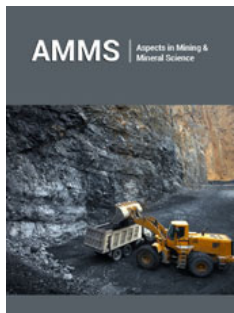


Dead Sea Salt Exploitation on Newly Emerged and Unstable Ground: A Recurrent Binational Engineering Problem

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Opinion

The exploitation of mineral resources from the Dead Sea relies on 250km² of solar evaporation ponds enclosed by on roughly 250km of earthen dikes. This industrial model has supported potash and associated chemical production for decades on both the Jordanian and Israeli sides of the southern Dead Sea. However, the apparent simplicity of the system conceals a major structural incompatibility: the infrastructure has progressively expanded onto land made available by the fall of the Dead Sea level, even as that same decline contributes to its destabilization [1-3]. These newly exposed surfaces are not stable industrial platforms. They are hydro geologically disturbed, geotechnically weak, and geomorphologically evolving terrains affected by subsidence, sinkholes, dissolution, seepage, collapse, and slope instability [3-5]. In this opinion paper, I argue that repeated failures, maintenance crises, remedial works, and litigation associated with Dead Sea dike systems should not be interpreted as isolated accidents, but as recurrent expressions of a structural problem. The degradation affects both Jordan and Israel. The long history of disputes involving owners, designers, contractors, subcontractors, and courts shows that technical uncertainty has accompanied Dead Sea salt exploitation since its earliest industrial phase [6-13]. A further lesson follows. Although the hazards related to evaporitic ground, seepage, differential settlement, and karstic discontinuities have been recognized for decades, the attribution of damage cannot be reduced, in scientifically satisfactory terms, to the execution chain alone. The Dead Sea case must therefore be read not only as an engineering problem, but also as a warning about institutional memory, risk governance, and the tendency to reframe as project incidents disorders rooted in a long-term geological and hydrogeological setting.

The industrial exploitation of Dead Sea salts is fundamentally based on the impoundment of brine within ~250km² solar evaporation ponds bounded by dikes. This model has turned the southern Dead Sea into one of the most intensively engineered evaporitic landscapes in the world. Yet its long-term viability depends on the stability of the ground beneath the dikes and ponds, and that is precisely where the system is most vulnerable. The Dead Sea has undergone a rapid, essentially anthropogenic decline since the 1960s, with the fall increasing from about 60cm/yr in the 1970s to around 1m/yr or more in the 2000s [1,2]. The causes are now well-known: the diversion of Jordan Basin waters for domestic and agricultural uses, damming and inter-basin transfers, and, in the southern basin, intensified industrial evaporation by mineral companies [1-3]. This regional water deficit has a direct engineering consequence. As the Dead Sea retreats, it exposes broad tracts of former lake floor and marginal flats that may

appear attractive for industrial expansion. Yet these lands are not mechanically mature ground. They recently emerged, saline, very low-gradient surfaces undergoing post-emergence deformation. In the Ghor Al-Haditha-Lisan sector, recent geomorphological analyses indicate that the Dead Sea level has fallen by about 45m since the 1960s, exposing a wave-cut platform locally 1.6 to 5km wide [4]. Historical shorelines from 1984 to 2018 do not match equivalent modern contours; lower present-day contours fit better, indicating persistent post-emergence lowering and continuing geomorphological reorganization [4]. The emerged margin is therefore not merely drying out. It is actively deforming.

Hazard inventories indicate that the Dead Sea basin is affected by well over 8000 sinkholes, probably approaching 10000. Instability is still expanding and damage affecting dikes and evaporation ponds must therefore be interpreted within a regional system of active geomorphic failure rather than at the scale of individual structures alone [14]. The binational dimension of the problem is no longer debatable. Environmental degradation in the southern basin affects neither one operator nor one country alone [2,3]. Increased industrial evaporation itself contributes to the continued lowering of the base level and therefore to the worsening of the conditions that favor dissolution, settlement, slope failures, and cavity formation [2]. The industrial system thus depends on a transforming landscape while simultaneously intensifying the processes that destabilize it [2,3]. The incompatibility is therefore not accidental. It is built into the logic of the exploitation itself. In Israel, declassified CORONA satellite imagery shows that major dike construction at Dead Sea Works (DSW) in Sedom was already underway in the early 1960s [10,11]. The engineering difficulties of brine impoundment at the Dead Sea were therefore recognized long before the recent phase of shoreline retreat and sinkhole proliferation. Richard Meehan captured this reality in the memorable remark that, at the Dead Sea, "nothing can sink ... but money" [10]. Aphoristic though it is, the phrase points to a persistent technical problem: brine-retention systems repeatedly encountered seepage, foundation instability, and costly dispute. Meehan's account further indicates that, once the dikes were completed, leakage rapidly developed beneath them and the matter escalated into litigation at The Hague. In his interpretation, the fundamental defect lay not in the impermeable cores themselves, but in the cracked and soluble salt foundation beneath the works [10].

The roster of experts drawn into these controversies is itself revealing. Meehan states that Tom Leps, who had previously worked with Karl Terzaghi, was retained as an expert in the Dead Sea dike case, while another historical account recalls that the Kaiser-appointed panel included Leps, Laurits Bjerrum, and Ralph B. Peck [10]. This was not a routine consulting exercise. It mobilized senior geotechnical authorities associated with the intellectual foundations of modern soil mechanics and foundation engineering. The implication is clear: the hazards affecting Dead Sea dikes were serious enough to engage figures from the Terzaghi-Peck-Bjerrum lineage, yet complex enough to resist straightforward engineering resolution [10]. Later Israeli industrial and hydrogeological records point in the same direction. Israel Chemicals Ltd. (ICL)

acknowledged in 2006 that sinkholes had already appeared in and around the DSW evaporation ponds and warned that a sinkhole developing beneath a dike could trigger embankment failure and brine loss [12]. It also recognized that the falling Dead Sea level was imposing increasing hydraulic constraints on pond operation [12]. That warning has since been reinforced by recent hydrogeological evidence: by 2024, the head difference between the Dead Sea and the ponds had reached about 48m, driving extensive and increasing leakage through a karst system beneath the ponds, with present losses of roughly 80-100 million cubic metres per year through the Ye'elim alluvial fan alone [15]. The conclusion is straightforward. On the Israeli side, dike instability, karst development, and brine leakage have long formed part of the core industrial risk environment [12,15].

The Jordanian side also provides one of the clearest examples of this structural incompatibility. Arab Potash Company (APC) began constructing its solar evaporation system in the mid-1970s and expanded it over the following decades [6]. By the early 1990s, dozens of sinkholes had already affected the projected alignment of Dike 18, yet the project proceeded [3]. Dike 19, part of APC's Stage III expansion, was designed in 1997, built between March 1998 and December 1999, and impounded in January 2000 [6]. On 22 March 2000, it failed catastrophically. The breach was about 2.3km long, with the sudden release of roughly 56 million m³ of brine [6]. The event remains an unambiguous geotechnical failure affecting a newly built dike founded on recently emerged and unstable ground. The collapse was preceded by clear warning signs. Active subsidence was detectable seven years before the failure and has already affected the sector of saltpan SP-0B and its surroundings [5]. The site was deformed before collapse and was structurally fragile. The falling Dead Sea level was already destabilizing the newly emerged ground at regional scale [5]. Damage later documented on Dike 18 and SP-0A confirms that karst-related deformation did not affect a single work only, but an entire environment undergoing rapid reorganization [3]. The demonstration is therefore straightforward: the hazard was neither hypothetical, nor marginal, nor discovered too late. It was already there. The problematic nature of the site was not ignored. A tender issued in 2003 for the re-tendered execution of remedial works on Dike 18 (saltpan SP-0A) concerned a 12km-long earthwork dike and did not describe routine maintenance [13]. The program included widening and raising works, local modifications of the berm and crest, the installation of monitoring instruments, and the placement of about 6.5 million cubic meters of fill [13]. The document is equally revealing in contractual terms: at least 30% of the value of the works had to be allocated to local companies, whether through joint venture or subcontracting, while the main contractor remained fully responsible for overall execution quality [13]. The reasoning follows directly. The hazard regime was known. The corrective measures were massive. Yet contractual exposure still moved downward along the execution chain.

The technical instability of APC's infrastructure quickly became a legal problem as well. The collapse of Dike 19 triggered arbitration and judicial proceedings that lasted for more than ten years [6,8,9]. The contractor sought arbitration immediately after

the failure. A majority arbitral decision favored the contractor. APC then challenged the award before the Jordanian courts [6]. Materials from the International Centre for Settlement of Investment Disputes (ICSID) later show that the dispute developed into a major investment treaty case in which the tribunal found that Jordan, acting through its courts, had violated ATA Construction's treaty-protected arbitration rights [8,9]. This legal history matters not because it retrospectively assigns final fault to one side or the other, but because it shows that, in the Dead Sea setting, geotechnical failures repeatedly generate disputes over design assumptions, supervision, liability, and state action rather than remaining confined to the technical sphere. A broader conclusion can be drawn by reading [15,16] studies. On the Jordanian side, the APC site was already interpreted as a young and rapidly evolving halokarst system, with site-wide deformation, sinkhole activity, and ground instability requiring continuous satellite-based warning and surveillance rather than a structure-by-structure reading alone. On the Israeli side, the Dead Sea Works case now demonstrates that the same regional logic is expressed through extensive and increasing brine leakage driven by a growing hydraulic gradient and by the expansion of fast-flow karst conduits, with present losses on the order of 80-100 million cubic metres per year through the Ye'elim alluvial fan and a measured head difference of about 48m between the Dead Sea and the ponds [15]. Taken together, these two studies point to the same conclusion: on both sides of the southern Dead Sea, industrial embankments and evaporation ponds are operating within an active evaporitic-karst system whose evolution is controlled by continued lake-level fall, groundwater circulation, dissolution, and migrating instability, so the relevant scale of interpretation is regional and dynamic rather than local and static.

The 2025 mini-review [17] extends the same line of reasoning. The Jordanian substrate emerges there as structurally complex, karst-prone, and still active under the continued fall of the base level. Pre-failure deformation, ongoing subsidence, steepening hydraulic gradients, evaporite dissolution, and the operational need for early-warning monitoring are articulated within a single causal chain [17]. SP-0A or SP-0B are therefore not the problem. It is a particularly well-documented limiting case within a broader, older, and more clearly binational system of instability [3,5,17]. That is the decisive point. The Dead Sea case reveals not only geotechnical incompatibility, but also a deficit of institutional memory. The owners and operators of these systems have worked for decades in an environment where seepage, soluble foundations, sinkholes, differential settlement, and ground deformation are documented, monitored, and documented again [3,5,10-17]. Yet when damage occurs, analysis still tends to focus rapidly on execution, local compliance, or the immediate performance of the structure. That reflex is intellectually weak. It reduces an old hazard regime to a project incident. It substitutes a long geological causality with a short contractual causality. It also forgets that Dead Sea dikes and evaporation ponds are not founded on inert support, but on a medium subject to deformation, dissolution, and the continuous migration of failure zones. Scientific caution therefore requires resistance to monocausal readings. In such an environment, the

simplified attribution of damage to the execution chain alone is reductive. The cumulative lesson is simple. Repeated failures, costly repairs, remedial programs re-tendered after distress, and recurrent litigation associated with Dead Sea dikes must not be read as separate episodes caused only by local mistakes in design, construction, or management. They must be understood as manifestations of a deeper structural incompatibility between an industrial model based on long earthen embankments and a landscape undergoing anthropogenic hydrological drawdown, karstification, differential settlement, and active geomorphological reorganization [1-5]. The problem affects both Jordan and Israel, and it has done so for decades [2,3,10-17]. The Dead Sea case thus illustrates a broader principle: when industrial expansion advances across rapidly changing evaporitic and karst-prone ground, environmental degradation and legal conflict become tightly intertwined. This paper should therefore be read as a warning signal. It is a warning to scientific and engineering communities, because the ground conditions involved in Dead Sea salt exploitation are neither simple nor stable [3,5,16,17]. It is also a warning to contractors and subcontractors, who may find themselves exposed to severe technical, legal, and financial consequences in a setting where the fundamental hazard regime has long been established [6-13]. It is finally a warning to operators themselves, because technical continuity without institutional memory increases the probability that the same structural problem will return under different project names, in different contracts, and through different corporate narratives [3,10-17]. The underlying question is therefore not whether the hazards are known. They are. The real question is whether they are genuinely taken into account when new works are planned, when remedial works are re-tendered, and when responsibility is later debated. In the Dead Sea case, the landscape retains the memory of drawdown, dissolution, and deformation. Institutions, by contrast, too often appear to rediscover the same lesson only after failure. That is why the recurrent exposure of contractors and subcontractors should not be regarded merely as a secondary legal effect of isolated engineering accidents. It should be understood as one symptom of a deeper and older disjunction between geological reality and institutional memory in the industrial exploitation of Dead Sea salts.

Acknowledgment/Dedication

This article is dedicated to the memory of Professor Richard L. Meehan (1939-2025), who passed away on 29 September 2025. His long career in geotechnical engineering, groundwater analysis, and forensic investigation remains a source of inspiration for all those concerned with the interaction between engineering works and unstable ground. Professor Meehan's recollection of his involvement in Dead Sea dike disputes is especially meaningful in the context of this paper. He wrote that in 1972 Tom Leps, aware of his research on the "invisible but calculable flow of groundwater," asked him to determine the movement of water beneath the southern Dead Sea near Sedom in connection with dikes built to capture and concentrate valuable salts. He observed that these dikes soon proved ineffective because water leaked beneath the

works, leading to litigation at The Hague [10]. This testimony is remarkable because it shows that the essential geotechnical problem discussed in this paper - seepage, soluble foundations, and the intrinsic instability of Dead Sea salt-exploitation infrastructure - had already been recognized several decades ago.

His words remain strikingly relevant today, not only for their technical insight, but also for their historical clarity. They remind us that the difficulties encountered in the industrial exploitation of Dead Sea salts are not recent anomalies, but part of a much older and more persistent struggle between engineering ambition and a uniquely unstable evaporitic environment. In that sense, I respectfully dedicate this paper to Professor Meehan's memory.

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