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Case Study



# Groundwater Vulnerability and Non-Economic Loss and Damage in the Periyar River Basin, Kerala State, India

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## Abstract

Groundwater (GW) is a critical yet increasingly threatened resource, particularly in India, the world's largest user. Climate change, through rising temperatures, increased evapotranspiration, and erratic rainfall, intensifies GW depletion by altering aquifer dynamics, while industrialization and unregulated quarrying exacerbate this degradation. The resulting losses extend beyond economic measures, manifesting as Non-Economic Loss and Damage (NELD), including displacement of livelihoods, cultural identity, traditional water-sharing practices, and collective well-being. Hydrogeochemical assessments and socio-ecological vulnerability analysis in the Periyar River Basin (PRB), —a climate-sensitive zone in the Southern Western Ghats—illustrate how consecutive droughts (2016–2017) and floods (2018–2019) induce profound, intangible losses, disrupting agrarian and fishing livelihoods and weakening cultural attachment to riverine ecosystems. This study highlights Non-Economic Loss and Damage (NELD) in the Periyar River Basin, showing how groundwater contamination, chemical changes, and rising climate-linked diseases like Dengue and Leptospirosis affect community health, and well-being. These impacts go beyond financial costs, emphasizing the need to consider ecological, cultural, and social dimensions in water management and climate adaptation planning. Incorporating NELD into GW governance is essential for climate justice, enabling recognition and quantification of these invisible losses, strengthening basin-level planning, supporting global engagement with climate finance mechanisms such as the Fund for Responding to Loss and Damage (FRLD), and fostering resilience while safeguarding social and ecological integrity in the Western Ghats.

## INTRODUCTION

### Groundwater as a Critical yet Fragile Resource

Groundwater, the vast but hidden freshwater reserve beneath the Earth's surface, remains the most vital source of water for human sustenance, accounting for more than one-third of global water use [1]. In developing nations, where municipal water supply systems are often unreliable, groundwater (GW) serves as a dependable alternative for drinking, domestic, and agricultural needs. However, population growth, urban expansion, and climate change have collectively placed immense pressure on this finite resource, intensifying the occurrence of droughts and floods [2]. Rising temperatures elevate evapotranspiration rates, reducing groundwater recharge (Central Water Commission 2016), while erratic rainfall—dominated by short, high-intensity events—has altered aquifer dynamics and decreased water tables across many regions. In India, the world's largest groundwater user, annual extraction exceeds 230 cubic kilometres [3-5]. Approximately 30% of the urban and 90% of the rural population rely directly on untreated groundwater or surface water [6]. The water-stressed city of Bangalore, facing a shortfall of nearly 500 MLD—one-fifth of its daily demand—reflects the growing dependence on groundwater. Such reliance underscores not only an economic dependence but also a social and cultural dependence on this vital resource. The depletion and contamination of aquifers thus represent a deeper layer of loss — a form of non-economic loss and damage (NELD) — encompassing disruptions to livelihoods, traditional practices, and community well-being that cannot be measured in monetary terms.

The United Nations Framework Convention on Climate Change (UNFCCC) describes non-economic loss and damage (NELD) as encompassing a wide variety of losses that cannot be readily measured in monetary terms or valued through market mechanisms. These losses go beyond tangible damages such as the destruction of property, infrastructure, assets, or reductions in agricultural yield and income that often accompany the effects of climate change.

Globally, climate policy and finance mechanisms are beginning to recognize the urgency of addressing such losses. The Fund for Responding to Loss and Damage (FRLD), launched during COP28 in Dubai in 2023, marked a historic step toward compensating unavoidable climate impacts. However, current frameworks under the UNFCCC—including the Warsaw International Mechanism (WIM) and the Santiago Network—have yet to systematically integrate NELD as a separate component [7]. For countries like India, where hydrological systems such as the Periyar Basin are both ecologically fragile and socially vital, embedding NELD considerations into adaptation and groundwater governance is critical to achieving climate justice and long-term resilience.

### Groundwater Degradation as a Source of Non-Economic Loss

The scarcity and degradation of groundwater lead to a cascade of non-economic impacts: loss of ecosystem integrity, reduced food and water security, increased social inequities, and psychological distress among affected communities. India's low ranking in the 2024 (176th rank) Environmental Performance Index (EPI score: 27.6) and its 143rd position in the sanitation and drinking water category illustrate

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these multidimensional vulnerabilities. For many rural and indigenous populations, water sources hold deep cultural and spiritual significance — their decline represents not just ecological damage but also the erosion of cultural identity, traditional knowledge, and collective memory.

## Hydrogeochemical Dynamics and Non-Economic Losses under Climate Extremes in the Periyar River Basin, Western Ghats

The Periyar River Basin (PRB) in Kerala, a climate-sensitive region (Figure 1), is undergoing significant and often irreversible changes in its groundwater systems as a result of the escalating impacts of climate change [8]. Hydrochemical assessments provide essential insight into the spatial and temporal dynamics of groundwater systems [2-9]. Several studies, through the use of bivariate plots, water quality indices, and multivariate analyses, have enhanced understanding of groundwater chemistry [8-10]. However, integrating such scientific observations with the NELD framework broadens their relevance, revealing how hydrochemical changes affect not only environmental parameters but also human-environment relationships, social resilience, and livelihood continuity.

The Periyar River Basin (PRB) in Kerala, situated within the Western Ghats (WG), can be classified as a critical zone where there is intersection between environmental stress and non-economic loss. While the economic implications of these changes—such as crop loss, infrastructure damage, and livelihood disruptions—are widely recognized, a significant share of the impacts remain unquantified and underrepresented in policy frameworks. These are the Non-Economic Losses and Damages (NELD)—losses that do not appear in conventional financial metrics but deeply affect communities, ecosystems, and cultural identities. Consecutive droughts in 2016–2017 followed by severe floods in 2018–2019 have profoundly altered the basin's hydrological equilibrium [11]. These climatic extremes have not only reshaped the physical landscape but also triggered intangible losses — including displacement of local populations, disruption of agrarian and fishing livelihoods, and loss of cultural attachment to riverine ecosystems.

The 2018 Kerala Floods further altered groundwater properties across space and time, with large areas remaining submerged for days, restricting access for sampling [2]. Analysis of 26 locations revealed notable changes in water quality: pH, hardness, bicarbonate, and calcium decreased from pre- to post-flood periods, while turbidity, sulfate, ammonia, sodium, and potassium increased, reflecting soil leaching and mixing of organic residues. Microbial contamination, particularly E. coli, exceeded WHO limits due to infiltration of sewage and waste, highlighting persistent public health risks. Hydrochemical analyses, including Piper and Gibbs plots, indicated that groundwater largely remained of Ca–Mg–$HCO_3$ type and rock-dominated in origin [2]. These patterns demonstrate that rapid industrial and human activities exacerbate groundwater stress, producing measurable changes in water quality while generating ongoing non-economic losses to ecosystem health and community well-being [12]. A comparative summary of the findings from these two studies, highlighting the Non-Economic Loss and Damage (NELD) associated with groundwater changes in the Periyar River Basin, is presented in Table 1.

As shown in Table 2, the reported cases of communicable diseases from 2013 to 2022, the study area experienced a dynamic and complex health profile that reflects the increasing impact of climate change and public health interventions. Extreme weather events like the 2018 Kerala floods, along with the awareness spurred by the COVID-19 pandemic, led to a sharp, sustained decrease in cases of mass illnesses like Acute Diarrheal Disorder (ADD) and Viral Fever after 2017, suggesting improved sanitation and hygiene practices. However, this progress was contrasted by a concerning upward trend in climate-linked, vector-borne, and zoonotic diseases, particularly Dengue and Leptospirosis, which saw

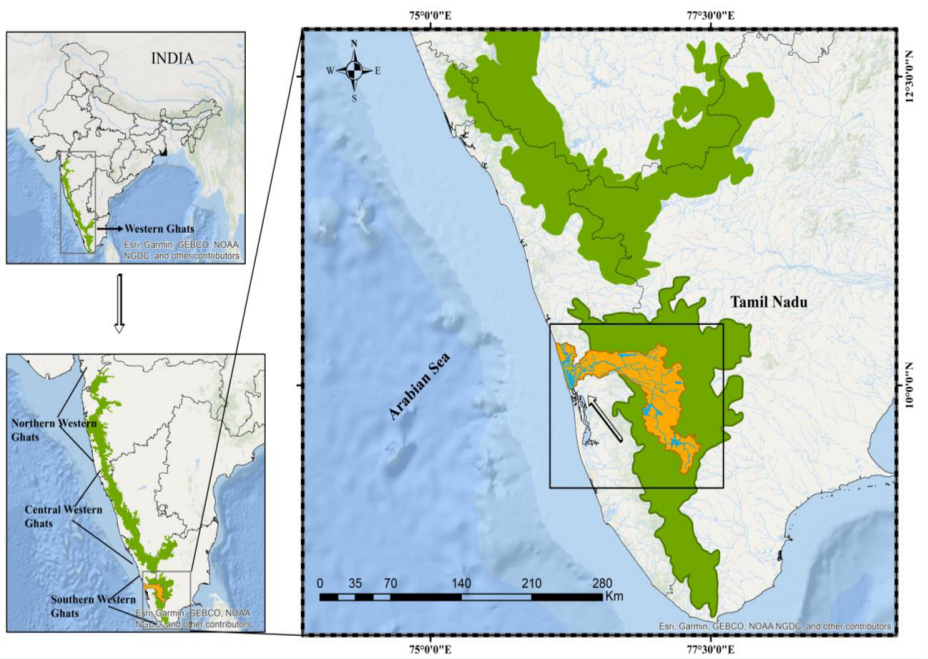


**Figure 1:** Location of Periyar basin along the WGs

**Table 1**: Manifestation of Non-Economic Loss and Damage (NELD) in the Periyar River Basin

| Aspect | Observed Change / Cause | NELD Implication |
|---|---|---|
| River health | Water quality improved during industrial lockdown | Loss of ecosystem services when polluted |
| Community well-being | Reduced access to clean river due to industrial pollution | Loss of cultural and social benefits |
| Groundwater quality (Post-2018 Flood) | Decrease in pH, hardness, bicarbonate, calcium; increase in turbidity, sulfate, ammonia, sodium, potassium due to flood-induced soil leaching | Loss of safe water and ecosystem function |
| Public health | E. coli contamination above WHO limits from sewage infiltration | Health risks and reduced water security |
| Hydrochemical stability | Groundwater remains Ca–Mg–$HCO_3$ type but altered by floods | Loss of geochemical balance and resilience |
| Climate vulnerability | Temporal changes in water chemistry after extreme floods | Loss of resilience to climate shocks |

**Table 2** : Reported cases of various communicable diseases in Periyar basin during 2013-22 period

| Name of disease | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 |
|---|---|---|---|---|---|---|---|---|---|---|
| Dengue | 107 | 61 | 54 | 130 | 289 | 65 | 212 | 85 | 492 | 466 |
| Malaria | 19 | 13 | 41 | 22 | 49 | 40 | 28 | 29 | 6 | 10 |
| Leptospirosis | 51 | 31 | 32 | 29 | 38 | 40 | 36 | 47 | 50 | 59 |
| Hepatitis | 36 | 23 | 14 | 8 | 76 | 45 | 19 | 12 | 28 | 42 |
| H1N1 | 2 | - | 21 | 72 | 46 | 28 | 21 | 1 | - | - |
| Viral Fever | - | - | - | - | 16,96,565 | 77,476 | 45,468 | 31,161 | 32,702 | 64,365 |
| Acute Diarrheal Disorder | - | - | - | - | 5,40,228 | 12,415 | 9,924 | 6,474 | 5,766 | 8,803 |
| Chickenpox | - | - | - | - | 4,783 | - | 1,678 | - | - | - |
| Typhoid | - | - | - | - | 19 | 9 | 1 | 2 | - | 4 |

significant case spikes toward 2021 and 2022. This suggests that while local efforts successfully managed widespread waterborne illnesses, the growing challenges of climate change is exacerbating diseases transmitted via vectors and animals, making them an emerging priority.

The rising cases of climate-linked diseases like Dengue and Leptospirosis in the Periyar River Basin represent Non-Economic Loss and Damage (NELD), reflecting impacts on community health, well-being, and resilience that go beyond financial costs.

Despite numerous studies on the PRB addressing pollution [2-12], flood dynamics [2], and saline intrusion [13], comprehensive research linking groundwater chemistry with socio-ecological impacts remains limited. Industrialization [12], unregulated quarrying [13,14], and land-use changes [15-17], have further intensified pressures on both surface and subsurface water systems. These transformations embody the non-economic dimensions of environmental degradation—loss of ecological stability, traditional water management practices, and community resilience. Therefore, integrating hydrogeochemical analysis with NELD perspectives is essential to fully understand and address the complex, layered consequences of groundwater stress in the various basins of Western Ghats.

## CONCLUSION

The case of the Periyar River Basin underscores the urgent need to move beyond traditional, economy-centric approaches to tackle climate risks and evolve water management practices. The recurring extremes of drought and flood have not only transformed the basin's hydrology but have also led to intangible, non-economic losses—the erosion of cultural landscapes, traditional water-sharing practices, intergenerational knowledge, and collective wellbeing. Recognizing and quantifying these invisible dimensions of loss is essential to designing holistic adaptation and recovery frameworks.

As the Fund for Responding to Loss and Damage Fund (FRLD) evolves, COP30 in Belém is expected to play a decisive role in shaping equitable and accessible pathways for financing NELD. Developing nations such as India can strengthen their negotiation positions by presenting empirical evidence of non-economic losses within regions of Peninsular India, like the Periyar Basin—illustrating how climate impacts extend beyond physical damage to threaten social fabric, heritage, and ecological identity.

The 2018 Kerala Floods and ongoing industrial activities have greatly affected groundwater quality in the Periyar River Basin, causing chemical changes and high microbial contamination. The rising cases of climate-linked diseases like Dengue and Leptospirosis in the Periyar River Basin further represent NELD, reflecting impacts on community health, well-being, and resilience that go beyond financial costs. These changes show the ongoing stress on groundwater and the Non-Economic Loss and Damage (NELD) to both ecosystems and local communities. Including NELD in groundwater management, basin planning, and national climate reporting can make sure these human and environmental losses are recognized, helping protect communities, preserve culture, and maintain healthy ecosystems such as those of the river basins in the Western Ghats.

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