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CYCLONE IMPACTS ON THE WATER-FOOD-ENERGY (WFE) NEXUS IN MADAGASCAR, GOVERNANCE CHALLENGES, AND POLICY PATHWAYS FOR RESILIENCE

Andrianasolomahefa Rovatiana Salema [1*]

[1] Faculty of Public Governance and International Studies, Doctoral School of Public Administration, National University of Public Service, Budapest, Hungary,
https://orcid.org/0009-0004-7726-8811
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Abstract

Tropical cyclones repeatedly disrupt Madagascar's water supply, food production, and energy services, yet these sectors are often planned and managed separately. This paper examines the cross-sector pathways through which cyclone impacts may cascade across the water–food–energy (WFE) Nexus and considers the governance conditions that shape preparedness and recovery. The study combines a structured review of peer-reviewed literature with a database of 34 significant cyclone events reported for January 2000–February 2026. Seven studies met the review's stated eligibility criteria. The event database records more than US$2.628 billion in reported direct physical damage; entries for 2025–2026 remain provisional and require confirmation through final post-disaster assessments. The analysis identifies six pathways linking sector disruptions and discusses eight governance challenges, including fragmented responsibilities, constrained financing, limited data, and weak accountability. It then proposes six policy pathways and assesses their implementation conditions, risks, and possible indicators. Because the peer-reviewed evidence base is small and recent event records are provisional, the findings should be interpreted as an evidence-informed synthesis rather than a definitive causal or loss-estimation model. The paper argues that resilience planning should assess cross-sector dependencies alongside sector-specific needs and strengthen the institutions and monitoring systems required to implement and evaluate integrated responses.

1 Introduction

Madagascar sits at a dangerous crossroads of poverty and climate exposure. The country is ranked among the three most climate-vulnerable nations in the world, a vulnerability that climate projections suggest will deepen as global warming intensifies tropical cyclone rainfall and wind speeds [19], yet it absorbs three to four named tropical cyclones every year. Approximately 75% of its population depends on subsistence farming, and rural electrification remains below 15%. [1][2] At a GDP per capita of around $518, placing Madagascar in the bottom ten percent globally, the 34-event database compiled for this study records more than $2.6 billion in direct cyclone damage. The

[*] Corresponding author.
E-mail address: andrianasolomahefa.rovatiana.salema@stud.uni-nke.hu ; rovatiana.salena@gmail.com

direct-damage total and a separate ARC seasonal-loss estimate use potentially different scopes and should not be compared without source harmonisation (Section 3.1).

Cyclones do not simply cause damage and go away. They set off chain reactions that move across water, food, and energy systems in ways that sector-by-sector governance cannot predict or handle. The Water–Food–Energy (WFE) Nexus framework [18] captures this interconnection: water is needed to irrigate crops and generate hydroelectric power; energy is needed to pump water and process food; and choices about food production affect how much water and energy are available. When a single cyclone simultaneously destroys irrigation infrastructure, cuts power lines, and contaminates drinking water, as happened in eight events between 2000 and 2026, the resulting harm is not the sum of three separate losses. It is far greater.

Cyclones can trigger connected disruptions across water, food, and energy systems. Damage to electricity infrastructure may interrupt water pumping and treatment; flooding can damage crops and irrigation networks; and disrupted transport or energy supply can delay food distribution and water-system repairs. These interactions provide a plausible basis for cascading and compounding impacts. This study examines these linkages qualitatively using published studies and event-level reports. It does not estimate a counterfactual total loss for each cyclone; therefore, “multiplicative” describes interacting mechanisms rather than a statistically estimated multiplier.

Cyclone Gezani (February 2026) is the most recent illustration. The storm struck Madagascar as a Category 3 cyclone on 11 February 2026, producing sustained winds of up to 180 km/h and gusts of 250 km/h. Within 24 hours, it damaged or destroyed up to75% to 90% of housing and infrastructure in Toamasina, the country's main port city, and exposed an estimated 1.8 million people to hazardous winds. [8] Cyclone Fytia had already saturated soils, flooded farmland, and partially breached a dam near the capital Antananarivo earlier in the same season. The compound effect of back-to-back storms is precisely the kind of multiplicative harm this paper seeks to explain and address.

1.1 Research Questions

This paper asks four questions:

1. How do cyclones disrupt Madagascar's water, food, and energy systems together, and what is the full scale of that disruption from 2000 to 2026?
2. Which cross-sector linkages make the harm worse than any single sector would suggest?
3. What governance failures have blocked effective responses, and how do they interact?
4. What integrated reforms, grounded in evidence, would build lasting WFE Nexus resilience?

2 Methodology

The study has two components: a structured review of peer-reviewed literature and a descriptive event database. For the literature review, Web of Science, Scopus, and Google Scholar were searched on 2026. The search combined terms relating to “cyclone” or “tropical storm” with “water,” “food,” “energy,” “nexus,” and “Madagascar.” Complete search strings, filters, and date limits are provided in Supplementary Material S1. Studies were eligible when they (i) reported empirical findings, (ii) examined a cyclone or a clearly justified analogous hazard, (iii) documented impacts on at least one WFE sector, and (iv) were published in English or French. Seven studies were included. The number of records retrieved, duplicates removed, records screened, full texts assessed, and full texts excluded with reasons must be reported from the screening log in a PRISMA-style flow diagram. Screening counts should not be estimated retrospectively or inferred from memory.

The event database covers significant cyclone events affecting Madagascar from January 2000 through February 2026. Each record should be traceable to its source and should distinguish confirmed observations from preliminary estimates and forecast exposure. For each event, the dataset records dates, source, reported deaths and affected or displaced population, reported direct damage, currency and price basis where available, and data status. The database is descriptive: source definitions and reporting completeness vary across events, so totals should not be interpreted

as a fully harmonised estimate of all cyclone-related economic and social losses. The final database, source log, extraction date, and reconciliation rules should be provided as supplementary material.

The small number of eligible studies may indicate a gap in research specifically addressing cyclone impacts across the WFE Nexus in Madagascar, but it may also reflect the databases, search terms, language restrictions, and eligibility criteria used. Accordingly, the review findings are treated as indicative and triangulated with institutional situation reports and the event database. Institutional reports are used for event context and preliminary impact reporting; they are not counted as peer-reviewed studies in the review.

Table 1. Studies Included in the Systematic Review

Paper	Cyclone Event	Location	Primary Sector	Key Finding
Mong et al., 2001 [4]	Hudah (2000)	NE coast	Water / Health	Disinfection kits cut contamination significantly
Harvey et al., 2014 [1]	Multiple seasons	3 regions	Food / Livelihoods	51% of farmers suffered cyclone damage in 5 years
Sinha, 2014 [7]	Gafilo (2004)	National	Governance	Government response tied to the political voice of the community
Carter et al., 2022 [5]	Haruna (2013)	SW coast	Marine / Food	Coral cover fell 15.8%, and fish biomass dropped
Weiskopf et al., 2021 [2]	Giovanna (2012) +	E, NE, W regions	Multi-sector	Cross-sector coordination is the key missing link
Rakoto Harison et al., 2024 [3]	Enawo (2017)	NE villages	Food / Livelihoods	Compound shocks multiply, not just add harm
Balaei et al., 2019 [6]	TC Pam (2015)	Vanuatu (comparator)	Water / Governance	Community social capital speeds water recovery

Sources: Compiled by the authors from included studies.

3 Cyclone Impacts 2000–2026: Scale and Pattern

3.1 The Aggregate Picture

The event database records more than US$2.628 billion in reported direct physical damage across 34 significant cyclone events between January 2000 and February 2026. This total is a descriptive sum of reported figures available for the selected events, not a complete estimate of all

direct and indirect losses. The coverage and price basis of individual estimates may differ, and the entries for 2025–2026 are provisional. The aggregate should therefore be interpreted cautiously and should not be compared directly with GDP growth or treated as a harmonized annual loss estimate. The database also identifies eight events in which available sources report disruption across water, food, and energy systems. This count describes co-occurrence in the source material; it does not quantify the additional loss attributable to cross-sector interactions.

Table 2. Key Aggregate Statistics: Madagascar Cyclones, 2000–February 2026

Indicator	Figure
Total significant events (2000–Feb 2026)	34 documented events
Total confirmed deaths (minimum)	1,138 (indirect mortality substantially higher)
Total people affected (cumulative)	>5.4 million across all events
Total people displaced / homeless	>1.5 million (major events only)
Total direct economic damage	>$2,628 million USD
Costliest single event	Cyclone Freddy (2023): ~$482M (~3.3% of GDP)
Deadliest single event	Cyclone Gafilo (2004): 237 deaths; 300,000 homeless
All-3-Sector Nexus events (W+F+E)	8 events: Gafilo, Ivan, Haruna, Enawo, Ava, Batsirai, Freddy, Gezani
Compound multi-cyclone seasons	4 documented seasons: 2007–08, 2021–22, 2022–23, and 2025–26 (the latter is provisional)
Category 4–5 landfalls since 2000	8 events, 8 of the 12 Cat 4–5 storms since 1911, occurred after 2000

Sources: EM-DAT [9]; ACAPS [8]; ARC [13]; UNDRR [14]; World Bank [16]. The event-database figures are direct damage only. Entries for 2025–2026 (the most recent compound-season row and any ranking that depends on it) are provisional pending final post-disaster assessment; see Section 2.

3.2 Cyclone Gezani (2026): A Compound Crisis in Real Time

All figures in this section are drawn from preliminary BNGRC, ACAPS, and WFP situation reports current as of mid-February 2026; as noted in Section 2, they are provisional and will be superseded once Madagascar's final post-disaster needs assessment is published.

Cyclone Gezani made landfall on 11 February 2026 as a Category 3 storm, hitting the Ankazobe district in Madagascar's Analamanga region with sustained winds of 180 km/h and gusts

reaching 250 km/h. [8] Red alerts were issued for five northeastern regions, Alaotra Mangoro, Analamanga, Analanjirofo, Atsinanana, and Betsiboka, and heavily populated cities, including Antananarivo, Toamasina, and Ambatondrazaka, faced the greatest danger.

By 12 February, the storm had directly affected roughly 250,000 people, displaced 6,800, and caused at least 31 deaths. Initial assessments by Madagascar's National Disaster Management Office (BNGRC) found that 75% to 90% of infrastructure and housing in the Atsinanana region, particularly around Toamasina, had been destroyed, with over 54,000 homes ruined and 11,000 flooded. [11] Exposure projections indicated that up to 1.8 million people could be affected as the storm moved westward through 15 February. These two figures measure different things and should not be added together: 250,000 is BNGRC's confirmed count of people directly affected as of 12 February, while 1.8 million is ACAPS/WFP's wind-field exposure projection, the population living in areas forecast to experience at least 60 km/h winds through 15 February, not a count of confirmed impact. Table 3 shows that exposure breakdown by region and by wind-speed threshold; its 3,298,285 grand total sums population across all three wind-speed bands and is a measure of exposure breadth, not of people confirmed affected.

The Gezani figures used here are preliminary estimates drawn from situation reports published in February 2026 (Figure 1). They should be treated as a dated snapshot, not as final impact totals. The manuscript distinguishes the number of people reported as directly affected by a specified date from the population living in areas forecast to experience winds above a given threshold. These measures answer different questions and must not be added together. Where exposure estimates are divided into nested wind-speed thresholds, the threshold totals may overlap; their sum must not be described as a count of unique people. All values in the accompanying table should be checked against the original dated source, including the definition of exposure, forecast period, and whether values are observed, estimated, or projected.

Table 3. Population Exposed to Cyclone Gezani Through 15 February 2026 (provisional)

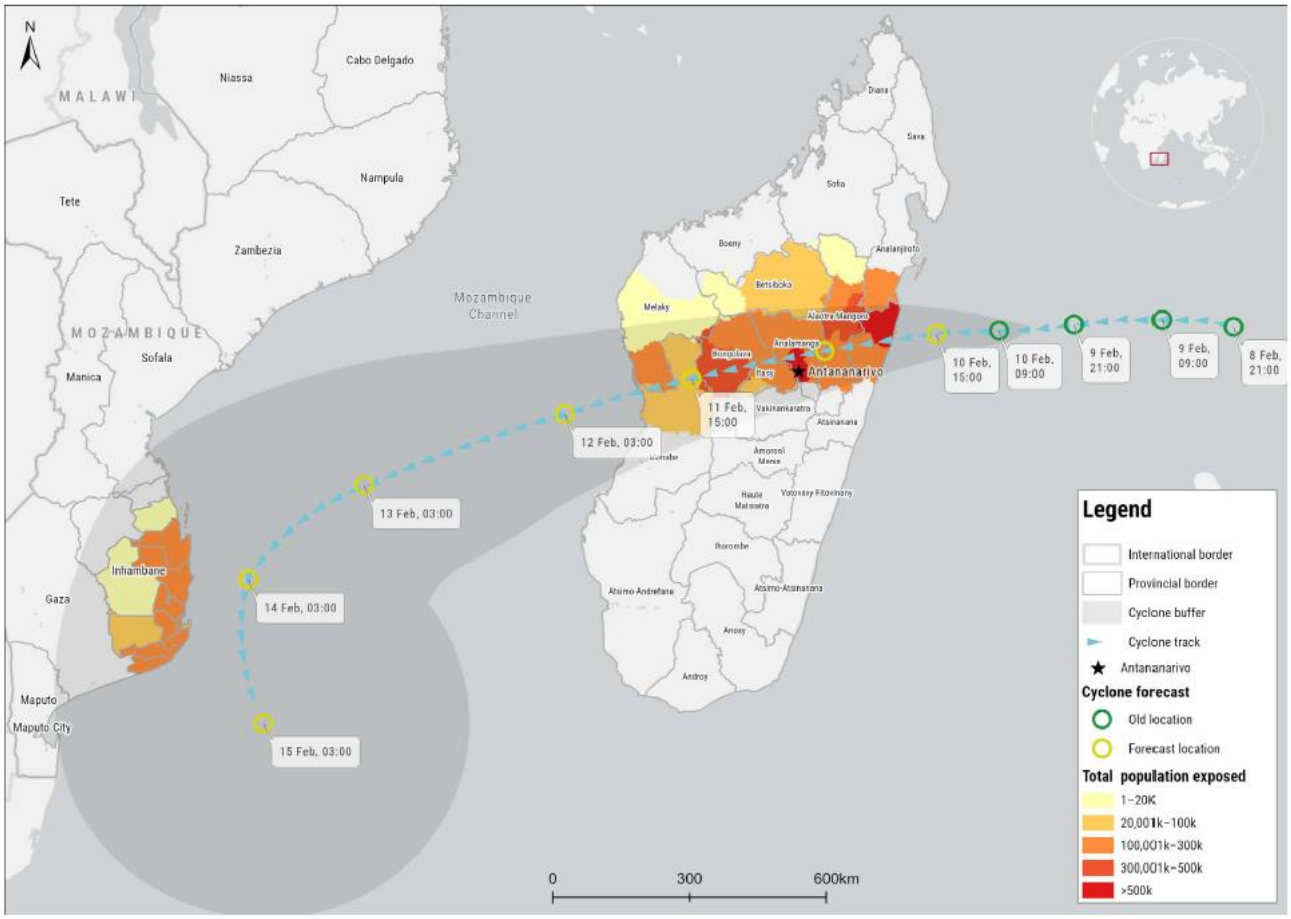
Regions	**Population exposed**	**Population exposed**	**Population exposed**	**Sum of threshold counts**
	≥60 km/h	**≥90 km/h**	**≥120 km/h**	not unique people
Alaotra Mangoro	384,004	161,528	259,211	804,743
Analamanga	321,582	105,675	61,964	489,221
Analanjirofo	266,308	131,056	20,670	418,034
Atsinanana	84,315	63,066	621,785	769,166
Betsiboka	51,383	3,387	3,233	58,003
Bongolava	339,629	41,229	-	380,858
Itasy	59	-	-	59
Melaky	144,957	-	-	144,957
Menabe	233,244			233,244
Total	1,825,481	505,941	966,863	3,298,285

Source: ACAPS using WFP data (unpublished) [8][12]; figures are preliminary situation-report estimates and subject to revision.

The scale of exposure was compounded by two aggravating factors. First, Cyclone Fytia had already saturated river systems and soils across nine regions and displaced 31,480 people. [17] Waterlogged ground converted Gezani's rainfall into high-velocity runoff rather than absorbing it, dramatically increasing the risk of flash floods and landslides. Second, Fytia had already caused a partial breach of the Analamanga dam near Antananarivo; further rainfall from Gezani brought that structure close to total collapse, threatening over 5,000 homes and 2,000 hectares of rice fields downstream. [8]

After crossing Madagascar, Gezani regained strength over the warm waters of the Mozambique Channel, reaching Category 2 intensity and bringing heavy rainfall and winds of up to 175 km/h to coastal Mozambique, particularly Inhambane Province, around 14 February. Forecast models then showed a potential southeastward shift that could have exposed Madagascar's Atsimo-Andrefana coast to further flooding. [8] La Niña conditions, still active at the time, enhanced precipitation across the wider region, increasing the risk of riverine and urban flooding in Malawi, central Mozambique, and Zambia as well.

Figure 1. Cyclone Gezani’s projected path through 15 February 2026



Source: ACAPS using data from WFP (accessed 12 February 2026).

3.3 Compound Multi-Cyclone Seasons

A central policy concern in Madagascar's cyclone risk is the occurrence of compound seasons in which multiple storms hit before communities have recovered from the last. Recovery from a major cyclone typically takes six to twelve months for households and several years for infrastructure. When a second storm arrives within weeks, communities face it with depleted resources, damaged

homes, compromised water supplies, and trauma. Rakoto Harison et al. found that “communities attempting to recover from one cyclone often faced additional shocks before fully recovering, creating a cycle of vulnerability.” [3]

Table 4 presents selected seasons in which more than one cyclone affected Madagascar before recovery from earlier impacts was complete. The table is illustrative rather than an exhaustive statistical analysis of compound-event frequency. For each sequence, dates and reported impacts should be verified against event-specific situation reports. The 2025–2026 sequence remains provisional until the Fytia and Gezani dates and cumulative caseloads are reconciled. Where sources use different definitions of “affected,” “displaced,” or “exposed,” the table should retain the original labels rather than combining values into a single total.

Table 4. Compound Multi-Cyclone Seasons: Back-to-Back Events

Season	Storm Sequence	Combined Damage	Key Consequence
2007–08	Fame + Ivan + Jokwe	$175M+	369,517 affected; near-simultaneous landfalls
2021–22	Ana → Batsirai → Dumako → Emnati	4 events in 40 days	1.14M near famine; concurrent southern drought
2022–23	Cheneso → Freddy	$522M combined	1.5M+ food insecure; Freddy-hit areas still recovering from 2022
2025–26	Fytia → Gezani	2 events in 11 days	174,100 ha flooded; Toamasina port destroyed; 750,000 affected

Sources: ARC [13]; OCHA [10]; ACAPS [8]; UNDRR [14]; UNDP [15]. The 2025–2026 season total (750,000 affected) combines cumulative Fytia and Gezani caseloads as of the most recent OCHA/ACAPS updates available at the time of writing; it is provisional and is not directly comparable to the single-storm, wind-threshold exposure breakdown in Table 3.

4 Cross-Sector Impacts by System

This section examines water, food, and energy impacts in turn before Section 5 traces how they interact across sectors.

4.1 Food Systems

Cyclones damage Madagascar's food system both directly, through flattened crops and damaged irrigation infrastructure, and indirectly, through the marine and energy linkages documented elsewhere in this paper. Harvey et al. found that 51% of smallholder farmers surveyed had suffered cyclone-related damage within a five-year period, with limited capacity to recover before the next shock. [1] Rakoto Harison et al.'s study of vanilla farmers following Cyclone Enawo (2017) documented how compounding shocks, cyclone damage layered on pre-existing price and pandemic-related stress, multiply rather than simply add to food-security losses. [3] Marine food sources are also affected: Carter et al. found that Cyclone Haruna (2013) reduced coral cover by 15.8% in southwest Madagascar, directly reducing the fish stocks many coastal communities depend on. [5] These food-sector impacts feed directly into the cross-sector pathways developed in Section 5, particularly Pathways 1, 2, and 5.

4.2 Water Systems

Mong et al.'s study of Cyclone Hudah (2000) documented significant microbiological contamination of household water after the storm, requiring the distribution of 11,700 emergency water kits. The key finding was practical and actionable: households that used both a disinfectant and a clean storage container showed significantly lower contamination than those using only one or neither. [4] Cyclone Ava (2018) showed the energy–water link in stark terms: when winds destroyed 90% of Toamasina's electricity infrastructure, the pumps supplying the city's water stopped working. [9] Cyclone Gezani (2026) repeated this pattern at the same city, leaving it running at just 5% of normal electrical capacity. [8] In Madagascar, where only 54.4% of the population has access to basic water services and only 12.3% to basic sanitation, storm disruption to water infrastructure has immediate and serious health consequences, including accelerated transmission of waterborne and communicable diseases such as cholera, a risk sharpened in February 2026 by Madagascar's concurrent national mpox outbreak.

4.3 Energy Infrastructure

Energy system damage is chronically under-reported in humanitarian assessments relative to its true importance. Cyclone Ivan (2008) knocked out electricity, water supply, and communications across 14 regions simultaneously. [9] Cyclone Ava (2018) produced documented job losses of 40%–90% in the informal sector, showing how power outages cascade into lost income and food insecurity. [9] When Cyclone Batsirai (2022) severed the RN2 highway, it cut off diesel supplies to backup generators, turning what should have been a temporary power outage into a sustained multi-sector breakdown. The fact that Toamasina suffered major energy infrastructure destruction in 2008, 2018, and again in 2026 points to a structural vulnerability that has never been addressed despite being entirely predictable [14].

5 How Harm Spreads: Six WFE Nexus Pathways

Combining the evidence from the literature review and the 34-event database, we identify six pathways through which cyclone damage in one sector triggers failures in the others. Taken together, these pathways explain why the total harm from a major cyclone is far greater than any single ministry's assessment would suggest.

Table 5. WFE Nexus Causal Pathways: Cyclone to Compound Crisis

Pathway	Water Sector Impact	Food Sector Impact	Energy Sector Impact
1. Direct Infrastructure Destruction	Pumping infrastructure destroyed	Crop fields flattened	The grid and lines are down
2. Energy–Water–Food Cascade	Water pumps fail when power is cut	Cold chain/food processing fails	Hydrocatchments degraded
3. Road Severance	Water treatment chemicals blocked	Food supply chain disrupted	Diesel for generators is cut off
4. Deforestation Feedback Loop	Watershed integrity degrades	Flooding worsens future harvests	Hydro generation declines
5. Marine Ecosystem Damage	(indirect fishery reliance)	Coral cover: –15.8%; overfishing risk	(indirect)
6. Compound Multi-Shock Sequence	Each storm finds weakened systems	Recovery interrupted; losses multiply	No time to repair before the next event

Sources: Harvey et al. [1]; Weiskopf et al. [2]; Rakoto Harison et al. [3]; Mong et al. [4]; Carter et al. [5]; ACAPS [8]; EM-DAT [9].

Pathway 1: Simultaneous destruction. When one storm takes out water infrastructure, flattens crops, and cuts power at the same time, the response demands of three sectors can overwhelm governance systems built to manage one at a time. Eight of the 34 events produced all-three-sector failures. These events illustrate the type of compounding loss that sector-specific assessments may miss. [9][8]

Pathway 2: Energy–Water Cascade: Madagascar generates roughly 70% of its electricity from hydropower. [2] When cyclones destroy transmission lines, water pumps fail, cutting off drinking water to entire cities. When deforestation clogs reservoirs with silt, hydro capacity falls even without storm damage. Cyclone Gezani (2026) left Toamasina at 5% of normal power capacity, disabling water supply and food cold chains simultaneously. [8]

Pathway 3: Road severance: Madagascar's RN2 highway carries food, fuel, water treatment chemicals, and emergency relief simultaneously. When Cyclone Batsirai (2022) severed it, the result was not one blocked supply chain but five simultaneously. No water treatment chemicals could reach affected towns; no diesel could reach backup generators; no food aid could reach isolated communities. [9]

Pathway 4: Deforestation feedback: When cyclones destroy crops, food-insecure families cut more trees to sell charcoal or expand farms. Rakoto Harison et al. found that villages with weaker forest law enforcement cut significantly more forest during cyclone recovery than those with stricter enforcement, showing the feedback is partly a governance choice. [3] More deforestation means worse flooding in the next storm, lower hydroelectric output, and reduced agricultural productivity, each cyclone making the next one more damaging.

Pathway 5: Marine cascade: Carter et al. found that Cyclone Haruna (2013) reduced mean coral cover by 15.8% in southwest Madagascar, cutting the fish available to coastal communities. [5] Weiskopf et al. documented that when climate shocks reduced agricultural yields, some communities switched to intensified fishing, potentially to the point of overfishing, trading short-term food security for long-run resource depletion. [2]

Pathway 6: Compound multi-shock cascade. When shocks arrive faster than communities can recover, each successive event finds people already weakened, crops already destroyed, and infrastructure already broken. Standard disaster assessments measure damage against a pre-event baseline and therefore may miss the accumulated deficit. [3] The 2021–2026 record underlines the need for resilience planning that can operate across successive shocks.

6 Governance Failures Blocking Resilience

The most important finding in this paper is uncomfortable: the main obstacle to resilience is not a lack of knowledge about what works, but governance failures that prevent putting known solutions into practice. [1][2] Table 6 maps eight structural failures and links each to a reform pathway.

Table 6. Governance Failures, Their Impacts, and Reform Pathways

Governance Failure	WFE Impact	Evidence	Reform Pathway
5 ministries; zero cross-sector protocols	WFE cascades invisible to any one agency	Harvey et al. [1]; Weiskopf et al. [2]	Nexus Resilience Council (Section 8.1)
BNGRC budget below 0.1% of GDP	No capacity for preparedness or coordination	Sinha [7]; national budget data	Ring-fence DRR finance; set the budget target through a costed fiscal analysis.
NAP and NDC siloed by sector	No integrated adaptation plan	Weiskopf et al. [2]	Revise NAP/NDC with WFE Nexus chapter
Forest enforcement inconsistent	Post-cyclone deforestation varies by village	Rakoto Harison et al. [3]	Standardise enforcement; expand alternative livelihoods
Donors fund W, F, E in isolation	Cross-sector co-benefits invisible to funders	Harvey et al. [1]	Joint WFE programming with co-benefit metrics
No integrated monitoring platform	Compound risk is invisible until a crisis	Weiskopf et al. [2]	Real-time WFE dashboard (Section 8.3)
Farmers cannot afford to adopt known strategies	Known solutions remain unused	Harvey et al. [1]	Safety nets combined with adaptation finance
Relief allocation tracks political voice, not need	Highest-risk communities often receive the least effective response	Sinha [7]	Political Accountability and Enforcement Reform (Section 8.6)

Sources: Harvey et al. [1]; Weiskopf et al. [2]; Rakoto Harison et al. [3]; Sinha [7]; EM-DAT [9].

Institutional silos. Four government ministries in charge of water (MEAH), agriculture (MPAE), energy (MEH), environment (MEDD), and the agency in charge of the disaster risk (BNGRC) each manage their own sector without any agreed protocols for working together during a cyclone. This means that the six cross-sector pathways described in Section 5 are invisible to any single agency with the authority to interrupt them. Harvey et al. called this the central governance gap; Weiskopf et al. identified cross-sector coordination as the single most important missing element in Madagascar's climate adaptation. [1][2]

Chronic underfunding. BNGRC, the agency responsible for disaster risk management, operates on a budget that appears severely constrained relative to the scale of annual cyclone risk; the precise share of GDP could not be verified against an official budget source at the time of writing and is not stated here. A protected disaster-risk-reduction budget line should be established, with its level determined through a transparent, costed fiscal analysis rather than an unsupported

percentage target. In 2025, international humanitarian aid to Madagascar fell by nearly 70%, with US contributions collapsing from about $78 million to under $6 million. In the Grand Sud region alone, around 15 community-level NGOs shut down. Major responders, including Action Against Hunger and the World Food Programme, scaled back their presence. [8] The UN Central Emergency Response Fund allocated $3 million for the Gezani response, enough to reach roughly 93,000 people, or about 5% of those likely to be affected.

Fragmented national planning instruments. Madagascar's National Adaptation Plan (NAP) and Nationally Determined Contribution (NDC) are each organized by sector, with no chapter addressing water, food, and energy systems together. Weiskopf et al. identify this absence of an integrated planning instrument as a structural barrier to adaptation, since no national strategy document currently directs resources toward the cross-sector pathways documented in Section 5. [2]

Inconsistent forest-law enforcement. Enforcement of existing forest regulations varies markedly between communes, and Rakoto Harison et al. found that villages with weaker enforcement cut substantially more forest during cyclone recovery than those with stricter enforcement. [3] Because deforestation degrades watersheds and reduces hydroelectric capacity (Pathway 4, Section 5), uneven enforcement is itself a governance failure with cross-sector consequences, not merely an environmental one.

Absence of integrated monitoring. No platform currently tracks water, food, and energy indicators together before, during, and after a cyclone. Weiskopf et al. identify limited local-scale climate and impact data as a binding constraint on adaptation planning more broadly. [2] Without shared, real-time data, the compound WFE risk documented in Section 5 remains invisible to decision-makers until a crisis is already underway.

The implementation trap. Harvey et al. document the most self-reinforcing governance failure: farmers know which adaptation strategies work but cannot afford to try them. Food-insecure households cannot risk a short-term yield drop while switching to a new farming practice, even if the practice would improve their resilience over time. The solution of social safety nets that allow households to take short-term risks requires the same governance capacity and financial resources that are most severely lacking. This is a poverty trap masquerading as a knowledge problem. [1]

Donor architecture. International donors typically fund water, food security, and energy projects through separate trust funds, evaluated by sector-specific criteria. This design makes the cross-sector co-benefits of integrated approaches financially invisible and rewards agencies for staying in their lane. Reforming donor frameworks is therefore not optional; it is a prerequisite for any of the other governance changes to stick. [1]

Political accountability. Sinha's analysis of government responses to Cyclone Gafilo (2004) found that how much relief communities received depended on how politically active and well-informed they were. Communities most exposed to cyclone risk were often those with the weakest political voice, meaning the governance failures were most severe precisely where effective disaster management was most needed. [7]

7 Resilience Strategies: What Evidence Shows

Not all adaptation strategies are equal. Table 7 distinguishes what has been demonstrated to work in Madagascar, what looks promising, and what is widely recommended but has never been properly evaluated.

The evidence categories distinguish geographic relevance and strength of the available evidence. “Demonstrated in Madagascar” should be used only where the cited study directly evaluates the intervention in Madagascar and reports an outcome relevant to the claim. “Promising—comparator evidence” should be used where support comes from another country or comparable

setting. “Not yet evaluated in the identified Madagascar evidence base” should be used where the reviewed sources recommend an intervention but do not evaluate its effectiveness in Madagascar. Absence of an evaluation in the identified sources does not show that an intervention is ineffective, nor does it prove that governance weaknesses caused the absence of evaluation.

Table 7. Resilience Intervention Evidence Matrix

Intervention	Sector	Evidence Status	Key Finding
Water disinfection kits + storage containers	Water	DEMONSTRATED	Households using both showed significantly lower contamination [4]
Marine no-take zones (LMMA)	Food / Marine	DEMONSTRATED	Higher fish biomass, reef recovery, and the need for community co-management [5]
Conservation agriculture	Food	DEMONSTRATED	Works for resilience; uptake blocked by poverty trap [2]
System of Rice Intensification	Food	DEMONSTRATED	Yield gains; blocked by resource access constraints [2]
Community water restoration	Water	PROMISING	Stronger social capital = faster recovery (Vanuatu comparator) [6]
Improved irrigation systems	Food / Water	UNEVALUATED	Recommended; no effectiveness data for Madagascar [1]
Early warning systems	Multi-sector	UNEVALUATED	Recommended by all studies; not scaled [2]
Livelihood diversification	Food	UNEVALUATED	Recommended; uptake limited by poverty trap [1]
Enhanced water infrastructure	Water	UNEVALUATED	Recommended; persistent investment gap [2]

DEMONSTRATED = measurable effectiveness in Madagascar or a direct comparator. PROMISING = positive evidence from an analogous context. UNEVALUATED = recommended but lacking empirical evaluation in Madagascar.

The three demonstrated interventions share important design features: they are relatively low-cost, they build on existing community practices, and they involve local governance rather than top-down delivery. These principles should guide how the evidence base is expanded. The majority of widely recommended strategies for irrigation improvement, early warning systems, and livelihood diversification remain unevaluated, not because they do not work, but because governance weaknesses have prevented both implementation and evaluation. Without implementation, there can be no evaluation; without evaluation, there can be no evidence-based policy. Breaking this paradox requires building evaluation capacity as an explicit component of governance reform.

8 Six Integrated Governance Pathways

The analysis points to six reforms that together would address the governance failures identified in Section 6. Each is grounded in evidence, calibrated to Madagascar's real institutional constraints, and designed to work across the WFE Nexus rather than within a single sector.

8.1 Pathway 1: National Nexus Resilience Council

A coordinating body under the Prime Minister's Office with representatives from all five line ministries should develop cross-sector cyclone risk assessments, agree response protocols before each season starts, monitor WFE feedback loops, and allocate resources across sectors during compound events. [1] Such a body needs binding accountability mechanisms; otherwise, coordination priorities may remain in policy documents rather than guide field decisions.

8.2 Pathway 2: WFE Nexus Investment Screening

All public investment proposals should be assessed not just for their primary purpose but also for how they affect adjacent sectors and how exposed they are to compound cyclone shocks. This creates incentives for integrated infrastructure, a water project that also improves energy resilience scores better than one that does not, and it aligns donor programming incentives with cross-sectoral outcomes.

8.3 Pathway 3: Integrated WFE Monitoring Dashboard

A real-time situational awareness platform tracking water, food, and energy indicators simultaneously before, during, and after cyclone events would make compound risk visible to decision-makers. Weiskopf et al. identified limited local-scale climate data as a binding constraint on all other adaptation efforts; [2] this platform addresses that gap directly. Investments in meteorological and hydrological monitoring generate cross-sector public goods that no individual ministry can justify or finance alone.

8.4 Pathway 4: Community-Centered Resilience Plans

Evidence from Balaei et al. (community social capital accelerating water recovery) [6] and Carter et al. (community co-management delivering measurable marine resilience) [5] supports commune-level Nexus Resilience Plans as a potentially scalable governance model. These plans would map local WFE systems, set early-warning triggers, pre-agree coping protocols, and maintain resource stockpiles. An inclusion strategy that accounts for differentiated responsibilities and decision-making roles should be explicitly considered in plan design. Legal authority over local natural resources, rather than NGO project-dependent co-management, is a prerequisite for making these plans durable.

8.5 Pathway 5: Regional Cooperation and Cross-Sector Climate Finance

The Indian Ocean Commission may provide an institutional vehicle for shared cyclone-risk tools, joint early-warning systems, and mutual-assistance protocols that individual island states may struggle to finance alone. Cross-sectoral proposals to GCF and GEF that address SDGs 2 (food), 6 (water), 7 (energy), and 13 (climate) simultaneously may better align project design with WFE interdependencies than single-sector applications. The $18 million WFP funding gap during Cyclone Gezani [12] illustrates the scale of resources required for a response.

8.6 Pathway 6: Political Accountability and Enforcement Reform

Technical reform alone is not enough. Sinha's evidence shows that government responsiveness depends on an informed and politically active citizenry. [7] Specific measures include community entitlement information systems so people know what relief they are owed;

transparent post-disaster aid tracking enabling civil society monitoring; standardized forest regulation enforcement across communities to interrupt the deforestation feedback loop; and integration of social protection with adaptation finance to eliminate the poverty trap that prevents uptake of demonstrated strategies.

8.7 Implementation Feasibility

The six pathways above are grounded in the governance failures of Section 6, but grounding is not the same as feasibility. Table 8 assesses each pathway against Madagascar's institutional, financial, administrative, technical, political, and social constraints, distinguishing a realistic short-term start from the medium- and long-term reforms that require sustained financing and political commitment. Recommendations grounded directly in evidence cited elsewhere in this paper are marked accordingly; the sequencing and mitigation columns reflect the authors' own judgment and are offered as a starting point for discussion, not as established findings.

Table 8. Policy Pathway Implementation Feasibility

Pathway	Lead institution / actors	Key prerequisite	Main constraint	Mitigation	Horizon	Progress indicator
8.1 National Nexus Resilience Council	Prime Minister's Office, with MEAH/MPAE/MEH/BNGRC/MEDD	Binding accountability mandate (grounded: Sinha, §6)	Risks repeating BNGRC's <0.1%-of-GDP underfunding (grounded: §6) unless separately financed	Ring-fence a distinct budget line; do not fold into BNGRC's existing allocation	Short term (season-ahead protocols); binding mandate medium term	Season-ahead cross-ministerial protocol signed and published
8.2 WFE Nexus Investment Screening	Ministry of Finance / Economic Development, applied to existing project appraisal	A scoring-rule change to current investment approval, not a new institution	Needs a named owner and enforcement authority to avoid becoming advisory only	Pilot on donor-financed infrastructure projects first, where screening can be a funding condition	Short term	Share of new public investment proposals screened for cross-sector exposure
8.3 Integrated WFE Monitoring Dashboard	BNGRC, with MEAH/MPAE/MEH data feeds	Reliable data feeds and connectivity, which collide with the ~70% aid decline documented in §6	Recurring hosting/connectivity cost in a severely constrained budget environment	Start from existing EM-DAT/ACAPS/BNGRC/WFP feeds before building new sensor infrastructure	Medium term (phase 1: existing-feed aggregation); long term (new monitoring)	Number of WFE indicators updated in near-real time during an active cyclone
8.4 Community-Centered Resilience Plans	Communes, with legal authority over local natural resources (grounded: Balaei, Carter, §8.4)	Legal authority over local resources, identified in the manuscript as the binding prerequisite	NGO/project dependency without that legal authority	Sequence legal-authority transfer before plan rollout, not after	Medium term	Number of communes with a ratified Nexus Resilience Plan and resource stockpile
8.5 Regional Cooperation and Cross-Sector Climate Finance	Indian Ocean Commission; GCF/GEF national focal point	Cross-sectoral proposals bundling SDGs 2/6/7/13	Donor-dependency risk, given the donor fragmentation §6 already identifies as a governance failure	Pair regional/GCF-GEF proposals with a domestic co-financing commitment	Medium to long term	Value of cross-sectoral (vs. single-sector) climate finance secured
8.6 Political Accountability and Enforcement Reform	Civil society and independent monitors, not government alone (grounded: Sinha, §6)	Informed, politically active citizenry (grounded: Sinha, §6)	Asks political actors to fund tools that increase their own accountability	Anchor entitlement-information and aid-tracking systems in civil-society or donor-monitored platforms	Long term	Independent aid-tracking coverage and forest-enforcement consistency across communes

Pathways 2 and 4 are the most feasible in the short term because they build on existing institutions and evidence. Pathways 1 and 3 are feasible only if their financing is explicitly separated from BNGRC's chronic underfunding. Pathways 5 and 6 inherit the governance failures they are meant to correct (donor fragmentation and weak political accountability, respectively) and are therefore the highest-risk, longest-horizon reforms; both are the right direction evidenced in this paper, but neither should be presented as low-risk or quickly achievable.

9 Conclusion

This paper has documented how tropical cyclones push Madagascar's water, food, and energy systems into simultaneous failure, traced the six pathways through which that harm multiplies, identified the seven governance failures that have prevented effective responses, and proposed six integrated reforms. Six findings stand out.

First, the 34-event database reports more than $2.6 billion in direct physical damage from January 2000 through February 2026, including provisional 2025–2026 entries for cyclones Fytia and Gezani, pending final post-disaster assessment. This record demonstrates that cyclones impose a substantial and recurring constraint on development.

Second, cyclone impacts on the WFE Nexus are plausibly multiplicative rather than additive: the six pathways in Section 5 describe how sector-by-sector analysis can systematically undercount cross-sector harm, though the magnitude of this multiplier is not independently estimated here.

Third, the evidence assembled in this paper points to governance, more than technology or scientific knowledge, as the binding constraint on resilience. Madagascar knows what works; what appears to be missing is the institutional capacity, cross-sector coordination, enforcement resources, and evaluation infrastructure to translate that knowledge into sustained action at scale. [1][2]

Fourth, three demonstrated interventions, water disinfection, marine no-take zones, and conservation agriculture, share design features that should guide expansion of the evidence base: low-to-moderate cost, alignment with community capacities, and integration of local governance. [4][5][2]

Fifth, the gap between knowing and doing food-insecure farmers looks like a structural poverty trap rather than a knowledge deficit. Safety nets integrated with adaptation finance may be a necessary complement to extension services, not a substitute for them. [1]

Sixth, the compound multi-cyclone seasons documented since 2021 illustrate why governance must prepare for successive and, in some cases, closely spaced shocks. The 2025–2026 entries remain provisional; nevertheless, the documented pattern supports maintaining WFE Nexus resilience across compound events rather than treating cyclones as isolated incidents. [8][17]

These conclusions rest on a literature base of six peer-reviewed studies and a 34-event database that includes provisional entries for the 2025–2026 season. Because the underlying evidence base is limited in this way, the findings should be read as evidence-informed synthesis rather than a definitive estimate of either the causal contribution of governance failures or the additional losses attributable to cross-sector interactions. Both the literature base and the event database should be strengthened as further research and finalized damage assessments become available, without altering the paper's central finding that governance, not technology or scientific knowledge, is the binding constraint on resilience.

The policy implications are accordingly framed as proposals for testing and evaluation rather than settled prescriptions. Priority actions include documenting cross-sector dependencies in cyclone plans, clarifying institutional responsibilities, improving the traceability of event and damage data, and designing monitoring indicators that capture water, food, and energy outcomes together. The proposed reforms should be phased according to legal authority, administrative capacity, financing, and the availability of baseline data. Future work should expand the peer-reviewed evidence base, publish a reproducible event-level dataset, and evaluate whether integrated interventions produce measurable benefits beyond sector-specific approaches.

Table List

Table 1: Studies Included in Systematic Review

Table 2: Key Aggregate Statistics, Madagascar Cyclones 2000-2026

Table 3: Population Exposed to Cyclone Gezani Through 15 February 2026

Table 4: Compound Multi-Cyclone Seasons: Back-to-Back Events

Table 5: WFE Nexus Causal Pathways Cyclone to Compound Crisis

Table 6: Governance Failures, Their Impacts, and Reform Pathways

Table 7: Resilience Intervention Evidence Matrix

Table 8: Policy Pathway Implementation Feasibility

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