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Effectiveness of alluvial gully remediation in a semi-arid rangeland catchment

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Abstract

Gully erosion is a globally significant form of land degradation that affects agricultural and rangeland productivity, ecosystem health and downstream water quality. In northern Australia, gully erosion is a major source of anthropogenic sediment delivered to the Great Barrier Reef (GBR) lagoon, driving substantial investment in landscape repair and gully remediation. However, quantitative assessments of remediation effectiveness remain limited, particularly for alluvial gullies in semi-arid environments where pre- and post-remediation water-quality monitoring is rarely available. This study evaluates remediation effectiveness using hydrological and water-quality monitoring from treated and control alluvial gullies in the Upper Burdekin catchment, a major sediment source to the GBR lagoon. Results from the post-remediation monitoring period indicate that high-intensity remediation, involving extensive engineering works and soil treatments, achieved sediment-yield reductions of up to 99%, despite the first post-treatment year receiving the third-highest annual rainfall on record since 1889. In contrast, medium-intensity remediation achieved lower effectiveness of 37% after one year. These findings show that high-intensity remediation can rapidly reduce sediment export from alluvial gullies but is costly and should be targeted to gullies where erosion processes, morphometric state and sediment-delivery potential justify intensive intervention. While vegetation recovery and longer-term landscape stabilisation may require additional time, immediate reductions in sediment export are achievable, supporting targeted remediation to reduce rangeland degradation and sediment delivery at gully scales. Continued long-term monitoring is needed to assess whether remediation outcomes persist under variable climatic conditions.

Introduction

Globally, gully erosion is a major land degradation process, affecting rangeland productivity and stability while also contributing disproportionately to catchment sediment yields (Poesen et al., 2002, Valentin et al., 2005). In northeastern Australia, alluvial gullies in catchments draining to the Great Barrier Reef (GBR) are of particular concern because they are ubiquitous across degraded rangelands, incise dispersive, clay-rich alluvial soils, and efficiently deliver fine sediment to downstream waterways (Bainbridge et al., 2024, Thwaites et al., 2022). Addressing alluvial gully erosion is therefore important not only for improving downstream water quality to protect the reef, but also for restoring on-site land condition and rangeland function. Although substantial investment has been made in gully remediation programs, quantitative evidence of treatment effectiveness remains limited, particularly for alluvial gullies, because most previous studies in GBR catchments have focused on hillslope management (Koci et al., 2020; Wilkinson et al., 2018). Recent alluvial-gully studies show that high sediment-reduction effectiveness (85-99%) can be achieved using integrated engineering and catchment-management approaches (Brooks et al., 2025, Hawdon et al., 2025), but further evaluation is needed in other GBR catchments where gully form, soils, rainfall, and hydrological connectivity differ.

Using event-scale rainfall, runoff, and suspended sediment data from treated and control alluvial gullies, this study quantifies contemporary sediment export from alluvial gullies and evaluates the effectiveness of remediation.

Methods

Five alluvial gullies in the Upper Burdekin were monitored using a paired control-treatment design from 2022 to 2026. Two gullies (JJ2 and GIL2) received high-intensity remediation involving full reshaping, drainage control, subsoil amelioration, surface cover, fertiliser application and seeding in

November 2024 (Figure 1). A third gully (LEI1) received medium-intensity remediation involving localised headscarp reshaping and mulch application in November 2025. Two untreated gullies were retained as controls (JJ5 and GIL1). Rainfall, stage, velocity and visual flow conditions were monitored continuously, while event-based water-quality and bed-sediment samples were collected using rising-stage samplers, pump-assisted samplers, autosamplers and bed samplers, depending on sampler availability at each gully. Samples were analysed for turbidity, total suspended solids, and suspended sediment concentration at the James Cook University TropWATER Laboratory. Event runoff, peak discharge, suspended sediment concentration and sediment load were calculated from monitored hydrographs and sample concentrations. Remediation effectiveness was assessed using before-after and control-impact comparisons following Hawdon et al. (2025), with responses evaluated using runoff ratio, peak discharge and annual specific sediment yield normalised to gully area.

Results

Effect of treatment on runoff, suspended sediment concentrations and yield

Following high-intensity remediation, annual runoff ratio (RR) declined at both treated gullies. At JJ2, RR declined from 40% before treatment to 24% in the first post-treatment wet season and 28% in the second post-treatment wet season (Figure 2). At GIL2, RR decreased from 67% before treatment to 23% in the first post-treatment wet season and 37% in the second post-treatment wet season. In contrast, the medium-intensity treatment at LEI1 showed little reduction during the first post-treatment year, with a slight increase from 53% to 57%.

Suspended sediment concentration (SSC) and sediment yield (SY) showed stronger treatment responses than runoff. At high-intensity treatment sites, geometric mean SSC declined by more than one order of magnitude, from 50,912 to 3,092 mg L⁻¹ at JJ2 and from 61,483 to 1,598 mg L⁻¹ at GIL2. In contrast, the medium-intensity treatment at LEI1 produced a less pronounced decline, with geometric mean SSC decreasing from 39,226 to 9,726 mg L⁻¹. Annual specific SY showed a similar pattern. At the high-intensity treatment sites, annual yield declined from 925 to 45 t ha⁻¹ yr⁻¹ at JJ2 and from 414 to 9 t ha⁻¹ yr⁻¹ at GIL2 after remediation. In contrast, the medium-intensity treatment at LEI1 showed a smaller reduction, declining from 262 to 67 t ha⁻¹ yr⁻¹ in the first post-remediation year.

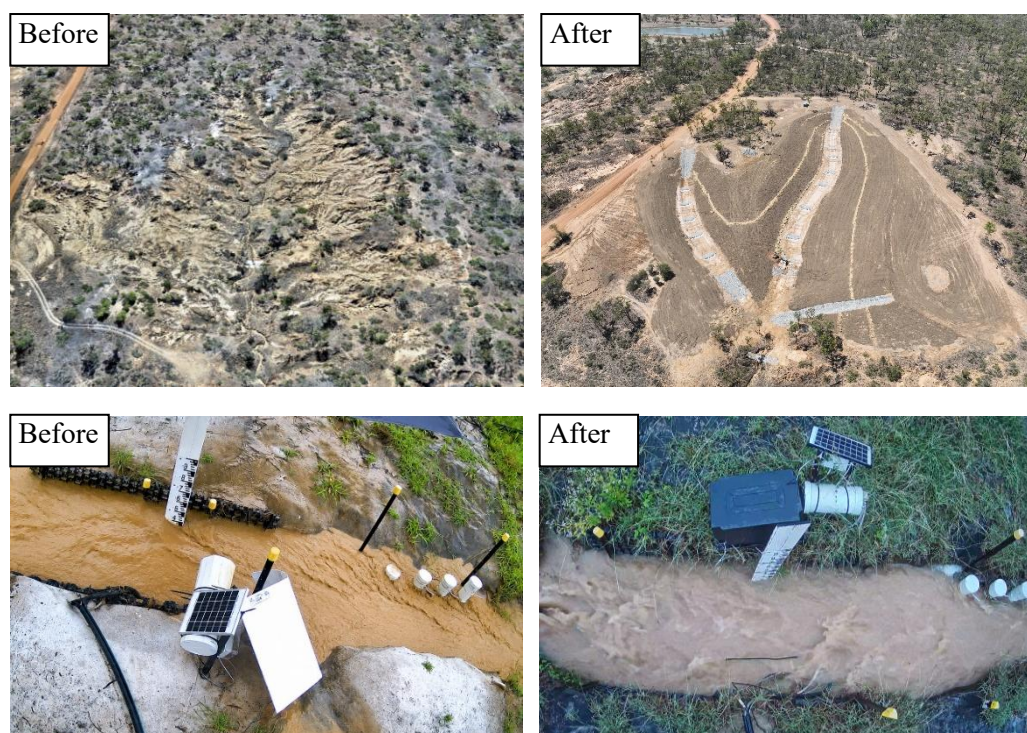


Figure 1. The top panels show aerial photographs of the JJ2 gully before and after remediation. Bottom panels show camera footage of runoff in the JJ2 channel before and after remediation.

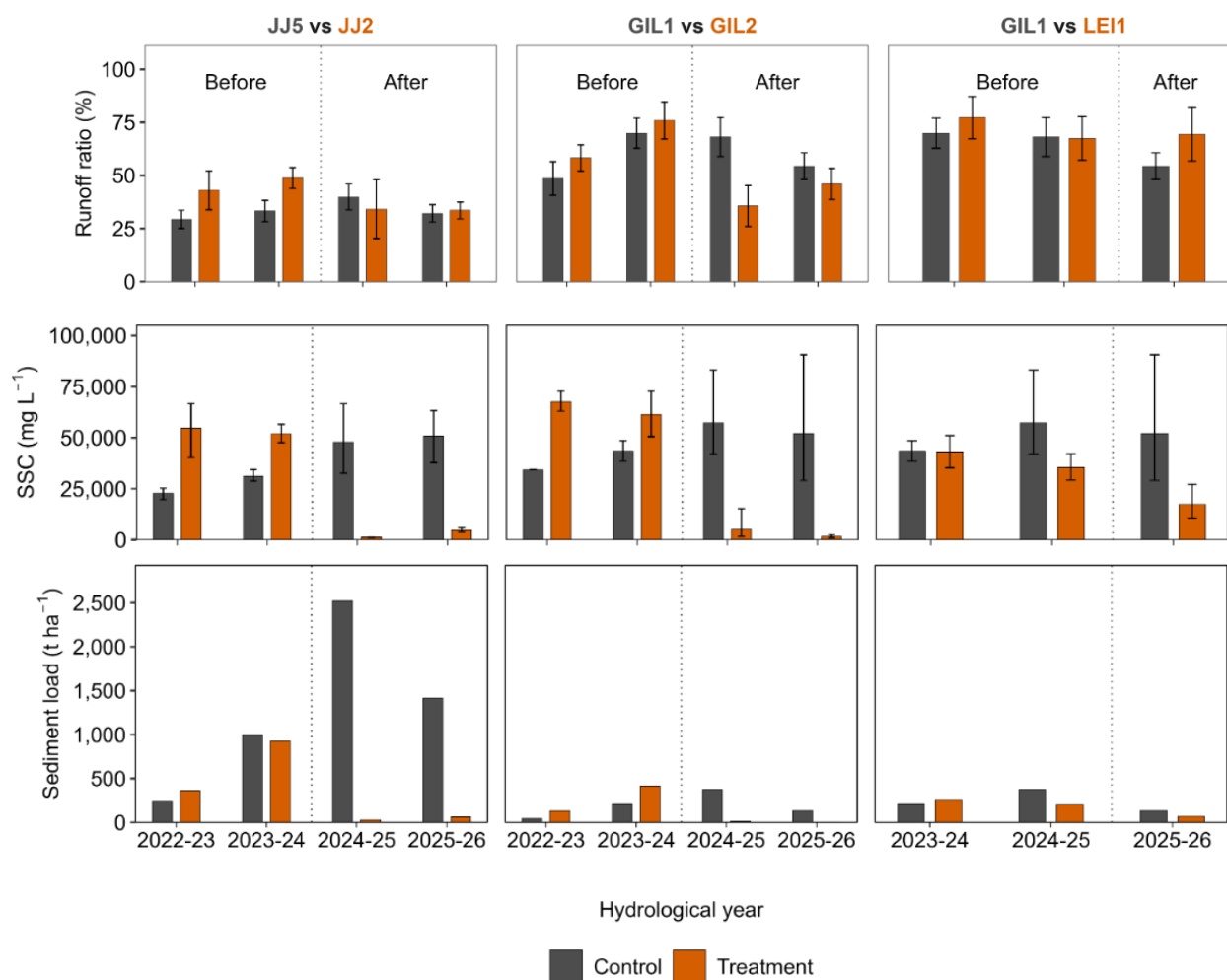


Figure 2. Annual mean runoff ratio, annual geometric mean suspended sediment concentration (SSC), and annual total sediment load for treated gullies and paired control gullies before and after remediation. Grey bars represent control gullies and orange bars represent treated gullies. Error bars show the standard deviation of event-scale values within each hydrological year. The vertical dotted line separates the before- and after-remediation periods for each paired comparison.

Effectiveness of remediation

Remediation significantly reduced runoff ratio, suspended sediment concentration and sediment yield at the high-intensity treatment sites ($p < 0.05$). Sediment-yield effectiveness was highest in the first post-treatment wet season, reaching 99% at JJ2 and 98% at GIL2, despite this being the wettest year of the monitoring period. Effectiveness declined slightly to 96% at JJ2 in the second post-treatment year but remained high at GIL2 across both post-treatment years. At LEI1, which received medium-intensity remediation, no significant effect was detected for runoff ratio or sediment yield. Correspondingly, sediment-yield effectiveness was lower at 37%.

Discussion

The results confirm that alluvial gullies in the Upper Burdekin are major contemporary sediment sources, with suspended sediment concentrations and specific sediment yields broadly comparable to alluvial gullies reported in other studies across GBR catchments (Brooks et al., 2025; Dorian et al., 2021; Hawdon et al., 2025). However, yields were much greater than those commonly reported from hillslope erosion in GBR catchments, supporting the continued prioritisation of alluvial gullies for fine-sediment reduction (Koci et al., 2021; Wilkinson et al., 2018). The high-intensity treatments produced sediment-yield reductions comparable to recent GBR alluvial-gully remediation studies, where effectiveness of approximately 84–99% has been reported (Brooks et al., 2025; Hawdon et al., 2025).

This indicates that intensive reshaping, drainage control, soil amelioration and surface stabilisation can rapidly reduce sediment export, even under very wet post-treatment conditions. In contrast, the weaker response at the medium-intensity site suggests that localised treatment may be insufficient where untreated erosion surfaces remain active, or that longer monitoring is needed before effectiveness can be confidently assessed. These findings indicate that remediation programs should prioritise high-yielding alluvial gullies, while matching treatment intensity to geomorphic state, dominant erosion processes and likely long-term cost effectiveness.

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