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Research paper

Partnering with our environment to manage our wastes: land application of drinking water treatment and wastewater treatment sludges in sandy soils

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The application of sewage sludge to agriculture is particularly risky in sandy soils, due to pollutant mobility. However, these nutrients are most needed in these soils, which are widely distributed in Southern Africa. This perspective piece investigates the co-amendment of water treatment residuals (WTR) to promote soil integrity, analogous to the sorptive properties of clay, fortifying nutrient-poor sandy soils to receive sewage sludge. Ecological motivations like biomimicry, environmental carrying capacity and evolutionary adaptation were explored. Land application was compared to other sludge re-use options, focusing on practical considerations. The local distribution of sandy soils and their agricultural consequences were mapped, with an exploration of the high-value crops ideal for this strategy – harnessing crop growth for pollutant remediation and minimizing downstream market risks. The economic benefits and challenges were explored in the 'sandbox' of the Philippi Horticultural Area, where a co-diversion strategy was modelled using simple cost analyses. Public participation was explored through the vehicle of eco-conscious markets and certification. Finally, a relatively consistent WTR and sewage sludge production ratio was shown across provincial, national and international urban development, a golden thread facilitating this waste management strategy.

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INTRODUCTION

With the development of every town or city worldwide, a dual network of water treatment systems co-develops. Potable water for human settlements is generated by cleaning dam or river water in drinking water treatment plants (DWTPs) (Krause and Bronstein, 2024). Water that has moved through human activities – household, medical and industrial wastewater – is then treated in wastewater treatment plants (WWTPs) (Turner et al., 2019). These plants aim to remove a complex array of pollutants, including carbon, nitrogen and phosphorus, microbial pathogens and industrial and pharmaceutical micropollutants.

DWTPs and WWTPs produce different types of sludge as a by-product (Krause and Bronstein, 2024). These waste streams are often destined for landfill (Krause and Bronstein, 2024; Turner et al., 2019; Hudcová et al., 2019), although some countries divert these sludges to productive applications (Turner et al., 2019; Lundin et al., 2004). Potable water treatment residuals (WTR) are typically clean dam or river sediment, flocculated with iron or aluminium oxyhydroxides and a polyelectrolyte (Herselman, 2013). Iron oxyhydroxides are used for flocculation in source water that is richer than normal in organics, whereas cheaper aluminium oxyhydroxides are more ubiquitously used. Sewage sludge from WWTPs is typically much more complex, with many potentially toxic elements (Turner et al., 2019).

Landfills are increasingly capacity-limited (Korhonen et al., 2018), and a circular economy requires the diversion of these sludges away from landfill to productive applications (Krause and Bronstein, 2024; Hudcová et al., 2019). For instance, in the Western Cape of South Africa, a recent (2017) municipal ban requires the diversion of 100% of organic waste from landfill to productive applications by 2027 (WCDEADP, 2022). Internationally, the United Nations promotes waste re-use under Sustainable Development Goals 11 (Sustainable Cities), 12 (Responsible Consumption and Production), 13 (Climate Action – landfill methane gas), 14 (Life Below Water – eutrophication), 15 (Life on Land – landfill expansion), and 17 (collaboration) (United Nations Department of Economic and Social Affairs, 2024).

Biomimicry: the ecology of sludge-to-agriculture diversion

One of the more common and accessible applications for sewage sludge is agriculture (Turner et al., 2019; Hudcová et al., 2019). In nature, the waste passing through animals is distributed across land as a heterogenous blanket of nutrients, accessible to plants via soil microbial metabolic turnover (Fig. 1a) (Waltner-Toews, 2013). Distribution patterns are determined by animal migration.

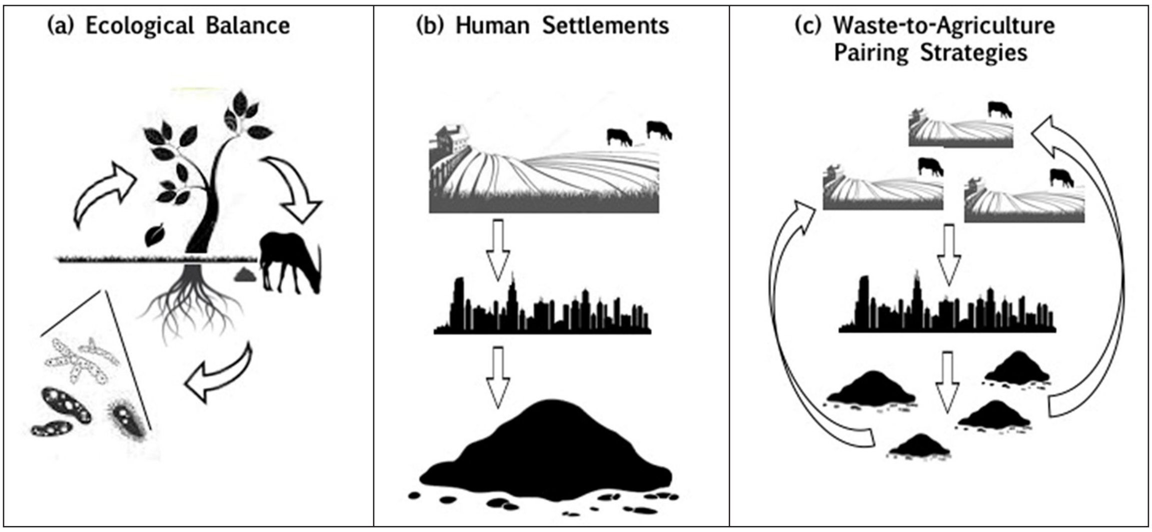

Figure 1. Sludge diversion into agriculture, informed by biomimicry. A nature-based biomimicry solution to the landfill capacity crisis (Korhonen et al., 2018) and the local municipal landfill organics ban (WCDEADP, 2022).

In contrast, in landfill, these nutrients are heavily concentrated in small tracts of land (Fig. 1b). Distribution of these waste sludges into agricultural land is thus a form of biomimicry in urban design (Fig. 1c). The linear system is understandable, as there are risks to distributing both waste sludges, including dispersing pathogens, heavy metals and micropollutants. Internationally, nutrient neutrality is a requirement, for instance in the Council Directive 92/43/EEC (European Economic Community) on the Conservation of Natural Habitats and Wild Flora and Fauna. However, the landfill containment strategy is becoming increasingly risky, considering land restrictions, pollutant migration (Mukherjee et al., 2015) and greenhouse gas emissions (Themelis and Ulloa, 2007) from landfill.

Realistic considerations: resource recovery or land application?

Peccia and Westerhoff (2015) encourage the implementation of novel technologies for high monetary value resource recovery, like energy or mineral nutrients. For instance, Germany promotes phosphorus recovery for all wastewater treatment plants sourcing waste from over 50 000 to 100 000 person equivalents (ATT, 2020).

However, many of the countries in the EU do apply most of their sewage sludge to agricultural land. As early as 2014, Ireland was diverting as much as 70% of their sewage sludge into agriculture (Turner et al., 2019). There are some positive reports of land application activities in well-regulated countries (Courtney, 2022). In developing Southern African countries, financial limitations and competing governance priorities (i.e. poverty) inhibit the wide-scale implementation of expensive technologies, such as phosphorus recovery (WCDEADP, 2021). Thus, agricultural applications are the most feasible current alternative, particularly for nutrient-rich sewage sludge. The risks are most effectively controlled by:

- Understanding the receiving soil and waste composition for careful pairing, preventing excessive nutrient and heavy metal loads
- Understanding the environmental carrying capacity of the receiving soil (the factors facilitating pollutant metabolism, sorption and turnover)
- Understanding and limiting pollutant mobility in the system (containment)
- Creating an effective monitoring system, after a baseline characterization of the waste, receiving soil and surrounding environment

Realistic considerations: pollutant mobility in sandy soils

For optimal sludge-to-soil pairing, the land application of sewage sludge is most useful in sandy soils. Sandy soils are generally nutrient-poor with low organic carbon content (Huang and Hartemink, 2020), and nutrients are not well-retained for microbial metabolism and plant access. When sewage sludges are applied to sandy soils, valuable nutrients wash into the water system and become pollutants via eutrophication.

Soil pollutants like heavy metals, microbes and micropollutants can be remediated via phytoremediation (Loffredo et al., 2021; Bian et al., 2020), soil biota competition (Samaddar et al., 2021) and physicochemical reactions (Menacherry et al., 2023). Textile crops are typically grown on sewage sludges, to prevent potential migration of pollutants and pathogens into the food chain. These crops are well-known for phytoremediation and pollutant uptake (Loffredo et al., 2021), especially with intercropping (Bian et al., 2020). However, they can only remediate the nutrients and pollutants that remain in the soil, and thus strategies to retain nutrients and pollutants in sandy soil systems are beneficial.

SANDY SOIL FORTIFICATION: CO-AMENDING WITH WTR TO RECEIVE SEWAGE SLUDGE

Clay delving is one strategy to overcome the problem of nutrient and pollutant mobility. Delving is a common practice in Australia, bringing lower layers of clay up into sandy topsoils for increased nutrient retention and reduced hydrophobicity (Hall et al., 2010). This is not well-suited to South Africa, where subsoil clay is often highly dispersive.

WTR is typically enriched in clays (phyllosilicates) compared to topsoil (Erskine et al., 2002), and the metal oxyhydroxides have similar sorption dynamics to clay (Heckman et al., 2018). Their high sorption capacity is due to a large proportion of micro- and mesopores, and consequently high surface area (Chiang et al., 2012). Thus, the addition of this clay-like material can fortify sandy soil to sequester nutrients and pollutants from sewage sludge, such as is achieved with clay delving.

In this waste diversion strategy, these two sludges are co-diverted from landfill to soil for textile crop growth (Fig. 2). The WTR fortifies the soil, and the sewage sludge provides nutrients. An individual WTR amendment limits soil phosphate (Krause and Bronstein, 2024; Clarke et al., 2019), and sewage sludge typically facilitates an excess of phosphate in soils when applied alone. The co-amendment improves crop growth through improved nutrient

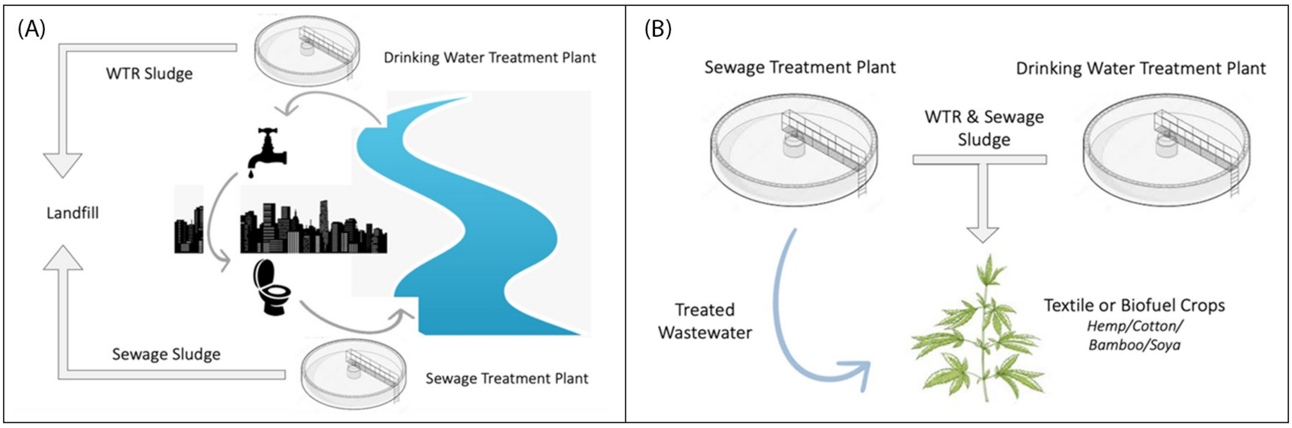

Figure 2. Potential diversion of the waste cycle from a linear (A) to a circular (B) economy, for high-value non-edible crops grown on soils amended with water and wastewater sludges

balances (Clarke et al., 2019), soil microbiology (Stone et al., 2021), soil-water dynamics (Stone et al., 2024) and the carbon storage capacity (Lukashe et al., 2024) of sandy soils. This circular strategy is financially beneficial to farmers, if logistically well-designed in terms of transport, as fertilizer prices rise (Tesfamariam et al., 2020).

Partnering with the environment: carrying capacity

The pollutant accumulation and transfer risks of sludge land application are high, but these are not necessarily mitigated in landfills. The primary risks of pollutant mobilisation in agriculture are (i) into the food chain (Turner et al., 2019), circumvented by growing non-edible crops (Loffredo et al., 2021; Bian et al., 2020), and (ii) into the surrounding environmental water resources, both surface- and groundwater (Mukherjee et al., 2015). However, water and soil-water systems are famously transboundary. Although point-source pollution can seem easier to control than dilute pollution sources, pollutants leach into the surface- and groundwater from landfills too. The complex concentration of wastes in landfills essentially eradicates any possibility of environmental remediation. In landfills, the pollutant concentrations exceed environmental carrying capacity, becoming toxic to the microbes and exceeding sequestration binding sites many-fold.

Here, it is argued that careful urban design can allow us to distribute pollutants into the environment in a controlled manner, and evaluate the thresholds at which natural bioremediation processes can transform pollutants. Natural bioremediation includes well-demonstrated mycorrhizal metabolic turnover (Loffredo et al., 2021; Bian et al., 2020), sequestration and binding (Ragle et al., 1997), solar radiation (Costa et al., 2020), and chemical degradation (Stangroom et al., 2000). Local regulations already protect us from risk, and require monitoring. Even in agricultural systems where biomass turnover is high, sludge application may not exceed 10 tonnes dry mass per hectare per year (Herselman and Snyman, 2009).

Partnering with the environment: adaptation

As described in Waltner-Toews' *The Origin of Feces: What Excrement Tells Us About Evolution, Ecology, and a Sustainable Society*, the wide distribution of waste has been central to evolution.

> As I watched the two East African [dung] beetles at work, I reflected that these animals were more than a curiosity. They embodied a question… How and why has excrement – which is absolutely necessary for the resilient functioning of our planet, and which has, in fact, been a solution to a myriad of biological problems thrown up by the long haul of evolution – become, in the past mere few thousands of years, a problem to be solved? When was the challenge of dancing through this amazing web of life-giving-life reduced to an issue of sustainable manure management?
>
> Every day, all around the world, by eating or burying what others consider waste, dung beetles turn water into wine, contaminated refuse into liveable landscapes. They are the Rumpelstiltskins of the animal world, weaving gold from dung-straw. They close the feedback loops of nutrients and energy that are essential for the resilience and health of the ecosystems that are our home. Can we learn from them? Is it important that we learn from them? (Waltner-Toews, 2013 p. 15–16)

We propose that the same can be said for the soil biota and plants in phytoremediation. Adaptive evolution is a positive process to be harnessed, and this type of text from the past reminds us of curiosity rather than utility in management. Through lower, chronic pollutant challenges (agricultural distribution) rather than acute, toxic pollutant challenges (landfills), the environment may be afforded enough of the critical parameter most necessary for evolution and adaptation: time.

Sandy soils: distribution and agricultural challenges

Although developed nations have led most research activities in this field, the optimal receiving soils for this waste co-amendment – nutrient-poor sandy soils – are distributed most widely across the developing world (Fig. 3; Huang and Hartemink, 2020). This is particularly relevant in South Africa (Fig. 4), as many farmers are farming on nutrient-poor, windblown, water-stressed (Steynberg et al., 1989) sandy soils requiring expensive fertilizer inputs (Huang and Hartemink, 2020). Soil fertility also has a bio-accumulative impact on plant and human health. Nutrient deficiencies in communities solely subsisting on crops grown in sandy soils in Maputaland, South Africa, cause elevated incidences of dwarfism and endemic osteoarthritis (Ceruti et al., 2003).

In addition, South African soils are carbon limited. For example, 58% of soils in South Africa have less than 0.5% soil organic carbon (SOC) and only 4% of soils have more than 2% SOC (Du Preez et al., 2011; Seboko et al., 2021). Recent carbon mapping shows how low the predicted long-term SOC averages are in South African biomes (Fig. 5), typically below 1 PgC in each biome (Venter et al., 2021). Comparatively, countries with vast peatlands and wetlands have much higher SOC, ranging from 5.4 PgC in Peru (Hastie et al., 2022) to 29.0 PgC in a 167 600 km^2 peatland in the Democratic Republic of the Congo (Crezee et al., 2022). This waste co-amendment strategy has been shown to improve soil carbon and nutrients, overcoming some of the fertility and structural agricultural deficiencies in local sandy soils (Clarke et al., 2019; Stone et al., 2021; Stone et al., 2024; Lukashe et al., 2024).

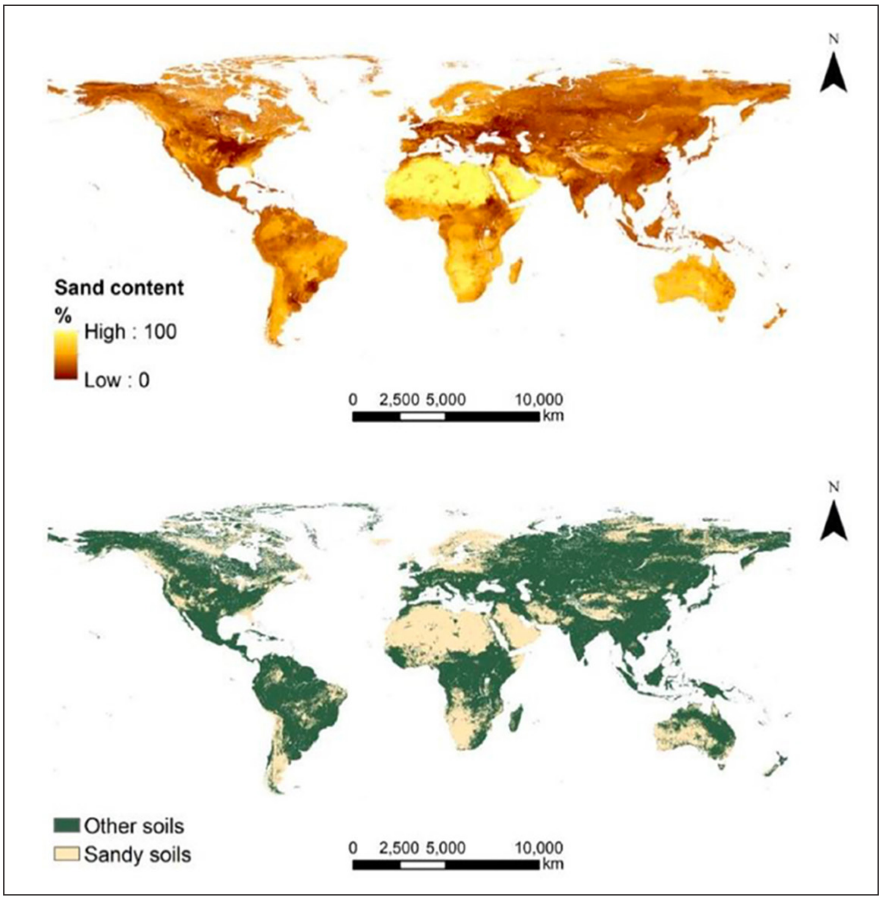

Figure 3. Spatial distribution of sand content (%) in the top 30 cm soil, and the distribution of sandy soils (sand, loamy sand and sandy loam) across the world, from Huang and Hartemink (2020)

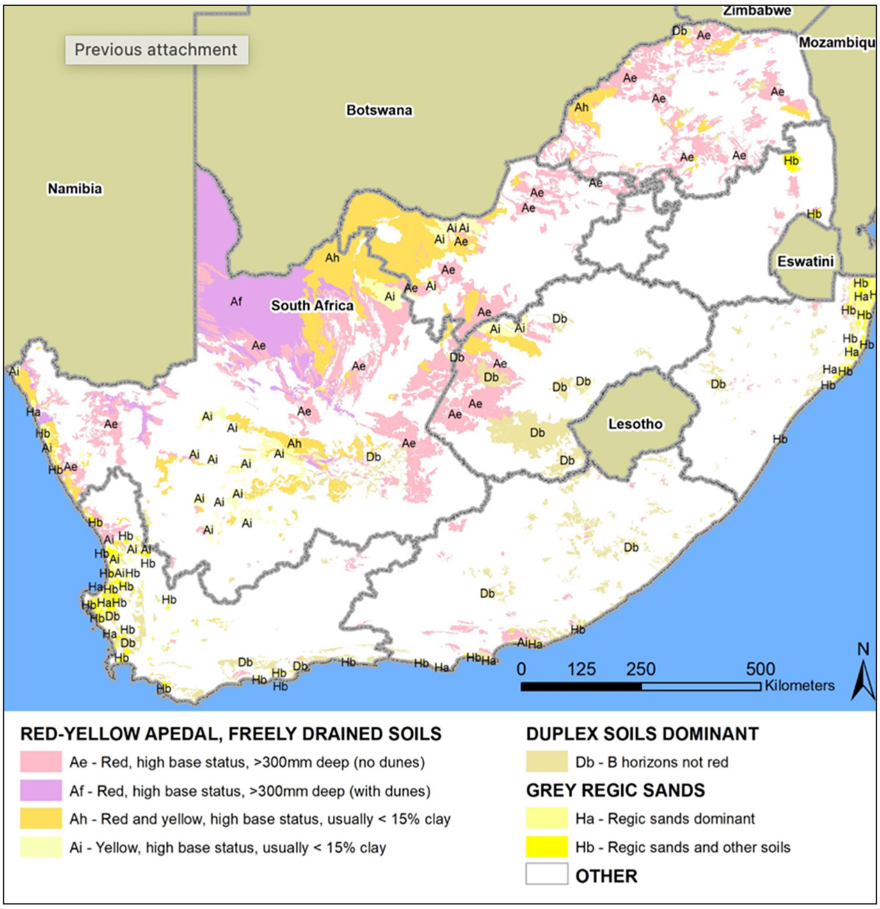

Figure 4. The wide South African distribution of sandy soils ideal to receive this co-diversion of WTR and sewage sludge, to improve soil fertility (Land Type Survey Staff, 1972–2006)

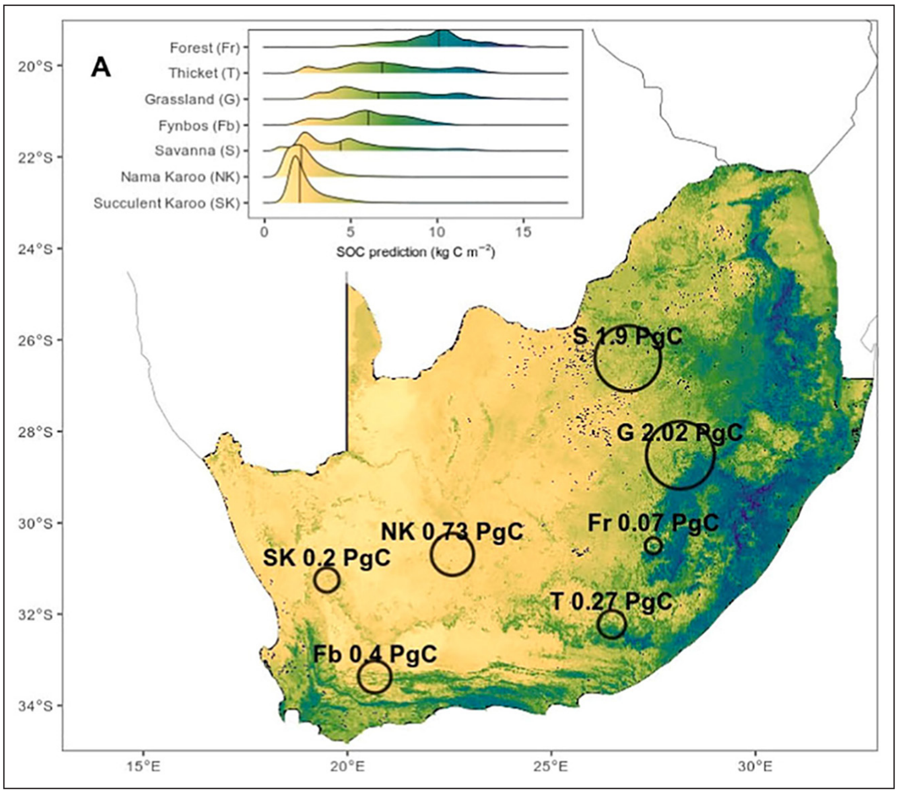

Figure 5. Predicted long-term average soil organic carbon (SOC) between 1984 and 2019, as mapped by Venter et al. (2021); text and circles indicate total SOC amounts within each biome in petagrams (10^{12} kg).

Table 1. A comparative assessment of local agronomic considerations, for farming non-edible crops on WTR and sewage sludges

Parameter	Crop				
	Cotton[a]	Hemp[b]	Soya[c]	Canola[d]	Bamboo[e]
Target industry	Textile	Textile	Biofuel	Biofuel	Textile
Growing season	Summer	Early spring–summer (photosensitive, daylight cycles)	Summer	Winter	Summer
Growing temperature	Warm summers, 15–28°C	Mild, temperate climate	Moderate (18–25°C), sensitive to extremes	Cool (0–15°C)	Wide range, tolerant of frost and drought, hardy
Soil pH	6–8.5	6–7.5	Acidic (>5.2)	5.5–7	5–6.5
Soil type	Sandy loam, well-drained	Loamy, >3.5% organic matter	Dense, nutrient-rich, high water-holding capacity	Clay-loam soils, but well-drained; sandy soils not recommended	Sandy soils, with clay additives, well-drained
Irrigation	4–6 days; drought-tolerant	Frequent during early phases, well-drained soils	Frequent during early phases, and pre-planting	Dryland conditions, but not drought-tolerant	Regular; twice per day in summer
Research interest	Well-established	New market	Well-established	Well-established	Increasing market interest

[a]DAFF (2012), [b]ARC (2018), [c]DAFF (2010), [d]DAFF (2016), [e]DPIRD (AU) (2014)

Market considerations: crop selection

As mentioned, high-value, non-edible crops like biofuel, and textile crops like cotton, hemp and bamboo, circumvent the risks of pollutant transfer in edible crops. Edible crops are also less likely to meet export criteria during droughts, which is a constant challenge across Southern Africa. Textiles and biofuels are less vulnerable to export criteria and are thus ideal drought buffer crops. Agro-economic considerations of high-value non-edible crops that can be grown on these wastes are outlined (Table 1). For all of these crops, from cannabidiol to biofuels and textiles, post-harvest processing is rigorous and crops are not ingested, minimizing the risk of pollutants migrating from the soil into the distribution chain.

A 'SANDBOX' EXPLORING ECONOMIC AND LOGISTICAL BENEFITS

The cost savings of this landfill-to-agriculture strategy can be demonstrated with a simple 'sandbox', describing sewage and WTR diversion in the Philippi Horticultural Area (PHA; Western Cape, South Africa). This area is renowned for extensive agricultural activities on nutrient-poor sandy soils. Since the PHA is dedicated to vegetable farming, tracts of marginal land –

potentially as part of an invasive species clearing strategy – would be more ideal. However, the PHA has been well-documented and is ideal for a model logistical exercise, which can be replicated by municipalities for marginal land.

The PHA spans 3 600 ha, of which 1 800 ha are still farmed (Land Type Survey Staff, 1972–2006). At the recommended national amendment rate of 10 tonnes per ha per year (Herselman and Snyman, 2009), a maximum of 18 000 tonnes of sewage sludge can replace fertilizers in the farmed area. Ideally, this needs to be paired more carefully, with soil and sludge characterization.

Since it is applied with WTR at a 1:1 ratio, the soil could receive 18 000 tons of sewage sludge, with 18 000 tonnes of WTR per year for soil fortification. Production of WTR is the limiting factor, at 12 000 tonnes per year (approximately 1 000 tonnes per month from the local Faure production plant; Blanckenberg, 2023). To distribute the full yearly WTR sludge footprint into surrounding agricultural land, it was hypothetically paired with sludge from two WWTPs (Zandvliet and Bellville). These were selected from those listed in Table 2, because together they generate approximately 1 000 tonnes per month (12 000 tonnes per year). Thus, they match the Faure annual WTR production rate at a 1:1 ratio, and their distances are logistically viable, in comparison to the current transport of WTR to Vissershok landfill (Table 3). This reduces transport costs and emissions (Fig. 6, Table 3).

Gate fees

The savings on landfill gate fees are also significant. WTR are often classified as special waste, but even if all sludges are conservatively costed as general waste, the diversion from landfill saves the Faure DWTPs alone over 7.7 million ZAR per year (12 000 tons, at 643 ZAR per tonne in 2020, Table 4).

Fertilizer

The well-characterised and well-quantified application of sewage sludge could reduce farmers' reliance on fertilizer entirely (Courtney, 2022; Tesfamariam et al., 2020). This would save the farmers over 2.8 million $ZAR{\cdot}yr^{-1}$ (1 800 ha, 105 $kg{\cdot}ha^{-1}$, 15 $ZAR{\cdot}kg^{-1}$; Table 4).

Transport

The transport costs (fuel, labour and greenhouse gas emissions) could be reduced by 43% (Table 3).

Ecological pollution cost

Nahman (2011) also quantified an ecological pollution cost to landfill in South Africa based on emissions and disamenities (Table 4). With inflation – not considering the compounding effects of the climate crisis – this pollution cost comes to over 7 million ZAR for this volume in 2024. However, it needs to be monitored if the pollutants (greenhouse gas emissions, heavy metals, pathogens, micropollutants) are remediated in the agricultural setting to justify this cost saving.

There are many logistical hurdles and considerations. A full life cycle analysis and cost-benefit analysis at municipal level is warranted, to begin carefully designed diversion trials.

Table 2. Sludge production volumes in the PHA surrounds. Two WWTP's were selected (grey highlight, Bellville and Zandvliet), to match the rate of sludge produced by Faure DWTP (right column), based on volumes per month and distances to the agricultural land. Sewage sludge was limited to waste activated sludge (WAS).

WWTP/DWTP	Sludge production rate ($t{\cdot}month^{-1}$)	Sludge type[a]
	WWTP	
Athlone[a]	543	WAS
Bellville[a]	269	WAS
Borchard's Quarry[a]	86	WAS
Fisantekraal[a]	171	WAS
Gordon's Bay[a]	11	WAS
Kraaifontein[a]	54	WAS
Macassar[a]	167	WAS
Melkbos[a]	27	WAS
Mitchell's Plein[a]	108	WAS
Potsdam[a]	299	WAS
Scottsdene[a]	88	WAS
Wesfleur[a]	30	WAS
Wesfleur[a]	25	WAS
Wildevoëlvlei[a]	83	WAS
Zandvliet[a]	726	WAS
Simon's Town[a]	3	AD
	DWTP	
Faure[b]	1 000	Fe-WTR

[a]Sewage sludge status quo report (WCDEADP, 2021); [b]Blanckenberg, 2023

Table 3. Comparative distances between the relevant DWTP and WWTP, and (1) Vissershok landfill versus (2) PHA agricultural land

D/WWTP to Vissershok Landfill	Distance (km)[a]	D/WWTP to PHA (mid-point)	Distance (km)[a]
Zandvliet WWTP	43.1	Zandvliet WWTP	21.7
Bellville WWTP	30.7	Bellville WWTP	19.3
Faure DWTP	51.9	Faure DWTP	30.5
Total	125.7		71.5

[a]Google Maps, Fig. 6

Table 4. Logistical information to inform a sludge diversion strategy from Visserhok Landfill to the farming activities in the Philippi Horticultural Area.

Cost type	Cost	Source
Fertilizer amount	104.6 kg·ha^{-1}	Knoema Data Atlas (2021)
Fertilizer cost	15 ZAR·kg^{-1}	AgriMark (2024)
Gate fee	643 ZAR·t^{-1} (general waste) 852 ZAR·t^{-1} (special waste)	GreenCape Waste Market Intelligence Report (2020)
Pollution cost	216.25 ZAR·t^{-1} (111 ZAR·t^{-1} plus inflation, 2011-2024)	Nahman (2011)

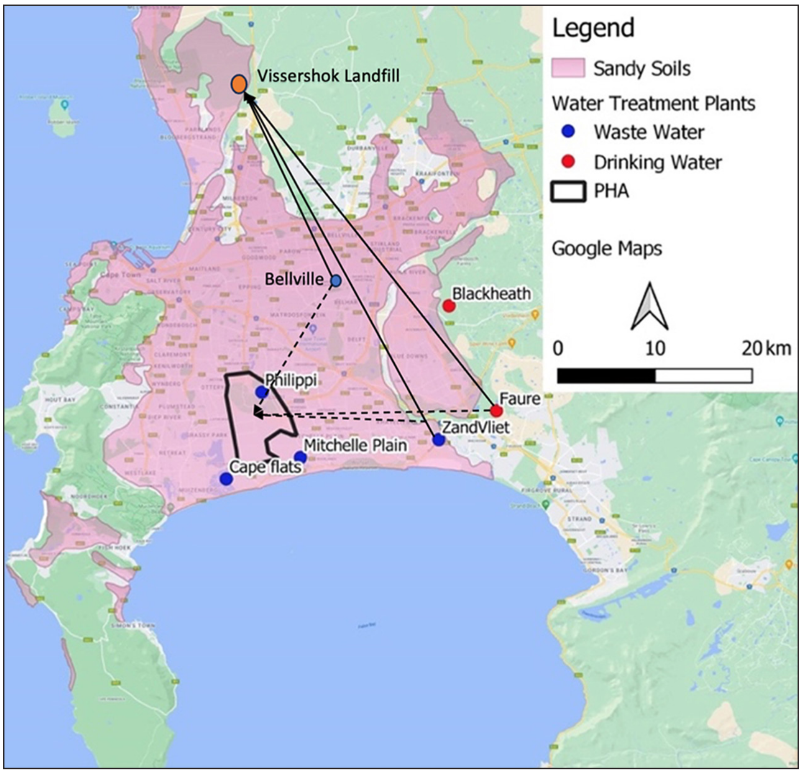

Figure 6. A hypothetical waste diversion case study co-diverting local sludges from landfill to agriculture. WTR from Faure DWTP (red points) and sewage sludge from Bellville and Zandvliet WWTPs are co-diverted from landfill (solid lines) to the Philippi Horticultural Area (dashed lines), in the sandy soils (pink area) of the Western Cape.

HURDLES TO THE STRATEGY

Distribution and logistics

For effective waste-to-market management, feedstock supply security is critical. Logistical management is necessary to maintain a consistent market and favourable public perception. Wu et al. (2022) propose a human-centric, localised 'strategic control model' for waste management, connecting strategic planning with demography and the local workforce. They suggest that such a human-centric localised waste value chain, separated from a national supply chain, is both positive in terms of greenhouse gas emissions (minimised transport) and promotes local job opportunities, facilitating societal development through personal engagement with environmental issues.

The Western Cape's sewage sludge status quo report (WCDEADP, 2021) describes some such localised management strategies in 16 WWTPs (WCDEADP, 2021). Wastewater is used to irrigate golf courses and rugby fields, and sludge is diverted to composting facilities, transported directly to farms or collected by farmers.

However, although Herselman (2013) has developed land application guidelines for WTR and Herselman and Snyman (2009) have developed land application guidelines for sewage sludge, WTR is not included in the above-mentioned City of Cape Town's sludge status report and diversion activities. The report expressly states (p. 5), "guidelines were not developed to include inorganic sludge produced by potable water treatment plants". But, where humans excrete, humans drink: both sludges are always produced in proximity to each other. Understanding this logistical golden ratio of urban WTR and sewage sludge production would assist municipalities to plan the co-diversion of WTR and sewage sludge efficiently via controlled trials, from landfill to agriculture.

The 'golden ratio' for planning

From literature and discussions with local DWTPs, there is little consensus on the national volumes of WTR produced per year. The most recent (2016) survey of local national WTR production describes extensive discrepancies in calculations (Mokonyama et al., 2017), between 300 000 and 405 000 tonnes of dry solids (tDS) per year (Mokonyama et al., 2017; Hughes et al., 2005). Some DWTPs in South Africa – using Fe-oxyhydroxide flocculants and dewatering with a centrifuge – produce 30 tons per day that are trucked to landfill daily (Blanckenberg, 2023). Others use Al-oxyhydroxide flocculants and dewater in dams, which are emptied at 3-year intervals (Abrahams, 2023). In 2014, it was shown that over 71% of the WTR produced in South Africa came from one plant (Mokonyama et al., 2017), facilitating simpler bulk sludge management in South Africa.

National estimates of sludge production rates

WTR

Here, we rely on the latest national review of WTR sludge production rates, i.e., 300 000 tDS per year (Mokonyama et al., 2017). The authors predicted a substantial increase, with pending increases in DWTP infrastructure. Global water consumption increases ~1% per year, according to the United Nations (Uhlenbrook and Connor, 2019), which is used here for simple projections.

Thus, we are estimating a current national WTR production rate of 322 000 tDS (rounded up from 321 641 tDS) per year (2024), based on a yearly 1% increase (2017 – 2024) from a 2017 baseline of 300 000 tDS per year.

Sewage

A 2022 review quantified the national sewage sludge footprint at 2 885 325 tDS per year in 2022, according to Eq. 1 (Table 5) (Apollo, 2022). Here, the mean of the tDS per WWTP per day was multiplied by 365 days and by 850 WWTPs in the country as reported in local Green Drop Reports. With a similar 1% increase per year, it is rounded down to 2 943 000 tDS per year in 2024.

$$\text{tDS·yr}^{-1} = 9.3\ \text{tDS·day}^{-1} \times 365\ \text{day·yr}^{-1} \times 850\ \text{WWTW·country}^{-1} \quad (1)$$
$$= 2\ 885\ 325\ \text{tDS·yr}^{-1}\ (2022)$$

Provincial estimates of sludge production rates

WTR

Provincial WTR sludge production is approximately 48 300 tDS per year. This is estimated based on the fraction of Western Cape DWTP generating WTR (15%; Mokonyama et al., 2017), of a national total of 322 000 tDS per year (as calculated above).

Sewage

The Western Cape sewage sludge production rate was 295 000 tDS per year in 2016 (WCDEADP, 2021), which is rounded down to 319 000 tDS per year in 2024 (1% yearly increase).

Global estimates of sludge production rates

Globally, WTR and sewage sludge tallies reflect a similar ratio.

WTR

In 2007, Babatundo and Zhao reported a 10 000 tDS·day^{-1} WTR production rate (Babatundo and Zhao, 2007). At the UN's 1% per year increase rate, according to Eq. 2, there is a current global WTR production rate of 4 323 000 tDS·yr^{-1}.

Sewage

Similarly, global sewage sludge production was estimated at 45 000 000 tDS·yr^{-1} in 2017 (Zhang et al., 2017), and a 1% cumulative increase results in 48 246 000 tDS·yr^{-1} in 2024 (Eq. 3).

$$\text{tDS·yr}^{-1} = [(10\ 000\ \text{tDS·day}^{-1} \times 365\ \text{day·yr}^{-1})$$
$$+ ((10\ 000\ \text{tDS·day}^{-1} \times 365\ \text{day·yr}^{-1}) \times 1\%\text{·yr}^{-1}]\ \text{for 17 yr} \quad (2)$$
$$= 4\ 322\ 711\ \text{tDS·yr}^{-1}\ (\text{rounded up to } 4\ 323\ 000\ \text{tDS.yr}^{-1})$$

$$\text{tDS·yr}^{-1} = [(45\ 000\ 000\ \text{tDS·yr}^{-1})$$
$$+ ((45\ 000\ 000\ \text{day·yr}^{-1}) \times 1\%\text{·yr}^{-1})]\ \text{for 6 yr} \quad (3)$$
$$= 48\ 246\ 091\ \text{tDS·yr}^{-1}\ (\text{rounded down to } 48\ 246\ 000\ \text{tDS.yr}^{-1})$$

This ratio (0.09–0.15, Table 5) suggests that, with the diversion of WTR to agricultural soils, 10–15% of the national sewage sludge footprint can be co-diverted to sandy soils, considering transport distances and farming practices. Therefore, the best quality sewage sludges can be selected to pair with WTR in these fragile soils.

Dam siltation: another potential co-diversion strategy

Another sludge source that needs to be diverted from landfill to practical applications is dam sediment. The National Dam Siltation Management (NatSilt) Programme's main objective is to create a national strategy backed by a wide range of technologies for efficiently managing siltation in the more than 300 sizable dams owned by the South Africa's national Department of Water and Sanitation (WRC, 2025). In 2021, there were 163 dams in South Africa with a 25% siltation level, 25 dams with a 25% to 50% siltation level, and two dams with a 90% siltation level. Beneficial alternatives for silt need to be considered, and these sludges can be channelled into this stream of investigations for land application in sandy soils. Although they will not have the same sorptive capacity as WTR, they are also rich in organic matter and can be slotted into this research stream for fortifying nutrient-poor sandy soils, by looking at pairing potentials between the sludge types. This might increase the volumes of sewage sludges that can be diverted from landfill to agriculture in this model.

Public perception and certification

Land bans and ordinances are often issued in response to fear-based reporting, encouraging the public to avoid crops grown on sewage sludge (Perkins, 2022; Kopycinski, 2014). In protecting their own crops and lands from micropollutants, they do not acknowledge the transboundary nature of the wastes, with almost no pristine sites on earth (Kallenborn et al., 2018).

In a study entitled, 'Not in my backyard, but let's talk', two primary drivers of public resistance emerged, including (i) participation deprivation, and (ii) a limited environmental understanding (Liu et al., 2018). The public can be invited into the process through markets and certifications. Farmers that are environmentally motivated enough to use sludge wastes are likely the same farmers that will farm organically. But, organic certification is too purist, and is compromised with waste re-use.

However, there is space for creativity. South Africa has a strong National Policy on Organic Production (DAFF, 2015) but there is no national certification system.

Table 5. Data for estimating a standard urban WTR-to-sewage sludge ratio, for land distribution

Region	Sewage sludge (tDS·yr^{-1})	Assumptions	Source	WTR (tDS·yr^{-1})	Assumptions	Source	Ratio (WTR: sewage)
National: South Africa	2 943 000	Eq. 1	Apollo (2022)	322 000	1% increase from 300 000 tDS·yr^{-1}, 2017–2024	Mokonyama et al. (2017)	0.11
Provincial: Western Cape	319 000	1% increase from 300 000 tDS·yr^{-1}, 2016–2024	DEA&DP (2021)	48 000	15% of national production	Mokonyama et al. (2017)	0.15
Global	48 246 000	Eq. 3		4 323 000	Eq. 2	Babtundo and Zhao (2007)	0.09

Three alternative certification strategies have emerged (SAOSO, 2024):

- First party organic certification: unverified self-claims legitimised by strong client relationships and trust
- Participatory guarantee systems: mutual accreditation systems for smallholders producing for local markets, based on stakeholder participation and social networks
- Third party certification: a formal process, typically used for export, through private local companies (ie. CERtification of Environmental Standards South Africa (Pty) Ltd. or Afrisco) or international bodies, requiring substantial funds and meticulous record-keeping to meet ISO65 standards

A proposed 'responsible waste circularity' certification could leverage existing independent strategies, from first party certification to international bodies. Creating a niche market through branding might expand the public imagination for waste re-use (Lui et al., 2018), and permit farmers who have included responsible waste circularity into the life cycle of their crops and products to access the premiums of the eco-conscious market.

CONCLUSIONS

This perspective piece explores the ecology, philosophy, and logistics of co-diverting water and wastewater sludges to agricultural productivity in nutrient-poor sandy soils. It provides support for Wu et al.'s (2018) human-centric, local 'strategic control model' for waste distribution and encourages Waltner-Toews' (2013) creative 'dance with evolution', both harnessing WTR to fortify the soil to receive sewage sludge nutrients, and harnessing crop growth to remediate the inevitable pollutants concentrated through our water treatment system. Understanding and monitoring the receiving soils and the waste profiles is key. The cost-benefit analysis shows that it will benefit municipalities and farmers financially, and certification strategies can facilitate this. The diversion will require a division of logistical responsibilities and investment costs. A full life cycle analysis, concurrent with some in-field trials, are the practical steps to shift this linear waste stream into a circular waste economy, meeting local and international requirements for diversion of organics from landfill to productive activities. This should be executed concurrently to developing industrial beneficiation processes, like phosphorus recovery. This study provides sufficient evidence for local municipalities to take the next concrete step in diverting water and wastewater sludges into a more ecologically relevant and agriculturally beneficial pattern of land distribution.

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AUTHOR CONTRIBUTIONS

WS: Conceptualisation; methodology; data collection; data analysis; validation; data curation; writing – the initial draft; writing – revisions; student supervision; project leadership; project management; funding acquisition. LM: methodology; data collection; data analysis; writing – the initial draft; writing – revisions. KLJ: Conceptualisation; validation; writing – the initial draft; writing – revisions. NSL: Conceptualisation; methodology; writing – the initial draft; writing – revisions. AJV: methodology; writing – the initial draft; writing – revisions. HW: methodology; data analysis; writing – the initial draft; writing – revisions. CEC: Conceptualisation; methodology; validation; writing – the initial draft; writing – revisions; student supervision; project leadership; project management; funding acquisition. All authors read and approved the final manuscript.

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