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From the Cacti Roses Grow: Eco-Governance Turning Political Desert Land to Urban Oases

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Abstract. This study revisits the *Arsaali paradox*, and the long-standing conflict rooted in the transformation of Arsaal, the largest village of Lebanon's arid Hermel region, from a traditional agropastoral landscape into an unlikely mosaic of stone fruit orchards. What initially appeared to be a promising agricultural innovation disrupted the fragile equilibrium of miniature transhumance practiced by tribal herders, whose livelihoods depended on the sparse, endemic flora of the quasi-desert. While the orchards *paradoxically* revitalized local arid agriculture, they gradually displaced pastoral systems, igniting deep sociopolitical unrest. Over two decades ago, the American University of Beirut (AUB), through its Environment and Sustainable Development Unit (ESDU), helped mediate this transformation by fostering participatory land-use planning and cooperative development. The resulting truce withstood even the early years of the Syrian refugee influx and Lebanon's growing governance vacuum. Today, however, the paradox returns with renewed vigor and pernicious mutations. Intensified climate change, urban sprawl, and accelerating land degradation now threaten not only livelihoods but entire ecosystems. Unregulated pollution, groundwater over-extraction, and veterinary collapse risk exterminating endemic species, alongside the vulnerable human communities sustaining this spiral. In response, AUB re-engages with nature-based solutions, such as Azolla-based wastewater treatment and horizontal-flow constructed wetlands, to restore ecological health, support transhumance traditions, and revive endemic plant and animal life. This strategy anchors biodiversity as a cornerstone of both conservation and peacebuilding. Promoting community stewardship through participatory action research, is grounded in the symbolic legacy of *the Kamouh of Hermel*, an ancient Pyramid styled mausoleum standing tall amid Hermel's desert, mystically fusing Seleucid and Assyrian cultures. Our study reframes environmental recovery as a pathway to local empowerment and governance reform in Lebanon's marginalized hinterlands. We call it Eco-Governance.

Keywords:
Arsaali Paradox, AUB, Eco-Governance, Sustainable Water Management.

1. Introduction

1.1. Land Like a Mirror

Lebanon is relatively small, approximately half the size of Paris, or the third of New York City. Yet, it contains almost every type of climate within a 3-hour drive [1]. The Mediterranean climate label finds itself drawn and quartered starting with the tropical tendencies of the coastal areas which smoothly give way to the temperate climate of the tree covered hills. A scattered pattern of water rich miniature plains nestles in-between the sinewing ranges of the parallel western mountain-chain blocks that form Mount Lebanon. These mid-mountain range areas enjoy a significantly cooler range of temperature yearlong. The temperate air of the mini-plains with its fleeing tropical hues from the coast, is wet enough to suit citrus and olives yet cool enough for some stone fruit varieties [2]. Notwithstanding the warm atmospheric rivers and heat storms, becoming the global staple of climate change and affecting the local ecosystem [3]. Ascending further, the setup morphs into a colder continental climate. Steeper and colder, the elevated countryside is home to the famous cedars of Lebanon, and some of the most exquisite apple species unique to those altitudes [4, 5]. Redescending into the Beqaa plain, hung at 1100 meters above sea level between 2 ranges of mountain-chains, the semi-arid characteristics dominate the eastern one separating Lebanon from Syria. The climate is distinctly semi-aridic and the sparsely covered alluvial setting contrasts with the densely vegetated side facing the coastal side [6]. The plain itself is home to a unique patchwork of desertic spots and wetlands. The southern side of the plain is home to the famous Lebanese vineyards, and larger wetlands, while the northern part increasingly give way to aridic landscapes. The northeastern Hermel area which includes the bordering mountain range with Syria houses a quasi-desert, as it’s referred to in Lebanon [1]. Underserved and remote at the present, it nevertheless boasts one of the most ancient monuments in Lebanon, the Hermel Pyramid. Combining Hellenistic and Oriental elements, the Hermel mausoleum could be read as a mark of cultural melting pot, in the tradition of the Caravan Routes of Petra [7-10].

1.2. Origin of Life or Root of All Conflict: When Trees Bloom in the Desert

In the heart of Lebanon’s arid Hermel region lies Arsaal, a surprising “dry” oasis that supports the country's largest domestic herd. Long defined by a delicate mosaic of desert vegetation and sustained through a seasonal transhumance system, Arsaal thrived as a resilient center of agropastoral life rooted in collective land use and mutual dependence on scarce resources. Water, though limited, sustained a social fabric as much as it did life. That balance was abruptly reconfigured three decades ago when a few local residents introduced fruit tree cultivation, an innovation that spread rapidly across the landscape. Thus, had appeared what came to be known as the *Arsaali paradox*: in an age of widespread deforestation and desertification, Lebanon's driest region became blanketed in orchards. Rainfed fruit trees brought a vision of prosperity and permanence to a region shaped by mobility and negotiation.

Yet in a cruel twist, this "green revolution" splintered communal grazing lands, restricted pastoral access, and ignited longstanding tensions over land tenure, water rights, and mobility. What began as a symbol of ecological promise became a seedbed of exclusion and conflict, turning once-shared pastures into fenced enclosures and shifting Arsaal from cooperation to contestation. In Arsaal, trees became both the origin of life and the root of conflict, revealing the high stakes of ecological transformation in fragile terrains. This story underscores a deeper truth: environmental interventions, no matter how well-intentioned, do not occur in a vacuum. Without mechanisms of Eco-Governance; that is, systems that mediate between nature, knowledge, and justice, such interventions risk unravelling the very social and ecological fabric they aim to renew [11].

1.3. Temporary Resolution, Perennial Fragility: A Truce Among Thorns

In the wake of mounting tension over land, water, and the meaning of sustainability itself, the first resolution to the Arsaali paradox took root not in the soil, but in the social imagination, nurtured by the Environment and Sustainable Development Unit (ESDU) at the American University of Beirut (AUB). Partnering with the International Development Research Centre (IDRC), ESDU initiated a bold experiment in community dialogue, grounded in participatory action research that gave voice to the very actors at the heart of the conflict: pastoralists and fruit growers, whose livelihoods, and worldviews, stood at odds in a rapidly shifting landscape. In a setting where mistrust ran deep and the ecology of cooperation had long eroded, early workshops built unlikely bridges. Tribal leaders, once wary of interference, cautiously engaged. Local officials, limited in political reach but rich in contextual knowledge, offered pathways for consensus. Academics brought tools of analysis, while herders brought lived knowledge. Progressive organizers, including a growing number of women seeking to claim their stake in Arsaal's evolving rural economy, added a vital dimension of equity. The result was a delicate but durable pact, rooted in collaborative land-use planning and community-based natural resource management. This locally owned framework withstood even the destabilizing shocks of the Syrian refugee influx and the collapse of central state functions. For a time, Arsaal became a case study in how participatory governance could harmonize competing claims over a fragile environment [12].

In recent years, however, that balance has been upended. As accelerating climate change, unchecked urban sprawl, and deepening land degradation tighten their grip on the Hermel region, Arsaal finds itself once again at a breaking point. Water scarcity has grown more acute, compounded by the proliferation of informal settlements and inadequate infrastructure.

What once was a conflict between trees and herds now unfolds as a broader ecological emergency, threatening not only livelihoods, but also the very biodiversity and ecosystems that had once enabled coexistence. From the perspective of political ecology and socio-ecological systems theory, these renewed tensions are not simply the fallout of misguided technology or environmental mismanagement.

At their root lies a more enduring failure: the inadequacy of governance systems to adapt, mediate, and protect. Technological fixes, no matter how well-designed, are insufficient when institutions fail to address issues of equity, accountability, and long-term environmental stewardship [13]. This is especially evident in the hidden but hazardous infrastructure failures that surround Arsaal's growing population. Unplanned sewage systems, often improvised as shallow dug holes or dumped directly into the drying riverbeds, threaten to contaminate the already scarce groundwater. As the volume of waste increases beyond the holding capacity of these makeshift pits, the risk of water table contamination becomes a looming catastrophe, one that blurs the line between human health, ecological degradation, and infrastructural neglect. In this context, the *Arsaali paradox* reasserts itself as a warning: that the roots of conflict are as much institutional as they are environmental. A solution must therefore follow a dual path; responding to ecological realities while embedding them within accountable, inclusive, and anticipatory systems. The time has come for a framework of Eco-Governance, not merely to manage natural resources, but to restore the possibility of living together in fragile landscapes shaped by both history and change [14]. The solution should therefore address both fronts, in a double pronged approach.

2. Theoretical Approach: Eco-Governance Amid Crisis and Renewal

2.1. Situating the Problematic Core: Shrinking Laws and Growing Deserts

Amid mounting pressures of armed conflict, accelerating aridity, haphazard urban expansion, overloaded sewage systems, and collapsing biodiversity, the environmental and social fabric of Arsaal continues to fray. In such fragile landscapes, environmental crises are never merely ecological, as they intersect with institutional fragility, legal ambiguity, and eroding civic trust. Shrinking laws, manifested in weak enforcement of water protection statutes and land-use regulations, converge with growing deserts, both literal and metaphorical, as governance vacuums widen and ecological thresholds are breached. In response, the American University of Beirut (AUB) has returned to the drawing table with a renewed commitment to nature-based and people-centered solutions, reaffirming its role not only as a technical partner but also as a convener of local knowledge, scientific innovation, and participatory governance. This role resonates with global debates in political ecology and environmental governance, where scholars emphasize that ecological integrity, social equity, and institutional accountability must be treated as mutually reinforcing pillars rather than competing priorities [15]. By framing governance through the common thread of environment, AUB situates Arsaal's challenges within a broader comparative literature that sees environmental degradation as both a symptom and a driver of institutional decay.

Innovations such as Azolla-based wastewater treatment systems, which employ aquatic ferns to absorb nitrogenous compounds and purify greywater, and horizontal-flow constructed wetlands which mimic natural filtration processes, demonstrate the promise of low-cost, decentralized technologies tailored to arid and conflict-sensitive landscapes [16, 17].

Yet these interventions are not ends in themselves. They are designed as catalysts to restore degraded rangelands, revive endemic plant species displaced by land fragmentation, and rebuild agropastoral resilience through co-designed solutions that respect cultural heritage and local ecology. By bridging ecological engineering with grassroots participation, AUB's model moves beyond temporary relief toward long-term adaptive capacity, laying the groundwork for a new form of ecology-centered governance rooted in both scientific rigor and civic trust. In this sense, ecological interventions double as political ones: each restored wetland, each revived species, and each communal grazing ground becomes a site of negotiated trust, where local communities, state authorities, and academic institutions reconfigure their relationships. These ecological approaches are also projected to safeguard endangered herpetofauna and fragile microbiomes, now in retreat due to habitat loss and unchecked urbanization [18]. Through this convergence of ecological and institutional renewal, Arsaal emerges not merely as a site of crisis, but as a test case for rethinking governance in the Anthropocene: where shrinking laws and growing deserts call for an integrated response that marries environmental restoration with civic reconstruction.

2.2. Theoretical Rationale for Action: Governance and Tried Solutions

Reframing biodiversity as a foundation for peacebuilding exemplifies a people-centered governance approach that situates the land at the heart of civic agency. Local and global interventions alike underscore the critical interdependence of ecological, social, and institutional systems. For instance, Abou Zeid et al. highlight persistent structural flaws across the pesticide management cycle in Lebanon. Through an extensive review of the impacts of pesticides on human and environmental health, as well as the existing policy framework, the study identifies gaps in legislation, enforcement, and resource management [19]. Recommendations for mitigating pesticide risks include the adoption of a minimum list of lower-risk pesticides, supported by:

- Comprehensive registration and prescription systems;
- Government-supported integrated pest management (IPM) or integrated crop management (ICM) credit systems;
- Traceability mechanisms for both agricultural commodities and pesticide containers;
- Stock management to minimize obsolete pesticide accumulation; and
- Container recycling programs to reduce environmental contamination.

On a broader scale, the study calls for binding global interventions, ideally under United Nations oversight, grounded in human rights principles to ensure access to safe food. Such initiatives would restrict the use of hazardous pesticides, except WHO class IV products, in developing countries that score low on international assessments of pesticide lifecycle management [19]. In parallel, global health authorities stress the inseparability of climate change and biodiversity loss. Chris Zielinski, on behalf of UK Health Alliance on Climate Change, reports that over 200 health journals have urged the United Nations, political leaders, and health professionals to recognize these dual crises as one indivisible challenge, framing them as a planetary health emergency. Currently, climate and biodiversity are often treated as separate agendas: for example, the 28th UN Climate Change Conference (COP28) is scheduled in Dubai, while the 16th COP on Biodiversity will convene in Turkey in 2024.

Research communities supporting these conference findings remain largely distinct, yet a 2020 joint workshop concluded that solutions require integrated consideration of climate and biodiversity to avoid maladaptation and maximize beneficial outcomes. This integrated perspective aligns with the planetary health framework, which conceptualizes the natural world as a single interdependent system. Damage to one subsystem (such as drought, wildfires, floods, or rising temperatures) can cascade, disrupting soil fertility, inhibiting carbon sequestration, and amplifying climate impacts, at least in a microcosm like Hermel. Climate change is projected to surpass deforestation and other land-use changes as the primary driver of nature loss, underscoring the urgency of holistic governance interventions that link environmental conservation, human health, and socio-economic resilience [20-22].

Grounded in participatory action research, AUB's approach cultivates more than technical solutions, it fosters citizen agency while anchoring interventions in shared cultural identity. This synchronic engagement, which draws meaning from both past and present, is powerfully symbolized by the *Kamouh of Hermel*; the ancient stone monument that rises from Lebanon's northern plateau as a sentinel of layered civilizational memory, and now, as an emblem of environmental recovery. Once a marker of geographic orientation and cultural inheritance, the *Kamouh* now stands at the crossroads of a new kind of navigation: the search for sustainable governance in an era of ecological uncertainty. It represents a unifying symbol in a fractured landscape, where environmental degradation and social fragmentation mirror one another. In a rare but revealing twist of natural history, species as elusive as the monument itself are found growing in its proximity. As noted by Denchev et al., *Tilletia lolioli*, a smut fungus recognized only on Loliolum, is known from just two locations: Lebanon and Iran. Its documented occurrence: "Bequa'a Plain, at the Hermel Pyramid." The biological rarity echoes the cultural singularity of the *Kamouh*, whose stone face bears an almost indecipherable combination of Hellenic and Babylonian insignia, a silent palimpsest of ecological, historical, and symbolic entanglements. Such coincidences are not incidental. They reflect the deeper logic of Eco-Governance: a governance of place that draws meaning from the intimate, often overlooked connections between heritage, habitat, and hope. Through this lens, the *Kamouh* is no longer a relic, but a living symbol, where ancient iconography, endemic biodiversity, and collective memory converge to inspire a new ethic of environmental stewardship [8, 23]. Furthermore, rural landscape transformations are shaped by a complex interplay of socio-economic, political, and environmental factors. One of the most significant drivers is the global trend of rural-to-urban migration: currently, 55% of the world's population resides in urban areas, a figure expected to reach 68% by 2050. In many parts of the Global South, smallholder farmers facing low agricultural returns often migrate in search of better livelihoods, accelerating land use and land cover (LULC) changes. These shifts are not merely ecological, they are accompanied by profound socio-economic transitions at the national and local levels. Despite this, few studies have adequately connected localized rural landscape change to the broader socio-economic forces and environmental stressors driving it. Transformations often unfold through distinct landscape processes, fragmentation, aggregation, attrition, and dissection, each leaving a signature on the land.

2.3. All Roads Lead to Eco-Governance: From Green Spaces to Green Bonds

While spatial-temporal metrics provide valuable tools for mapping land use and biodiversity changes, they are insufficient on their own to inform policy, planning, and sustainable development. In regions such as Arsaal and the Hermel plateau, where ecological, cultural, and heritage values intersect, research must integrate human dimensions, recognizing that landscapes are both ecological and social constructs. Farmers, as primary stewards of the land, occupy a pivotal position at the intersection of ecological dynamics, economic pressures, and governance frameworks. Their decisions are influenced not only by personal aspirations and livelihoods, but also by access to infrastructure such as roads, water, and markets, and by policy incentives or regulatory constraints. When these decisions are embedded within participatory governance structures and linked to ecological restoration initiatives, they can produce cumulative, far-reaching impacts. Local interventions, whether through reforestation, soil rehabilitation, or biodiversity-friendly land management, can propagate across landscapes, generating ecological corridors, enhancing resilience, and providing models for broader regional sustainability. In parallel, these locale-based approaches create opportunities for sustainable tourism initiatives that valorize biodiversity, cultural heritage, and traditional knowledge, translating ecological stewardship into socio-economic benefits. A recent agronomic assessment of the Hermel district revealed significant potential for agricultural reclamation and ecological restoration, challenging prevailing assumptions about the region's aridity. Nearly 70% of the district was classified as having manageable limitations for productive use. Of this, 54.2% comprises soils requiring only moderate conservation interventions, concentrated in the east, central south, and north-western zones of Hermel. Key constraints include soil erosion and moderately unfavorable textures, which can be mitigated through targeted soil management practices such as cover cropping, contour farming, and organic amendments. An additional 12.7% of the land is characterized by steeper slopes or imperfect drainage. In these areas, terracing and runoff management not only enhance agricultural productivity but can also function as ecological corridors, facilitating the replenishment of native plant and animal species. Finally, 28.1% of the district, dominated by stony soils and petrocalcic layers (friable calcium carbonate formations 30–50 cm thick), presents opportunities for wetland creation and biodiversity regeneration, highlighting the potential for multi-functional landscapes that integrate agriculture, habitat restoration, and ecosystem services.

These findings underscore the strategic importance of place-based interventions that align agronomic potential with conservation priorities, providing a foundation for Eco-Governance approaches that simultaneously address ecological restoration, local livelihoods, and regional sustainability [6, 18, 24, 25]. Central to this effort is water resource management, a critical axis where environmental degradation, public health, and food security intersect. The challenge is compounded by untreated wastewater, which not only threatens aquifers and soils but undermines the viability of any long-term ecological recovery [26]. AUB's research offers nature-based, low-cost solutions to address this gap. In its 2023 GreenMetric entry, *Wastewater to Wetlands: Turning the Tide with Azolla Ferns*, researchers explored the use of Azolla pinnata to combat eutrophication by absorbing ammonium and phosphorus. This floating fern, long valued in traditional agriculture, emerges here as an ecological ally, capable of enhancing water availability and reducing nutrient pollution. In fragile regions like Hermel, such interventions can support sustainable agricultural and urban ecosystems, even under conditions of political instability and environmental stress [17].

Complementing this, AUB's ongoing work with horizontal-flow constructed wetlands offers an additional pathway for greywater reuse. These systems replicate natural filtration processes to treat wastewater effectively and affordably, especially in rural and peri-urban contexts [27]. Eco-Governance extends beyond the management of green spaces to the innovative mobilization of financial and institutional instruments. For example, green bonds, payment for ecosystem services (PES), and biodiversity credits can provide sustainable financing for conservation while reinforcing accountability, transparency, and institutional capacity. By linking local ecological action to measurable outcomes, these mechanisms incentivize both public and private stakeholders to invest in long-term sustainability, transforming isolated projects into systemic interventions that strengthen civic trust and institutional resilience. Ultimately, the trajectory from green spaces to green bonds illustrates the comprehensive logic of Eco-Governance: sustainability is not achieved solely through ecological interventions or policy mandates, but through the synergistic integration of local agency, participatory governance, financial innovation, and institutional reinforcement. This approach recognizes that effective environmental stewardship requires the alignment of ecological, social, and economic dimensions, ensuring that local actions contribute to regional resilience and global sustainability goals. By operationalizing this integrated vision, Eco-Governance provides both a conceptual framework and a practical roadmap for harmonizing human development with ecological integrity [28].

3. Methodology

Among the solutions developed, the Azolla filtration method provides a practical case study, published as part of AUB's GreenMetric initiative [17]. Considering the physical and economic constraints typical of non-arable arid ecosystems like Hermel, the Azolla-based water regeneration method offers a compelling alternative. Unlike conventional secondary (SW) or tertiary (TW) treatments, this nature-based solution incurs significantly lower initial and operational costs, while still achieving marked improvements in water quality over time.

4. Implementation and Expected Results

The data presented in Table 1 reinforce this point, showing that Primary Treated Wastewater (PW), when combined with Azolla treatment over a 56-day period, achieves color and odor scores comparable to more advanced treatments. At Day 0, PW recorded a color score of 1 (extremely turbid and black) and an odor score of 0 (extremely smelly), making it clearly unsuitable for any form of reuse. However, by Day 56, the PW color score improved to 4 (colorless and clear); matching the performance of the positive control (PC), and equalling or surpassing both SW and TW treatments. Similarly, its odor score rose to 4 (grassy smells), just one point shy of the odorless rating recorded in the PC and NC samples. This progression not only indicates effective pollutant removal through low-cost biofiltration but also positions Azolla as a viable agent for environmental restoration.

The method's ability to transform low-quality wastewater into a resource suitable for wetland replenishment, soil hydration, or biodiversity corridors, especially in areas with friable petrocalcic layers and minimal arable potential, further strengthens its ecological and economic appeal. Given the significant savings in infrastructure and energy costs compared to secondary or tertiary systems, the Azolla method emerges as both an environmentally sound and fiscally responsible model for decentralized water regeneration in Hermel and similar dryland regions.

In addition to improvements in visual clarity and odor, the Azolla-based treatment method demonstrates promising results in terms of water chemistry parameters critical to agricultural and ecological usability, namely pH and electrical conductivity (EC). Over the 56-day treatment period, Primary Treated Wastewater (PW) treated with Azolla exhibited a steady normalization of pH, rising from an initially acidic 6.92 to a more neutral 7.39. This brings it in line with optimal pH ranges (6.5–7.5) suitable for both plant growth and microbial soil health, making the treated water compatible with the rehabilitation of semi-arid ecosystems and marginal lands in Hermel.

Similarly, the EC values, which reflect the concentration of dissolved salts, show a notable decline from 954.33 µS/cm at Day 0 to 657.00 µS/cm at Day 56. For reference, EC levels remained higher in the more advanced Tertiary Treated Wastewater (TW) (787.33 µS/cm) at Day 56, suggesting that Azolla not only competes favorably with tertiary treatment in terms of ion reduction but may also be better suited for localized ecosystem reuse, where lower salt loads are critical to preventing secondary salinization. While still above the ideal threshold for sensitive crops (< 700 µS/cm), this value falls within an acceptable range for drought-tolerant and native species commonly used in dryland restoration, rangeland support, and soil stabilization efforts. Taken together, the improvements in pH and EC underscore the suitability of Azolla-treated water for ecological restoration and selective agricultural use in Hermel. When coupled with its affordability and decentralized implementation potential, this method offers a technically sound and ecologically adaptive model of Eco-Governance, capable of transforming wastewater from a liability into a life-supporting resource (Table 2). Beyond aesthetic and agronomic concerns, the environmental safety of reclaimed water must be evaluated through its impact on aquifer health and animal exposure, particularly regarding soluble reactive phosphorus (SRP). Excess SRP can contribute to groundwater contamination, eutrophication of downstream water bodies, and toxicity in grazing systems, making its reduction a key indicator of ecological suitability.

Table 1. Change in the Color and Odor in the Five Treatments: PW, SW, TW, PC, and NC, over the Three Sampling Dates

	Average Color and Odor Score over Three Sampling Dates					
	Sampling Date	**PW**	**SW**	**TW**	**PC**	**NC**
Color	Day 0	1	2	3	4	4
	Day 20	2	4	4	4	4
	Day 56	4	4	4	4	4
Odor	Day 0	0	1	1	5	5
	Day 20	3	4	4	5	4
	Day 56	4	4	4	3	5

*Negative Control (NC), Positive Control (PC), Primary Treated Wastewater (PW), Secondary Treated Wastewater (SW) and Tertiary Treated Wastewater (TW).

*Color scale: 0=extremely turbid and black, 1=slightly turbid and grey, 2=slightly turbid and green, 3=not turbid and light green, 4=colorless and clear

*Odor scale: 0=extremely smelly, 1=slightly smelly with burns, 2=fishy smells, 3=burns smells, 4=grassy smells, 5=odorless.

Table 3 reveals that Primary Treated Wastewater (PW) began with an extremely high SRP concentration of 8.06 ± 0.25 mg/L, a level that poses clear risks to both water table integrity and animal health, especially in unconfined aquifers or regions with shallow, friable soils like Hermel. However, following 56 days of Azolla treatment, SRP levels in PW dropped dramatically to 0.15 ± 0.12 mg/L; a reduction of over 98%, bringing it into a range comparable with Tertiary Treated Wastewater (TW) (0 ± 0 mg/L) and significantly safer than the Positive Control (PC) (0.013 ± 0.009 mg/L).

This substantial decrease demonstrates the biofiltration and nutrient absorption capacity of Azolla pinnata, whose rapid growth and symbiotic nitrogen-fixing capabilities allow it to efficiently sequester excess phosphorus from wastewater. Given that long-term phosphorus leaching is a primary vector for aquifer degradation and bioaccumulation in livestock, the effective mitigation of SRP through this method offers critical safeguards, especially in pastoralist communities where animals graze near or around water regeneration sites. In short, the Azolla-based method not only meets visual and agronomic reuse standards, but also satisfies biochemical safety thresholds, reducing long-term ecological risk. This reinforces its value as a low-cost, low-impact solution aligned with the principles of Eco-Governance, linking public health, environmental resilience, and rural livelihoods in a single, scalable intervention.

Table 2. Average pH and EC (µS/cm) in the Five Treatments: PW, SW, TW, PC, and NC, over Three Sampling Dates

	Average pH and EC (µS/cm) over Three Sampling Dates					
	Sampling Date	**PW**	**SW**	**TW**	**PC**	**NC**
pH	Day 0	6.92	6.93	6.88	6.95	6.93
	Day 20	7.32	7.54	7.48	7.24	7.28
	Day 56	7.39	7.46	7.5	7.34	7.22
EC (µS/cm)	Day 0	954.33	738.33	751.33	820.33	811.67
	Day 20	701.67	594.33	598.33	564.00	512.33
	Day 56	657.00	721.67	787.33	686.50	638.00

*Negative Control (NC), Positive Control (PC), Primary Treated Wastewater (PW), Secondary Treated Wastewater (SW) and Tertiary Treated Wastewater (TW).

Table 3. Change in the Concentration of SRP (im mg/L) in the Five Treatments: PW, SW, TW, PC, and NC, over the Course of 56 Days

	Average pH and EC (µS/cm) over Three Sampling Dates				
	PW	**SW**	**TW**	**PC**	**NC**
Day 0	8.06±0.25 Aa**	0.028±0.004 Ba	0.06±0.01 Ba	1.23±0.12 Ca	0.007±0.003 Ba
Day 20	0.29±0.07Ab	0.06±0.001 Aa	0.05±0.01 Aa	0.3±0.03 Ab	0.05±0.005 Aa
Day 56	0.15±0.12 Ab	0.005±0.002 Aa	0±0 Aa	0.013±0.009Ab	0.02±0.01Aa

*Negative Control (NC), Positive Control (PC), Primary Treated Wastewater (PW), Secondary Treated Wastewater (SW) and Tertiary Treated Wastewater (TW).
*SE is the standard error
**Values are deemed significant for p-value <0.05. Different capital letters refer to significant values within the same row and different small letters refer to significant values within each column.

The implications of this biochemical efficacy go beyond wastewater treatment alone. Given the demonstrated ability of Azolla-based systems to reduce soluble reactive phosphorus (SRP) to ecologically safe levels within 56 days, the reuse of treated water becomes a viable strategy not just for irrigation, but for strategic ecological restoration. In particular, the creation of localized reservoirs, designed to replenish wetlands and support the regeneration of endemic flora, offers a scalable, nature-based solution for degraded dryland environments such as Hermel. The placement of these reservoirs, however, must be carefully guided by environmental constraints and land potential. In this regard, the spatial mapping work of Abou Najem et al. proves invaluable (Figure 1). While their study did not propose reservoir construction, it identified key zones across Hermel based on soil suitability, land gradient, and erosion vulnerability, criteria that directly inform where ecological interventions are likely to succeed or fail. By overlaying our proposed reservoir sites with their zoning maps, we are able to identify priority areas where reclaimed water can be channelled to support wetland recreation, soil hydration, and biodiversity corridors, while minimizing risk to aquifers or productive lands. This integration of biofiltration science with landscape-level spatial planning reflects a broader shift from ad hoc water reuse toward a coordinated model of territorial regeneration, anchored in the principles of Eco-Governance, where restoration is not only ecologically viable, but also socially and spatially intentional [25].

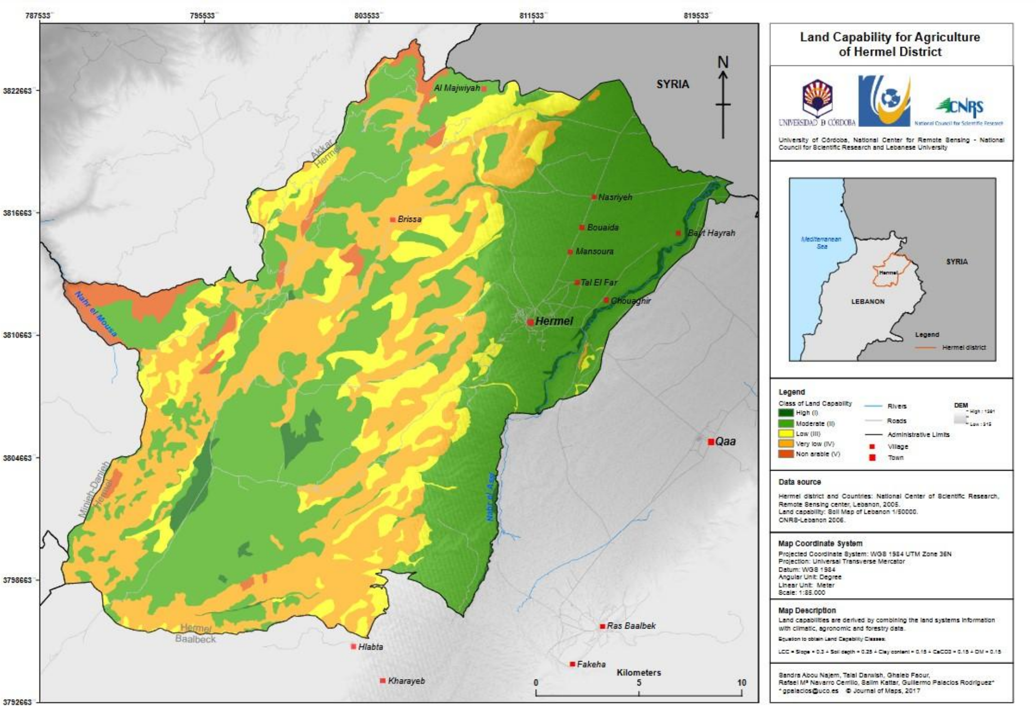

Figure 1. Land capability for agriculture map of Hemel District

The biochemical efficacy of Azolla-based systems shown to reduce soluble reactive phosphorus (SRP) to safe levels within 56 days, makes the reuse of treated water a viable strategy for replenishing wetlands, supporting endemic flora, and rehabilitating arid pastures. Making sure ecologically sound operational efficiency is met, the placement of decentralized reservoirs must be guided by two primary factors: environmental suitability and proximity to urban concentrations.

The first criterion builds on the spatial zoning work of Abou Najem et al., whose mapping of Hermel’s soil characteristics, land gradients, and erosion risk provides a foundational reference for identifying areas with high ecological receptivity. While their research did not propose any form of infrastructure development, their mapped zones allow us to preliminarily identify priority sites where regenerated water can be used to sustain biodiversity corridors or restore fragile soils without damaging aquifers. The second criterion concerns logistical feasibility. To avoid excessive transport or high-cost irrigation networks, reservoirs should ideally be placed midway between urban settlements and the target zones for reuse, whether those are commercial orchards, replenished wetlands, or dryland pastures. This approach minimizes pumping distances and supports decentralized, community-scale management of treated water resources. This primary siting suggestion, reflected in the latest zoning map (Figure 2), offers a preliminary framework for action. Final placement would be refined through site-specific assessments, taking into account infrastructure access, community priorities, and the planned function of each reservoir.

Together, these spatial and ecological considerations reinforce the vision of Eco-Governance; one that coordinates environmental restoration, rural livelihoods, and infrastructural logic into an adaptive and locally grounded strategy. This proposed placement strategy, based on the latest zoning map (Figure 2), serves as a preliminary recommendation, offering a spatial framework that balances ecological suitability and logistical efficiency. It is intended as a starting point, to be further refined through dedicated, site-specific studies of the targeted zones and evaluated in relation to their intended end use, whether for irrigation of commercial crops, wetland regeneration, or restoration of arid-type pastures.

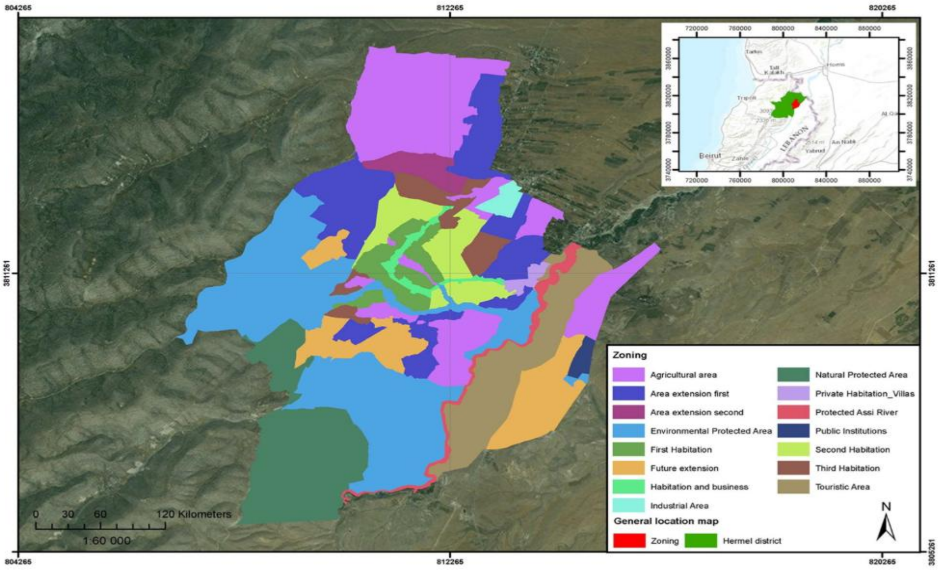

Figure 2. Map of Hermel Zoning

5. Conclusion

From the cacti, roses grow; a paradox befitting Hermel's own transformation, where conflict-scarred, arid landscapes can, through care and collective vision, blossom into living systems of renewal. The environment here is not merely a natural resource; it is a cultural and ecological archive, engraved in the land and symbolized by monuments like the *Kamouh of Hermel*, where rare endemic species still quietly echo a forgotten balance.

Two decades earlier, the Environment and Sustainable Development Unit (ESDU) at AUB helped navigate this fragile terrain, resolving the initial sequelae of the Arsaali paradox through participatory land-use planning and community-led negotiation. That work laid the foundation for what now re-emerges as a broader framework: not just of environmental recovery, but of Eco-Governance; the practice of turning political desert land into urban oases of resilience, knowledge, and coexistence. Yet, the road to such transformation has not been linear. The deterioration of trust in public institutions, compounded by entrenched local corruption and opaque power structures, has weakened the collective will to maintain or expand on earlier gains. This erosion of civic confidence cannot be reduced to external forces. As Hamadeh and Zurayk have shown in their study of Lebanon's "rivers and rivalries", it was not foreign pressures, such as the often-cited Syrian influence, that led to the collapse of watershed governance. Rather, it was domestic mismanagement, the absence of accountability, and the deliberate fragmentation of institutional authority that unravelled the capacity of communities and agencies to cooperate over shared resources. That lesson resonates strongly in Hermel, where the downward spiral is less a function of environmental inevitability than of systemic political decay; a breakdown not of nature, but of governance. Without credible institutions or mechanisms of redress, even the most innovative ecological solutions risk becoming isolated interventions.

Eco-Governance, then, must confront not only physical degradation but also the institutional voids and civic disillusionment that perpetuate cycles of neglect. Only by restoring trust and rooting action in transparency, equity, and shared cultural meaning can the will to transform truly take hold and guide arid, conflicted territories toward lasting renewal. Through innovations such as *Azolla*-based filtration and constructed wetlands, coupled with community-centred implementation, AUB demonstrates that nature-based solutions, when grounded in participatory action research, can do more than mitigate harm, they can regenerate meaning. When biodiversity conservation is anchored in heritage and stewardship becomes a shared endeavor, landscapes once seen as lost or degraded can reveal new futures. In this light, Hermel is not a periphery, but a prototype: a place where roses may grow from cacti, and where sustainable development begins with recognizing that even in the driest ground, renewal is possible; if guided by systems rooted in equity, ecology, and enduring local wisdom.

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Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

Authors Contribution

R.E. is the sole author of this manuscript and was responsible for all aspects of the research and writing. This includes the conceptualization of the study, development of the theoretical framework, methodology design, data collection and interpretation, and the integration of ecological, governance, and socio-political analyses. **R.E**. conducted the full literature review, prepared all figures and narrative sections, and drafted, revised, and finalized the manuscript. All research decisions, analytical directions, and interpretations reflect the author's independent work. Inspiration and contextual insights from acknowledged colleagues and prior scholarship are recognized in the Acknowledgments section, no other individuals contributed to the authorship, analysis, or writing of this paper.

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