification was performed using the comparative method, comparing the doctrines of "New Cangaço" (terrestrial environment) and "Domínio de Rios" (fluvial environment), with Emphasis on the effectiveness of energy-efficient materials (ANFO *versus* Emulsions) and on the hydrodynamics of propagation of shock waves.

Given the nature of the research, which is primarily documentary, it was not necessary to adhere to... Ethical and legal issues arise, since there was no interference with human sources.

Furthermore, the bibliographic references adopted by the research were compiled with the assistance of The research tools *Google Scholar, Scopus ,* and SciELO helped in gathering references. Current and relevant. The sources accessed online, cited and referenced in the article, are available. as per the respective links presented in the reference list.

3. Discussion of the results

3.1 Criminal geopolitics and the territorialization of "river control"

3.1.1 From "New Cangaço" to "Domination of Cities": Conceptual Evolution and Adaptation

To understand the magnitude and specificity of the current threat in the Amazon, it is It is imperative to dissect the evolution of the criminal modalities that gave rise to it, tracing a A genealogical line connecting classic rural banditry to modern narcoterrorism tactics.

The "New Cangaço" initially emerged in the mid-1990s and early 2000s. 2000, as a type of property crime focused on small towns in the interior. from Brazil, where the police force is small and the defense infrastructure is weak. The actions They are characterized by extreme violence, the use of hostages as human shields (a tactic known as "human shield" or "living shield") and the massive use of heavy weaponry (assault rifles)

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to subdue the local state response, targeting the theft of cash from bank branches and cars-strong (Costa, 2016). The researcher Carlos André Viana da Costa, in his seminal analysis on the A phenomenon in the state of Pará, the New Cangaço is defined as a manifestation of organized crime. which exploits regional vulnerabilities and the absence of the State, using terror as a method of momentary control of the population and security forces (Costa, 2016). The "spectacularization" Violence is a central component of this strategy, serving both to intimidate witnesses both to demonstrate power in the face of the State and rival factions.

However, the sophistication of operations has evolved over the last decade to what... Specialized literature on public safety refers to "City Control" or actions of "Third Generation Gangs" (Russo et al. 2023). Unlike the traditional New Cangaço, which focuses on quick raids and immediate escape after looting *(hit-and-run),* the City Domination It is a demonstration of strength and territorial control, albeit temporary, resembling a Light infantry operation. This type of operation involves militarized planning that includes:

1) Physical and Logistical Blockade: This tactic aims to prevent the arrival of reinforcements. To achieve this, criminals block roads with physical barriers—such as logs and burning vehicles—and have frequently adopted the use of improvised explosive devices (IEDs) to ensure this " *tactical lockdown .* "
2) Containment of Forces: The strategy focuses on neutralizing the state's response at its source. Through coordinated and simultaneous attacks on battalions and police stations, criminals apply a suppression of fire that prevents the departure of local troops (fire suppression tactic).
3) Advanced Technology: The current differentiating factor includes the use of drones for live reconnaissance and encrypted communication channels, such as messaging applications. Furthermore, the firepower is disproportionate, with the use of calibers such as the .50 (Browning M2), effective against armor and police aircraft (Russo; Racorti; Lenarduzzi, 2023).

In this vein, more than just aiming for immediate profit, the phenomenon of the Domination of Cities are seeking the momentary collapse of public security's response capacity. The goal is... to operate with absolute impunity, which represents a direct affront to state sovereignty by creating, in In practice, these are temporary zones of exception where the State loses control.

From another perspective, when this tactical logic is transposed to the Amazonian scenario, the following emerges: "River Control." In this model, the "site" of the city is replaced by the control of river channels. and trains. In this way, the factions adapt the principles of containment to the local reality, utilizing the intricate nature of the hydrography — straits, channels, islands, and sandbanks — as force multiplier. The terrain becomes a weapon to ambush barges carrying valuables, cargo of fuel and even vessels belonging to rival groups (Queiroz, 2024).

It is worth noting that Queiroz, in scrutinizing piracy on the Solimões River, points out that... “Spatial fragility” and “territorial vulnerability” in the Amazon are structuring elements. of this character. Then, the non-existence or insufficiency of the State in vast portions (voids) demographic and institutional factors) and the logistical difficulty of monitoring thousands of kilometers of

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Waterways provide conditions for these organizations to act as a parallel power. They
They control the flows, collect tolls (“protection fees”), and impose their own code of conduct.
and movement deciding who navigates, when they navigate and what they transport, (Queiroz, 2024).

3.1.2. Factional Dynamics: CV, PCC, and Co-opted "Piracy"

Riverine violence in the Amazon is not a monolithic or disorganized phenomenon; it is the
A direct result of a tectonic fracture in the Brazilian criminal underworld. The rupture of the alliance.
historical relationship between the Primeiro Comando da Capital (PCC), originating from São Paulo, and the Comando
The Vermelho (CV) operation in Rio de Janeiro, which took place in 2016, had a direct impact on drug trafficking routes.
international, transforming the Northern region into a strategic battleground (Siqueira and Paiva,
2019).

The Solimões River, in particular, became the epicenter of this geopolitical dispute, serving
as the main artery ("Avenida Solimões") for the flow of high-purity cocaine and paste.
The base is produced in Peru and Colombia and shipped to Atlantic ports (for export to Europe and Africa) and the
Brazilian domestic market. Reference????

In this context of factional warfare, the traditional figure of the "river pirate" or "water rat"
— local criminals who acted autonomously and often in a rudimentary way, robbing
Riverine communities and small trading vessels—were absorbed or exterminated. The large factions
nationals, realizing the strategic value of the "spatial capital" of these criminals (the knowledge
intimately familiar with the local geography, the channels, the streams, and the flood and ebb cycles), they began to
to co-opt these groups (Instituto Combustível Legal, 2025). The PCC and CV provided the former
Pirates possessed previously unimaginable military and logistical resources for local crime:

1) Weaponry: Modern assault rifles (5.56mm, 7.62mm and .50 caliber), light machine guns and grenades.

2) Mobility: Fast boats ("voadeiras") equipped with multiple high-power outboard motors (200HP, 300HP or more), often handcrafted armor plating.
3) Explosives: Access to industrial explosives (emulsions, dynamite) diverted from quarries and construction sites, essential for breaking open safes on barges and for intimidation.

In exchange for this technological and financial "upgrade," the factions demand absolute loyalty.
payment of "fees" on the loot from robberies and, above all, the use of navigation *expertise* for
transporting ("mule") large shipments of drugs and weapons through the most difficult routes and
unknown individuals, avoiding the checkpoints of the Federal Police and the Arpão Base.

The Legal Fuel Institute (ICL) highlights in its reports that piracy on the rivers and the
Deficiencies in border control are the biggest obstacles in combating crime in the region.
One alarming fact is that fuel theft is not limited to resale on the black market.
to generate profit; it functions as a vital logistical input for the very sustainability of

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Drug trafficking operations (Legal Fuel Institute, 2025). The fleets of speedboats of Gangs consume massive amounts of fuel to cross the Amazon at high speed. And the theft of fuel barges ensures the operational autonomy of these groups without the need... to purchase the supplies legally, which would leave financial traces.

Siqueira and Paiva (2019) describe how the Família do Norte (FDN) — a local faction that was later decimated and largely absorbed by the CV after massacres in prisons — and the CV itself established a "government of crime" that transcends the prison walls. establishing itself along river routes and in riverside communities. This criminal governance regulates The daily lives of local populations, imposes curfews, resolves local disputes, and decides the How the logistics flow works.

The factions established a true "criminal governance" over riverside territories. and borders. The report by Gabriel Funari (2024) for the *Global Initiative Against Transnational Organized Crime* illustrates how cities on the tri-border area, such as Tabatinga (Brazil) and Leticia (Colombia), they function as integrated logistics *hubs* , where criminal governance regulates not not only the illicit market, but everyday life, exacerbating lethal violence and promoting... Environmental degradation through illegal mining and deforestation for airstrips. clandestine (Funari, 2024).

The following table summarizes the operational and strategic differences between the modalities. criminals, focusing on adapting their *modus operandi* to the riverine environment:

Operational Parameter New Cangaço (Land-Based)		**River Domain (Amazonian Fluvial System)**
Primary Target	Bank branches, armored trucks, valuables depots.	Cash barges, fuel trains, drug trafficking "mules" (rivals).
Approach Tactics	Trains of SUVs (pickup trucks) traveling at high speed.	Fast boats ("voadeiras") camouflaged or silent night approach (electric motor or drift).
Response Containment	"Miguelitos" (twisted nails) on the road, vehicles set on fire on bridges, siege of the barracks.	Submerged steel cables, floating logs in the waterway, port mining, ambushes in narrow "holes".
Use of Explosives	Breaking loads focused on safes and ATMs.	Sinking charges, armor-piercing hull breaching, floating IEDs, contact mines.
Escape Route	Rural roads, vehicle swapping (abandonment of the "hot" ones).	Streams, complex channels, submersion of equipment and drugs for later recovery, mixing with the riverside population.
Support Logistics	Farms and ranches in rural areas (temporary captivity).	Co-opted or coerced riverside communities, mobile floating structures, camps in the flooded forest (igapó). bases

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3.2 Explosives engineering in the Amazonian environment: chemical and operational challenges

The effectiveness of explosives used by both criminals and teams of *Explosive Ordnance Disposal* (EOD) is severely tested by environmental conditions. Amazonian extremes: relative air humidity frequently above 90% (reaching saturation), daily torrential rains, intense heat, and the constant operational need for use in an environment Aquatic or underwater. A deep understanding of the physical and chemical properties of materials. Energy is fundamental to understanding detonation failures, the risks of accidents (detonations). (accidental) and the tactical choices of criminal organizations in selecting their arsenals.

3.2.1. ANFO's Vulnerability to Hygroscopy and Chemical Degradation and the Possibility of Private Sale

ANFO *(Ammonium Nitrate Fuel Oil)* is the most widely used civilian explosive globally. Mining and quarries are used due to their low cost, ease of manufacture, and relative safety. handling and transport (often classified as a blasting agent or *blasting company),* (requiring a strong initiator). Composed of a stoichiometric mixture of approximately 94% ammonium nitrate (NHÿNOÿ) in the form of porous *prills* (granules) and 6% fuel oil (usually diesel oil), its simplicity is its greatest strength and, in the Amazon, its greatest weakness. (Munaretti, 1997).

Munaretti (1997), in his in-depth thesis on the use of ANFO, explains that the The efficiency of the detonation depends primarily on the intimate mixing between the oxidizer (the nitrate) and the fuel (the oil). This mixing is facilitated by the physical porosity of the nitrate granules *(prills).* ammonium compounds, which absorb the oil by capillary action and allow the rapid chemical reaction necessary for sustain the detonation wave (Munaretti, 1997).

However, ammonium nitrate is an extremely hygroscopic inorganic salt. It has a natural chemical craving for water molecules present in the environment, absorbing moisture from the air. with great ease. In the Amazon region, where humidity is omnipresent and intense, ANFO It undergoes rapid and severe degradation if not stored in airtight containers. closed, which rarely occurs under the conditions of clandestine transport used by the factions.

Water absorption by *prills* causes two main detrimental effects that compromise The usefulness of ANFO for "River Domain":

Coalescence and Loss of Porosity: Water dissolves the crystalline surface of nitrate granules. As moisture cycles (with temperature variations), this dissolution and Recrystallization causes microscopic pores—essential for oil retention and for... formation of " hot *spots "* that concentrate energy during initiation — whether filled or collapsed. Without these aerated voids, the shock wave does not find the points of nucleation of energy necessary to propagate through the explosive mass, resulting in failure.

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(Forsyth; Cameron; Miller, 1995).

Thermal Desensitization: Water acts as a heat sink .

Extremely efficient due to its high thermal capacity and latent heat of vaporization. During the attempted detonation, the energy that should be used to sustain the chain reaction The exothermic decomposition of nitrate and oxidation of the fuel is, instead, consumed in The absorbed water vaporizes the reaction front, thus slowing its rate. of the chemical reaction and often leading to a misfire *or* a deflagration of low order, in which the explosive burns or “smokes” without detonating with full force (Forsyth; Cameron; Miller, 1995).

Furthermore, a moisture content higher than 8-10% is already sufficient to render ANFO inert. or incapable of detonating efficiently (Munaretti, 1997). In riverine criminal operations, this This results in faulty devices that, paradoxically, increase the risk for police officers and forensic experts. A failed (negative) ANFO IED may contain intact and sensitive detonators and an explosive mass. unstable, requiring complex remote neutralization protocols. Furthermore, incomplete burning is a risk factor. Wet ANFO generates dense clouds of nitrogen oxides (NOÿ), orange/brown colored gases that They are highly toxic. Although inhaling these gases may seem harmless at the time, This often leads to delayed pulmonary edema and death hours after exposure, which is a risk. serious for anyone approaching the crime scene without adequate respiratory protection (Munaretti, 1997).

3.2.3. Explosive Emulsions: The Technology of Water Resistance

In response to the severe limitations of ANFO in humid environments and seeking greater efficiency in attacks on hardened targets such as armored vehicles and, more recently, armored vessels of In the transport of valuables, organized crime has technologically migrated to the use of emulsions. Explosive.

Technically, an explosive emulsion is a thermodynamically two-phase colloidal system. An unstable (but kinetically stable) water-in-oil (W/O) solution. An aqueous solution. supersaturated with oxidants (mainly ammonium nitrate and sometimes sodium or calcium nitrate) It is dispersed in microscopic droplets within a continuous fuel phase (mineral oil, waxes and paraffins), stabilized by specific emulsifying agents (surfactants) (Maranda et al., 2025).

Consolin (2019) elucidates in his research that the stability and performance of these emulsions They are preserved by additives and emulsifiers that prevent the crystallization of ammonium nitrate, a a thermodynamically favorable process that would degrade the emulsion structure and render it inert. (Consolin, 2019). This molecular architecture gives the emulsion intrinsic and robust protection.

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against external water. The continuous oily phase surrounds each microscopic droplet of oxidant, creating an impenetrable hydrophobic barrier. This allows emulsions (whether in cartridge form, commonly known as "bananas" or "cartridged emulsion," or bulk pumped) are used in water boreholes or submerged for long periods without any significant loss of performance or sensitivity.

Critical Properties of Emulsions for River Crime

High Velocity of Detonation (VOD): Modern emulsions achieve VODs between 4,500 m/s and 5,500 m/s, values significantly higher than that of ANFO (which is around 3,000 m/s). m/s in ideal diameters) (Consolin, 2019). This high velocity generates a detonation pressure *(brisance)* much larger, capable of shearing (cutting) the naval steel of rafts and ship hulls Armored vehicles. The ANFO, with its predominantly thrusting *(heave) effect,* is excellent for moving earth. and rock, but it would have difficulty cutting steel efficiently in small, confined loads, such as The ones used in robberies.

Chemical and Physical Awareness: Maranda et al. (2025), in a comprehensive review on the The influence of sensitizers highlights that chemical sensitization (generation of gas bubbles in matrix through reactions such as that of sodium nitrite) and physical (addition of glass microspheres or Hollow plastics are the most efficient methods for adjusting the density and sensitivity of these. emulsions (Maranda et al., 2025). The microbubbles or microspheres act as *hot spots,* collapsing adiabatically under the shock wave of the initiator and generating the heat necessary to propagate the detonation.

Safety in Transportation and Lethality: This technology makes the explosive relatively safe for transport and handling (often classified as 1.5D or 5.1 oxidizer before the final awareness in pumping operations), but extremely lethal when initiated by a high-potency booster *(such* as pentolite) (Queiroz, 2024).

The recurring seizure of packaged emulsions (with visible trademarks) and *The presence of boosters* at Harpoon Base demonstrates that the factions possess sophisticated supply chains and Infiltration into the civilian explosives sector, diverting these materials from mining companies, quarries, and large corporations. Infrastructure works for use in river sabotage and traps (Funaki; Lenzi; Santos, 2023). Funaki, Lenzi and Santos (2023) describe rigorous stability testing methods (such as centrifugation and thermal cycles) ensure that these materials, even when stored Improperly stored by criminals in jungle hideouts ("mocós"), they retain their lethality and capability. detonation for extended periods (Funaki; Lenzi; Santos, 2023).

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3.2.4. The Detonating Cord as an Amphibious Tactical Tool

The detonating cord acts as the central nervous system of demolition operations and complex sabotage. It consists of a Pentrite core (PETN – Tetranitrate of Pentaerythritol) — a high-power, high-sensitivity secondary explosive — coated with Layers of reinforced textile fibers and an outer plastic coating (usually PVC or polyethylene). This construction makes the cord flexible, strong to the touch and, crucially, waterproof, with a very high VOD of approximately 7,000 m/s (Munaretti, 1997).

In the context of the "Domain of Rivers," the triggering cordel (a type of Brazilian folk poetry) plays a dual essential role:

Redundant and Distributed Startup System: Allows connection of multiple loads. explosives (for example, charges placed in different watertight compartments of a barge or in the supporting pillars of a river port) and initiate them simultaneously from a single trigger point. This ensures the effectiveness of the structural attack even underwater, where systems Electrical systems could fail or require complex insulation.

Linear Shear Load: High grammage twines (above 10g/m or 40 grains/foot) have They have enough power to be used directly as cutting tools. They can cut cables. made of steel mooring lines, anchor chains, hydraulic pipes, or thin metal sheets. Its Flexibility allows the cord to be wrapped or tied around irregular targets (knots, junctions), functioning as a precise, fast, and lightweight cutting tool, ideal for actions of sabotage where the transport of large explosive loads (“bananas” or bags) is unfeasible or indiscreet (Munaretti, 1997).

The water resistance and high reliability of the detonating cord (PETN is not hygroscopic) such as ammonium nitrate) make it the ideal accessory for riverine operations, allowing that Criminals set up underwater traps or trigger systems that resist the current. Strong and prone to prolonged immersion, typical of Amazonian rivers, remaining active for days waiting for a target.

3.3. Hydrodynamics of detonation and pathophysiology of trauma in an aquatic environment.

The interaction of an explosion with the aquatic environment generates distinct physical phenomena and, in many aspects, far more dangerous and lethal than those observed in the air. This results in a profile of lethality and *blast injury* that challenges conventional medical knowledge of trauma and requires enhanced security protocols. The determining physical property of this amplification of The problem is the incompressibility of water.

3.3.1. Shock Wave Propagation: Enhanced Lethality

Water is about 800 times denser than air and, for practical purposes of blast ballistics In hydrodynamics, it is considered an incompressible fluid. When an explosive detonates in air, a large amount of energy is generated. Part of the energy released is dissipated in the compression, heating, and displacement of the molecules of adjacent gas (air). Due to the compressibility of air, the pressure of the shock wave decays significantly.

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quickly with the distance (approximately with the cube of the distance, in the ratio of $1/R^3$)
(Munaretti, 1997).

In water, the shock wave behaves radically differently. Due to
incompressibility and the higher speed of sound in the medium (~1,500 m/s in water versus ~340 m/s in
In air), the shock wave travels much faster and the peak pressure decays much more slowly than
that in air (the decay is closer to a function of 1/R). This significantly increases the radius.
Effective lethality. An explosive charge that would be lethal 5 meters in the air can cause fatal injuries.
or incapacitating at distances of 15, 20 or even more meters in the water, depending on the confinement and
from the depths.

Lance, Capehart, and Bass (2015), in a seminal study published in *PLoS ONE* on criteria
of human injury in underwater explosions, exhaustively reviewed historical data (including
(cases from World War II) and experimental measures to establish new safety parameters.
They determined that the risk of fatality for submerged humans is 50% with an impulse.
of a shock wave of 302 ± 16 kPa·ms (kilopascal-millisecond). This study was fundamental for
to overturn old and inaccurate guidelines, often based on assumptions from the 1940s that
They mistakenly equated human resistance with the surface tension of water or used models
unsuitable animals (Lance et al., 2015).

In addition to its extended range, the acoustic impedance of water is very close to the impedance of water.
of the soft tissues of the human body (which are composed mostly of water). This allows a
Near-perfect energy coupling: the shock wave passes from the water to the human body with
minimal reflection on the skin. In the air, much of the shock wave energy reflects off the body due to
There is a large impedance difference between air and solid/liquid tissue. In water, this "protection" does not exist.
It exists; the wave transmits destructive energy directly to the internal organs as if the body...
was transparent to the wave (Munaretti, 1997).

3.3.2. The ***Bubble Pulse*** Cycle and Structural Effects

A unique and devastating characteristic of underwater explosions is the formation and
The oscillation of the gas bubble, known as a *bubble pulse.* The products of the detonation — gases
Extremely high pressure and temperature — form a spherical cavity that expands radially against
The hydrostatic pressure of the surrounding water. Due to the inertia of the water's movement, the bubble expands.
if it goes beyond its pressure equilibrium point (having an internal pressure lower than that of water),
and then it stops and collapses violently under the pressure of the water. This collapse compresses the gases.
again, generating a new peak in pressure and temperature, and a subsequent expansion. This
The expansion-collapse cycle (pulsation) can occur several times as the bubble migrates to the
surface area due to buoyancy (Munaretti, 1997).

Effect on Structures (Whipping *Effect):* If the explosion occurs under the hull of a

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On the vessel, the interaction with the bubble is catastrophic. The initial expansion of the bubble lifts the ship in the center. (lifting effect). The subsequent collapse creates a void that removes the supporting structure. Water seeps under the middle of the ship, causing the keel to break under the weight of the vessel itself. (Violent *hogging* and *sagging* movements – sluggishness). Experimental and numerical studies. Tests on steel plates demonstrate that the final plastic deformation is a result of the combined action of the wave. of the initial shock and, crucially, of the subsequent pulsations of the bubble, which can be as or more more destructive than the primary detonation (LANCE et al., 2015). Furthermore, during the collapse of the bubble Near a solid surface (the hull), a high-speed jet of water is formed *(water jetting).* which can pierce metal like a hollow-charge projectile (Munaretti, 1997).

Effect on Humans: The secondary pressure waves generated by the pulsations of the bubble. They can reach the victim milliseconds after the primary shock wave. This exacerbates internal injuries. and subjects the body to repeated cycles of rapid compression and decompression, increasing the risk of trauma. mechanical in hollow organs and delicate tissues (Munaretti, 1997).

4. Mechanisms of Primary Injury from Underwater *Blast*

Injuries caused by primary shockwaves in water are insidious and frequently lethal, even without obvious external signs of trauma. They occur predominantly at the interfaces where there is a drastic change in density, that is, between liquid/solid tissues and gas pockets. (lungs, intestines, sinuses). The specialized medical literature, including the chapter "Biodynamics of Blast Injuries" in the book *Reconstructing the War Injured Patient* by Abu-Sittah, Hoballah and Bakhach (2017) highlight that damage is maximized at these biological interfaces due to difference in wave propagation speed in different media (Abu-Sittah; Hoballah; Bakhach, 2017).

The main mechanisms of injury are:

Spalling : When the compression wave travels through dense tissue (such as the thoracic wall or the lung parenchyma) and reaches an interface with a less dense medium (the (alveolar air), kinetic energy is transferred to the separation surface. This ejects fragments of Dense tissue moves into the air space (the alveolus), causing physical rupture of the alveoli and capillaries. The result is severe pulmonary hemorrhage, bruising, and edema, a condition known as "blast lung," *which* leads to acute hypoxia and respiratory failure (Munaretti, 1997).

Implosion and Water Hammer Effect: The shockwave violently compresses the bubbles. of gas present in the intestines and lungs. The subsequent explosive re-expansion of these bubbles (which (This occurs due to the negative phase of the shock wave or the oscillation of the explosion bubble) lacerates the tissues.

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surrounding lesions from the inside out. In the intestine, this causes multiple perforations, fecal peritonitis, and...
Massive internal bleeding. Rapid compression can also force gas bubbles into the...
Disrupted blood circulation causes arterial gas embolism, which can travel to the brain.
(leading to stroke) or to the coronary arteries (causing immediate cardiac arrest) (Munaretti,
1997).

Crucial Clinical Differences: Unlike air *blast ,* where eardrum rupture is a
A common and sensitive indicator of significant overpressure exposure, in underwater *blast* victims
They can suffer lethal abdominal and pulmonary injuries without exhibiting tympanic membrane rupture or any other symptoms.
Visible external skin lesions. Lance et al. (2015) identified, through case analysis...
Historical data suggests that the prevalence of severe bowel damage is a distinctive and unique characteristic of...
Underwater blast injuries, in contrast to airborne trauma where the lung is the primary target.
more sensitive (Lance et al., 2015). This makes screening and diagnosis extremely difficult.
early intervention by rescue teams not specifically trained for this scenario can lead to
preventable deaths due to undiagnosed internal abdominal bleeding.

Conclusion

This study also highlights the crucial importance of an interdisciplinary approach.
continuous. The Bubble Pulse phenomenon and its associated pathology are not isolated problems of
This is not just about engineering or medicine in isolation, but rather a complex challenge that requires constant dialogue.
among physicists, naval engineers, doctors, security specialists, and crisis managers. A
The evolution of threats, such as the use of improvised devices or new explosive materials, requires
that research keeps pace with this dynamic, constantly updating forecasting models of
damages and care protocols. Therefore, the conclusion is not a final point, but an appeal for
The maintenance and funding of collaborative research networks that can translate discoveries
Theoretical solutions that translate into practical and timely lifesavers.

Finally, the analysis undertaken reinforces that mitigating the devastating effects of
Underwater explosions are, ultimately, an investment in resilience. Building
more robust vessels, better trained crews, and the development of diagnostic systems.
More agile measures are those that strengthen a nation's ability to respond to accidents or
attacks. The most profound lesson is understanding the unique violence of the underwater blast and its character.
The insidious nature of their injuries is not merely a technical issue—it is an ethical and strategic imperative for
To preserve lives, protect property, and ensure safety in maritime operations, a
An environment that, as demonstrated, does not forgive ignorance or inadequate preparation.

Academically, this work offers a significant contribution by synthesizing and
to analyze, in an interdisciplinary way, the physical and pathophysiological mechanisms of explosions.

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underwater, focusing on the devastating Bubble Pulse effect. By integrating classic literature (such as Munaretti, 1997) with recent experimental and numerical research (such as Lance et al., 2015) and Based on medical-surgical evidence (Abu-Sittah et al., 2017), the study consolidates a robust theoretical model. about the dynamics of the bubble and its sequential effects on structures and the human body. The main The contribution lies in highlighting and detailing the crucial differences between underwater and aerial blasts. particularly the predominance of lethal internal injuries (especially intestinal) in the absence of External signs, vital knowledge for the fields of underwater medicine, naval engineering and security. However, the exclusively personal nature of this approach is recognized as an intrinsic methodological limitation. The research is documentary, as it does not include interviews, primary data collection, or case studies. The application depends on the scope and depth of the secondary sources consulted. Despite this Despite this limitation, the relevance of the research remains high, as it organizes a body of knowledge. complex and dispersed, establishing a clear scientific basis for future empirical research and development of mitigation technologies.

Institutionally and socially, the study transcends mere theoretical review by formulating Urgent practical recommendations. For maritime security, defense and rescue institutions, the This work highlights the critical need for specific screening and diagnostic protocols for Victims of underwater explosions, training teams to identify hidden signs of trauma. Abdominal and pulmonary. For naval engineering and ship design, it reinforces the imperative The need to consider the effects of whipping and water jetting in integrity calculations. structural. For society in general, the study highlights the specific and often... Underestimated risks of operations in explosive underwater environments. The main recommendation A derivative is the adoption of an integrated security paradigm, which combines advances in the design of pulsation-resistant bubble structures with the implementation of specialized medical guidelines. for emergency response, aimed at preserving lives and reducing material damage. catastrophic.

It is concluded that a detailed understanding of the Bubble Pulse phenomenon and its mechanisms is essential. Risk management is a fundamental pillar for safety in hazardous underwater environments. This work, by consolidating physical and medical knowledge on the subject, demonstrated that the threat It goes far beyond the initial shockwave, residing in the kinetic energy cycles of the bubble and in the Silent internal injuries that can lead to preventable deaths. Therefore, the appropriate response requires... a coordinated and proactive action between the fields of scientific knowledge and development technological and operational preparedness. The future challenge lies in translating these contributions. academic standards, projects

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