

Sustainable Solutions for Ensuring Safe Drinking Water in Remote and Indigenous Communities in Australia

B.M.J. Kalpana Balasooriya

School of Civil and Environmental Engineering, Faculty of Engineering, Queensland
University of Technology (QUT), Brisbane QLD 4001, Australia

kalpanabalasooriya1990@gmail.com

Jay Rajapakse

School of Civil and Environmental Engineering, Faculty of Engineering, Queensland
University of Technology (QUT), Brisbane QLD 4001, Australia

jay.rajapakse@qut.edu.au

Chaminda Gallage

School of Civil and Environmental Engineering, Faculty of Engineering, Queensland
University of Technology (QUT), Brisbane QLD 4001, Australia

chaminda.gallage@qut.edu.au

ABSTRACT

Access to safe drinking water remains a significant challenge in many remote and Indigenous communities globally, including in Australia. This is particularly evident in parts of Queensland, where elevated levels of iron (Fe) and manganese (Mn) persist in drinking water sources. Despite conventional treatment technologies, water quality often remains non-compliant with Australian Drinking Water Guidelines (ADWG), especially regarding Fe and Mn concentrations. This study presents a comprehensive analysis of drinking water quality data from 61 remote and Indigenous councils in Queensland, identifying critical exceedances in water quality parameters. In response to these challenges, two low-cost, sustainable treatment approaches were developed and evaluated: (i) biochar and activated carbon derived from locally sourced agricultural biomass including sugar cane bagasse, sugar cane mulch, barley straw, wood shaving, chickpea stubble, sorghum stubble and (ii) calcined clay-biomass composite media using common brick mix, harvest cream clay, enhanced with selected agricultural wastes. Among these materials, biochar derived from chickpea stubble achieved over 90% removal of Fe and Mn in both single and binary ion systems. When chemically activated, wood shavings proved highly efficient for dual-ion removal with lower feedstock mass. Meanwhile, the clay-biomass composites (25% common brick mix and 75% harvest cream, referred to as CH4, with 1%–6% agricultural waste additions) exhibited excellent removal capacity, offering a viable, chemical-free filtration solution for application in decentralized water treatment systems. These findings underscore the potential of locally sourced, circular economy-driven materials to serve as sustainable solutions for improving drinking water quality in remote, and Indigenous communities.

KEYWORDS: Safe drinking water, biochar, activated carbon, calcined clay, iron and manganese removal, remote communities, Indigenous Australia

1 INTRODUCTION

Access to clean and safe drinking water is essential for protecting human health, fostering economic development, and maintaining social equity. Yet, it remains a critical challenge in many remote and Indigenous communities globally, including in Australia (Rajapakse et al., 2022). Despite considerable global progress, a significant number of people still lack reliable access to potable water. In 2022, while around 6 billion individuals had access to safely managed drinking water services, approximately 2.2 billion remained dependent on basic or limited sources such as untreated surface water, springs, or unprotected wells. This disparity is most severe in low-income, informal, or marginalized communities where geographic and socioeconomic factors compound existing inequalities (World Health Organization, 2023).

In the Australian context, water security challenges are particularly acute in regional and remote areas. According to recent estimates, over 400 such communities lack access to consistently safe and dependable drinking water (CSIRO, 2023). While Australia has made marginal progress in the United Nations Sustainable Development Goals (SDGs), advancing from 38th in 2022 to 37th in 2024, its performance under SDG 6 focused on clean water and sanitation remains moderate.

In Queensland, a number of remote and Indigenous communities face persistent water quality issues. Elevated levels of hardness, turbidity, total dissolved solids (TDS), fluoride, iron, and manganese have been reported, often exceeding the limits outlined in the Australian Drinking Water Guidelines (Balasooriya et al., 2023, 2024). In some instances, iron levels have reached as high as 13.6 mg/L in raw water and 6.33 mg/L in treated water, while manganese has been detected at concentrations of up to 61 mg/L in raw and 4.5 mg/L in treated water far above the recommended limits of 0.3 mg/L for iron and 0.1 mg/L for manganese.

A variety of treatment technologies have been explored to tackle these contaminants, including biological filtration, electrochemical processes, and membrane-based systems such as forward osmosis and hybrid forward osmosis (FO) - Reverse osmosis (RO) configurations. While effective under specific conditions, these methods are often unsuitable for rural and remote application due to their complexity, operational costs, maintenance requirements, and energy demands (Doble et al., 2023). Other promising methods involve gas chlorination, ozonation, membrane filtration systems such as (FO) and FO-RO hybrids, membrane distillation, and adsorption. Despite their effectiveness, these technologies face notable limitations, including the production of disinfection by-products, the need for high operational concentrations, significant capital investment, frequent chemical cleaning, and substantial energy demands.

Given these challenges, a comprehensive water quality analysis was undertaken to investigate drinking water issues specific to remote regions, particularly within the Australian context, and to explore emerging alternative solutions. Among the promising solutions identified is the use of locally available clay and biomass as low-cost filtration media. These materials offer a sustainable and practical approach to removing iron and manganese without reliance on chemical oxidants. Early laboratory and bench-scale trials have shown encouraging results, suggesting strong potential for application in rural and Indigenous water treatment systems.

2 MATERIALS AND METHODS

2.1 Comprehensive drinking water quality data analysis

Drinking water quality data from 45 rural and remote councils and 16 Indigenous councils in Queensland were collected and reviewed using their publicly available Drinking Water Quality Management Plans (DWQMPs). The analysis focused on identifying exceedances of the Australian Drinking Water Guidelines (ADWG) across 61 councils. Key water quality parameters assessed included iron, manganese, turbidity, total dissolved solids (TDS), hardness, colour, fluoride, and others known to be problematic in remote supply systems.

2.2 Biochar and Activated carbon from biomass feedstock

Agricultural waste materials were sourced from remote areas of Queensland, including sugarcane bagasse (SCB), sugarcane mulch (SCM), barley straw (BS), wood shavings (WS), chickpea stubble (CS), and sorghum stubble (SS). These feedstocks were first converted into biochar via low-temperature pyrolysis at 450°C. For activated carbon production, selected biomass samples were chemically treated with 85 wt.% phosphoric acid (H₃PO₄) and then subjected to thermal activation at 450°C for 40 minutes. The resulting biochar and activated carbon were characterized through a series of physical and chemical analyses to assess their potential as filtration media.

2.3 Calcined clay-biomass composite filter media

Two locally available clays; Common Brick Mix (CBM) and Harvest Cream (HC)—were selected to assess their suitability for filtration applications. Both clays are rich in kaolinite, a clay mineral with the formula Al₂Si₂O₅(OH)₄, known for its contribution to water treatment. HC contains approximately 41% kaolinite, while CBM contains 33%. To identify the optimal base composition for filter media, the two clays were blended in various ratios (as outlined in Table 1). Spherical clay balls with a 50 mm diameter were formed from each mixture, this size was chosen based on a prior, unpublished study conducted at QUT. The samples were then subjected to firing across a temperature range of 450°C to 1050°C to evaluate their thermal behaviour and physical integrity.

To enhance porosity and filtration performance, selected organic waste materials (sugarcane bagasse (SCB), sugarcane mulch (SCM), barley straw (BS), wood shavings (WS), chickpea stubble (CS), and sorghum stubble (SS)) were added in small percentages (1–6%) to the optimal clay mixture. The final formulation was identified based on its mechanical stability, porosity, and removal efficiency for iron and manganese.

Table 1 Mixing schedule of main materials

Sample ID	Common Brick Mix	Harvest Cream
CH1	100	0
CH2	75	25
CH3	50	50
CH4	25	75
CH5	0	100

Note: In the sample IDs CH1, CH2, CH3, CH4, and CH5, 'C' represents Common Brick Mix (CBM) and 'H' represents Harvest Cream (HC).

3 RESULTS AND DISCUSSION

3.1 Water quality data analysis

An analysis of drinking water quality data from remote regional councils in Queensland, compared against the Australian Drinking Water Guidelines (ADWG), revealed several significant exceedances across key parameters (Table 2). While treatment processes typically reduce contaminant concentrations, raw water in many locations exceeds ADWG thresholds for parameters such as total hardness, total dissolved solids (TDS), colour, turbidity, silica, sodium, chloride, fluoride, iron, and manganese. Nitrate was the only parameter consistently within guideline limits. Alarming, even after treatment, almost all the parameters including iron, manganese and turbidity continue to surpass ADWG limits, indicating the need for improved treatment technologies or enhanced source water management strategies.

Table 2 Reported maximum parametric concentrations in remote regional councils

Parameter	ADWG	Max value in Raw water	Location	Max value in finished water	Location
Conductivity	N/A	5100	Quilpie SC	2500	Quilpie SC
Total Hardness	200 as CaCO ₃	1145	Isaac RC	510	Isaac RC
TDS	600 mg/L	2970	Quilpie SC	1500	Quilpie SC
Colour	15	1940	Isaac RC	120	Isaac RC
Turbidity	5 NTU	2242	Isaac RC	30.1	Isaac RC
Silica	80 mg/L	88	Quilpie SC	147	Goondiwindi RC
Sodium	180 mg/L	640	Quilpie SC	350	Quilpie SC
Chloride	250 mg/L	1300	Quilpie SC	560	Quilpie SC
Fluoride	1.5 mg/L	1.8	Boulia SC	1.9	Boulia SC, Quilpie SC
Nitrate	50 mg/L	46	Burdekin SC	53	Goondiwindi RC
Iron	0.3 mg/L	13.6	Tablelands RC	6.33	Blackall-Tambo RC
Manganese	0.1 mg/L	61	South Burnett RC	4.5	Isaac RC

The water quality data from all 16 Aboriginal council highlights the Pormpuraaw ASC and Yarrabah ASC where report highest value for every parameter (Table 3). In the raw water, Pormpuraaw ASC exceeds the ADWG recommendations for conductivity, total hardness, and TDS, while Yarrabah ASC surpasses the guidelines for total hardness, TDS, colour, and turbidity. While treatment improved water quality in both communities, several key indicators particularly turbidity, colour, iron, and manganese remained above guideline levels in finished water.

Table 3 Reported maximum parametric concentrations in Aboriginal councils

Parameter	ADWG	Max value in Raw water	Location	Max value in finished water	Location
Conductivity	N/A	1100	Pormpuraaw ASC	200	Yarrabah ASC
Total Hardness	200 as CaCO ₃	240	Pormpuraaw ASC	25	Yarrabah ASC
TDS	600 mg/L	610	Pormpuraaw ASC	160	Yarrabah ASC
Colour	15	110	Yarrabah ASC	53	Yarrabah ASC
Turbidity	5 NTU	54	Yarrabah ASC	12	Yarrabah ASC
Iron	0.3 mg/L	8.54	Yarrabah ASC	4.89	Yarrabah ASC
Manganese	0.1 mg/L	0.191	Yarrabah ASC	0.271	Yarrabah ASC

Iron and manganese remain critical concerns. Conventional chemical oxidation methods—such as potassium permanganate (KMnO₄) are commonly used to precipitate these metals. However, these methods often produce fine colloidal particles, especially for manganese, which are difficult to filter and lead to rapid filter clogging, reduced run times, and increased backwashing frequency.

3.2 Biochar and Activated carbon produced from agricultural wastes

The biochar and activated carbon produced from agricultural waste shows high removal efficiencies, as shown in Figure 1 and 2, with yields above 24% for biochar and 34% for activated carbon. Both materials demonstrated high porosity and surface area compared to raw biomass, which explains their superior removal performance.

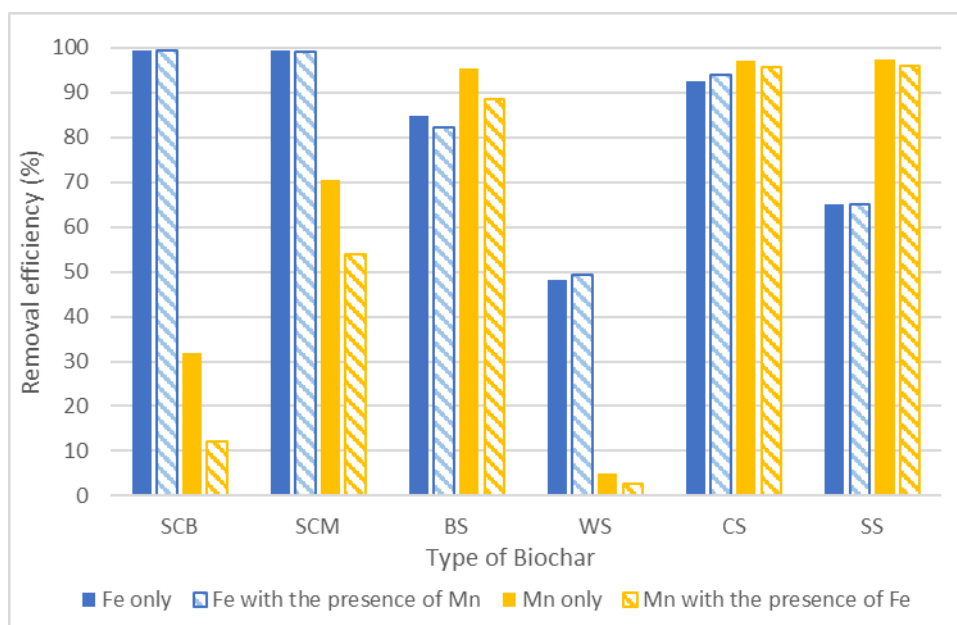


Figure 1: Fe and Mn removal efficiencies of different biochar

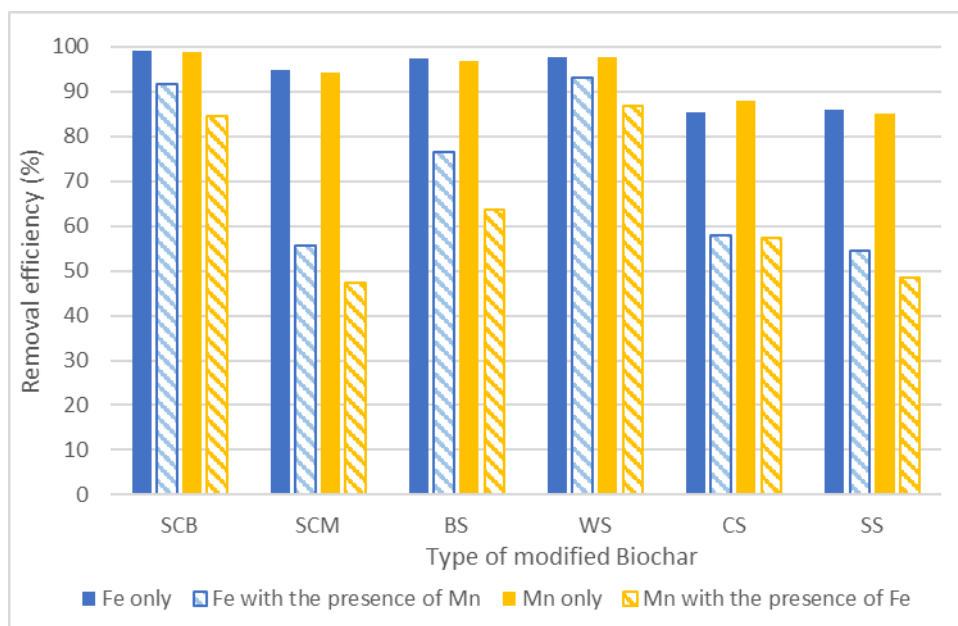


Figure 2: Fe and Mn removal efficiencies of different activated carbon

Activated carbon derived from sugarcane bagasse (SCB), sugarcane mulch (SCM), barley straw (BS), and wheat straw (WS) demonstrated over 90% removal efficiency for both Fe and Mn in single ion systems, although efficiency decreased in binary ion systems. However, chemical activation is necessary for producing activated carbon.

Conversely, biochar showed excellent Fe removal efficiency for SCB and SCM in both single and binary ion systems, while manganese removal was notably high for chickpea stubble (CS) and sorghum stubble (SS). Remarkably, chickpea stubble biochar achieved over 90% removal for both Fe and Mn in single and binary ion systems. Therefore, biochar could be considered an alternative to activated carbon despite requiring approximately 10% more raw material, with the choice depending on specific treatment requirements and material availability.

3.3 Calcined clay-biomass composite

As an initial phase of batch testing, Common Brick Mix and Harvest Cream were used in various proportions to identify the most favorable material combination. Five formulations of clay balls were created by mixing Common Brick Mix and Harvest Cream as outlined in Table 1. Mass changes at 1050°C were recorded at each stage and summarized in Table 4.

Table 4: Changes in the mass of clay balls at the end of each stage

Material Label	Common Brick Mix (%)	Harvest Cream (%)	Average mass of the clay ball			
			Wet/bulk	Air-dry	Oven Dry	Burned
CH1	100	0	135.805	117.965	116.875	104.1
CH2	75	25	135.175	116.945	115.92	103.105
CH3	50	50	134.385	116.05	115.08	102.16
CH4	25	75	132.215	113.4	112.485	99.63
CH5	0	100	126.015	106.84	106.01	93.825

Increasing the proportion of Harvest Cream (HC) in the clay mixtures led to a reduction in the density of the clay balls. To evaluate performance, removal efficiencies were compared

in both single-ion and binary-ion solutions. Among the formulations, CH4 demonstrated superior removal of both Fe and Mn in the binary system. Based on this performance, CH4 was selected for further investigation by incorporating varying percentages of selected agricultural waste materials. Final products were produced by adding 1–6% of these waste materials to the CH4 clay mixture, as supported by laboratory-scale experiments.

4 CONCLUSION

This study addressed the persistent challenge of iron and manganese contamination in drinking water across remote and Indigenous communities in Queensland, Australia, regions where conventional treatment systems often fall short due to cost, complexity, and operational demands. A comprehensive analysis of water quality data from 61 local councils confirmed widespread exceedances of Australian Drinking Water Guidelines (ADWG) for multiple parameters, with Fe and Mn posing particularly significant risks to public health.

To provide sustainable, context-appropriate solutions, two low-cost treatment media were developed and evaluated: (i) biochar and activated carbon derived from locally available agricultural residues, and (ii) a calcined clay-biomass composite using regional clays and selected organic agri-wastes. The study found that biochar from chickpea stubble achieved high Fe and Mn removal efficiencies (>90%) in both single and binary ion systems, while chemically activated wood shavings showed strong performance with lower feedstock input. Additionally, the optimized clay-biomass composite (CH4 formulation, incorporating 25% common brick mix, 75% harvest cream clay, and 1–6% agricultural waste) demonstrated excellent removal efficiency without the need for chemical additives.

These findings support the viability of circular economy-inspired materials as sustainable, scalable, and locally implementable alternatives for improving drinking water quality in underserved regions. Future work should focus on long-term pilot-scale testing, integration into existing infrastructure, and engagement with local communities to ensure adoption and operational sustainability.

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