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Why Do Reforestation Systems Collapse? Governance Failure, Utility Insolvency, and Livelihood Trajectories of Green Infrastructure in the Great Green Wall Sahelian Drylands

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ABSTRACT

The success of restoration projects generally depends on planted area or canopy cover. Infrastructure that is responsible for sustaining the life of seedlings (such as vehicles, water source, pumps and processing units) receives very little attention. This paper asks why infrastructure built under Pillar 3 ("Climate-Resilient Infrastructure") of the Great Green Wall (GGW) stops working, and who is able to repair it. We present a qualitative case study of three sites in the Ferlo region of northern Senegal (Widou Thiengoly, Koyli Alpha, Mbaye Awa) and, for comparison, a field observation and documentary case study of Tigray, Ethiopia, where armed conflict prevented comparable fieldwork. The Senegal data are based on (N = 120) semi-structured interviews, (N = 7) focus group discussions and structured infrastructure inspection conducted between September 2025 and February 2026. We organised and interpreted them using categories drawn from the Social-Ecological Systems framework and Access Theory. At the Senegal sites we found: a shrinking vehicle fleet at the Widou station; water cut-offs after the GGW agency fell behind on payments to the rural water utility (SDE-R); solar pumps without storage and an idle milk-processing unit; and administrative control that blocked women's groups from funding their own water storage. For Tigray, published studies report deliberate destruction of nurseries and water schemes during the war. Seedling loss and abandoned assets therefore look alike in both places but have different causes: administrative neglect in Senegal and armed conflict in Tigray. We conclude that restoration funding should cover maintenance, utility bills and spare parts, not only planting.

Key Words: Great Green Wall; Restoration infrastructure; Maintenance; Governance; Sahel; Tigray.

1. Introduction

The world's arid and semi-arid drylands constitute 41% of the Earth's total surface area and accommodate more than two billion people, most of whom depend on agriculture-based economies that are sensitive to climate change (IPCC, 2023; Mirzabaev et al., 2023; Elouafi, 2025). Due to climatic challenges faced by vulnerable zones like the African Sahel and the Horn of Africa, climate-related problems, in the form of hydrological extremes, prolonged drought conditions, and thermal stresses, have led to land degradation and increased rural food insecurity (D'Odorico et al., 2023; Turner et al., 2023). In order to counteract these challenges, international groups, along with the African Union, have applied a wide array of Nature-Based Solutions (NbS) to rehabilitate degraded lands and communities (Chausson et al., 2020; Seddon et al., 2021).

The leading project of the pan-African region is that of the Great Green Wall (GGW) project (Goffner et al., 2019; FAO, 2024). Originally designed as a corridor of trees for preventing desertification, the GGW has become more diverse with time (Turner et al., 2023). In Pillar 3 of GGW "Climate-Resilient Infrastructure" the project has focused on socio-technological systems, which include solar-powered boreholes, seedling nursery communities, agro-processing plants, and and Integrated Community Agricultural Farms (known by their French acronym FACI[1]) (FAO, 2024). Apart from the financial insufficiency for investment in capital projects (Zhu et al., 2025), there still remains a stark disparity between macro-level policy discourses and the socio-ecological conditions on the ground (Bastien-Olvera et al., 2024; Zoomers et al., 2010). Both state agencies and foreign evaluators tend to evaluate the results of GGW projects by using techno-deterministic biophysical indicators like remote sensing estimates of vegetative canopy cover, biomass density, and total hectares of reforestation (Higginbottom et al., 2023; FAO, 2024). There is an underlying assumption that the mere physical placement of green infrastructure necessarily implies ecological rehabilitation and socio-economic stability.

Studies on technology and power show that infrastructure is never only a technical construct. Who pays for it, who controls it and who may repair it shape what if does (Winner, 1980; Star, 1999; Graham & Thrift, 2007). Work on tree planting also warns that projects that ignore local land and water rights can disadvantage the people they claim to help (Fairhead et al., 2012; Fleischman et al., 2020). Studies from other sectors, such as river restoration,

[1] Fermes Agricoles Communautaires Intégrées.

reports that missing maintenance is a common cause of project failure (Moore & Rutherfurd, 2017). What is missing for the GGW is close, site-level evidence on how restoration infrastructure breaks down in practice and on which governance arrangements allow or prevent repair.

This study investigates why Pillar 3 infrastructure stops working at selected GGW sites, using Senegal as the main case and Tigray as a contrasting case. The questions this study seeks to address are: (RQ1) What logistical, utility and engineering breakdowns occurred at the infrastructure sites? (RQ2) How do the financial regulations and administration influence the repair of these breakdowns? (RQ3) How does this process differ in the case of administrative decay (Senegal) and armed conflict (Tigray)? RQ1 and RQ2 have been answered with the help of interviews, focus group discussions and on-the-spot inspection in Senegal while RQ3 has been answered using the published literature and field observation in Tigray.

This paper is organized into sections as follows: Section 2 provides the theoretical framework of the analysis and transforms it into a coding scheme (Table 1). Section 3 outlines the research design, study setting, subjects, methods, and the documentary approach applied to Tigray. Section 4 provides the findings; the findings from Senegal (Sections 4.1 to 4.4), the case of Tigray (Section 4.5) and comparative analysis of the two cases (Section 4.6). Section 5 provides the discussion of the findings, their linkages to the existing literature, policy and practice implications, and section 6 the conclusion and limitations of the study.

2. Theoretical Framework

The adoption of Ostrom's Social-Ecological Systems (SES) framework and the Theory of Access by Ribot and Peluso is justified as for Table 1. because of their respective and complimentary analytical strengths. The (SES) Framework by Ostrom is made up of a resource system, resource units, a governance system, and users (Ostrom, 2009; McGinnis & Ostrom, 2014). The framework provides us with a way to track where in the system there is a failure. The disadvantage of this framework is that it does not provide any information about the issue of power: who is excluded and what prevents that from happening (Leach et al., 1999; Epstein et al., 2015). This is why we complement the SES Framework with the Theory of Access by Ribot and Peluso (2003), which concentrates on the possibility to benefit from a resource, not just a legal right to it. Access depends on technology, capital, authority,

knowledge, labor, and social relations. The SES framework provides us with the "where" while the access theory provides us with the "who can act".

The diagnostic model put forward by Ostrom (2009) is particularly appropriate for dryland environment analysis as it entails dissection of a whole landscape into four interconnected sub-systems such as Resource System (RS – Sahelian dryland environment), Resource Unit (RU – amounts of water, biomass, survival of seedlings), Governance Systems (GS – AU policies, state forestry agencies, utility companies) and Actors/Users (U – pastoralists, small farmers, female empowerment groups) (McGinnis & Ostrom, 2014).

Nevertheless, standard institutionalist SES models fail to show how structural power inequalities, oppression and conflicts result in governance failure and exclusion of specific actors (Leach et al., 1999; Epstein et al., 2015). To resolve this limitation, we integrate Ribot and Peluso (2003) theory of access because of its shift from property rights to access. Access Theory allows us to understand the dynamics of how factors such as capital, technology, market, labor control, power, and special knowledge create "a bundle of powers" to determine control over resource flows (Ribot & Peluso, 2003).

Table 1. Analytical themes linking theory to data and results

Framework element	What we looked for	Example themes
SES: resource system and units	Water sources, souls, seedling survival	Borehole dependance; seedling loss; broken wells
SES: technical systems	State of vehicle, pumps, tanks, processing units	Vehicle count; pump without storage; idle plant
SES: governance system	Agencies, utilities, donor rules, funding cycles	Payment arrears; central targets; phone monitoring
SES: users	Pastoralists, farmers, women's groups and what they do	Self-funded investments; coping strategies
Access: capital and technology	Who can pay for, run or repair equipment	Spare parts, fuel, utility bills
Access: authority and knowledge	Who decides, who is allowed to act, whose knowledge counts	Permission blocked, targets set centrally
Access: labour and land relations	Effects on herding, work and land use	Land enclosure, unpaid work, reduced mobility

3. Methods

3.1. Design and purpose

This is a qualitative and exploratory multi-site case study. The objective of this research is to understand why and how the restoration infrastructure fails and who should mend it, but not its frequency of failure. This was achieved through interviews and focus groups for understanding the reasons of failures according to the stakeholders' perception and field observation of the actual condition of the asset. Data collection took place from September 2025 to February 2026. As the sites varied drastically from each other, comparisons between them were not possible. For that reason, Senegal and Tigray have been considered as two contrasting cases rather than two matched ones; the former represents breakdown without war, whereas the latter represents breakdown with war.

3.2 Study sites

The three Senegalese sites are situated in the Ferlo region where pastoralism constitutes the main form of living. The choice of these sites was made due to the reason that these sites possess different Pillar 3 elements:

The Widou Thiengoly represents a pastoral community located in the hyper-arid zone of the so-called "triangle of thirst" (Assouma et al., 2019). It depends mainly on one borehole installed in the 1960s (Mazzero et al., 2021). It has a GGW station which includes nurseries and a vehicle fleet. The Koyli Alpha site is jointly managed by FAO and the Senegalese GGW agency (ASERGMV[2]) reserve and solar-powered pumping systems. The Mbaye Awa site has nurseries, FACI, and a milk-processing unit. SDE-R represents the Senegalese Public Rural Drinking Water Service.

Tigray, Ethiopia has a rich experience of using community exclosures and soil and water conservation. The war between the years 2020 and 2022 brought about extensive destruction of these structures (Meaza et al., 2025; Hishe et al., 2024; Berhane et al., 2025). Constraints of security and communications have hindered any form of household surveys and fieldwork in the area.

3.3 Participants and sampling

[2] *L'Agence Sénégalaise de la Reforestation et de la Grande Muraille Verte.*

We adopted a combination of purposive and snowball sampling in order to select individuals that had different roles in the system (Ahmad & Wilkins, 2025). The recruitment process was terminated for each site in Senegal once additional interviews ceased to bring any new themes to light. In all, 120 key informants were selected from three different categories: agro-pastoralists and small farmers impacted by water scarcity, land enclosure, and farm closure (n = 68); members of women groups operating the FACIs and dairy production facilities (n = 34); and employees of the national GGW institution, forestry department, and water services (n = 18). Table 2 gives the breakdown by site.

Table 2. Participants and activities by site and group

Site	Agro-pastoralists and smallholders	Women's group leaders and members	State and utility staff	FGDs
Widou Thiengoly	32	24	12	6
Koyli Alpha	24	8	5	1
Mbaye Awa	12	2	1	-
Tigray[3]	-	-	-	-
Totale	**68**	**34**	**18**	**7**

3.4 Data collection

Interviews. Semi-structured interviews were conducted in local languages (French, Pulaar) and (English, Tigrinya) following an interview guide. The interview guide touched on the background of natural resource management, institutional coordination, utility services, work and household coping strategies.

Focus group discussion. Seven focus group discussions were held involving women groups managing community farms. Participatory maps were developed to map out obstacles to accessing resources, animal mobility, and underutilized facilities.

Field observation and inspections were made to assess the infrastructure regarding its functionality, fueling, maintenance, billing, nurseries, boreholes, solar panels, vehicles, and processing units. Pictures were taken from the field observations.

3.5 Analysis and quality control

[3] Field observation in Tigray took place from September to October 2026.

The interviews and focus groups were (audio-recorded/noted), transcribed and translated to (English/French). Thematic analysis was employed. Any differences that arose were sorted out through discussion. Cross checks were carried also in comparison with field notes and photographs. Any findings were considered valid only when they came from at least two independent sources (Table 3). Any accounts that opposed the developing understanding were identified and included in the results section. This study meets the quality indicators of credibility, transparency and reflexivity as suggested by Tracy (2010).

4. Results

Each subsection states the finding, the evidence behind it and then a representative quotation. Table 3 lists the evidence for each finding. Photographs illustrate what inspectors saw; they are not treated as proof on their own. Findings 1-7 are from Senegal (Primary data). Section 4.5 summarises Tigray (Field observation and Documentary data).

Table 3. Evidence base for the main Senegal findings.

No.	Finding	Evidence types	Site(s)
1	Vehicle fleet at the Widou station fell from ten to one, used mainly for administration	Interview (nursery worker); photographs (Fig. 1)	Widou Thiengoly
2	Seedling held in nurseries beyond planting date and lost	Interviews; inspections, photographs (Fig 1-2)	Widou, Mbaye Awa
3	Little supervision or watering after planting; planted trees lost	Interview (resident)	Mbaye Awa
4	Dependence on one 1960s borehole, more broken than working wells	Interview (women' federation members); photographs (Fig. 3)	Widou Thiengoly
5	Water cut-offs at nurseries and FACIs after agency arrears to SDE-R	Interviews; Field observation	Widou Thiengoly; Koyli Alpha, Mbaye Awa
6	Solar pumps with no storage or pressure control, idle milk-processing unit	Inspections; photographs (Fig 4-5)	Koyli Alpha, Mbaye Awa
7	Women's group' self-funded water storage blocked by GGW officials; monitoring done by call phone	Interviews (Women's group representatives; field officer)	Koyli Alpha, Mbaye Awa

4.1. Vehicle loss and broken delivery of seedlings (Senegal)

At the Widou Theingoly station, the vehicle fleet needed to carry seedlings to planting sites has largely failed. A nursery worker reported that the station once had ten all-terrain vehicles

and now has one, used mainly for administrative tasks (Table 3, finding 1). Seedlings stay in nursery bags past their planting date, and many die (Fig. 1). *"In the past, we had ten machines active; now we don't even have one active... We grow so many plants in the nursery, but we lack space and resources to plant all of them. We lose so many plants per season for this reason alone"* (GGW Nursery Worker, Widou-Thiengoly, January 2026).



Figure 1. Illustrative inspection photographs, Widou Thiengoy (Senegal). (Left) Healthy seedlings held in nursery bags beyond their planting schedule because transport is unavailable. (Right) After a long delay, roots are constrained and seedlings dry out and die: they are abandoned in bulk. (Photographs: first author, 16 November 2025).

The problem continues after planting. At Mbaye Awa, a resident described planting without follow-up: *"There is an important failure in the management of after-planting activities. The trees are planted, but there is no supervision or water sources. When you visit back, the trees that have been planted disappear completely… these plantations need logistics" (Local Resident, Mbaye Awa, December 2025).*



Figure 2. Illustrative inspection photographs, Mbaye Awa (Senegal). (Left) Seedlings in plastic bags left after the planting season, showing leaf damage and coiled roots. (Right) Seedling raised in soil blocks are lost completely when abandoned, because the container breaks down and the soil dries out (Photographs: first author)

4.2 Water supply and utility arrears (Senegal)

Two kinds of water problems appeared. At Widou Thiengoly the problem is physical: the village depends on a borehole drilled in the 1960s, now used beyond its design capacity because of population and herd growth (Fig. 3). At Koyli Alpha and Mbaye Awa the problem is financial: informants said water to nurseries and FACI was cut because the Senegalese GGW agency (ASERGMV) hat not paid the water utility SDE-R, not because aquifers had run dry (Table 3, finding 5). "*The problem is water, we have more broken wells than functioning wells, and therefore we cannot continue our activities constantly because if the water runs out, we have to stop as well*." (Women's federation member, Widou Thiengoly, January 2026). *"With no water, we cannot continue working; that is why a lot of activities have been abandoned"* (GGW nursery local workers, Mbaye Awa, January 2026).



Figure 3. Illustrative inspection photographs of water constraints, Widou Thiengoly (Senegal). (Left) An animal-drawn cart with a water container used to haul water from the village's only working borehole. (Right) Livestock around a dry concrete trough linked to the central water tower. (Photographs: first author)



Figure 4. Illustrative inspection photographs of neglected equipment, Mbaye Awa (Senegal). (Left) A broken water tank at the GGW nursery, damaged by sun and lack of maintenance. (Right) Water pipes and irrigation hose coils lying uninstalled outside. (Photographs: first author)

4.3. Technological sending gaps and blocked local initiative (Senegal)

Some installed equipment could not work as designed. Solar pumps at Koyli Alpha had no water storage or pressure control, so water was pumped only in strong sunlight, with none available at night. At Mbaye Awa a fully equipped milk-processing unit stood idle, with information linked to the lack of a secure water and electricity supply (Table 3, finding 6; Fig. 5). Monitoring by call phone had replaced field supervisions, as a field officer put it: *"The GGW current administration has become just a presence control... everything is done over the phone, because even the officials are not physically present"* (Field Officer, Senegal, January 2026).



Figure 5. Illustrative inspection photographs of equipment that does not work together. (Left) Water running continuously from a borehole pipe onto open ground, with no flow-control valve. (Right) Processing machinery (steel tank, electric motor, additive storage) not connected to field-level supply. (Photographs: first author)

The women's group tried to respond. A representative said that some members had tried to pay for their own water system for community gardens, but that this was blocked: "*Some women within the group have tried to find ways to pay for an independent water system, but this has been systematically thwarted by the GGW authorities*" (Women's group representative, field interview).

4.4. Funding cycles and control (Senegal)

Informants and field observations pointed to two features of administration that made repair harder. First, funding comes in cycles of about three to five years that favour start-up costs, such as land clearing and planting, over running costs such as nursery care, water and spare

parts (Zhu et al., 2025). Second, budgets, timelines and evaluation criteria are set centrally, including by the Pan-African Agency of the GGW (PAAGGW). Local technicians reported having to meet sapling-number targets even where soil and water made them unrealistic.

4.5 Tigray

This subsection draws only on published, monitoring and field observation sources. Seedling losses and weak stewardship were already reported before the war in some districts (Gebrekidan et al., 2020). Studies since 2020 describe damage to natural-resource management, conservation structures and vegetation, and to water infrastructure in battle areas (Hishe et al., 2024; Nyssen et al., 2024; Berhane et al., 2025; Meaza et al., 2025). Conflict monitoring reports that destruction and loss of access hindered environmental recovery (CEOBS, 2022; Schulte to Bühne et al., 2025). Observers also note that satellite greenness indices can show recovery while ground assets such as irrigation schemes and nurseries are damaged. In this case, the main cause of failure was armed conflict, not administrative neglect.

5. Discussion and Policy Implications

The empirical results of the current study shows the dominant paradigm in drylands restoration where poor performance of restoration efforts is usually blamed on the apathy of local communities or hostile environment. Comparing the processes after fieldwork conducted in Senegal and Ethiopia, the current comparative study (Table 4) demonstrates that the problem of restoration failures is basically a socio-technical and institutional collapse (Moore & Rutherfurd, 2017; Epstein et al., 2020; Zeratsion et al., 2024).

Table 4. Comparison of the two cases.

	Senegal	**Tigray**
Main cause	Arrears, poor maintenance, control control, design gaps	Armed conflict, siege, destruction
How assets failed	Gradual: vehicles, water supply, pumps and plants left idle	Sudden and deliberate damage to nurseries, terraces and water schemes
Who could repair	Mostly the control agency; local self-funding was blocked (finding 7)	Local institutions disrupted or destroyed
Visible result	Seedling loss, idle assets, abandoned activities	Seedling loss, damage conservation structures and water systems
Evidence type	Interviews, focus groups, inspections	Published studies and field observation

In both West and East African cases, high capacity for grassroots stewardship management is regularly obstructed by weak, malfunctional, or destroyed socio-technical chains (Nkiaka et al., 2024). Despite the similarity of the operational manifestations (high mortality rates, fragmentation of the landscape, etc.), the underlying political ecology reasons are completely different. West Africa's disruption is marked by the bankruptcy of the bureaucracy, the centralization of the administration, and institutional gatekeeping (Epstein et al., 2020) that sees territorialization of the state prioritizing the institutional agenda over the ecological one, with modern technologies left untapped to showcase its potential (Ferguson, 1990; Loftus, 2012; Peluso & Lund, 2011). Disruption in East Africa comes from conflict-induced structural violence and military blockades where physical destruction of tree nurseries, terraces, and irrigation systems in times of war transforms pre-conflict weaknesses into an infrastructural collapse (CEOBS, 2022; Ranieri, 2022; Nyssen et al., 2024).

This research draws attention to an important contradiction of global environmental governance referred to as upward accountability capture (Ebrahim, 2003; OECD, 2022). Nowadays, multilateral organizations employ remote sensing and geospatial dashboards via satellites to track their restoration goals (Turnhout et al., 2014). Even though the mentioned technological mechanisms allow for continuous reporting to international donors, they result in a situation of double invisibility during geopolitical crises (Fairhead & Leach, 2012; Schulte to Bühne et al., 2025). The satellite metrics praise tree planting programs sponsored by states on international stages while ignoring the destruction of hydrosocial infrastructure, mortality of seedlings in the region, and distress of the local community (Boelens et al., 2016; Linton & Budds, 2014; Swyngedouw, 2009). In order not to turn major environmental programs like the GGW into temporary, highly mortal tree planting events, policy frameworks need to move from top-down capital-intensive implementation to socially embedded governance models (Goldman, 2008; Li, 2007; Svarstad et al., 2018).

Both international donors and state governments need to give up their short-term grant funding approaches for long-term funding schemes that will last through the whole operational life cycle of projects (Li, 2007; Svarstad et al., 2018). Such schemes should allocate certain funding for such expenses as post-planting maintenance costs, utilities payments, spare parts, and maintenance costs for transport. Only when funds are allocated in this way planting goals will not be financed without guarantee of multiyear maintenance

(Moore & Rutherfurd, 2017; Zeratsion et al., 2024). State authorities need to give up their monopoly over restoration infrastructure by creating such legislation that will give communities the opportunity to finance themselves (Eugene Chigbu et al., 2024), administer micro-utilities, and build additional water storage facilities (Ribot & Peluso, 2003). Such decentralization will turn willingness into effective maintenance (Boelens et al., 2016; Nkiaka et al., 2024).

Any technologic intervention must be conducted in accordance with socio-technological completeness in order for the donor states to stop financing technologic interventions without sufficient storage capacities, distribution capacities, and connection to electricity (Loftus, 2012; Howe et al., 2015; Frietsch et al., 2023). Furthermore, global environmental agencies have to reevaluate their approaches in monitoring interventions by linking satellite monitoring with ground truth observatories and communities' reporting, along with hydrologic auditing of seedling survival and infrastructure, not just temporary distribution of seedlings (Turnhout et al., 2014; Hambira et al., 2024; Nyssen et al., 2024). Finally, in cases where territories are affected by conflicts, conflict-sensitive infrastructural planning should be included into policies of landscape restoration. The local hydrosocial infrastructure is to be regarded as protected civilian objects, while at the same time the rapid response procedures should be set (CEOBS, 2022; Schulte to Bühne et al., 2025; Berhane et al., 2025; Nyssen et al., 2024).

6. Conclusion and limitations

In this paper, it is shown that infrastructure for ecological restoration in drylands cannot be viewed as a static asset that can either be there or not be there. In fact, its efficiency can only be achieved through maintenance of socio-technical, political, and institutional networks that sustain it. The approach in this analysis differs from previous discussions that explained problems that occur after tree planting by referring to lack of interest among communities or difficulties associated with the dryland environment. Through incorporation of socio-technical transitions, hydrosocial territories (Boelens et al., 2016; Swyngedouw, 2009), and structural access (Ribot & Peluso, 2003), it is demonstrated that sustainability of investments in the GGW relies on functioning socio-technical supply chains and supporting institutional frameworks (Moore & Rutherfurd, 2017; Zeratsion et al., 2024).

However, even though the post-planting challenges have the same impacts, which are reflected in such features as mortality rates, dried up boreholes and fragmented landscapes, the processes of disruption of relations related to maintenance in each case are different. The relations of the infrastructures are mainly hindered by bureaucratic insolvency, administrative gatekeeping and technocratic short-sightedness in implementation of the projects rather than maintenance of them in West Africa (Senegal) (Ferguson, 1990; Loftus, 2012). Operational relations in East Africa (Tigray, Ethiopia) are impeded by structural violence, war, sieges and destruction of the hydrosocial infrastructures (CEOBS, 2022; Nyssen et al., 2024).

The findings can be used practically in the context of restoration activities conducted internationally by such initiatives as the United Nations Decade on Ecosystem Restoration and the Bonn Challenge. The restoration of sustainable landscapes cannot be done through large-scale afforestation efforts, which are capital-intensive and the sole measure of evaluating the density of the canopy cover through remote sensing (Schulte to Bühne et al., 2025). Rather, in a climate-resilient infrastructure policy, sustainable functioning is key through decentralized governance, maintenance, resilient logistics, and environmental protection institutions within the local geopolitics (Goldman, 2008; Li, 2007; Svarstad et al., 2018).

However, despite the important comparative findings provided in this research, there are certain methodological and empirical constraints which need to be discussed. For instance, although the approach to comparative cases which uses site observatories, semi-structured interviews, and documentation analysis is perfectly applicable for uncovering complex political-ecological processes (Svarstad et al., 2018), it does not include any quantified information on seedling survival rates, soil moisture changes, and biomass production within the intervention areas (Gebrekidan et al., 2020; Gebru et al., 2019). Also, due to ongoing military operations in the region, primary data collection in Tigray after 2020 was limited by security threats, telecommunication outages, and lack of access to conflict areas.

In order to overcome such constraints, future work ought to involve mixed-method approaches that combine studies in political ecology with long-term, high-resolution biophysical assessment (drone-enabled remote sensing and hydrologic accounting). Conducting further fieldwork in other member states of the GGW, for example, Niger, Chad, Mali, and Burkina Faso, will also help evaluate the wider applicability of the socio-technical

supply chain framework under differing levels of state capacity, vulnerability to climate change, and civil unrest.

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