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When the water table falls, the peatland becomes fuel: a reflective commentary on hydrology and catastrophic forest fire

Abstract

The water table is the principal ecological boundary separating protected, waterlogged peat from dry and combustible organic material. In an intact tropical peatland, groundwater remains close to the surface, limiting oxygen penetration, slowing decomposition, and maintaining the high moisture content that prevents peat from sustaining combustion. Drainage canals, prolonged drought, deforestation, and excessive water extraction lower this boundary. Consequently, a progressively thicker layer of peat becomes aerated, decomposed, cracked, and vulnerable to ignition. A falling water table does not itself create the initial flame. Human activity, burning vegetation, lightning, machinery, or glowing woody material usually supplies the ignition. Nevertheless, hydrological degradation determines whether that ignition is extinguished or develops into an extensive, persistent, and smoke producing fire. The objective of this reflective commentary is to explain how water table decline transforms peat from a protected carbon store into a three-dimensional fuel body and thereby increases the probability, depth, persistence, spatial extent, and environmental severity of peatland and forest fires. It also connects this hydrological process with recurring haze in Indonesia and the wider Association of Southeast Asian Nations (ASEAN) region. This commentary argues that fire prevention must begin before smoke or flames appear through continuous groundwater monitoring, drainage and canal management, peatland rewetting, native vegetation recovery, and land uses compatible with wet peat conditions.

Keywords: drainage, forest fire, groundwater, peatland hydrology, rewetting, smouldering combustion, tropical peat

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Introduction

Peatland (*tanah gambut* in Malay) fire is commonly described as a consequence of extreme heat, prolonged drought, careless burning, or deliberate land clearing. Forest fire is often imagined through what can be seen above the ground. We picture dried leaves, dead branches, grasses, shrubs, and trees becoming sufficiently dry to burn. We also associate forest fire with visible human activities, such as open burning, agricultural land clearing, unattended campfires, and the careless disposal of still glowing cigarette butts. These explanations are reasonable because such activities can provide the initial flame, ember, or heat required for ignition. However, they do not fully explain why a relatively small surface fire can continue for weeks, disappear beneath the ground, spread beyond its visible boundary, and later reappear at another location.

A frequently overlooked feature is the enormous quantity of dried organic fuel lying beneath the forest floor. Peat is not an ordinary mineral soil. It consists largely of partially decomposed leaves, roots, branches, trunks, and other plant remains that have accumulated under waterlogged conditions over hundreds or thousands of years. When peat remains saturated, this ancient biological material is naturally protected from combustion. When it is drained and dried, however, the same accumulated carbon becomes a deep and continuous underground fuel body. Visible vegetation may carry the first flames across the surface, but dried peat beneath it can sustain smouldering combustion long after the surface flames have disappeared. What appears to be a forest burning above the ground may therefore be an ancient organic soil burning silently below it.

The missing ecological explanation is frequently water. More specifically, it is the vertical position of groundwater within the peat profile. The water table governs how much peat remains saturated, how deeply oxygen can penetrate, and how much stored organic carbon becomes exposed to drying and combustion. Hydrological modelling has confirmed that including water table depth and soil moisture considerably improves predictions of tropical peat fire activity.[1] The water table does not strike the match, discard the cigarette, or begin the open burning. Nevertheless, its position can determine whether the resulting heat is rapidly absorbed and extinguished or transferred into a thick layer of dried peat that can smoulder for weeks.

Ecologically, the water table can be regarded as the peatland's protective shield. When groundwater remains close to the surface, much of the peat stays wet, cool, and biologically preserved. Water occupies the peat pores, restricts oxygen movement, absorbs heat, and slows microbial decomposition. When the water table falls, this protective shield also moves downward, leaving an increasingly thick layer of unsaturated peat above it. The exposed organic material gradually dries, while oxygen enters spaces that were previously filled with water. Aerobic decomposition accelerates, carbon is lost, the peat shrinks, the land subsides, and cracks develop. These cracks can subsequently provide pathways through which oxygen, heat, embers, and smouldering combustion move into deeper peat layers.

Although public discussion commonly concentrates on the immediate source of ignition, the condition of the receiving fuel is equally important. A still glowing cigarette butt falling onto saturated peat may cool and be extinguished. The same cigarette butt falling onto severely dried peat may initiate a reaction that survives underground.

Human activity may therefore provide the immediate trigger, while the lowered water table creates the deeper ecological vulnerability. The spark explains how the fire begins, but peatland hydrology largely explains why it becomes deep, persistent, geographically extensive, and exceptionally difficult to extinguish.

Accordingly, the objective of this reflective commentary is to explain how the lowering of the peatland water table transforms waterlogged organic soil into a dry, oxygenated, and increasingly combustible fuel body, thereby increasing the probability, depth, persistence, spatial extent, and environmental severity of forest and peat fires. It also seeks to connect this hydrological mechanism with recurring haze in Indonesia and the wider Association of Southeast Asian Nations (ASEAN) region and to reflect on why groundwater monitoring, drainage control, rewetting, vegetation recovery, and land use compatible with wet peat should be treated as essential forms of fire prevention.

The haze is coming back in ASEAN

The consequences of peatland hydrological degradation are repeatedly visible across Indonesia and the wider ASEAN region. In October 2023, smoke from fires in Sumatra and Borneo contributed to serious haze conditions affecting Indonesia and neighbouring countries. Schools in Palembang and Jambi were instructed to conduct remote learning, while air pollution warnings were issued in parts of Peninsular Malaysia and Sarawak. These fires occurred within landscapes where drainage and agricultural land clearance had dried peat deposits and made them highly vulnerable to combustion.[2] This episode demonstrated that haze is not solely an atmospheric problem. It begins with the ecological disturbance of land, vegetation, and, most fundamentally, peatland hydrology.

The regional connection became evident again in July 2025, when haze from forest and peatland fires on Sumatra was detected moving into Malaysia. More than 140 fires were reported in Riau Province, with heavy haze reducing visibility to approximately one kilometre in some affected districts. Satellite observations showed smoke moving north-eastward toward Negeri Sembilan, illustrating how a locally degraded peatland can become a regional source of atmospheric pollution.[3] Smoke from comparable Indonesian fires has previously affected Singapore, Malaysia, and southern Thailand. These repeated events demonstrate how the lowering of a water table in one locality can eventually affect air quality, public health, transportation, education, and daily life across national boundaries.

The ecological warning became even more urgent in August 2026. Indonesia experienced a longer and more severe dry season as El Niño intensified, creating conditions favourable for drought, vegetation drying, and the expansion of forest and peatland fires. By June 2026, approximately 107,465 hectares had been affected by fire, representing a 110% increase compared with the corresponding period in 2023. Fire control operations concentrated on Riau, Jambi, South Sumatra, West Kalimantan, Central Kalimantan, and South Kalimantan, all of which contain substantial peat landscapes. Hazardous smoke forced schools in Pontianak to conduct classes online, while unhealthy air quality was recorded in parts of Sarawak.[4]

Indonesian authorities correctly observed that drought did not directly ignite these fires but acted as a catalyst that allowed them to spread more widely.[4] From an ecological perspective, however, the meaning of this catalyst must include what was occurring underground. Prolonged dry weather and falling water tables were progressively increasing the thickness of peat capable of sustaining combustion. The visible flames may have begun through human activity, but their eventual scale reflected the dryness, continuity, and depth of the available fuel. Once combustion entered the peat, the fire could survive beneath the surface and continue producing smoke even when the most obvious flames had declined.

The regional emergency continued later in August 2026, when Indonesia authorised Malaysian agencies to enter its airspace to undertake coordinated cloud seeding. Forest and land fires across several Indonesian provinces had generated haze severe enough to cause school closures in both Indonesia and Malaysia. Sarawak was particularly affected, while unhealthy air pollution levels were also recorded in several districts of Peninsular Malaysia.[5] This international intervention demonstrated the enormous geographical consequences of fires whose ecological vulnerability may have originated with local drainage and groundwater decline.

This response also invites a deeper reflection. Cloud seeding and aerial firefighting attempt to return water from the sky only after the peat has dried, ignited, and begun producing regional haze. These emergency measures may suppress surface flames, improve air quality, or slow the immediate spread of fire. However, the more fundamental solution is to retain water within the peatland before combustion begins. It is far more ecologically rational to prevent the underground carbon store from becoming combustible than to search for sufficient water after a large and concealed fire has already developed.

The ASEAN haze problem must also be interpreted carefully because not every episode originates entirely outside the country experiencing the pollution. Malaysia has encountered haze associated with domestic peat fires and open burning in addition to pollution transported from neighbouring regions. During an April 2023 haze episode, Malaysian environmental authorities identified peat fires and local open burning as contributing causes while recognising that haze was simultaneously affecting several ASEAN countries.[6] This observation prevents the discussion from becoming restricted to national blame. Peat drainage, inappropriate fire use, drought, and hydrological mismanagement occur across political boundaries. The atmosphere merely makes their ecological connection visible.

News reporting usually begins when hotspots are detected, visibility declines, schools close, or air pollution reaches unhealthy levels. Yet the decisive ecological changes may have begun months or years earlier. Drainage canals gradually lower groundwater, expose peat to oxygen, accelerate decomposition, and cause subsidence. During a prolonged dry period, the unsaturated and potentially combustible layer expands further. A surface flame, burning root, windblown ember, or land clearing fire can then enter this dried organic deposit. The water table does not provide the initial ignition, but it strongly determines whether that ignition disappears or develops into extensive three-dimensional smouldering combustion.

The return of haze should therefore be interpreted as more than another seasonal air pollution episode. It is evidence that the underlying ecological conditions capable of producing large peat fires remain unresolved. Emergency firefighting may end one visible crisis, but it does not necessarily repair the degraded hydrology that made the crisis possible. Until peatlands are rewetted and their water tables protected, ASEAN may repeatedly confront the same sequence: drainage, drought, ignition, underground combustion, toxic smoke, regional disagreement, emergency intervention, and temporary relief. The haze returns because, beneath the smoke, the deeper water problem remains.

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The water table as an ecological fire barrier

Figure 1 illustrates how a high-water table protects intact peat by filling its pores with water, restricting oxygen diffusion, absorbing heat, and maintaining the slow anaerobic decomposition that allows carbon rich plant material to accumulate over centuries or millennia. An ember landing on wet peat is likely to cool and extinguish, whereas drainage lowers the water table and exposes a thicker unsaturated peat layer to oxygen, drying, cracking, thermal decomposition, and subsurface smouldering. As shown in Figure 1, water table position varies with rainfall, evapotranspiration, topography, canal proximity, vegetation, season, and peat hydraulic properties. Water table depths of 40 or 60 cm below the surface should therefore be interpreted as useful management warning levels rather than universal ignition thresholds, because actual fire risk also depends on the duration and extent of water table decline, peat moisture, vegetation, weather, and the availability of an ignition source.

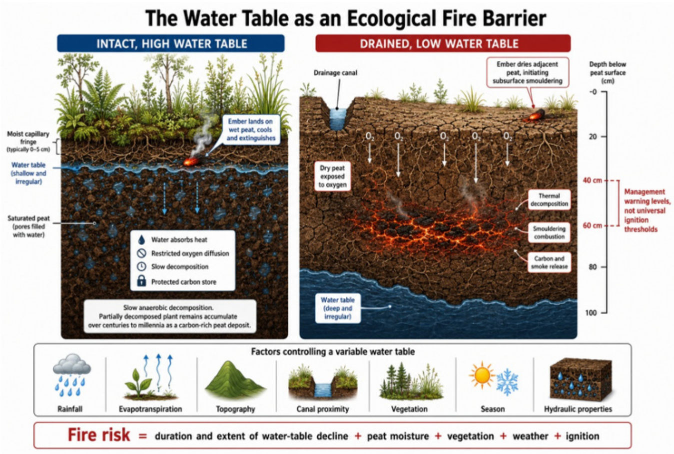

Figure 1 The Water Table as an Ecological Fire Barrier: Contrasting Fire Resistance in Saturated Peat with Smouldering Vulnerability in Drained Peat.

Peat develops because plant production exceeds decomposition under saturated conditions. Water fills peat pores, greatly restricting oxygen diffusion. Anaerobic decomposition continues, but it is generally slower than aerobic decomposition. The partially decomposed plant material consequently accumulates over centuries or millennia as a carbon rich organic soil.

Saturated peat requires considerable energy to burn because water must first be heated and evaporated. Water also absorbs heat, reduces oxygen availability, and interrupts the transfer of energy into adjacent fuel. An ember that lands on wet peat may cool and disappear. The same ember landing on drained peat may remain hot enough to dry the surrounding material, initiate thermal decomposition, and establish smouldering combustion.

The water table is not a perfectly flat underground surface. Its depth varies with rainfall, evapotranspiration, peat topography, canal proximity, vegetation, season, and local hydraulic properties. Surface peat may also remain moist for some time after groundwater begins falling because capillary forces draw water upward. Therefore, no single water table threshold can predict every fire in every peatland. Values such as 40 or 60 centimetres below the surface are useful management warnings, but they should not be treated as universal ignition points. Fire risk reflects the duration and spatial extent of water table decline together with peat moisture, vegetation, weather, and ignition availability.

How drainage converts peat into fuel

Figure 2 illustrates the five-stage ecological conversion of intact, waterlogged peat into an aerated and combustible underground fuel body. Canal construction, drought, and vegetation loss lower the water table, allowing oxygen to replace water within peat pores and stimulating aerobic microorganisms, decomposition, oxidation, and carbon dioxide release. Continued drying causes volume loss, increased bulk density, subsidence, and deep cracking, which create pathways for oxygen, heat, embers, and burning roots. Once ignited, the exposed peat can support persistent smouldering that moves laterally and downward until it encounters material that remains too wet to burn. As shown in Figure 2, drainage increased wildfire carbon loss ninefold in one experimental peatland, while drained peat burned to a mean depth of 0.19 m compared with 0.07 m in undrained peat.[7,8] Fire damage then reduces vegetation cover, increases sunlight exposure and drying, and reinforces future vulnerability. Drainage does not directly ignite peat, but it quietly prepares and enlarges the underground fuel long before flames become visible.

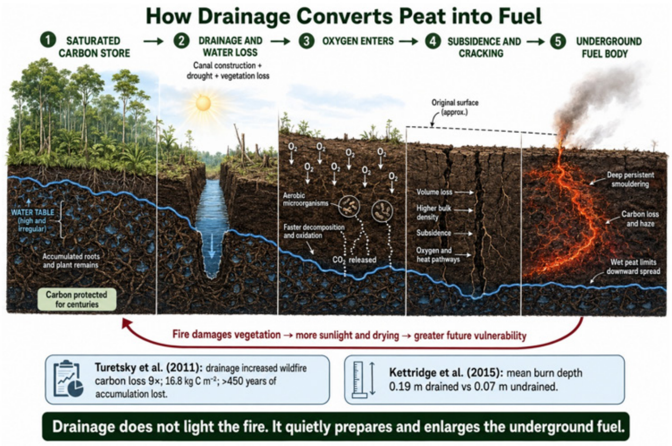

Figure 2 How Drainage Converts Peat into Fuel: From a Saturated Carbon Store to a Deep and Persistent Underground Fire.

Drainage canals rapidly remove water from a peat dome and disrupt the hydrological conditions under which peat was originally formed and preserved. Once the water table falls, water drains from peat pores and is replaced by air. This newly available oxygen stimulates aerobic microorganisms, which accelerate the decomposition and oxidation of organic matter. Carbon that had remained stored for centuries is gradually released as carbon dioxide, while the peat loses volume, becomes denser, and begins to subside. Hydrological modelling confirms that water table depth and peat moisture are major controls on tropical fire activity, particularly during severe drought when drainage further intensifies subsurface drying.[1] Drainage therefore does more than remove excess water for agriculture or land development. It changes the peat from a saturated carbon store into an aerated and progressively combustible soil.

The conversion develops through a connected ecological sequence. Canal construction, drought, deforestation, and vegetation loss lower the water table, producing a thicker unsaturated peat layer above the groundwater boundary. This exposed layer undergoes drying, aerobic oxidation, structural shrinkage, subsidence, and cracking. The cracks allow oxygen to penetrate deeper into the peat and may also provide pathways for embers, heat, and burning roots. As drying continues, material that was once protected by groundwater becomes available for ignition and smouldering combustion. The resulting fire releases further carbon, damages vegetation, exposes the surface to

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stronger sunlight, and increases subsequent drying. Drainage, fire, and vegetation loss consequently reinforce one another, creating a degradation cycle in which each disturbance increases the peatland's vulnerability to the next fire.

Experimental evidence demonstrates how strongly hydrological drying can amplify peat combustion and carbon loss. Turetsky et al.[8] found that long term experimental drainage increased wildfire carbon losses ninefold in a northern peatland. The fire released approximately 16.8 kg of carbon per square metre, representing the loss of more than 450 years of accumulated organic matter. Although tropical and northern peatlands differ in vegetation, climate, peat composition, and fire regime, the fundamental ecological lesson remains applicable: drainage exposes old organic material that would otherwise remain protected by water. Once the protective water table is lowered, fire does not consume only recently fallen leaves and surface vegetation. It can also enter a carbon deposit produced by centuries of incomplete decomposition.

Kettridge et al.[7] similarly demonstrated that drained peat burned substantially deeper than undrained peat, with approximately 0.19 m consumed in the drained area compared with 0.07 m in the undrained area. The important question is therefore not merely whether ignition occurs, but how much peat has become dry enough to participate in combustion. If the water table falls from near the surface to one metre below it, the thickness of the potentially aerated fuel layer increases greatly, although actual combustibility still depends on peat moisture, density, composition, oxygen availability, and drying duration. Fire can then move laterally and vertically through cracks, roots, woody fragments, and porous organic layers until it encounters peat that remains too wet to sustain combustion. In this sense, drainage does not light the fire, but it quietly prepares and enlarges the underground fuel body long before the first flame becomes visible.

Why a low water table produces a larger fire

Figure 3 illustrates how a falling water table enlarges peat fire vulnerability both horizontally and vertically. Under a high-water table, only a thin unsaturated peat layer is available for combustion, limiting the depth and lateral extent of fire. Drainage networks spread drying across the landscape, while groundwater decline exposes a much deeper volume of aerated peat through which fire can travel along cracks, roots, and porous organic layers. This slow, flameless smouldering requires relatively little oxygen, retains heat within the surrounding peat, and may persist for days or weeks beneath an apparently extinguished surface before resurfacing elsewhere.[9] Although its spread may be measured in centimetres per hour, continuous combustion across a large three-dimensional fuel body can produce substantial cumulative carbon loss and transboundary haze. The atmospheric significance of this process was demonstrated during the 1997 Indonesian fires, which released an estimated 0.81 to 2.57 gigatonnes of carbon from burning peat and forest.[10]

A falling water table increases both the horizontal and vertical dimensions of fire vulnerability. Drainage networks spread drying across large landscapes, while vertical water table decline exposes deeper peat. A surface vegetation fire can therefore enter an extensive three-dimensional fuel deposit instead of consuming only leaves, grasses, and branches.

Peat burns principally through smouldering, a slow, flameless form of combustion. Its oxygen demand is relatively small, and the surrounding peat insulates the reaction zone. Fire may survive below an apparently extinguished surface and reappear through cracks or near roots. Rein and Huang[9] explained that smouldering peat fires are exceptionally persistent, difficult to detect, and major producers of incomplete combustion emissions. Their slow movement should not be confused with ecological insignificance. A combustion front advancing only centimetres per hour can operate continuously for weeks and consume enormous quantities of carbon.

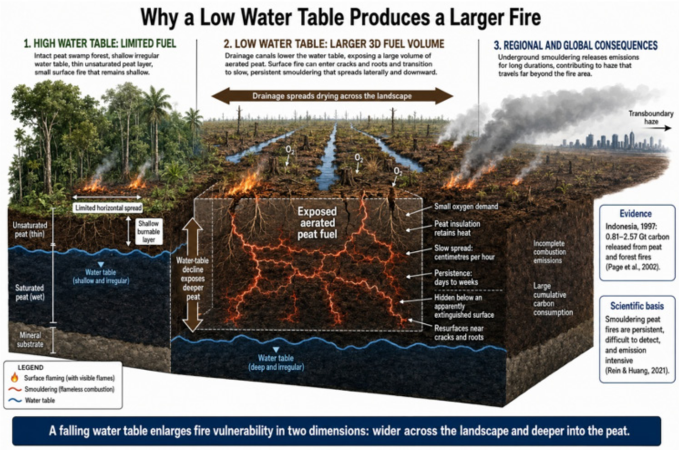

Figure 3 Why a Low Water Table Produces a Larger Fire: Horizontal Expansion, Deeper Smouldering, and Regional Haze Formation.

The 1997 Indonesian fires illustrated the atmospheric scale of this hydrological failure. Page et al.[10] estimated that peat and forest fires released between 0.81 and 2.57 gigatonnes of carbon. The uncertainty was large, but the study demonstrated that drained tropical peat can produce global consequences when drought and ignition coincide. The haze visible in distant cities is therefore the atmospheric expression of a water table that had already fallen within the source landscape.

A reflection on causation and responsibility

Figure 4 illustrates why responsibility for peat fire cannot be assigned solely to either the immediate spark or the lowered water table. An ember, open flame, burning root, or hot machinery may explain how combustion begins, while drainage, groundwater decline, and peat drying explain why it survives, travels underground, resists extinction, and produces extensive smoke. As shown in Figure 4, these hidden ecological changes can develop for months before hotspots, flames, and haze trigger an emergency response. Preventive governance should therefore combine dip wells, automated groundwater sensors, rainfall records, peat moisture measurements, and canal water observations to detect dangerous drying early. Monitoring results must guide adaptive canal blocking and rewetting, which can raise groundwater, reduce subsidence, support native forest recovery, improve shade and humidity, and lower fire occurrence.[11] Rewetting should not mean indiscriminate flooding, and restoration success must be evaluated through measured water table recovery, peat moisture, subsidence reduction, vegetation response, canal block maintenance, and declining fire occurrence rather than the physical presence of restoration structures alone.

It would be scientifically incorrect to say that a low water table directly ignites peat. Fire still requires sufficient heat. However, concentrating responsibility only on the individual spark is equally incomplete. Ignition explains how combustion began; hydrological condition explains why it survived, travelled underground, became difficult to extinguish, and released such a large quantity of smoke.

This distinction matters for governance. Firefighting usually begins after hotspots, flames, or haze are detected. By then, the ecological failure may have been developing for months through drainage and gradual groundwater decline. Water table monitoring should therefore be treated as fire prevention, not merely as restoration research. Dip wells, automated groundwater sensors, rainfall records, peat moisture measurements, and canal water observations can identify dangerous drying before smoke emerges.

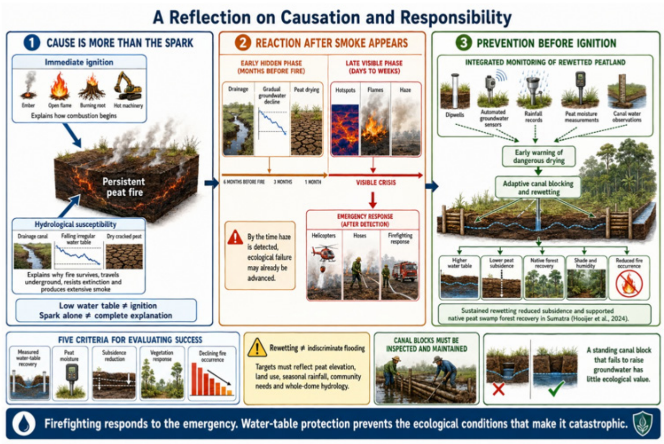

Figure 4 A Reflection on Causation and Responsibility: Distinguishing Immediate Ignition, Hydrological Susceptibility, Emergency Response, and Preventive Peatland Management.

Rewetting reduces fire vulnerability by blocking or modifying drainage canals and retaining water within the peat landscape. Hooijer et al.[11] found that sustained rewetting in Sumatra reduced peat subsidence and supported spontaneous recovery by native peat swamp forest species. These outcomes are important because vegetation recovery improves shade, humidity, surface protection, and ecological resilience.

Rewetting does not mean indiscriminately flooding every settlement, plantation, or road. Water targets must reflect peat elevation, land use, seasonal rainfall, community needs, and the hydrology of the entire peat dome. Canal blocks also require inspection and maintenance. A structure that remains standing but fails to raise groundwater has little ecological value. Success must be evaluated through measured water table recovery, peat moisture, subsidence reduction, vegetation response, and declining fire occurrence.

Conclusion

The water table determines whether peat remains an ecological archive or becomes a vast underground fuel reserve. When groundwater falls, peat dries, oxygen enters, decomposition accelerates, the surface subsides, cracks develop, and progressively deeper carbon becomes available for combustion. The initial spark may be small, but the hydrologically exposed fuel body can be immense. The central conclusion is that catastrophic peat fire begins long before the first flame. It begins when water is removed and the decline is accepted as an ordinary requirement of land development. Fire suppression addresses the emergency, but water table protection addresses its ecological cause. If water is kept within the peat, ancient carbon remains beneath the forest. If water is continuously removed, that same carbon may eventually return through smoke, toxic haze, land collapse, and irreversible ecological loss.

Declaration on the use of artificial intelligence

The author declares that generative artificial intelligence tools were used in a supportive capacity during the preparation of this manuscript. These tools assisted with language refinement, structural organisation, and stylistic clarity of the text. All ideas, interpretations, reflections, and conclusions presented in this paper are the author's own and are grounded in personal experience and scholarly judgment. The author retains full responsibility for the content, accuracy, originality, and integrity of the manuscript.

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None.

Conflicts of interest

The author declares there is no conflict of interest.

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