THE DEVELOPMENT OF A FRAMEWORK FOR THE REVIEW OF THE SLUDGE MANAGEMENT GUIDELINES

Report to the
Water Research Commission

by

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WRC Report No. 3164/1/24
ISBN 978-0-6392-0651-6
August 2024

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This is the final report of WRC project no. C2021/2022-01096.

EXECUTIVE SUMMARY

The Water Research Commission (WRC) identified a need to revise the Sludge Management Guidelines of 2006 and 2009 taking into account developments since 2009, including macro drivers such as circular economy principles, emerging contaminants, electricity costs, local economy, etc. The WRC launched this project as the first step in the process to develop a framework for the revision of guidelines and in doing so, describe a way forward for, and identify key theme areas which would be defined through stakeholder engagement.

This terms of reference for this project were developed by the WRC. As a directed project, the WRC requested the following to be completed:

1. Develop a framework for revising and updating the Sludge Management Guidelines
2. Provide a comprehensive literature review of sludge policy, regulation, standards, etc. from the publication of the Sludge Guidelines in the 2000s and after publication
3. Undertake a series of stakeholder consultations (including regulators, municipalities, consultants) in developing the framework for revision.
4. Produce dissemination material linked to outputs of study, including a Policy Brief

The approach followed included the development of a draft framework which was discussed with the reference group for guidance before embarking on a series of stakeholder workshops. The final framework was informed by (1) a literature review; and (2) extensive consultation with local government and authorities.

The framework details the vision, narrative, key themes and strategy for the revised guidelines.

The vision of the updated sludge guidelines is to create an ***enabling environment for local government and the private sector to include energy and/or resource recovery during the stabilisation of the wastewater sludge to generate a product that contributes to sustainable down-stream beneficial use.***

The framework outlines the next steps to realise the vision for the updates sludge guidelines and includes:

1. Aspects that require immediate attention, before the revision of the Sludge Guidelines;
2. Knowledge gaps and research which should be initiated before the revision that would add value and inform the revised Sludge Guideline;
3. Terms of reference for the revision of the Sludge Guidelines.

The project also identified bottlenecks at a local government level that should be relatively easy to resolve. The first is the sector confusion on whether the DWS or DFFE are the lead authority on sludge management. DWS indicated that it should be the lead authority because it was related to the water industry, while DFFE indicated that sludge is a waste and therefore DFFE should be the lead authority to manage the waste. High level discussion between DWS and DFFE is required to unpack this and to devise a way forward for communication to the sector.

The second is the exclusion of wastewater sludge intended for beneficial use from the legal definition of waste. The successful outcome of an application in terms of regulations GN 715 of 2018 will be a significant step towards enabling the beneficial use of wastewater sludge. Ideally, the submission should be an industry-wide application to the DFFE for wastewater sludge to be excluded from the definition of waste where it will be used beneficially as a fertilizer source in agriculture, landscaping, parks, golf courses, instant lawn, etc.

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LIST OF ABBREVIATIONS

ASD	Asian Development Bank
CARA	Conservation of Agricultural Resources Act
CE	Circular Economy
DFFE	Department of Forestry, Fisheries and the Environment
DME	Department of Mineral and Energy
DoA	Department of Agriculture
DWS	Department of Water and Sanitation
ECoCs	Emerging Constituents of Concern
EHTP	Enhanced Hydrothermal Polymerisation
ESG	Environmental, Social, and Governance
GN	Government Notice
LC	Leachable Concentrations
MoU	Memorandum of Understanding
NEMA	National Environmental Management Act
NEMAQA	National Environmental Management: Air Quality Act
NEMWA	National Environmental Management: Waste Act
NEMWAA	National Environmental Management: Waste Amendment Act
NSS	Non-sewered Sanitation
NWMS	National Waste Management Strategy
PAHs	Poly Aromatic Hydrocarbons
PFAS	Per- and Polyfluoroalkyl Substances
SaNiTi	Sanitation Transformational Initiative
SANS	South African national Standards
SAR	Site Assessment Report
SDS	Safety Data Sheets
SoWR	State of Waste Report
TC	Total Concentrations
ToR	Terms of Reference

1 BACKGROUND

All wastewater treatment processes generate a sludge which is considered as a resource for downstream beneficial use. For wastewater sludge to be used or disposed, it needs to be characterised or classified to assess the potential impact on the receiving environment. Currently, sludge is classified in three main categories in a decreasing quality order of metal content, potential to cause odour nuisances and fly-breeding as well as to transmit pathogenic organisms to the environment. These categories are described in the WRC Sludge Management Guidelines of 2006 and 2009, which are currently referred to in all Water Use Licences (WUL) issued by the Department of Water and Sanitation (DWS) responsible for water to stipulate the regulatory requirements for sludge management. The WRC invested a significant portion of funding to develop the South African sludge guidelines from 2000 to 2009 and published a set of 5 Volumes each focussing on the management of different use and disposal options:

- Volume 1: Selection of management options (Snyman and Herselman, 2006a, TT 261/06)
- Volume 2: Requirements for the agricultural use of sludge (Snyman and Herselman, 2006b; TT 262/06)
- Volume 3: Requirements for the on-site and off-site disposal of sludge (Herselman and Snyman, 2009, TT 349/09)
- Volume 4: Requirements for the beneficial use of sludge (Herselman and Moodley, 2009, TT 350/09)
- Volume 5: Requirements for the thermal sludge management practices and for commercial products containing sludge (Herselman et al., 2009, TT 351/09)

These documents have steadily been adopted by the local authorities. It has been over a decade since the publication of the Sludge Management Guidelines and only Volume 2 (Agricultural use) has been updated with an addendum. While the guidelines were developed with the best available knowledge at the time to guide the South African water sector towards the beneficial use of wastewater sludge and more responsible disposal, there has been significant progress in water, sanitation and environmental legislation, policy and guidelines as well as in research, development and innovation over the years. For example, the Department of Forestry, Fisheries and the Environment (DFFE) require different assessments and classification for sludge to be disposed than the Minimum Requirements which were in use during development of the Sludge Management Guidelines. Many municipal landfill sites refuse to accept the sludge generated by their own sister water department based on inaccurate information. This has led to confusion in the sector and sadly, the practice of stockpiling sludge on site is again common practice. There are also other drivers that require consideration and consultation. For example, electricity costs were considered very low in the early 2000s, which is now the complete opposite, making energy generation from sludge much more attractive going forward.

Therefore, a revision of the Sludge Management Guidelines is necessary to take into account developments since 2009, including circular economy principles, emerging contaminants and SABS for non-sewered systems. The revision and update of the guidelines will provide improved long-term sustainability planning and management approaches. The first step in the process is the development of a framework for the revision of guidelines and in doing so, describe a way forward for and identify key theme areas which would be defined through stakeholder engagement. The framework must outline the vision, narrative and key themes and strategy for the revised guidelines.

2 TERMS OF REFERENCE FOR THE DIRECTED WRC PROJECT

This terms of reference for this project were developed by the Water Research Commission (WRC). As a directed project, the WRC requested the following to be completed:

1. Develop a framework for revising and updating the Sludge Management Guidelines
2. Provide a comprehensive literature review of sludge policy, regulation, standards, etc. from the publication of the Sludge Guidelines in the 2000s and after publication
3. Undertake a series of stakeholder consultations (including regulators, municipalities, consultants) in developing the framework for revision
4. Produce dissemination material linked to outputs of study, including a Policy Brief.

3 APPROACH

3.1 Draft Framework

The Draft Framework was based on the team's broad sector experience and assisted in framing the agenda for the consultation with national and local government and the water sector. The project team have been engaging with local government, regulators and the research community assisting in developing sludge management plans, audits, sludge classification, waste classification, training and research since the Guidelines were published in 2006 and 2009. There have also been numerous discussions with the DFFE and DWS regarding the legislative requirements especially related to regulations published under the National Environmental Management: Waste Act (NEMWA) 59 of 2008 for the classification and assessment of waste: (1) SANS 10234 waste classification as detailed in the Waste Classification and Management Regulations of 23 August 2013 (GN R.634 of 2013); and (2) Waste assessment according to the National Norms and standards for the assessment of waste for landfill disposal (GN R.635 of 2013). The DFFE also developed an enabling mechanism (Waste Exclusion Regulations, GN. 715 of 2018) to exclude a waste from the definition of waste if the intended use of such waste is proven to be beneficial.

3.2 Literature Review

The literature review has been conducted by the Department of Plant and Soil Sciences at the University of Pretoria, guided by the senior project team members. The literature review included the following aspects:

- The South African legislative environment and regulations pertaining to the management of sludge and faecal sludge
- International regulatory trends in sludge and faecal sludge management including the underlying motivation for adopting such regulations

- International standards and limits based including the scientific rationale
- Emerging technological trends for sludge and faecal sludge stabilization, beneficiation and management
- Risk assessment trends and emerging risk factors such as persistent pollutants, micro plastics, endocrine disrupting compounds, microbiological agents
- Case studies on the application of the circular economy, energy generation, greenhouse gas reduction or offsetting, etc.
- Macro drivers such as development, finance and impact of climate change.

3.3 Stakeholder consultation

Face-to-face stakeholder consultations as well as on-line workshops were conducted to seek input from Local Government and wastewater treatment service providers; the Regulators at local and national level; consultants, laboratories and researchers. The following workshops/consultations were conducted:

- Eastern Cape: Nelson Mandela Metropolitan Municipality (Port Elizabeth);
- Western Cape: City of Cape Town;
- KwaZulu-Natal: City of eThekwini (Durban);
- Gauteng: City of Tshwane (Pretoria); and,
- On-line workshops: three workshops with one dedicated to National DWS and DFFE.

The following were discussed at the workshops:

- Current sludge management practices and use of Sludge Guidelines;
- Critical appraisal of the Sludge Guidelines;
- Stumbling blocks experienced in implementation of the Sludge Guidelines; and,
- Envisioning and local nuances.

Feedback and discussions of these workshops gave valuable insight into the problems and obstacles experienced by the sector regarding sludge management. It also showed that the Sludge Guidelines are indeed used by the sector for classification and selection of management options. Agricultural use is the preferred beneficial use option.

3.4 Final Framework

This report includes the vision, key themes and strategy for the revised guidelines for consideration by the WRC appointed Reference Group, including:

- Research projects needed to fill knowledge gaps;
- Policy and regulation changes needed to achieve certain agreed goals aligned with Government priorities;
- Training needs for the sector to improve sludge management and promote beneficiation and beneficial use of sludge;

- Best practice guidance for the interim; and,
- Terms of reference for the update of the sludge guidelines.

4 FRAMEWORK FOR THE REVISION OF THE WASTEWATER SLUDGE GUIDELINES

4.1 Vision

The following vision is proposed:

An enabling environment for local government and the private sector to include energy and/or resource recovery during the stabilisation of the wastewater sludge to generate a product that contributes to sustainable down-stream beneficial use.

This vision is supported by not only through national strategies, but also local research.

The 2020 National Waste Management Strategy (NWMS, 2020) was gazetted for implementation on 28 January 2021. The NWMS incorporated the waste management hierarchy as well as circular economy (CE) principles which includes waste minimisation as a key principle. The treatment of wastewater in South Africa is predominantly based on the linear economy approach. There is a need to re-evaluate the water and sanitation value chain for transitioning to a CE which embraces the new thinking of the cradle-to-cradle approach. According to the NWMS, 45% of waste must be diverted from landfill within the next 5 years, 55% within 10 years and 70% within 15 years, leading to zero waste going to landfill (NWMS, 2020). The diversion of wastewater sludge from landfill, stockpiling and dedicated land disposal to beneficial use of wastewater sludge is therefore essential to achieve these NWMS goals.

Research into energy conservation and generation in wastewater management as well as wastewater effluent reuse has been undertaken in recent years through the support of the Water Research Commission (WRC). A study conducted by Van der Merwe-Botha et al. (2016) on the design and operation of wastewater treatment plants (WWTPs) with biogas and power generation showed that the total biogas production is estimated at 282 671 m^3/day, which translates to electrical energy of 657-765 kWh/day. At a unit cost of 60 cents per kWh electricity, this energy value represents a potential saving of R144 million per annum which could be even higher if the WWTPs are used to full design capacity and upgrading of the anaerobic digesters.

Large metropolitan municipalities (Metros) have also recently started investigating and implementing treatment processes and technologies that support the CE. The findings of a recent WRC project "*The Role of Emerging Innovative Wastewater Sludge to Energy Technologies in Transitioning to a Circular Economy in the Water Sector: A South African Case Study*" (Musvoto and Mgwenya, 2022) demonstrated that multi-biomass processing technologies like the enhanced hydrothermal polymerisation (EHTP) technology process can be successfully incorporated into WWTPs and process wastewater sludge combined with low-cost sanitation systems faecal sludge and other waste biomass from the community to produce hydrochar that can be beneficially used for successful transition to a

CE. The technology can also be coupled with other technologies to convert WWTPs into resource recovery centres.

These treatment processes also result in a better quality, stable sludge which could potentially be used beneficially without many restrictions.

It is therefore important to establish an enabling environment for local government to include energy and/or resource recovery during the stabilisation of the wastewater sludge to generate a product of a quality which supports sustainable down-stream beneficial use.

4.2 Key themes

This section includes pertinent aspects addressed in the Literature Review (Appendix A) contextualised for the draft framework. It included sludge management trends in both developed countries (USA, European Union, Canada, and Australia) and developing countries (Brazil, Mexico, and China).

4.2.1 International trends

Beneficiation and the circular economy

The European Union sewage sludge legislation directive 2000/60/EC (Water Framework Directive; WFD 2000/60/EC, 2000) defines wastewater sludge as a product of wastewater treatment and no longer as a waste. The operational directive document of the WFD (WFD 91/271/EEC) is focused mainly on the reuse of wastewater sludge as valuable material.

According to Lacroix et al. (2014), the energy requirements of wastewater treatment plants could be reduced by up to 35% by coupling anaerobic digestion to biogas production. A Polish case study by Werle and Sobek (2019) on the gasification of wastewater sludge for energy generation within a circular economy generated a valuable phosphorus fertilizer resource of 22.06% by mass of the residue (ash), which is close to the natural phosphate rock concentration (28%). Similarly, the ash produced had an adsorption capacity close to the adsorption capacity of commercial activated carbon.

The Asian Development Bank (ASD) promotes beneficial use of sludge in China. In a report published in 2012, the ASD indicated that beneficial use of sludge are increasing (Table 1).

Classification trends

Regarding wastewater sludge classification, the following trends have been noticed during the literature review:

- Other than faecal coliforms and helminth ova, salmonella and enteric viruses are also used for microbiological classification; and
- Updated pollutant ceiling limits and loading rates.

Table 1 Beneficial use of sludge in selected countries (ASD, 2012)

Country or Region	Sludge Utilization Rate (%)	Sludge Production (Million tons dry solids per year)	Main Sludge Applications
United Kingdom	85	1.05	Land application, energy recovery
Australia	80	0.36	Land application
South Africa	80	1.0	Land application
India	80	...	Land application
Japan	74	2.2	Energy recovery, construction products (including products of incineration ash)
Germany	60	2.3	Land application, energy recovery
United States	55	17.8	Land application
European Union	40	9.0	Land application
Republic of Korea	6	1.9	Land application, construction products
Singapore	0	0.12	...
Hong Kong, China	0	0.3	...

... = information not available.
Source: East Asia Department, ADB.

Several international studies have been conducted on the concentrations of emerging constituents of concern (ECoCs) in wastewater sludge (Appendix A). Although these studies indicated that ECoCs are of concern, there is no indication on the persistence of these in the environment when the sludge is used beneficially. Neither has ECoCs been included in the classification of wastewater sludge intended for beneficial use.

4.2.2 Beneficial use in SA

According to the State of Waste Report (SoWR, 2018) there were 824 large-scale municipal and private wastewater treatment works generating around 632 749 ton sludge/year. Only 14% of the sludge is used beneficially while 86% is disposed to land. A WRC project is underway where Partners in Development (PID) will conduct a desktop status quo review on sludge management and beneficial use (WRC Project Number C2023-2024-01290).

Attendees of the Stakeholder workshops indicated that 25-75% of sludge is used beneficially in the areas they represented (Deliverable 2). These beneficial use options include:

- Agriculture;
- Rehabilitation;
- Brick manufacturing;
- Turf grass/instant lawn;
- Composting;

- Golf courses; and
- Landfill cover.

The Stakeholder consultation indicated that the industry realises the fertilizer value of sludge and want to use it beneficially rather than disposal. However, legal authorisations hamper the process, resulting in on-site disposal and uncontrolled stockpiles. It is therefore important to clarify the legislation not only at national level, but also at local government level to create an enabling environment for the stabilisation and beneficiation of wastewater sludge. The current legislative framework related to sludge management is detailed in Section 4.2.3.

Stakeholders also reported challenges with the rigidity of the procurement system at local government level. This included aspects related to:

- Innovative approaches which could be seen as supporting unproven technologies;
- Supporting entrepreneurs;
- Awarding long term contracts as service providers need to establish the infrastructure which only becomes viable after a period of time and hence requires long term contracts;
- Institutional arrangements; and
- Financing and financial models.

4.2.3 Regulatory framework

Collectively a hierarchy of policies and legislation, which includes South Africa's international commitments, the Constitution, applicable Acts of Parliament, Provincial Legislation and Local Government Bylaws, govern environmental management in South Africa. Amongst these the National Water Act (Act No. 36 of 1998) (NWA), National Environmental Management: Waste Act (59/2008) (NEMWA), National Environmental Management Act, 1998 (Act No. 107 of 1998) (NEMA) and depending on the specific case, the National Environmental Management: Air Quality Act, Act No. 39, 2004 (NEMAQA) serve as the primary legislation that guide waste management and pollution control and accordingly are the key statutes guiding sludge management and disposal.

The Department of Water and Sanitation (DWS) is the lead regulatory authority for the licencing of wastewater treatment plants. The WUL typically require the licensee to adhere to the Sludge Guidelines. However, wastewater sludge is covered under the definition of waste in NEMWA unless it is excluded from the definition of waste. Therefore, additional authorisations such as a waste management licence (WML) issued by the Department of Environment, Forestry and Fisheries (DFFE) might be required.

4.2.3.1 National Water Act (Act 36 of 1998) NWA

Section 19 of the NWA deals with pollution prevention, in particular where pollution of a water resource occurs or might occur as a result of activities on land. The person who owns, controls, occupies or uses the land in question is responsible for taking measures to prevent pollution of water resources. If these measures are not taken, the catchment management agency concerned may itself do whatever is necessary to prevent the pollution or to remedy its effects and to recover all reasonable costs from the persons responsible for the pollution.

Section 21 of NWA sets out general principles for water use. The use, storage, and/or disposal of wastewater (and sludge) is classified as a Section 21(e) (irrigation of wastewater or other controlled activities) and/or 21(g) (disposing of waste in a manner which may detrimentally impact on a water resource) water use activity by the NWA. This also includes the storage of water containing waste for the purpose of either re-use or disposal. The irrigation of land with waste or water containing waste generated by a wastewater treatment plant is governed by the General Authorisations (GN 665 of 2013).

4.2.3.2 Water Services Act (Act 108 of 1997) (WSA)

The National Water Services Act (No 108 of 1997) governs the provision of services to consumers. Section 3 of the Act states that "everyone has a right of access to basic water supply and sanitation". Basic sanitation is defined as: "*the prescribed minimum standard of services necessary for the safe, hygienic and adequate collection, removal, disposal or purification of human excreta, domestic wastewater and sewage from households, including informal households*". The WSA instructs water services authorities to develop bylaws which contain conditions for the provision of water services which include controls of any system through which industrial effluent is disposed of. These bylaws will need to be consulted for certain sludge management options.

4.2.3.3 National norms and standards for domestic water and sanitation services (GNR 982 of 2017)

The norms and standards set out in this document are based on the NWA, WSA, the 2016 National Sanitation Policy and all the other legislation, including but not limited to the lessons that the sector has learned to date. One of the principles of GNR 982 is the protection and conservation of the environment.

Part 2, Section 6.2 deals with pollution risk management and 6.2.4 specifically deals with wastewater and sludge management. The goal of section 6.4.2 is "*Sanitation services shall implement effective and sustainable wastewater and sludge management practices to protect public health and prevent pollution of the environment*". In essence the GNR 982 states that wastewater and sludge shall be managed by local authorities and service providers in an environmentally acceptable manner by adhering to the current Sludge Guidelines Volumes 1 to 5, but additional management measures are also included where it is not covered by the Sludge Guidelines.

4.2.3.4 National Environmental Management: Waste Act (Act 59 of 2008) (NEMWA)

NEMWA was amended by Act 26 of 2014 (National Environmental Management: Waste Amendment Act) (NEMWAA) to include Schedule 3: Defined wastes. According to Schedule 3 of NEMWAA, wastewater sludge is Category A: Hazardous waste *(#17 Wastes from waste management facilities (c) hazardous portion of stabilized wastes, (d) hazardous portion of wastes from aerobic treatment of solid wastes, (e) hazardous portion of wastes from anaerobic treatment of waste*).

4.2.3.5 National Environmental Management: Waste Act (59/2008): National Waste Management Strategy, 2020 (GN 56 of 2021) (NWMS)

The main aim of the 2020 NWMS is to create a circular economy: '*there is no waste in a circular economy – when we have finished with something it becomes the raw material for something else*' (Minister Barbara Creecy, DEFF Budget Policy Statement 2019/20).

The two (2) key principles of waste minimisation is (i) waste prevention and (ii) waste as a resource. The emphasis of waste prevention is avoiding and reducing waste before substances, materials and products are discarded, i.e. before they become waste through a focus on the design and packaging of products and cleaner production. This is not possible at wastewater treatment facilities since there will always be wastewater sludge after wastewater treatment.

The 'waste as a resource' principle focuses on stimulating a secondary resources economy based on recycling and recovery of materials and energy from waste, i.e. interventions that take place after a product or material has become waste. In terms of the waste management hierarchy practices, recycling of waste for reuse and recovery of materials is prioritised over recovery of energy from waste. The main economic driver lies in exploiting the full potential value of waste. Since wastewater sludge can be regarded as a valuable resource, this principle applies to wastewater treatment facilities and will aid in diverting sludge from landfill disposal.

The waste minimisation strategy of the 2020 NWMS aim at 45% of waste from diverted from landfill within 5 years; 55% within 10 years; and at least 70% within 15 years leading to Zero – Waste going to landfill. One of the interventions to achieve this outcome is to divert organic waste (including wastewater sludge) from landfill through composting, beneficial use and the recovery of energy.

The NWMS provides and enabling regulatory framework for the beneficiation of wastewater sludge.

4.2.3.6 Waste classification and management regulations (GNR 634 of 2013)

Annexure 1 of GNR 634 identifies wastes that do not require classification or assessment according to SANS 10234 or GNR 635. Wastewater sludge is not listed under item 2 of Annexure 1 and therefore requires classification and assessment. SANS 10234 primarily classifies chemical substances and mixtures and sludge may not meet the hazard identification and classification criteria under SAN10234 for a hazardous waste (based on chemical composition). However, the potential presence of pathogenic and/ or infectious agents in sludge may pose a health hazard to the public and workers and compels hazardous classification and an accompanying safety data sheet for sludge.

4.2.3.7 National norms and standards for the assessment of waste for landfill disposal (GNR 635 of 2013)

GNR 635 is applicable to disposal (on-site and off-site) of wastewater sludge on land. The standards provide the requirements for the assessment of waste prior to disposal to landfill and requires the identification of chemical substances in the waste, both total concentrations (TC) and leachable concentrations (LC) of the elements. Based on the waste assessment (Type 0-4) applicable barrier design requirements will apply (GNR 636 of 2013).

These regulations are applied for the assessment of wastewater sludges in the sector. Volume 3 of the sludge guidelines which deals with the on-site and off-site disposal of wastewater sludge still refer to the Minimum Requirements, 2006 and therefore need to be aligned with GNR 635.

4.2.3.8 Regulations regarding the exclusion of a waste stream or a portion of a waste stream from the definition of waste (GNR 715 of 2018)

GN R. 715 of 2018 was promulgated in terms of the NEMWA with the purpose to:

- Apply for the exclusion of a waste stream (or portion thereof) for beneficial use from the definition of waste
- Exclude permitted uses of a waste stream (or portion thereof) from the definition of waste and
- Promote diversion of waste from landfill disposal to its beneficial use.

The exclusion application can be made by a group of waste generators (WWTWs, mines, power stations, etc.), who generate the same type of waste, rather than by a single waste generator on their own. The applicability of these regulations for the exclusion of wastewater sludge from the definition of waste will be discussed during the consultation with the regulators.

4.2.3.9 National norms and standards for the remediation of contaminated land and soil quality (GNR 331 of 2014)

NEMWA makes provision for the management of contaminated land in Part 8 of NEMWA which was promulgated on 2 May 2014 when the GN R.331 of 2014 were gazetted. On-site disposal and beneficial use at high loading rates could potentially lead to contaminated land which might need assessment according to GNR 331. In cases where the repeated application of wastewater sludge to land have led to significant contamination, a Part 8 process will apply.

4.2.3.10 National Environmental Management Act (Act 107 of 1998) (NEMA)

Section 28 of National Environmental Management Act (No 107 of 1998) (NEMA) imposes a general duty of care on any person who causes, has caused or may cause significant pollution or degradation of the environment to take reasonable measures to prevent such pollution or degradation from occurring, continuing or recurring, or is so far as such harm to the environment is authorised by law or can reasonably be avoided or stopped, to minimise and rectify such pollution or degradation of the environment.

The duty of care therefore requires certain stipulated persons to take preventative, reactive, and corrective steps in respect of pollution and degradation of the environment.

4.2.3.11 The Fertilisers, Farm Feeds, Agricultural Remedies and Stock Remedies Act (Act 36 of 1947)

- The Fertilizers, Farm Feeds, Seeds and Remedies Act 36 of 1947 aims:
- to provide for the registration of fertilizers, farm feeds, sterilizing plants. and certain remedies;
- to regulate the importation and sale of fertilizers, farm feeds, seeds and certain remedies, and
- to provide for matters incidental thereto.

This Act will apply in cases where wastewater sludge is used to manufacture a soil ameliorant or fertiliser.

4.2.3.12 The Conservation of Agricultural Resources Act (Act 43 of 1983) (CARA)

To provide for control over the utilization of the natural agricultural resources in order to promote the conservation of the soil, the water sources and the vegetation and the combating of weeds and invader plants.

4.2.4 Local government challenges

Numerous challenges/stumbling block have been identified by the stakeholders, including:

- Education, awareness and capacity building:
  The public perception of sludge should be changed through capacity building to realise the value of sludge. This could also be achieved through developing a separate Guideline intended for public use. Children should be educated from early childhood stage in this regard. Waste separation at source will also aid in keeping foreign objects from reaching the wastewater treatment plant.

  Regular training/capacity building for WWTP Operators and Government Officials is also required to stay on top of developments in the sector. Dedicating and annual 'Water Wheel' edition to sludge management will also add value.

- Political:
  The benefits of investment in wastewater treatment should be advocated at Council level. The potential return on investment must be explained to ensure financial ring-fencing to maintain and operate the infrastructure. Furthermore, WWTPs should be declared National Key-points to be exempted from loadshedding to ensure optimal treatment and security.

- Finances & procurement:
  This was reported as the biggest obstacle in beneficial use of sludge. The following could be implemented to alleviate the problem:

    - Indicate early on in the process that revenue generation from selling A1a sludge/compost could off-set capital investment in the WWTP;
    - Ringfencing income and funding for WWTP operation and maintenance;

  - Allocate funding towards sludge treatment and handling and not only effluent;
  - Explaining the ‘Cradle to grave’ concept to economic sector;
  - Define ‘circular economy’ for WWTPs;
  - Public-Private Partnership contracts are specialised skill which is a barrier to implementation of beneficial use options;
  - Simplify procurement systems;
  - Environmental, social, and governance (ESG);
  - Life-cycle cost calculations;
  - Carbon footprint calculators;

- Enforcement and monitoring of bylaws:
  - Build capacity for monitoring and fining of perpetrators (industries discharging bad quality wastewater);
  - Educating the public on the impact of indiscriminate disposal of objects, wastes, liquids and chemicals in the sewer system;
  - Hold individuals and companies accountable;
  - Criminal charges to executives if non-compliant;
  - Extended producer responsibility.

5 STRATEGY FOR THE REVISION OF THE SLUDGE GUIDELINES

This project included substantive stakeholder consultation with local government and authorities. A summary of the outcomes of the consultation workshops and meetings is attached in Appendix B. It was clear from the consultation that the sector prefer stand alone guidelines for the management of wastewater sludges which is aligned to the regulatory framework. This is aligned to international trends as wastewater sludges have unique risks and opportunities for beneficiation that may not explicitly be addressed in waste legislation. The sector also acknowledged that some aspects of the 2006 and 2009 Wastewater sludge guidelines require an update and agreed that the guidelines need to be revised.

The strategy for the revision of the Sludge Guidelines should be focused on the following:

- Aspects that require immediate attention, before the revision of the Sludge Guidelines;
- Knowledge gaps and research which should be initiated before the revision that would add value and inform the revised Sludge Guideline;
- Terms of reference (ToR) for the revision of the Sludge Guidelines.

5.1 Aspects requiring immediate attention

5.1.1 Consensus between lead authorities

During the stakeholder consultation process, it became evident that there was no consensus between DWS and DFFE on who the lead authority is on sludge management. DWS indicated that it should be

the lead authority because it was related to the water industry, while DFFE indicated that sludge is a waste and therefore DFFE should be the lead authority to manage the waste.
Stakeholders from the water sector (Local Government, municipalities and operators) indicated that authorisations often hamper the implementation of beneficial use options because it was unclear which authorisations are required and should take preference. Therefore, clarity regarding which authorisations are required for which beneficial use option is essential. Ideally, one Authority should handle all authorisations related to wastewater sludge.

High level discussion between DWS and DFFE is required with a Memorandum of Understanding between these Departments on who the leading authority will be and which legislative instruments are applicable.

5.1.2 Exclusion of sludge from the definition of waste

The regulations (GNR 715 of 2018) provides a method to exclude stabilised wastewater sludges suitable for beneficial use from the legal definition of waste.

GN R. 715 of 2018 was promulgated in terms of the NEMWA with the purpose to:

- Apply for the exclusion of a waste stream (or portion thereof) for beneficial use from the definition of waste
- Exclude permitted uses of a waste stream (or portion thereof) from the definition of waste and
- Promote diversion of waste from landfill disposal to its beneficial use.

An ideal solution will be to submit an industry wide application to the DFFE for wastewater sludge to be excluded from the definition of waste where it will be used beneficially as a fertilizer source in agriculture, landscaping, parks, golf courses, instant lawn, etc. In the application process, a sludge specific risk assessment and risk management plan will be developed for the different beneficial use options. This updated risk assessment and risk management plans can then be incorporated into the revised Sludge Guidelines.

If such an application is successful and sludge used beneficially is excluded from the definition of waste, sludge management will be guided by the Sludge Guidelines (as specified in the WUL of the WWTP) and the specific risk management plans included in the application, without any other authorisation required.

5.1.3 Best practice guidance

The publication of an Interim Best Practice Guideline on sludge management and the legal requirements, as soon as the memorandum of understanding (MoU) between DWS and DFFE has been signed, will create an enabling environment for the water sector to use sludge beneficially. This guide should be short and concise to motivate and convince the sector that beneficial use is the best option.

5.1.4 Training

When the current Sludge Guidelines were implemented, it was accompanied with training and capacity building. However, >15 years have since past and it became evident during the stakeholder consultation that training and capacity building in the water sector is required. This training should include sludge classification, legal requirements, beneficial use options as well as management of on-site disposal areas to protect the environment.

5.2 Knowledge gaps

Current research which could fill the knowledge gaps include:

- WRC Project Number: C2022/2023-01191: Understanding the current trends and advances in municipal sludge technology and innovative options related to sludge management (Dr J Burgess, ISLE)
- WRC Project Number 2021/2022-01100: Strategies to Recover Resources from Sanitation Waste: Developing a National Sanitation Resource Recovery Policy Based on Material Flows (Quantity and Quality) (Musvoto et al., 2018)
- WRC Project Number: C2023-2024-01290: What are municipalities doing with their municipal sludge? Understanding the current practices and the cost associated with municipal sludge disposal with case studies (J Neethling, PID)

5.3 Research and development

Proposed research and development projects are divided into projects that are required before the revision of the Sludge Guidelines and those which can be done concurrently to inform and add value to the beneficial use of sludge include the following:

- Before revision of the Sludge Guidelines:
  - Primary sludge as food source for fly larvae;
  - National sludge quality survey to determine changes in sludge quality since the 2003 investigation; and,
  - Quality of sludge and ash from energy recovery plants (quality expected to be better than sludge from normal treatment technologies).
- Concurrently with revision of Sludge Guidelines:
  - Research into the lifecycle and consequence of micro-plastics, per- and polyfluoroalkyl substances (PFASs) as well as emerging contaminants of concern in the environment;
  - Survival of viruses in different treatment options; and,
  - Effectiveness of cell lyses on stability of sludge.

The above studies do not necessarily have to be research programmes, but could be limited to a desk top assessments.

5.4 Classification

All stakeholders agreed that a specific classification system is required for wastewater sludge. The current 3-tier classification system is still applicable, but the microbiological indicators and pollutant limits should be updated based on recent local and international research findings. The pollutant class limits for sludge intended for disposal should be aligned with the concentration thresholds of the Waste Classification and Management Regulations (GNR 635 of 2013). Stakeholders also requested the Stability class options should be re-visited and simplified.

6 TERMS OF REFERENCE

Stakeholders were divided on whether the revised Sludge Guidelines should be published as one comprehensive book rather that different volumes. However, ≈75% of attendees agreed on a single volume with different chapters/sections. The Legislative Framework could be a separate section to make updates easier as legislation changes in future. Although stakeholders prefer a single volume, they still want all relative information in the same document (not condensed).

Since incineration and thermal treatment as well as commercial products are governed by different legal processes than sludge (i.e. Atmospheric Pollution Prevention Act, Hazardous Substances Act, National Health Act, etc.) it is proposed that Volume 5 of the current Sludge Guidelines be omitted during the revision.

6.1 Upfront work

Before the revision of the Sludge Guidelines, the following is required (see section 5.1):

1. Consensus on lead authority for sludge management;
2. Industry wide exclusion from the definition of waste (GNR 715) application for wastewater sludge intended for beneficial use;
3. Best practice guidance; and,
4. Training.

6.2 Chapter 1: Legislative framework

The Legislative framework must include reference to all policies and legislation, which includes South Africa's international commitments, the Constitution, applicable Acts of Parliament, Provincial Legislation and Local Government Bylaws which govern environmental management in South Africa. It should also give clear guidance on the Lead Authority for sludge management and a list of relevant licenses required for each sludge management option.

6.3 Chapter 2: Assessment, classification and management options

The assessment, classification and selection of appropriate management options based on sludge quality is an important chapter to guide the user. This chapter must include the following:

- How to take sludge samples;
- Where to take sludge samples;
- Analyses required and specify analytical methods;

- Classification system and how to classify sludge;
- Decision roadmap based on sludge quality;
- Identification of appropriate management options
- Additional analyses and classification/assessment required if landfill is the only option (sludge quality not good enough for beneficial use);
- Sludge quality monitoring requirements (frequency based on size of WWTP, analyses required for monitoring).

6.4 Chapter 3: Agricultural use

Agricultural use of wastewater sludge is the beneficial use option of choice, as indicated by stakeholders. Currently, the maximum application rate for agricultural use is ≤ 10 ton/ha/year. Continuous research was funded by the WRC since the implementation of the Sludge Guidelines, which gained valuable insight into long-term effects of agricultural use, characterisation of sludge for agricultural use (Tesfamariam *et al*., 2012, Tesfamariam *et al*., 2015). This, and other relevant research findings should be included in this section.

Assuming that the exclusion application in terms of GN R. 715 of 2018 is successful, the risk assessment and risk management plan specific to agricultural use must be incorporated. If the application was unsuccessful or not submitted, a risk assessment methodology/procedure as well as a risk management plan must be developed and included.

6.5 Chapter 4: High-rate application

High-rate sludge application (> 10 ton/ha/year) to land is another beneficial use option where the fertilizer value of sludge is used. The following options should be considered:

- Once-off high-rate application:
    - Rehabilitation of disturbed/degraded soils (nutrient depletion, erosion, acidity and salinity, poor physical properties, reduced biological activity) after mining activities, intensive farming and industrial activities; and,
    - Establishment of golf courses, racecourses, vineyards, road embankments, public parks.
- Continuous high-rate application:
    - Natural forests and plantations;
    - Growth medium for plants, flowers and seedlings;
    - Cultivation of grain and fruit trees;
    - Industrial crops (non-food crops); and
    - Instant lawn cultivation.
- Landfill cover: Stabilised sludge can be used as daily and/or final cover on landfills. Sludge with a solids content of 50% looks and functions much like soil. It will increase the water holding capacity of the final cover of the landfill facility and has high odour absorbing abilities.

Using sludge as cover material is, in essence, seen as co-disposal of wastewater sludge with municipal solid waste on landfills.

- Rehabilitation of mine tailings: Inorganic waste material such as mine tailings could benefit from the addition of organically rich material. However, in some cases, the addition of organic material could cause other environmental problems. These activities must therefore be done responsibly. The process to follow to use sludge in the rehabilitation of organically poor material such as mine tailings should be included.

Each of these beneficial use options will require a specific risk management plan based on the risk assessment of the option. If the exclusion application in terms of GN R. 715 of 2018 for these options was successful, the risk assessment and risk management plan specific to these options must be incorporated. If not, guidance on the risk assessment methodology and risk management plan should be included in the section.

6.6 Chapter 5: Disposal

Sludge disposal must be the last management option considered by WWTPs. However, it is acknowledged that beneficial use is not always a feasible option, therefore this section should include:

- Managing the phasing out of uncontrolled stockpile facilities. The indefinite storage of sludge on unlined facilities without a waste management licence is illegal and was supposed to have been phased out by 2022. This volume should assist the industry to decide on an alternative management option and to rehabilitate the footprint of the stockpile.

- Operating existing dedicated land disposal sites. This section needs to provide guidance on determining the environmental impact of the current practices and how to manage an existing dedicated site to minimise any further environmental impacts. If this work shows an exceedance of the assimilative capacity of the receiving environment and/or a negative environmental impact, this practice should cease, and the area rehabilitated.

- Rehabilitation and phasing out of dedicated land disposal sites. Research has proven that the sudden termination of dedicated land disposal activities without the managing the site closure properly could have additional detrimental effects on the environment. However, if the site proves to have an unacceptable impact, it will have to be phased out in a responsible manner. This section must detail the steps to be taken to phase out a dedicated land disposal site in a responsible manner.

- Off-site disposal of sludge to landfill. This section should specifically address the co-disposal of sludge in municipal or commercial landfill facilities.

- On-site disposal of sludge in a mono disposal landfill or lagoon. This section should specifically address the disposal of sludge in dedicated on-site mono-disposal facilities and sludge lagoons.

- Disposal of sludge to the marine environment. This disposal option is still used by coastal Municipalities and should be included in the revised Sludge Guidelines. Currently this management option is based on the "Operational Policy for the Disposal of Land-derived Water Containing Waste to the Marine Environment of South Africa – Edition 1, 2004" (Department of Water Affairs and Forestry, Water Quality Management Series, Sub-Series No. MS 13). During the revision it should be investigated whether this is still the best practice and if there are more recent policies which could be included. Due to the controversy and stakeholder pressure associated with marine disposal of sewage that contains wastewater sludge, a dedicated workshop is needed to decide whether the sludge guidelines is indeed the appropriate instrument for the management of wastewater discharge to the marine environment. The following groups should be invited to the workshop:
    - The relevant directorates of the DFFE and DWS at national and provincial level and especially the regional departments responsible for issuing the coastal waters discharge permits;
    - Representatives of the wastewater and coastal discharge at coastal metros, cities and local municipalities; and,
    - Subject matter experts.

6.7 Additional aspects

6.7.1 Faecal sludge disposal at a wastewater treatment plant

There is consensus that the management of faecal sludges collected from on-site sanitation installations, must be excluded from the wastewater sludge guidelines because its inherent composition and hazards differ vastly from that of the wastewater sludge generated by a municipal wastewater treatment plant.

The WRC also invested in the research and development of non-sewered sanitation since the early 2000s. This included development of appropriate technologies and assessment of environmental risk/impact assessment, beneficiation and disposal options. The WRC has partnered with various state departments, donors and stakeholders through its national initiative called the Sanitation Transformational Initiative (SaNiTi) which aims to mainstream non-sewered sanitation (NSS) through a very different platform, that of a new Sanitation Industrial Pathway (Pillay and Bhagwan, 2021). The SaNiTi strategy incorporates elements of behaviour change, industrial development, policy development for NSS, technology standards and regulations, technology testbeds, and a sanitation academy that builds the next cohort of skills and artisans required to service this new frontier.

There is however a need for guidance on the disposal of faecal and septic tank sludges content to a wastewater treatment plant. Many municipalities make use of contactors to empty septic tanks and chemical toilets which is then discharges into the sewers or even at the wastewater treatment plants. This causes upsets in the operation and performance of the wastewater treatment plants. This is particularly evident at smaller municipalities who requested the development of good practice guidelines for the disposal of faecal and chemical toilet waste into the sewer and wastewater treatment plant inlet works.

6.7.2 Other guidance required

Several additional needs were identified during the stakeholder workshops (Appendix B). These include a need for the following to either be included in the updated guidelines or standalone guidance documents be provided:

- Typical municipal bylaws that can lead to the improvement of sludge quality and management;
- Good practice guidelines for sludge minimisation and the evaluation of sludge minimization technologies;
- Good practice guidelines for sludge stabilization and the evaluation of sludge stabilization technologies;
- Good practice guidelines on the development of a sludge management plan and sludge master plan, especially for smaller municipalities. This need is linked to one of the Green Drop assessments requirements;
- Print ready templates and customizable information posters and flyers for local government to disseminate to citizens, schools and public forums to educate the public on wastewater treatment and the beneficial safe use of wastewater sludge;
- Rules and regulations for the transport of wastewater sludge on national roads;
- Generic SANS 10234 classification and safety data sheets (SDS) for different sludge types; and,
- Good practice guidelines on the disposal of package plant sludge.

7 CONCLUSIONS

The WRC identified a need to revise the Sludge Management Guidelines of 2006 and 2009 taking into account developments since 2009, including macro drivers such as circular economy principles, emerging contaminants, electricity costs, local economy, etc. The WRC launched this project as the first step in the process to develop a framework for the revision of guidelines and in doing so, describe a way forward for and identify key theme areas which would be defined through stakeholder engagement.

This outlines the vision, narrative and key themes and strategy for the revised guidelines. It is underpinned by a literature review, the current regulatory framework and extensive stakeholder consultation.

The vision of the updated sludge guidelines is to create an ***enabling environment for local government and the private sector to include energy and/or resource recovery during the stabilisation of the wastewater sludge to generate a product that contributes to sustainable down-stream beneficial use.***

The framework outlines the next steps to realise the vision for the updates sludge guidelines and includes:

- Aspects that require immediate attention, before the revision of the Sludge Guidelines;
- Knowledge gaps and research which should be initiated before the revision that would add value and inform the revised Sludge Guideline;
- Terms of reference for the revision of the Sludge Guidelines.

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APPENDIX A: Literature Review

by

EH Tesfamariam, HG Snyman & JE Herselman

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Conservation of Agricultural Resources Act (CARA)

Department of Agriculture (DoA)

Department of Forestry, Fisheries and the Environment (DFFE)

Department of Mineral and Energy (DME)

Department of Water and Sanitation (DWS)

National Environmental Management: Air Quality Act (NEMAQA);

National Environmental Management:Waste Act (NEMWA)

National Environmental Management: Waste Amendment Act (NEMWAA)

National Environmental Management Act (NEMA)

Non-sewered Sanitation (NSS)

Poly Aromatic Hydrocarbons (PAHs

Sanitation Transformational Initiative (SaNiTi)

Site Assessment Report (SAR)

Waste Management Licence (WML)

Water Research Commission (WRC)

Water Services Act (WSA)

Water Use Licences (WUL)

National Waste Management Strategy (NWMS)

1 HISTORY OF DEVELOPMENT OF SLUDGE GUIDELINES IN SOUTH AFRICA

Prior to 1970, control of activities such as sewage sludge treatment, disposal and utilisation were generally accepted as the sole responsibility of local authorities. During the decade from 1970 to 1980 the Department of Health realised its responsibility and expanded departmental activities in the environmental health sphere. The Department of Health embarked on a research project during 1979, to obtain the necessary information for controlling the use of sewage sludge (Viviers et al., 1988).

At that stage, the regulatory requirement was governed by Section 20 of the Health Act, 1977 (Act 63 of 1977) which stated that: "Every local authority shall take all lawful, necessary and reasonable practicable measures to maintain its district in a hygienic condition and to prevent the occurrence of nuisances, unhygienic or offensive conditions or any other condition which will or could be harmful or dangerous to the health of any person within its own district or the district of any other local authority and where such conditions have occurred, to abate or to remedy such conditions." In general, these duties and related powers pertained to sewage purification and sludge treatment, storage, processing, utilisation and disposal.

Viviers *et al*., (1988) developed a set of guidelines that had the following features:

- All types of sewage sludge may be utilised.
- A limited number and only essential requirements and conditions were imposed.
- A limited number of quality control determinations were required.
- Some flexibility in application was allowed.
- The unsatisfactory impact on human health and the environment could be minimised to acceptable levels.

The Sludge Management Division (SMD) of the Water Institute of Southern Africa (WISA) was formed in 1988 as a Working Group of WISA. At the beginning of 1989, the Sludge Management Working Group became the Sludge Management Division. This group compiled an information document titled: "Sewage sludge utilisation and disposal information document" edited by Prof. GA Ekama who at that time was the chairperson of the Sludge Management Division (Water Institute of Southern Africa, 1993). This document contained a copy of the "Guide: Permissible utilisation and disposal of sewage sludge" published by the Department of Health (1991) by which sludge application to land was managed in terms of the Health Act.

The 1991 guidelines were subject to considerable debate as consensus was not reached by all the government departments that had an interest in sludge application to land; i.e. Department of Health, Department of Water Affairs and Forestry, Department of Agriculture and the Department of Environment Affairs and Tourism. The 1991 guideline was therefore used as an interim guideline while negotiations were taking place between the government departments. Lötter and Pitman (1997) also described the different legal requirements for metals by the Department of Health and the Department of Agriculture. A final draft of the "Guide: Permissible utilisation and disposal of sewage sludge" was published in June 1994.

The "Permissible utilisation and disposal of sewage sludge, Edition 1" known as the 1997 Sludge Guidelines, was finally published in 1997 and was aimed at assisting organisations involved in sewage treatment to promote safe handling, disposal and utilisation of sewage sludge (WRC, 1997). In essence, the South African sludge classification remained the same. Sewage sludge was classified in four categories according to the potential to cause odour nuisances, fly breeding and transmit pathogenic organisms to man and his environment: Type A (worst quality) – Type D (best quality).

Sludge of type A to C can be utilised as a soil ameliorant under certain restrictions and the sludge producer remains responsible for the safe handling and disposal/use of the sludge. The restrictions on the use of the sludge types were amended in the 1997 guideline. Type D sludge could be used without restrictions to a maximum of 8 t/ha/year. Some of the maximum permissible metal concentrations for sludge aimed for unrestricted use (type D) were amended considerably Table 1. 1. The new metal limits were derived based on a risk factor calculation to minimise the risk to the aquatic environment (Department of Water Affairs and Forestry, 1998).

The guideline published in 1997 (WRC, 1997) was perceived to be overly restrictive, specifically with regard to some of the metal standards. For example, of the sludges from 77 wastewater treatment plants evaluated for compliance with type D sludge, none of the sludge, including those from plants treating mainly domestic sewage, complied (Snyman et al., 2000). However, when the origin of these limits were investigated, after publication of the guidelines, it was found that from the way the allowable concentrations were calculated, they appeared to be the available metal fraction and not the total extractable metal fraction as originally interpreted. This was not stipulated in the guideline. It therefore seemed as if the Cd, Cu, Pb and Zn limits were overly stringent.

1.1 The origin of the maximum allowable metal concentrations for a type D sludge in the 1997 Sludge Guidelines

The sludge guidelines metal limits were the result of a Water Research Commission facilitated round-table debate between the Department of Agriculture and Land Affairs, Department of Health, Department of Water Affairs and Forestry and the Water Institute of Southern Africa to agree on one set of metal limits to include in the 1997 Sludge Guidelines. Each department had a set of maximum metal concentration values based on criteria that are applicable to the population or resource the specific department was mandated to protect. For example, the consultant for the Department of Water Affairs and Forestry was briefed to recommend maximum metal concentrations for a type D sludge that would ensure the prevention of pollution of the aquatic system. At that stage, the consultant was also involved with the development of the Waste Management Series, Minimum Requirements (Department of Water Affairs and Forestry, 1998), which deals exclusively with the handling, classification and disposal of waste. He was asked to evaluate the metal limits within the framework of the Minimum Requirements, concentrations and total load of selected inorganic and organic contaminants in sewage sludge. He had to make certain assumptions and accepted the same worst-case scenario of 1.5% for runoff from sludge applied land areas to surface waters as used in the risk models employed in the Minimum Requirements (Department of Water Affairs and Forestry, 1998).

The recommended maximum permissible metal concentration for a type D sludge that was therefore recommended by the Department of Water Affairs and Forestry was based on the report submitted by their consultant (Fourie, 1996). Table 1. 1 illustrates the metal concentrations allowed in sewage sludge when applied at a rate of 8 dry t/ha/year for twenty-five years based on the load principles stated by the Minimum Requirements (Department of Water Affairs and Forestry, 1998).

The recommended values presented by the other parties remained those published earlier by the Department of Health (1991) as “Guide: Permissible Utilisation and Disposal of Sewage Sludge” (Draft 2, A11/2/5/4, 1991). Lötter and Pitman (1997) tabled the requirements of the Department of Health and the Department of Agriculture. The authors presumed that these were the values that were discussed at the round table discussion during the development of the 1997 Sludge Guidelines. Table 1. 1 lists the maximum allowable metal values for sewage sludge suggested by the different governmental departments.

Table 1.1 Recommended maximum allowable metal values for sewage sludge in different guideline documents

Metal	**Department of Water Affairs and Forestry[1]**	**Department of Health[2]**	**Department of Agriculture[3]**
	Concentration (mg kg^{-1} dry sludge)	**Concentration (mg kg^{-1} dry sludge)**	**Concentration (mg kg^{-1} dry sludge)**
Cd	15.7	20	20
Co	3 485	NR*	NR*
Cr(III)	2 373	1 750	1 200
Cu	50.5	750	1 200
Hg	11.1	10	25
Mo	NR*	25	NR*
Ni	575	200	200
Pb	50.5	400	1 200
Zn	353.5	2 750	3 000
As	30.3	15	80
Se	131	15	NR*
B	NR*	80	100
F	NR*	400	NR*

Sources: [1] Fourie, 1996; [2] Ekama, 1992; [3] Lötter and Pitman, 1997,

*NR = No recommendation was made

Since consensus could not be reached between the different government departments, it was agreed that they would publish the lowest values for each of the metals resulting in the allowable limits of the 1997 Sludge Guidelines as listed in Table 1. 1.

1.2 Comments made by the wastewater industry on the 1997 Guideline

The wastewater industry was concerned since none of the wastewater treatment plants in South Africa could comply with the new guidelines. However, in the foreword of the 1997 Sludge Guidelines, it was indicated that the guide was a consultative publication, seeking comments from all concerned parties on the criteria and approaches adopted to ensure the upgrading and improvement of the guide.

Cape Town Metropolitan Council took the initiative to organise a forum to formally comment on the 1997 Sludge Guidelines in September 1999. These comments were forwarded to the Department of Water Affairs and Forestry. At this meeting Prof. GA Ekama explained the basis on how the allowable metal concentrations for the Cd, Cu, Pb and Zn were calculated by the consultant representing the Department of Water Affairs and Forestry. A sample calculation for Cd is detailed in Table 1. 2.

Table 1.2 Calculation of metals limits – 1997 guidelines

METAL	Cadmium (Cd)	
Teratogenicity	Negative	
Carcinogenicity	Positive, Class B but <1%	
Acute Ecotoxicity Acceptable Risk	NOEC = 31 ppb = 0.031 mg/ℓ ppm = Highly Hazardous, HG2 0.1 x 0.31 = 0.031 mg/ℓ (ppm) = 31 ppb = EEC	
Total amount / ha (runoff)	$\frac{30}{0.66} \text{ x } \frac{100}{1.5}$	= 3 133 g /ha
Concentration / hectare soil	$\frac{3\,133 \text{ x } 1\,000 \text{ mg}}{1\,520\,000 \text{ kg soil}}$	= 2.06 ppm
Maximum load of sludge (Health)	8 000 kg / ha / yr	200 000 kg / ha / 25 yr
Cd concentration allowed in Sewage Sludge at rate of 8 000 kg / ha / yr for 25 years (DWAF)		$\frac{3\,133 \text{ x } 1\,000 \text{ mg}}{200\,000 \text{ kg sludge}}$ $= 15.7 \text{ mg / kg (ppm)}$

Snyman et al. (2000) and Snyman (2001) explained the basis and the impact of these assumptions. These publications explain the metal limits set for a type D sludge. Cd, Cu, Pb and Zn levels in the 1997 Sludge Guidelines should be interpreted as the available fraction and not the total fraction, as is the case for the other elements indicated in Table 1. 2. The reason for this interpretation is explained in section 1.1.3.

1.3 The interpretation of the Cd, Cu, Pb and Zn limits in the 1997 Sludge Guidelines

The Waste Management Series, Minimum Requirements (Department of Water Affairs and Forestry, 1998), aims to protect the environment by recommending that the load of a certain contaminant should not exceed an acceptable risk level. In a waste disposal site, this load is calculated as the Estimated Environmental Concentration (EEC) that represents the exposure from a hazardous substance in waste, should it enter into the environment. The EEC is compared to the acceptable risk level (ARL) calculated as 10% of the LC_{50} to determine whether a substance can be delisted (Table 1. 6). Ten percent (0.1) of the LC_{50} represents the concentration at which the risk to the population (for example Daphnia) would be one in 300 000 and could potentially leach to the groundwater. Delisting is the reclassification of the hazardousness of a compound from a high hazard rating to a lower hazard rating. Delisting can be achieved in one of two ways.

The following example details the scenario based on Copper:

- If the EEC is less than the acceptable risk level, the waste can be delisted. In the case of sewage sludge, if a sludge contained > 50.5 mg Cu, kg^{-1} dry sludge, it would exceed the acceptable risk level and remain in a Hazard Rating 2 that would need to be disposed of in a H:H landfill site. This is the case of a sludge being disposed of at a rate of 8 t $(ha\ yr)^{-1}$ for 25 years. However, the Minimum Requirements do allow for a second route of delisting a waste.
- The effective estimated environmental concentration can be determined by using the Toxicity Characteristic Leaching Procedure (TCLP). The EEC can therefore be re-evaluated by doing a TCLP to prove that, because of the low mobility, the substance is less hazardous than that indicated by the original tests based on the total concentration. Therefore, if a Cu concentration in a sewage sludge sample is extracted using the TCLP and reveals a concentration < 50.5 mg kg^{-1}dry sludge, the sludge can be delisted to be disposed of in a general landfill site ($G:B^+$).

The TCLP (which represents the leachable fraction) was developed to measure leachability of specific compounds from a waste and hence the risk to pollute groundwater. The TCLP (leachable) is typically used when a waste is to be landfilled in a site that receives a variety of organic and inorganic wastes. The procedure simulates the dissolving action of the organic acid leachate formed in a landfill, where hazardous waste has been co-disposed with general waste. It can be used to determine the mobility of organics and inorganics in liquid, solid, and multiphase wastes. As explained, the revised metal concentrations in Table 3.5 are considered to be less or equal to the acceptable risk level, which is derived as 0.1 x LC_{50} (Department of Water Affairs and Forestry, 1998). The TCLP (leachable) has historically not been used by the wastewater industry to assess the amount or quality of sludge that can be safely used in agricultural practices. Most wastewater laboratories have used the aqua regia (total) extraction, which gives a measure of the acid soluble fraction.

1.4 The development of an addendum to the 1997 Sludge Guidelines

The Water Research Commission, Department of Water Affairs and Forestry, Department of Agriculture and Department of Health, with the assistance of Sludge Consult and a committee representing the different sectors of the water industry, compiled an explanatory addendum of the 1997 Sludge Guidelines. Addendum to Edition 1 (1997) of the Permissible Utilisation and Disposal of Sewage Sludge (WRC, 2002) served to clarify certain of the issues in the 1997 Sludge Guidelines (WRC, 1997). The addendum now advised to use both total and leachable extraction methods to characterise sewage sludge. Based on the results of these methods a decision can be made on the best treatment and disposal route for a specific sludge. The document also guides the reader through the legislative route that should be followed and the relevant regulatory agency.

1.5 Principles applied internationally in the development of sludge guidelines

Internationally, opinions and policies regarding sludge management differ widely. The difference may be ascribed to two sources. The first may be broadly defined as geographical factors, including geo-political, technical, and economic constraints. The second may be considered as the philosophical or ethical factors in developing environmental policies, and specifically here, the acceptable practices for sludge disposal (Dentel, 2003).

Philosophies and policies should provide management principles to guide action to achieve certain objectives. In the case of the management of sewage sludge, it is important to decide what these objectives should be.As a developing country, sustainable development is of utmost importance and the developers of all the environmental legislation and guidelines adopted this principle in the last few years. This is especially relevant after the World Summit on Sustainable Development held in South Africa in 2002.

> Sustainable development defined as…
> "development that improves the total quality of life, both now and in the future, in a way that maintains the ecological processes on which life depends"
> (Australian National Strategy)

This definition of sustainable development includes factors such as financial viability (BATNEEC), availability of appropriate skills and management principles such as the precautionary principle. It is proposed that the development of the 2nd Edition of the South African Sludge Guidelines should adopt "sustainable sludge management" as a guiding principle.

1.5.1 Sustainable sludge management options

With current knowledge, there are three ways in which sustainable management of sewage sludge can be achieved:

- Utilising the calorific energy value of the sewage sludge; or
- Utilising useful constituents (carbon and nutrients); or
- Extracting useful constituents from the sludge.

The guidelines of some countries support one or more of these options for that particular country. In the USA the US EPA Part 503 (US EPA, 1993; US EPA, 1994) developed legislation that supports several options:

- Land application of sewage sludge.
- Surface disposal of sewage sludge.
- Sewage sludge incineration.

South Africa adopted a similar approach to encourage the implementation of one of the above management options, rather than trying to develop a single guideline to address all the management options. Each volume of the guidelines was dedicated to the management, technical and legislative aspects associated with a particular management option. Each of the management options have different regulatory requirements. Also, the characterisation requirements for each option would be different. For example, the pathogenic content of the sludge is much more important for land application than for incineration. Similarly, the acceptable nutrient, metal, organic and inorganic concentrations will be different depending on the management option and the resource (and receptors) that needs to be protected.

The following series of documents were published for the South African Sludge Guidelines (Snyman & Herselman, 2006):

Volume 1: Selection of Management Options
In this volume, the user is guided to decide on the appropriate management option for the particular case.

Volume 2: Requirements for the agricultural use of Wastewater sludge
This volume will address appropriate sludge quality, load, soil and crop requirements for the beneficial use of sewage sludge in agricultural practices. The legal and management requirements will also be addressed.

Volume 3: Requirements for the on-site and off-site disposal of Wastewater sludge
This volume will address the legal, technical and management requirements associated with various disposal options such as landfill and lagoons, dedicated land disposal and ocean disposal. This volume will highlight that these practices are not sustainable. The appropriate remediation approach for some of the options, such as dedicated land disposal will also be addressed in this volume.

Volume 4: Requirements for the beneficial use of wastewater sludge
This volume will address the legal, technical and management requirements associated with the use of sewage sludge in the production of commercial products such as bricks, cement and fertilisers.

Volume 5: Requirements for the thermal sludge management practices and for commercial products containing wastewater sludge
This volume will address the legal, technical and management requirements associated with the incineration of sewage sludge.

1.5.2 Agricultural use

To date, the South African sludge guidelines (Water Institute of Southern Africa, 1993; WRC 1997) were mainly focussed on beneficial use of sewage sludge in agricultural practices. Through the publication of the addendum (WRC, 2002), the other options were also addressed.

Internationally many authors argue that the agricultural use of sewage sludge is a sustainable management option.

For example, New Zealand has recognised and documented that land application of sludge to agricultural land is considered a viable long-term strategic option when carried out in accordance with EPA guidelines (GHD, 2003). The USA, Canada, Australia, Mexico and some European countries support agricultural use of sludge. Most of these countries, do however, distinguish between sludge and sewage sludge. Sludge include sewage sludges mixed with other materials that have been treated and/or stabilise to the extent that they can be safely and beneficially applied to land. Sludge have significant fertilising and soil conditioning properties as a result of the nutrients and organic material content (GRD, 2003).

Agricultural use of sewage sludge in Europe

In Europe, the debate on sludge recycling and disposal has recently received growing interest. This is due to some concerns expressed regarding the potential risks of the agricultural use of sludge to human health and the environment (European Commission, 2002). The debate on the use of sludge in agriculture originated mainly in Northern Europe at the beginning of the 1990s, before gaining in momentum from 1995 onwards. Analysing the context of this period is crucial to understanding the various stakeholders' attitudes, motivations and positions concerning the use of sludge. In particular, the health "scares" related to GMOs (Genetically Modified Organisms), dioxins have cast doubts on the safety of food products on the markets and on the ability of existing regulations and controls to minimise human exposure to potential risks.

The concern expressed about food safety is also related to growing pressure on the agricultural sector, which in certain countries is considered by consumer associations or nature protection associations as being too focused on intensive production and not sufficiently concerned about the impact of its activities on human health and on the environment.

The above holds true for most European countries, however, certain countries are under considerable pressure from both sewage sludge, i.e. a high rate of production per inhabitant, and from other fertilising materials, in terms of nitrogen and phosphate content. This is one reason why the debate has not been the same in all countries and has been most heated in the Netherlands, Flanders and Scandinavian countries (European Commission, 2002).

- Past and current events show that it is possible to divide countries up into the following groups (European Commission, 2002):
- In the Netherlands and Flanders, the debate on the use of sludge in agriculture is over, as the regulatory requirements have blocked almost all use of sewage sludge in agriculture since 1991 in the Netherlands and 1999 in Flanders. The effect of this legislation is clearly indicated in Table 3.2.1(a).

- In countries such as Denmark and the United Kingdom, the debate is now mostly over. In Denmark, new regulations on the use of sludge in agriculture have played a large part in ending the debate, as they are considered sufficiently strict to reduce risks to an acceptable level. In the United Kingdom, the debate on sludge recycling was heated until an agreement was reached in September 1998 between Water UK, representing the 14 UK water and sewage operators, and the British Retail Consortium (BRC), representing the major retailers. In addition, farmers' associations support the agricultural use of sludge, both for economic and for agronomic reasons.
- The cases of Germany and Sweden are special. In Sweden, a voluntary agreement was signed in 1994 between the Swedish Environmental Protection Agency (SEPA), the Swedish Federation of Farmers (LRF) and the Swedish Water and Waste Water Association (VAV) concerning quality assurances relating to the use of sludge in agriculture. However, in October 1999 the LRF recommended that their members stop using sludge because of concerns about the quality of sludge. In Germany, opinion has recently swung in favour of agricultural land spreading, mainly because this practice is considered economically viable and it is considered that the potential risks are sufficiently reduced by the existing legislation. However, political developments in 2001 have considerably heated the debate, which is quite high at present as some Länder support further regulatory constraints on sludge land spreading.
- In Austria, France and Walloon, a national (or regional) agreement is currently under negotiation between the different parties, and hence the debate is heated. The situation is particularly tense in France where the farmers' unions supported, until recently, the development of the agricultural recycling of sewage sludge, on the condition that additional quality controls and an insurance fund system were set up. The situation has now changed, as farmers' unions (the FNSEA and CDJA) have asked for a ban on the use of sewage sludge, officially because the current methods used are not considered to be sufficient to address the risks related to the agricultural recycling of sludge.
- In Finland and Luxembourg, the farming community is generally hostile towards the use of sludge for land spreading, mainly because of the pressure to use animal manure for land spreading. For example, the Finnish Union of Agricultural Producers asked for a ban on the use of sewage sludge for land spreading in 1990, and have renewed their stand against the use of sludge in agriculture in 2001.
- In Ireland and Portugal, farmers support, in some cases, the agricultural use of sludge, both for economic and for agronomic reasons (mainly in terms of organic matter and phosphorus content) although it is difficult to obtain information on this matter. In both countries, the use of sludge seems to be too recent an issue to generate much public debate.
- In Spain, Italy and Greece, the debate remains limited, as far as can be judged from the available information.

A comparison with the national legal requirements also demonstrates that "tight" legal constraints (such as very low limit values for pollutants in sludge) do not necessarily imply a greater acceptance of the use of sludge in agriculture. The Swedish experience demonstrates this best (European Commission, 2002). Table 1. 3 illustrates the percentage sludge applied to land in Europe.

Table 1.3 Status of agricultural use of sewage sludge in Europe

Country	Status	% to Land
Australia	Under negotiation between relevant parties	20%
Denmark	Accepted use	62%
Finland	Farming community against/banned land application	31%
France	Farmers Union ask for ban until risks addressed	60%
Germany	Supported in some provinces, debate ongoing	40%
Luxemburg	Farming community against land application	70%
Netherlands	Regulations practically prevent land application	<4%
Spain	Debate is limited	46%
Sweden	Farmers group recommended stop using sludge due to concerns about quality	35%
United Kingdom	Agreement between water companies and retailers to apply sludge to land	54%

(GHD, 2003)

<u>Agricultural use of sewage sludge in the USA</u>

Since the early 1970s, the US Environmental Protection Agency (EPA) and the wastewater treatment industry have promoted recycling of sewage sludge. With the prohibition of ocean disposal of wastewater residuals in 1992, the use of sewage sludge as soil amendments (soil conditioners or fertilizers) or for land reclamation has increased to reduce the volume of sewage sludge that must be landfilled, incinerated, or disposed of at surface sites. Approximately 5,6 million dry tons of sewage sludge are used or disposed of annually in the United States, approximately 60% of that is used for land application.

The regulation governing land application of sewage sludge was established by EPA in 1993 in the Code of Federal Regulations, Title 40 (Part 503), under Section 405 (d) of the Clean Water Act (EPA, 1993). The regulation is intended to protect public health and the environment. The Part 503 rule established management practices for land application of sewage sludge, concentration limits and loading rates for chemicals, and treatment and use requirements designed to control and reduce pathogens and attraction of disease vectors (insects or other organisms that can transport pathogens).

The chemical and pathogen land-application standards in the Part 503 rule were developed differently. For chemicals, EPA conducted extensive risk assessments that involved identifying the chemical constituents in sludge judged likely to pose the greatest hazard, characterising the most likely exposure scenarios, and using scientific information and assumptions to calculate concentration limits and loading rates (amount of a chemical that can be applied to a unit area of land). Nine inorganic chemicals in sludge are currently regulated, and EPA is considering the addition of a class of organic chemicals (including dioxins) to its regulation. Monitoring data on some of the regulated inorganic chemicals indicate a decrease in their concentrations over the past decade, due in part to the implementation of industrial and commercial wastewater pre-treatment programmes. Thus, the chemical limits for sludge can be achieved relatively easily. In contrast to the chemical standards, the pathogen standards are not risk-based concentration limits for individual pathogens but are technologically based requirements aimed at reducing the presence of pathogens and potential exposures to them by treatment or a combination of treatment and use restrictions. Monitoring sludge is required for indicator organisms (certain species of organisms believed to indicate the presence of a larger set of pathogens) (EPA, 1993; National Academy of Science, 2002).

In 2002, the Committee on Toxicants and Pathogens in Sludge Applied to Land published a document (National Academy of Science, 2002) in which they reported the results of their re-assessment of the scientific basis of the Part 503 rule and to address public-health concerns at the request of the EPA. The committee convened by the National Research Council (NRC) did an independent evaluation of the technical methods and approaches used to establish the chemical and pathogen standards for sludge, focusing specifically on human health protection and not ecological or agricultural issues.
They found no documented scientific evidence that the Part 503 rule has failed to protect public health. No causal association between sludge exposures and adverse health outcomes has been documented. However, they recommended additional scientific work to reduce persistent uncertainty about the potential for adverse human health effects from exposure to sludge. There have been anecdotal allegations of disease, and many scientific advances have occurred since the Part 503 rule was promulgated. To assure the public and to protect public health, they recommended an update of the scientific basis of the rule to:

- Ensure that the chemical and pathogen standards are supported by current scientific data and risk-assessment methods.
- Demonstrate effective enforcement of the Part 503 rule.
- Validate the effectiveness of sludge management practices (National Academy of Science, 2002).

These activities indicate the US EPA plans to continue supporting the use of sewage sludge in agricultural practices, but it will be more regulated in future (Abo-Orf, 2003)

<u>Agricultural use of sewage sludge in South Africa</u>

The data presented in section 3.2 argues that the agricultural use of sewage sludge is still a popular management option in many countries even after some countries revisited their regulations. In South Africa no scientific proof of adverse environmental or human health effects from the agricultural use of sewage sludge could be found. This does not include practices such as dedicated land disposal, lagoons or other storage mechanisms such as stockpiles, where evidence of NO_3 pollution has been reported in the underlying groundwater resource (Herselman *et al.*,2004).

According to Ekama (1993), 42 % of South African sewage sludge is applied to land. A more recent study done by Herselman *et al*. (2004) indicates that a large percentage of works (33 %) of the more than 200 works interviewed are stock piling their sludges (Figure 1. 1). This practice is not sustainable and the sludge guidelines should encourage other management options.

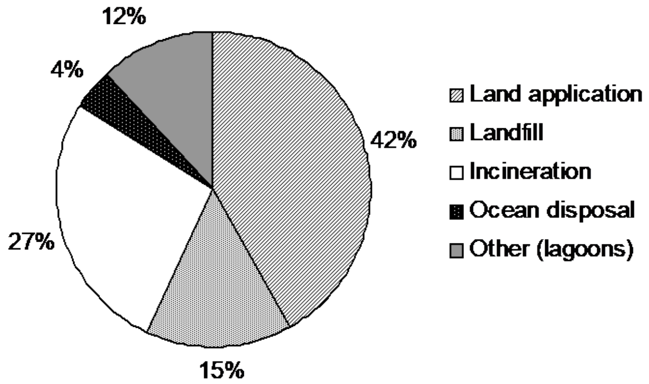

Figure 1.1 Estimated percentage of total sludge mass disposed of by different methods (adapted from Ekama, 1993)

There are several advantages associated with using sludge in agricultural practices. Sludge acts as a soil conditioner to facilitate nutrient transport, increase water retention and improve soil tilth (Ekama, 1993). The improvement of the soil physical properties through the increase in organic carbon could play an important role in promoting the agricultural application of sewage sludge in the future in S.A. Generally, many soils in S.A. are low in organic matter due to rapid decomposition by microorganisms and the use of mineral fertilizers. This has led to the occurrence of widespread erosion and deterioration of soil physical status (Korentajer, 1991). Sludge also serves as a partial replacement for chemical fertilizers. The major plant nutrients (nitrogen, phosphorus and potassium) in sludges are not substantially removed during sludge processing, therefore the nutrients could improve the soil's nutritional status after sludge application. Sludge also contains essential plant micronutrients such as Cu, Zn, Mn and B (Ekama, 1993). These characteristics should be utilised whilst managing the potential risks associated with the sludge through appropriate guidelines and/or legislation. Table 1. 4 lists the potential risks and benefits associated with the use of sewage sludge in agricultural practices (Smith, 1996).

Table 1.4 Environmental impact risk and benefit assessment for sewage sludge recycling to agricultural land

Environmental parameter	Metals	Organic contaminant	Pathogens	Nitrogen	Phosphorus	Organic matter
Human health	L	P(L)	L	B	B	B
Crop yield	L	L	L	B	B	B
Animal health	L	L	L	B	B	B
Groundwater	L	L	L	P	L	L
Surface water	L	L	L	P(L)	P(L)	B
Air quality	L	L	L	P(L)	na	na
Soil fertility	P	L	L	B	B	B
Natural ecosystems	P	P	L	P	P	B

(B = beneficial effect, L = low risk, P = possible risk, na = not applicable) (SMITH, 1996)

Based on the evidence presented in this section, the project team recommends that the guideline development should support the continued agricultural use of sewage sludge. This is due to the unique environmental and socio-economical situation. The remainder of the literature survey will focus on international guidelines and regulatory documents pertaining to the use of sewage sludge in agricultural practices.

2 INTERNATIONAL SLUDGE CLASSIFICATION TRENDS

This section discusses the sludge classification regulatory frameworks for beneficial use of sewage sludge in representative developed countries (USA, European Union, Canada, and Australia) and representative developing countries (Brazil, Mexico, and China) in terms of their:

- Pollutants (heavy metals),
- Pathogenic organisms, and
- Vector attraction.

The information is extracted from the sludge guidelines of each country and some information was extracted from "*A global atlas of excreta, wastewater sludge, and biosolid management: moving forward the sustainable and welcome uses of a global resource* (UN-HABITAT, 2008).

2.1 Microbiological parameters

The microbiological criteria for the selected countries in this review was extracted from each country's sludge guideline and other additional sources and is presented under two categories: developed countries and developing countries. The developed countries considered in this review are, the USA, European Union (EU), Australia, and Canada while the developing countries are Brazil, Mexico, and

China. A brief summary of the microbiological parameters used for sludge classification for each country are presented below:

- USA - The USA classification considers faecal coliform, salmonella, viable helminth ova, and enteric virus density to classify sludges according to their microbiological parameters.
- European Union - The EU 86/278/EEC directive does not classify sludge according to their microbiological parameters. There are, however, some member states, which have developed their own microbiological limits.
- Australia - The Australian national sludge guideline uses the amount of Salmonella and *E. Coli* to classify sludge according to their microbiological content.
- Canada - The Canadian national sludge guideline does not have specific pathogenic organism limits. The guidelines for Nova Scotia, one of the territories (provinces) of Canada, however uses faecal coliforms and salmonella to classify sludge according to their microbiological contents.
- Brazil - The Brazilian sludge guidelines uses *E Coli* to classify sludges according to their microbiological contents.
- Mexico - The Mexican sludge guideline uses faecal coliforms, salmonella, and Helminth ova to classify sludges according to their pathogen composition.
- China - The Chinese sludge guideline considers faecal coliforms, helminth ova, and contagious pathogen to classify sludge according to their microbiological composition.

2.1.1 USA

The pathogen standards for the US 503 regulatory approach to classification is predominantly based on a combination of validated technologies, ongoing monitoring of process control parameters and compliance with bacterial limits. The valid treatment processes included processes that conform to generic temperature-time curves, specific pH-temperature-time criteria, processes that are listed in the regulations as Processes to Further Reduce Pathogens (PFRP's), or processes that have been more recently assessed and considered as 'equivalent' to PFRP's (US EPA., 2018).

To be classified as Class A sludge, the treatment process must operate within defined specifications and achieve a bacteriological standard of < 1000 faecal coliform per gram dry weight (dw) or < 3 *Salmonella* per 4 grams dw. The bacteriological standard applies immediately after treatment process is completed and also after periods of storage (Reid 2003). Sludge from an unlisted process can be classified as Class A if the product achieves the bacteriological limit (i.e. < 1000 faecal coliforms per gram dw or < 3 *Salmonella* per 4 grams dw), < 1 viable helminth ova per 4 grams dw and an enteric virus density of < 1 PFU per 4 grams dw (US EPA, 2018).

In addition to the above requirements, meeting the Class A criteria also requires vector attraction reduction (VAR) measures to be undertaken by either biological degradation of putrescible organics, inhibition of biological activity prior to application (e.g. by drying or increasing pH), or through the use of physical barriers (e.g. injection or soil incorporation (US EPA, 1999; Vesilind and Spinosa, 2001).

Products that comply with the Class A criteria and the VAR measures are available for unrestricted use from a microbiological perspective.

2.1.2 European union

In accordance with Directive 86/278/EEC, there are no specific requirements for pathogens in sludge used in agriculture. However, several national regulations have added limitations on pathogens content to standard requirements for sludge quality in order to reduce possible health risks as a result of pathogens. The most common pathogens addressed by these countries are salmonella, enterovirus, and helminth eggs. For instance, the salmonella limit values in sludge for use in agricultural lands in France, Italy, and Poland are 8, 1000, and 0 most probable number (MPN) per gram dry mass of sludge, respectively. Other pathogens included in the guidelines for France are enterovirus 3 MPN cytophatic number per 10 gram of dry sludge mass and helminth eggs 3 in 10 grams of dry sludge mass (European Commission DG Environment, 2001).

2.1.3 Australia

National Australian guideline

The National water quality management quality management strategy (NWQMS) *Guidelines for Sewerage Systems – Biosolids Management* classifies sludges into two categories (P1 and P2). The unrestricted grade (grade P1) includes microbiological criteria of < 1 *Salmonella* per 50 grams dw (i.e. undetected) and < 100 *E. Coli* (or thermotolerant coliforms) per gram dw. The second category of sludge, grade P2, consists of sludges with < 10 *Salmonella* per 50 grams dw and < 1000 *E.coli* (thermotolerant coliforms) per gram dw. These types of sludge are prohibited from use in recreational or residential landscaping (NWQMS, 2004).

South Australia

The South Australia (SA) sludge guideline follows similar classification with Australian national guideline (NWQMS) in the classification of pathogens (Grades A and B). The SA sludge guideline, however adds additional pathogen restrictions (1 virus per 50 gm total solids (dry weight) and 1 viable helminth ova per 50 gm total solids (dry weight)) for Grade A sludge on top of the Salmonella and E. Coli as described in the NWQMS. The SA sludge guideline for Grade B sludge excludes salmonella as a restriction and considers only E. coli (EPA South Australia, 2020).

Western Australia

The Western Australian sludge guideline categorises sludges based on their pathogen levels into four (P1, P2, P3, and P4) as presented on Table 2. 1. Grade P1 sludges are aimed for unrestricted use including crops consumed raw and in contact with the biosolid. Grade P2 are suitable for urban land scaping (not household), horticultural crops, and crops that may be consumed raw but not in direct contact with the biosolid. Grade P3 sludge are suitable for pasture and crops that are processed before being consumed, but not root crops, forestry direct land application, and rehabilitation (eg. Mine sites, contaminated or degraded sites, within the wastewater treatment plant boundary). Grade P4 is not suitable for direct use. It could be considered for composting, landfill, or thermal processing.

Table 2.1 Western Australia sludge classification according to their pathogen levels (Department of Environmental Conservation, 2012)

Pathogen grade	Maximum pathogen level
Grade P1 Low pathogen levels with minimum Regrowth potential	Coliphages <10 **pfu** per 10 grams of dry final biosolids **AND** *E. coli* less than 100 counts per gram of dry final biosolids Strongyloides & Hookworm (viable Ova) <1 per 50 grams of dry final biosolids
Grade P2 – Low pathogen levels with some regrowth potential	*E. coli*[2] – less than 1,000 counts per gram of dry final biosolids Strongyloides & Hookworm (viable Ova) <1 per 50 grams of dry final biosolids
Grade P3 - Low- Medium Pathogen levels with some Regrowth potential	*E. coli*[2] – less than 2,000,000 counts per gram of dry final biosolids Strongyloides & Hookworm (viable Ova) <1 per 50 grams of dry final biosolids
Grade P4 - Medium – high or Unknown pathogen levels with Minimum pathogen reduction. All biosolids are considered P4 until proven otherwise.	*E. coli*[2] – greater than 2,000,000 counts per gram of dry final biosolids

[2] *E. coli* – counts per gram of final biosolids and product containing biosolids is based on geometric mean of seven samples.

2.1.4 Canada

The legal and guidelines documentation that was sourced does not specifically refer to pathogenic organism limits. The sludge guidelines for Nova Scotia, one of the Canadian provinces, however, classifies sludges according to the pathogen levels into two (Class A, and Class B) (Nova Scotia Environment, 2010). Sludges grouped into class A, have faecal coliform of less than 1000 MPN per gram total dw or Salmonella of less than 3 MPN per 4 gram total dw. While class B sludges have faecal coliform counts of less than 2 000 000 per gram dw. A Class A municipal biosolid is a treated and stabilized municipal biosolid that meets very high standards for pathogen, metal, and contamination concentrations. Hence it is not considered as generated waste, wastewater, or wastewater sludge that requires approval according to the section 23 of the Activities Designation Regulations. While class B sludges meet lower standards for metal, pathogens and contaminant concentrations. Hence, they are considered as generated waste and require approval in accordance with section 23 of the Activities

Designation Regulations. Despite being similar to Nova Scotia's sludge guideline, the Saskatchewan guideline only considers Class A pathogen reduction requirements (Water Security Agency, 2015).

2.1.5 Brazil

The Brazilian sludge guideline classifies sludge for land application according to their pathogen contents into two (Class A and Class B). Only *E Coli* was included in the guideline for sludge classification based on pathogen content. The maximum pathogen limit for class A sludge is 1000 E. Coli per gram dw. While the maximum pathogen limit for class B sludge is 1 000 000 E coli per gram dw. (CONAMA, 2020).

2.1.6 Mexico

The Mexican sludge and biosolids guideline for land application groups sludges into three classes (A, B, and C) according to their pathogen content levels (NOM-004-SEMARNAT-2002, 2003). The guideline considers three microbiological groups (bacteriological indicators, pathogens, and parasites) to classify the sludges as presented in Table 2. 2.

Table 2.2 Mexican maximum permissible limits for pathogens and parasites in sludge and biosolids (NOM-004-SEMARNAT-2002, 2003)

Class	**Bacteriological indicator of contamination**	**Pathogens**	**Parasites**
	Faecal coliforms (MPN/g dw)	*Salmonella spp.*MPN/g dw	Helminth eggs/g on dry basis
A	Less than 1000	Under 3	Under 1 (viable helminth eggs
B	Less than 1000	Under 3	Less than 10
C	Less than 2 000 000	Less than 300	Under 35

According to the guideline, sludges of A class are considered as excellent quality and could be used in urban with direct public contact during its application. Class B is considered as of excellent to good quality and could also be use in urban but direct contact during its application is prohibited. Class C is also **considered** as excellent to Good and could be used for application in forests, soil improvements, and agriculture use.

2.1.7 China

According to the Chinese sludge guideline, the maximum permissible concentration of microbiological contaminants in sludge for land application is based on the soil pH as indicated on Table 2. 3 (He, 2008).

Table 2.3 Maximum permissible concentrations of microbiological contaminants in sludge for land application in China (He, 2008)

Item	Unit	Maximum permissible concentration	
		pH < 6.5	pH > 6.5
Faecal coliforms	-	>0.01	>0.01
Helminth ova mortality rate	%	>95	>95
Contagious pathogens	–	undetected	undetected

2.2 Stability parameters

The stability criteria for the selected countries in this review was extracted from various sources and is presented in two categories: developed countries and developing countries. The developed countries considered in this review are, the USA, European Union (EU), Australia, and Canada while the developing countries are, Brazil, Mexico, and China. The stability parameters (vector reduction criteria) for each country is presented below. A summary of the vector attraction reduction measures for the candidate countries is presented below:

- USA - Recommends 10 vector reduction measures for sludge application in agricultural lands, forest, a publica contact site and reclamation site. While for sludge application to a lawn, home garden, and sold in a bag, eight vector reduction measures are recommended.
- European Union - The EU 86/278/EEC directive recommends vector attraction measures (biological, chemical, heat treatment, or long-term storage or any other process) before a sludge could be applied in agricultural lands.
- Australia - The national Australian guideline (NWQMS, 2004) recommends vector attraction reduction measures such reducing the moisture content of biosolids, reducing the organic matter content of biosolids via aerobic or anaerobic digestion, adding alkalis and/ or heating, composting, and incorporation or injection of biosolids into the soil.
- Canada - The Canadian province of Nova Scotia sludge guideline issues approvals for sludge land application if one of the three recommended vector reduction measures are implemented.
- Brazil - The Brazilian sludge guideline recommends a sludge to meet one of the vector attraction reduction criteria for use in agricultural lands.
- Mexico - The Mexican sludge guideline recommends nine vector attraction reduction measures for sludges to be applied in agricultural lands.
- China - The Chinese sludge guideline recommends vector attraction reduction of sludge using anaerobic digestion, aerobic digestion, or composting.

2.2.1 USA

The EPA CFR 2018 guideline recommends different combinations of vector attraction reduction measure for biosolid land applications in different agricultural environments as presented below.

a) When bulk sludge is applied to agricultural land, forest, a public contact site, or a reclamation site vector reduction requirement of 1 through 10 (listed below) shall be met.
b) When bulk sewage sludge is applied to a lawn or a home garden, vector attraction reduction requirements 1 through 8 shall be met.
c) When sewage sludge is sold or given away in a bag or other container for application to the land, vector attraction reduction requirements 1 through 8 shall be met.

Vector reduction measures

1. The mass of volatile solids in the sewage sludge shall be reduced by a minimum of 38 percent.
2. When the 38 percent volatile solids reduction requirement in number 1 cannot be met for an anaerobically digested sewage sludge, vector attraction reduction can be demonstrated by digesting a portion of the previously digested sewage sludge anaerobically in the laboratory in a bench-scale unit for 40 additional days at a temperature between 30 and 37 degrees Celsius. When at the end of the 40 days, the volatile solids in the sewage sludge at the beginning of that period is reduced by less than 17 percent, vector attraction reduction is achieved.
3. When the 38 percent volatile solids reduction requirement in number 1 cannot be met for anaerobically digested sewage sludge, vector attraction reduction can be demonstrated by digesting a portion of the previously digested sewage sludge that has a percent solid of two percent or less aerobically in the laboratory in a bench-scale unit for 30 additional days at 20 degrees Celsius. When at the end of the 30days, the volatile solids in the sewage sludge at the beginning of that period is reduced by less than 15percent, vector attraction reduction is achieved.
4. The specific oxygen uptake rate (SOUR) for sewage sludge treated in an aerobic process shall be equal to or less than 1.5 milligrams of oxygen per hour per gram of total solids (dry weight basis) at a temperature of 20 degrees Celsius.
5. Sewage sludge shall be treated in an aerobic process for 14 days or longer. During that time, the temperature of the sewage sludge shall be higher than 40 degrees Celsius and the average temperature of the sewage sludge shall be higher than 45 degrees Celsius.
6. The pH of sewage sludge shall be raised to 12 or higher by alkali addition and, without the addition of more alkali, shall remain at 12 or higher for two hours and then at 11.5 or higher for an additional 22 hours.
7. The percent solids of sewage sludge that does not contain unstabilized solids generated in a primary wastewater treatment process shall be equal to or greater than 75 percent based on the moisture content and total solids prior to mixing with other materials.
8. The percent solids of sewage sludge that contains unstabilized solids generated in a primary wastewater treatment process shall be equal to or greater than 90 percent based on the moisture content and total solids prior to mixing with other materials.
9. i) Sewage sludge shall be injected below the surface of the land. (ii) No significant amount of the sewage sludge shall be present on the land surface within one hour after the sewage sludge is injected. (iii) When the sewage sludge that is injected below the surface of the land is Class

A with respect to pathogens, the sewage sludge shall be injected below the land surface within eight hours after being discharged from the pathogen treatment process.

10. (i) Sewage sludge applied to the land surface or placed on an active sewage sludge unit shall be incorporated into the soil within six hours after application to or placement on the land, unless otherwise specified by the permitting authority.(ii) When sewage sludge that is incorporated into the soil is Class A with respect to pathogens, the sewage sludge shall be applied to or placed on the land within eight hours after being discharged from the pathogen treatment process.

2.2.2 European Union

Directive 86/278/EEC recommends the treatment of sludge (biologically or chemically, heat treatment, or long-term storage or any other process to reduce its fermentability and health hazards from its use) before its application to agricultural lands. The same directive allows the use of untreated sludge if it is injected or worked into the soil. Many EU members follow this provision while some members such as Denmark, Finland, Germany, Greece, Italy, The Netherlands, Portugal, Spain, and Belgium-Flander prohibit the use of untreated sludge for agricultural use (European Commission DG Environment, 2001).

2.2.3 Australia

The national Australian guideline (NWQMS, 2004) recommends for vector attraction reduction for all biosolids classes. According to the guide, vector attraction reduction could be achieved through one of the following methods:

- Reducing the moisture content of biosolids,
- Reducing the organic content of biosolids be either aerobic or anaerobic digestion,
- Adding alkalis (e.g. lime) and/or heating,
- Composting, or
- Incorporation or injection of biosolids into the soil.
-

The Australian guide recommends the USEPA (1999) for further guidance on vector attraction control options.

South Australia

Similar to the national Australian sludge guideline, the South Australian guide recommends for vector attraction reduction as presented on Table 2.4.

Table 2.4 South Australian recommended vector attraction reduction methods

Vector attraction reduction	Biosolids most suited
Treatment process reduces volatile solids by ≥38%	All biological anaerobic or aerobic processes
Biosolids containing no unstabilised solids dried to ≥75% solids content	Fully stabilised by anaerobic or aerobic processes
Biosolids containing unstabilised solids dried to ≥90% solids content	Heat dried biosolids
Aerobic treatment for ≥14 days at temperatures: minimum 40oC and average >45oC	Composted
Alkaline treatment pH raised to ≥12, and without addition of further alkali pH maintained at ≥12 for 2 hrs and then at pH ≥11.5 for an additional 22 hours	pH (alkali/lime addition) and temperature
Injection or incorporation of biosolids soon after application	

Western Australia

The Western Australia sludge guideline recommends several vector attraction reduction measures adapted from US EPA environmental regulations and technology 503 (2003) and draft South Australian EPA biosolids guideline (2009) as indicated in Table 2. 5.

Table 2.5 Vector attraction reduction measures recommended by Western Australian sludge guideline ()

Suggested vector attraction reduction measures	Biosolids and products containing biosolids suited to these measures
Volatile solids reduced by ≥38% in the Digester	Anaerobically or aerobically digested Sludge
Drying to ≥75% solids	Stabilised, anaerobically or aerobically digested sludge
Drying to ≥90% solids	Heat dried unstabilised sludge
Aerobic treatment for ≥14 days at average temperature >45oC and temperature never <40oC	Composted product
pH raised to ≥12, and without further addition of alkali maintained at ≥12 for 2 hours and ≥11.5 for an additional 22 hours	Alkali amended product (LAB)
Specific Oxygen Uptake Rate (SOUR) at 20^{o}C ≤ 1.5mg O2/hr/g total solids	Liquid sludges from aerobic processes operating at 10 to 30oC
Injection or incorporation of biosolids into soil within 6 hours of surface application	Partially stabilised or unstabilised sludges

2.2.4 Canada

The Canadian province of Nova Scotia only issues approvals for stabilised municipal biosolids (Nova Scotia Environment, 2010). The guideline considers a municipal biosolid stabilised only if one of the following conditions are met.

a) volatile solids in sewage sludge have been reduced by at least 38% during treatment.

b) The specific oxygen uptake rate (SOUR) of the sewage sludge is less than 1.5 mg O_2/hr/g. of total sludge on a dry weight basis corrected to 20 ^{O}C. This test is only applicable to liquid aerobic municipal biosolids withdrawn from an aerobic process.

c) Sufficient alkaline material has been added to the sewage sludge in order to produce a homogenous mixture with a minimum pH of 12 after 2 hours of vigorous mixing. Facilities adding supplemental alkaline material must maintain the pH of the sludge during interim sludge storage periods

The guideline recognizes the following as suitable stabilization methods: composting**,** aerobic digestion, anaerobic digestion, alkaline/lime stabilization, heat drying, heat treatment, and pasteurization. The Saskatchewan guideline recommends similar vector attraction reduction measures for sludge stabilization processes.

2.2.5 Brazil

The Brazilian sludge guideline recommends that a biosolid for land application must meet at least one of the vector attraction reduction criteria presented in Table 2. 6.

Table 2.6 Vector attraction reduction criteria of biosolids for land application (CONAMA 498, 2020)

a) Stabilized organic fraction of the biosolid, which must be proven by a ratio between volatile solids and total solids of less than 0.65, with the sludge coming from one of the following sewage treatment processes: - UASB type reactor (up flow reactor and sludge blanket) and anaerobic filter; - stabilization ponds; - activated sludge with sludge age equal to or greater than 18 days, or A/M ratio equal to or less than 0.15 kg BOD5/ kg SSVTA; - aerobic and anaerobic digestion and chemical stabilization of the sludge, in accordance with current technical standards, and - Constructed flooded systems.	
b) Sanitary sewage sludge comes from one of the processes and meets one of its respective criteria, described below:	
I. Anaerobic digestion	Criterion 1: The volatile solids (SV) concentration must be reduced by 38% or more. The reduction of SV is measured by comparing its concentration in the affluent, from anaerobic digestion, with its concentration in sanitary sewage sludge ready for use or final destination. Criterion 2: if the reduction of 38% of SV of the sewage sludge is not reached, after it is submitted to an anaerobic digestion process, the adopted process will only be accepted if, in laboratory scale, the same sample of sanitary sewage sludge, after an additional period of 40 days of digestion, with temperature varying between 30 and 37 ºC, present a reduction of VS lower than 17%.
II. processes of aerobic digestion	Criterion 1: Volatile solids (SV) concentration must be reduced by 38% or more. The reduction of SV is measured by comparing its concentration in the affluent of aerobic digestion, with its concentration in sanitary sewage sludge ready for use or final destination. Criterion 2: if the reduction of 38% of SV of the sewage sludge is not reached, after it is submitted to an aerobic digestion process, and the sanitary sewage sludge has a concentration of total solids (TS) lower than 2%, the The process adopted will only be accepted if, on a laboratory scale, the same

	sample of sanitary sewage sludge presents a reduction in SV of less than 15% after an additional period of 30 days of digestion, with a minimum temperature of 20 ºC. Criterion 3: after the digestion period, the specific rate of oxygen consumption (SOUR -Specific Oxygen Uptake Rate) must be less than or equal to 1.5 mg O2/[hour x gram of total solids (TS)] at 20°C. Criterion 4: during the process, the temperature must be kept above 40º C for at least 14 days. The average temperature during this period must be greater than 45°C.
III. Process of composting	Criterion 1: during the process, the temperature must be kept above 40ºC for at least 14 days. The average temperature during this period must be greater than 45 °C.
IV. Process of stabilization chemical	Criterion1: at a temperature of 25OC, the amount of alkali mixed with the sanitary sewage sludge, must be sufficient for the pH to be raised to at least 12 for a minimum period of 2 hours, remaining above 11.5 for another 22 hours. These values must be achieved without additional application of alkali.
V. Processes of drying	Criterion 1: related to drying with forced or thermal ventilation for sewage sludge that has not received the addition of raw primary sludge after the drying process, the solids concentration must reach at least 75% ST, without mixing any additives. Mixing with other materials to achieve the required percentage of total solids is not acceptable. Criterion 2: related to heating or air drying, for sewage sludge that received the addition of raw primary sludge after the drying process, the solids concentration must reach at least 90% ST, without mixing any additives. Mixing with other materials is not acceptable to reach the required percentage of total solids.
VI. Subsurface application process processes	Criterion 1: related to the application of sewage sludge to the soil in liquid form, the injection of liquid sewage sludge under the surface will be accepted as a process to reduce the attraction of vectors if the presence of a significant amount of sewage sludge in the soil is not verified. surface of the soil, after one hour of its application. In the case of class A biosolid, the injection must be made within a maximum period of up to eight hours after the completion of the pathogen reduction process.
VII. Incorporation into the soil	Criterion 1: related to the application of biosolid in the soil: in this situation, the biosolid must be incorporated into the soil within six hours of its application in the area. If the biosolid is class A, it must be applied and incorporated within a maximum of eight hours after being discharged from the pathogen reduction process.

2.2.6 Mexico

The Mexican sludge guideline recommends the following vector attraction reduction measures for sludge land application.

Option 1: Reduction in volatile solids content

Vector attraction is reduced if the mass of volatile solids in biosolids is reduced by at least 38% during treatment. This percentage is equivalent to that achieved by aerobic or anaerobic digestion plus any further reduction that occurs after the biosolids leave stabilization facilities, such as processing in drying beds or lagoons or by composting.

Option 2: Additional digestion of anaerobically digested biosolids

Frequently, biosolids have been recycled through biological wastewater treatment or have transited long periods of time through sewage systems. During this time, they undergo substantial biological degradation. If the biosolids are subsequently treated by anaerobic digestion, their attraction to vectors will be appropriately reduced. Because they enter the digester partially stabilized, the reduction in volatile solids after treatment is often less than 38%. Under these circumstances, the 38% reduction required in option 1 may not be feasible. Option 2 allows the operator to demonstrate vector attraction reduction by testing a portion of the previously digested biosolids in a laboratory scale unit.

Option 3: Additional digestion of aerobically digested biosolids

This option is appropriate for aerobically digested biosolids that cannot meet the option**1**, includes those produced by extended aeration plants where the minimum residence time for biosolids in the sewage train generally exceeds 20 days. In these cases, the biosolids will already be substantially degraded prior to aerobic digestion. Under this option, aerobically digested biosolids with 2% solids or less are considered to have achieved reduced vector attraction if after 30 days of aerobic digestion in a laboratory test at 20°C, reduced solids volatiles is less than 15%. This test is only applicable to aerobically digested liquid biosolids.

Option 4: Aerobic processes at more than 40°

This option applies primarily to composted biosolids that also contain partially decomposed organic bulking agents. Biosolids must be treated aerobically for 14 days or more, during which time the temperature must always exceed 40°C and the average will be higher than 45°C. This option could be applied to other aerobic processes, such as aerobic digestion, however, options 3 and 4 seem easier to fulfil for the other aerobic processes.

Option 5: Addition of alkaline matter Biosolids are considered to adequately reduce their vector attraction if sufficient alkaline matter is added to achieve the following: Raise the pH to at least 12, measured at 25°C, and without adding more alkaline material, maintain it for 2 hours, and Maintain a pH of at least 11.5 without the addition of further alkaline matter for another 22 hours. These conditions are intended to ensure that biosolids can be stored for at least several days in treatment facilities, transported, and subsequently applied without the pH dropping to levels where putrefaction occurs and vectors are attracted.

Option 6: Reduction in moisture of biosolids that do not contain unstabilized solids

Vector attraction is considered to be reduced if biosolids do not contain unstabilized solids generated during primary treatment and their solids content is at least 75% before being mixed with other materials. Therefore, the reduction must be achieved by removing water and not by adding inert materials. It is important that biosolids do not contain unstabilized solids because the partially degraded food waste that would surely exist in such biosolids would attract birds, some mammals and possibly insects even if the solids content is greater than 75%.

Option 7: Reduction in moisture of biosolids containing unstabilized solids

It is considered that the ability to attract vectors of any biosolid is adequately reduced if its solids content is increased to 90% or more regardless of whether it is biosolids from the primary treatment. The increase should be achieved by removing water and not by dilution with inert solids. Drying to this point severely limits biological activity and destroys or decomposes vector-attracting volatiles. The manner in which dried biosolids are handled, including their storage prior to application, may encourage vector attraction. If these are exposed to high humidity, the outer surface will have a high moisture content and possibly attract vectors. This must be properly prevented.

Option 8: Specific Rate of Oxygen Absorption (TEAO) for Aerobically Digested Biosolids

Aerobically digested biosolids are often circulated through biological aerobic wastewater treatment processes for up to 30 days. In these cases, the biosolids entering the aerobic digester are already partially digested, making it difficult to comply with Option 1. The Specific Rate of Oxygen Absorption (TEAO) is the mass of oxygen consumed per unit of time and per unit of mass in dry weight of the total solids of the biosolids. The reduction in the attraction of vectors can be demonstrated if the TEAO of the biosolids that are applied, determined at 20°C, is equal to or less than 1.5 mg of O2/h/g of total solids (dry weight). This test is based on the fact that if biosolids consume too little oxygen, their value as a food source for microorganisms is too low to attract them. Other temperatures may be used for the test if the results are corrected on the basis of 20°C. This test is only applicable to aerobic biosolids.

Option 9: Incorporation of biosolids into the soil

Biosolids must be incorporated into the soil within 6 hours after their application on the ground. Incorporation is achieved by ploughing or by some other method that mixes the biosolids with the soil. If the biosolids are Class A with respect to pathogens, the time between application and processing should not exceed 8 hours.

2.2.7 China

The Chinese pollutants discharge standard of municipal wastewater treatment plant (National Standard No. GB18918-2002) states that sludge should be stabilised before being discharged (He, 2008). The guideline recommends for sludge stabilization standards as indicate in Table 2. 7.

Table 2.7 Requirements for sludge stabilization (He, 2008)

Stabilization process	Controlled parameter	Controlled value
Anaerobic digestion	Organics degradation rate	>40%
Aerobic digestion	Organics degradation rate	>40%
Composting	Moisture content	<65%
	Organics degradation rate	>50%
	Mortality rate of worm egg	>95%
	Faecel coliform	>0.01

2.3 Pollutant criteria

The pollutant criteria for the selected countries in this review was extracted from various sources and is presented in two categories: developed countries and developing countries. The developed countries considered in this review are, the USA, European Union (EU), Australia, and Canada while the developing countries are, Brazil, Mexico, and China. The metal limits for each country is presented in a comparative form with the South African metal limits. The following trend was observed in the metal limits of these countries:

- The USA sludge guideline, the EU directive, the Australian national sludge guideline, the Mexico and China sludge guidelines do not have maximum limits for Mo.
- The USA sludge guideline and EU directive excluded Cr from the list of contaminants.
- The Australian guideline encourage each province/territory to have its own limits considering the variation in the mineralogical and geological differences among the territories. It also provides a general country level limits for use by territories that do not have their own guides.
- We could not find National metal limits for Canada. However, territories such as Nova Scotia have developed their own limits, which is presented in this review.
- Brazil and South Africa have similar list of contaminants considered in their guideline.

2.3.1 United State of America

The US EPA (2018) offers several options for sewage sludge land disposal. First, the sewage sludge must be of a good quality, where the concentration of all mandatory pollutants in the sludge do not exceed the ceiling concentration (Table 2. 8).

Table 2.8 Sludge ceiling limits, cumulative loading rates, monthly average concentrations, and annual pollutant loading rates of heavy metals

Pollutant	South Africa[2]	United State of America[3]			
	Ceiling concentration (mg/Kg)[1]	Ceiling concentration (mg/Kg)[1]	Cumulative loading rate (Kg/ha)	Monthly average concentration (mg/Kg)[1]	Annual loading rate (Kg/ha/yr.)
As	15	75	41	41	2
Cd	20	85	39	39	1.9
Cr	1750				
Cu	750	4300	1500	1500	75
Pb	400	840	300	300	15
Hg	10	57	17	17	0.85
Mo	25	75			
Ni	200	420	420	420	21
Se	15	100	100	100	5
Zn	2750	7500	2800	2800	140

[1] Dry weight basis.

[2] Guideline for the Utilization and Disposal of Wastewater Sludge (Snyman and Herselman, 2006).

[3] 40 CFR Part 503, Standards for the Use and Disposal of Sewage Sludge (US EPA, 2018).

To apply sludge to agricultural lands, reclamation sites, public contact sites, and forests, one of the following conditions must be met: 1) the cumulative loading for each of the mandatory pollutant shall not exceed the set cumulative pollutant loading rate, and 2) the concentration of each mandatory pollutant shall not exceed its monthly average concentration.

To apply sludge to home garden or lawn the only condition is that the concentration of each mandatory pollutant shall not exceed its monthly average concentration (Table 2. 8). To apply sludge to any land other than the ones mentioned above, one of the following conditions must be met: 1) the concentration of each mandatory pollutant shall not exceed its monthly average concentration, and 2) the product of the concentration of each mandatory pollutant and the annual whole sludge application rate shall not exceed the annual pollutant loading rate (Table 2. 8).

There are similarities between South Africa and the USA (US EPA, 2018) regarding the selection criteria for heavy metals to consider when qualifying sludge for land application with the exception of chromium, which is not in the USA criteria list. Generally South African ceiling concentration levels are more stringent than the USA. For example, ceiling concentration for copper in USA (4300 mg/kg) is five to six times higher than that of South Africa (750 mg/kg).

2.3.2 European Union

The EU Directive 86/278/EEC (EU DG Environment, 2001) prohibits the use of sewage sludge in agricultural lands if: 1) the concentration of heavy metals in the sludge exceeds the limits set in the directive, and 2) the concentration of heavy metals in the receiving soil exceeds the limit values stated in the directive (Table 2. 9). Several countries, within the EU, have established their own limit values and the maximum annual average load in the soil. This includes countries such as Netherlands, Germany, Greece, Belgium, France, Finland, Luxembourg, Denmark, and Spain.

The number of heavy metals considered in the EU directive are less than that of South Africa. Heavy metals such as As, Cr, Mo, and Se are not in the list of the EU directive. The South African guideline has also more stringent limit compared to the EU directive for all pollutants under consideration.

Table 2.9 Maximum allowable concentration of heavy metals in the sludge, receiving soil, and the maximum allowable amount that can be introduced to the soil annually

Pollutant	South Africa[2]	European Union[3]		
	Maximum allowable concentration in sludge (mg/Kg)[1]	Maximum allowable concentration in sludge (mg/Kg)[1]	Maximum allowable concentration in receiving soil (Kg/ha)[4]	Allowable amount that can introduced to the soil (Kg/ha/yr.)
As	15			
Cd	20	20 - 40	1.0 - 3.0	0.15
Cr	1750			
Cu	750	1000 - 1750	50 - 140	12
Pb	400	750 - 1200	50 - 300	15
Hg	10	16 - 25	1 - 1.5	0.1
Mo	25			
Ni	200	300 - 400	30 - 75	3
Se	15			
Zn	2750	7500	150 - 300	30

[1] Dry weight basis.

[2] Guideline for the utilization and disposal of wastewater sludge (Snyman and Herselman, 2006).

[3] Council directive 86/278/EEC of June 1986 on the protection of the environment and in particular of the soil when sewage sludge is used in agriculture (EU CEC, 186).

[4] Soil with a pH of 6 to 7.

2.3.3 Australia

The Australian sludge guideline for maximum allowable heavy metal concentration in sludge is derived to reflect the following key objectives (NWQMS, 2004):

- Ensure that contaminants do not reach levels in the soil that threaten the safety of agricultural produce,
- Ensure that contaminants do not reach levels in the soil that exceed relevant limits for protection of ecosystems and human health.

- Ensure compliance with local regulatory requirements e.g. limits of contaminant concentrations in products used as fertilisers.

According to the guideline, the most stringent limit of the three is used as the basis for grading. This is to ensure that the use of sludge does not result in future land use limitation because of the variation in soil types, environmental conditions, and agricultural activities across the country. Hence the various states/territories in Australia can develop a guideline that suits their environment. For the states/territories that do not have their own guideline, the national guideline recommends the following heavy metals to be considered for sludge classification: As, Cd, Cr, Cu, Pb, Hg, Ni, Se, and Zn (Table 2. 10).

Table 2.10 Maximum allowable concentrations of heavy metals in sludge for land application (NWQMS, 2004)

	Maximum allowable concentration in sludge (mg/kg dry weight)			
Pollutant	**South Africa[1]**	**Australia (National)**	**South Australia[2]**	**Western Australia[3]**
As	15	60	-	-
Cd	20	20	20	20
Cr	1750	500-3000	1[a]	1[a]
Cu	750	2500	2500	2500
Pb	400	420		-
Hg	10	15		-
Mo	25	-		-
Ni	200	270		-
Se	15	50		-
Zn	2750	2500	2500	2500

[1] Guideline for the utilization and disposal of wastewater sludge (Snyman and Herselman, 2006).

[2] Guideline for safe handling and reuse of biosolids in South Australia (EPA-South Australia, 2020).

[3] Western Australia guideline for biosolids management (Department of Environment and Conservation Western Australia, 2012).

[a] Concentration for chromium (VI).

Generally, the Australian national sludge guideline is less stringent compared with that of South Africa except for Cd, which was the same as that of South Africa and Zn, which was lower than that of South Africa. The Southern Australia (EPA-South Australia, 2020) and Western Australian (Department of Environment and Conservation Western Australia, 2012) sludge guidelines, however excludes As, Hg, Pb, Mo, Ni, and Se from the list.

2.3.4 Canada

The sludge guideline for the province of Nova Scotia in Canada sets two maximum acceptable metal limits depending on the sludge class (Class A and Class B) (Nova Scotia Environment, 2010). According to this guideline, metal contaminant levels that exceed the maximum concentration for Class B sludges, are not acceptable for land application. The guideline asserts that soils receiving class B sludge must have a pH between 6.0 and 8.0 to minimize metal leaching. However, it also allows the use of alkaline stabilised sludges to soils with lower pH in the proviso that the sludge application will rise the pH to 6.0 or higher. According to the guideline, the concentration of heavy metals in soils receiving sludge should not exceed the maximum allowable concentration as stated in Table 2. 11.

Table 2.11 Maximum allowable concentration level of heavy metals in sludge and receiving soils, Nova Scotia, Canada (Nova Scotia Environment, 2010)

Pollutant	South African maximum allowable concentration (mg/kg dw)	Nova Scotia – maximum allowable concentration (mg/kg dw)		
		Class A sludge	Class B sludge	Receiving soil (pH 6-8)
As	15	13	75	12
Cd	20	3	20	1.4
Cr	1750	210	1060	64
Cu	750	400	760	63
Pb	00	150	500	60
Hg	10	0.8	5	0.5
Mo	25	5	20	4
Ni	200	62	180	32
Se	15	2	14	1.6
Zn	2750	700	1850	200

[1] Guideline for the utilization and disposal of wastewater sludge (Snyman and Herselman, 2006).

[2] Guideline for land application and storage of municipal biosolids in Nova Scotia (Nova Scotia Environment, 2010).

dw dry weight basis.

The maximum allowable concentration for five out of ten of the heavy metals (Cd, Cu, Mo, Ni, and Se) was similar for South Africa and Nova Scotia. The upper limits for two of the metals (As and Pb) was higher for Nova Scotia while Hg and Zn were higher for South Africa.

2.3.5 Mexico

The Mexican sludge guideline categorizes sludge based on their heavy metal contents into excellent and good (Table 2. 12). Excellent class sludge could be used in urban with direct contact during its application. While the Good class sludge is meant for use in urban areas without direct public contact during its application, on forests, soil improvements, and agricultural lands (NOM-004-ECOL-2002, 2002).

Table 2.12 Mexican maximum heavy metal allowable limit for land application (NOM-004-ECOL-2002, 2002)

Pollutant	South African maximum allowable concentration[1] (mg/kg dw)	Mexican maximum allowable limits in sludge[2] (mg/kg dw)	
		Excellent	Good
As	15	41	75
Cd	20	39	85
Cr	1750	1200	3000
Cu	750	1500	4300
Pb	400	300	840
Hg	10	17	57
Mo	25	-	-
Ni	200	420	420
Se	15	-	-
Zn	2750	2800	7500

[1] Guideline for the utilization and disposal of wastewater sludge (Snyman and Herselman, 2006).

[2] Summary of the Mexican official standards for the use or disposal of sludge (NOM-004-ECOL-2002, 2002.).

The Mexican guideline excludes Mo and Si from the list for monitoring. The maximum allowable concentration levels for As, Cd, Cu, Hg, and Ni for the excellent sludge class from Mexico guideline was twice higher than that of South Africa. While Pb for the excellent sludge class from Mexico was lower than that of South Africa. The maximum allowable limits of all heavy metals under consideration for sludges from Mexican good class sludge was twice higher than that of South Africa.

2.3.6 Brazil

The Brazilian sewage sludge guideline classify sludge into Class 1 and 2, according to the maximum permitted heavy limits (NOM-004-ECOL-2002, 2020). The guideline prohibits land application of sludge if the heavy metal concentration exceeds the class 2 maximum limits as presented in Table 2. 13. The guideline further states that class 2 sludges should be applied to the soil as long as the application of the sludge will not lead to exceeding the maximum annual rate and the maximum cumulative load (Table 2.13).

Table 2.13 Maximum allowable concentration of heavy metals in sludge and soil for Brazil (NOM-004-ECOL-2002, 2020)

Pollutant	South African maximum allowable concentration in sludge (mg/kg dw)[1]	Brazilian maximum allowable heavy metal in sludge			
		Sludge (Class 1) (mg/kg dw)[2]	sludge (Class 2) (mg/kg dw)[2]	Annual rate for Class 2 sludge (kg/ha/yr.)[2]	Accumulated load (kg/ha)[2]
As	15	41	75	12	41
Cd	20	39	85	1.4	39
Cr	1750	1000	3000	64	3000
Cu	750	1500	4300	63	1500
Pb	400	300	840	60	300
Hg	10	17	57	0.5	17
Mo	25	50	75	4	13
Ni	200	420	420	32	420
Se	15	36	100	1.6	100
Zn	2750	2800	7500	200	2800

[1] Guideline for the utilization and disposal of wastewater sludge (Snyman and Herselman, 2006).

[2] National Council of the Environment, Resolution No. 498 (NOM-004-ECOL-2002, 2020).

The South African sludge guideline is more stringent in terms of the maximum allowable heavy metal concentration in sludge for all the pollutants.

2.3.7 China

The Chinese sludge guideline for maximum allowable concentration of heavy metals in sludge for land application is dictated by soil pH in order to limit leaching to ground water (UN-Habitat, 2008; Table 2.14). When the soil pH is less than 6.5, stringent maximum acceptable levels of certain heavy metals in sludge are considered.

Table 2.14 Chinese maximum allowable concentration limits of heavy metals in sludge

Pollutant	South African maximum allowable concentration in sludge[1]	Chinese maximum allowable concentration in sludge (If soil pH < 6.5)[2]	Chinese maximum allowable concentration in sludge (If soil pH ≥ 6.5)[2]
	(mg/kg dw)		
As	15	75	75
Cd	20	5	20
Cr	1750	600	1000
Cu	750	800	1500
Pb	400	300	1000
Hg	10	5	15
Mo	25	-	-
Ni	200	100	200
Se	15	-	-
Zn	2750	2000	3000

[1] Guideline for the utilization and disposal of wastewater sludge (Snyman and Herselman, 2006).

[2] UN-Habitat. 2008. Global atlas of excreta, wastewater sludge, and biosolids management: moving forward the sustainable and welcome uses of a global resource (UN-Habitat, 2008).

According to the information from UN-Habitat (2008), heavy metals Mo and se are not included in the Chinese sludge guideline. The maximum allowable limit for As and Cu was higher for China. While other metals such as Cd, Pb, Hg, Ni and Zn are within the same ranges and Cr was higher for South Africa.

3. EMERGING RISKS FROM EMERGING CONTAMINANTS

There are human and environmental health concerns associated with the use of wastewater sludge in agricultural lands. These concerns include: pathogens, trace metals and contaminants of emerging concern (ECoCs). ECoCs are a group of chemical compounds which are of natural or synthetic origin (Puri et al., 2023) and have recently been recognized as potentially dangerous to humans and the environment (Krishnakumar et al., 2022), but for which there are currently no regulatory standards (Necibi et al., 2021). The recent discovery of most of the ECoCs as a result of the development of new sensitive analytical techniques is one of the main causes for the lack of published health standards to provide guidelines on treating of these contaminants (Gogoi et al., 2018)

ECoCs include pharmaceuticals, personal care products (PPCPs), flame retardants (FRs), pesticides, artificial sweeteners (ASWs), nanomaterials, microplastics and their transformation products (Pastorino and Ginebreda, 2022).

The presence of endocrine disrupting compounds (EDCs) have been reported in the biological fluids of pregnant women (Woodruff et al., 2011; Derakhshan et al., 2021). Epidemiological evidences suggest the association between exposure to EDCs and negative neurodevelopmental outcomes in children (Cediel-ulloa et al., 2022). For instance, exposure to EDCs has been associated with disorders indicative of developmental neurotoxicity (DNT) such as autism spectrum disorder (ASD), attention deficit hyperactivity disorder (ADHD), and intellectual disabilities (Rivollier et al., 2019). The detrimental effects of Bisphenol A (BPA) on executive functions (England-Mason et al., 2020), working memory (Brown et al., 2017), and academic achievement (Jackson-Browne et al., 2020) have been reported. Similarly, BPA, phthalates and perfluoroalkyl substances (PFAS) have been associated with ASD and ADHD-related neurobehavioral traits with BPA (Arbuckle et al., 2016), phthalates (England-Mason et al., 2020; Ku et al., 2020) or organic persistent pollutants (Lenters et al., 2019). It was also reported that EDCs are associated with human reproductive organ disorders such as infertility, endometriosis, breast cancer, poor sperm quality and/or function (Sifakis et al., 2017; Marlatt et al., 2022)

3.1 ECoCs in wastewater influent and effluent

The concentration of ECoCs in wastewater sludge in general vary among sources of waste, season of the year (Papageorgiou et al., 2016; Marca. ntonio et al., 2020), socioeconomic composition of the population that feeds the WWTPs (Tran et al., 2018) and treatment process which they undergo (Tesfamariam et al., 2022). A review report by Tran et al. (2018) indicated that the concentration of antibiotics in wastewater treatment plants influent and effluent samples varied significantly depending on the compound, usage patterns in each country, water consumption per person per day, water catchment characteristics (e.g. land use, population size, and population density), weather conditions, sewer systems (combined or separate sewer systems), environmental persistence, and elimination efficacy of wastewater treatment processes. According to the review, some groups of antibiotics such as sulfonamides, fluoroquinolones, macrolides, and trimethoprim were reported in both influent and effluent samples worldwide. While the occurrence of -lactams (amoxicillin, ceftazidime, and meropenem), tetracyclines (e.g. chlortetracycline, minocycline, and oxytetracycline), chloramphenicol, and vancomycin in the influent and effluent was rarely reported for North American and European countries, but they were still present in WWTP influent and effluent from Asian countries such as China, India, Japan, Singapore and Thailand.

Chloramphenicol was absent or present at low concentrations in the influents of European (Kasprzyk-Hordern et al., 2009; Gracia-Lor et al., 2012) and other developed countries (Tran et al., 2016) because it is banned in many developed countries (Tran et al., 2018). This is in contrast to China where concentrations up to 2430 ng/L in influents and 1050 ng/L in effluents were detected, which is attributed to the easy accessibility of the compound in over the counter markets (Tran et al., 2018). The concentration of most antibiotics in effluents and the antifungal and antibacterial agents triclocarban and triclosan within influents and effluents from WWTPs of most developing Asian countries tend to be higher than those reported in European and North American countries (Tran et al., 2018). According to Tran et al. (2018), the concentration of the antifungal and antibacterial agents (Triclocarban and triclosan) in both influents and effluents from developing Asian countries were higher than their predicted no effect concentrations for aquatic organisms and could pose a considerable threat if discharged to water bodies.

The most widely used pain killers and nonsteroidal anti-inflammatory drugs (NSAIDs) such as acetaminophen, codeine, diclofenac, fenoprofen, ibuprofen, indomethacin, ketoprofen, naproxen and salicylic acid are often detected in influents of WWTPs at concentrations of up to several hundreds of micrograms per liter (Miege et al., 2009). Of this drugs, acetaminophen, ibuprofen, and naproxen are the most abundant NSAIDs are detected in influents mainly because they are widely used as non-prescription NSAIDS for the relieve of pain, swelling, fever, cold, flu symptoms and headaches (Tran et al., 2018). This is in contrast to the prescription NSAIDs such as fenoprofen, diclofenac, indomethacin, and ketoprofen, which are controlled and therefore are found at lower concentrations in influents compared to the non-prescription NSAIDs. Tran et al. (2018) reported that the concentration of the NSAID acetaminophen within the influents from WWTPs in North American countries were significantly higher than those of Asian and European regions.

Similar to NSAIDs, lipid regulating drugs such as bezafibrate and gemfibrozil are frequently detected pharmaceuticals both in influents and effluents of WWTPs (Kasprzyk-Hordern et al., 2009; Kosma et al., 2014). The median concentration of lipid regulators such as gemfibrozil in influent of WWTPs in Asian countries was two order of magnitude lower than that of European and North American regions, which could be related to the demographical pattern and obesity rate of the population (Tran et al., 2018). Asian countries such as China, India, Japan, and Korea have significantly lower obesity rates than North America and Europe (OEDC, 2017). The concentrations of these lipid regulators such as bezafibrate and gemfibrozil in influents and effluents from European countries were higher than their predicted no effect concentrations (PNPECs) for aquatic animals and could pose a series risk to aquatic organisms if released to water bodies (Tran et al., 2018).

Beta-adrenoceptor blocking agents, which are used for the treatment of high blood pressure and migraine among several other diseases were reported both in influents and effluents (Mohapatra et al., 2016; Sun et al., 2016; Tran and Gin, 2017). The concentration of the beta-adrenoceptor blocking agent atenolol in the influent from Asian countries were significantly higher than those from Europe and North American (Tran et al., 2018). Tran et al. (2018) reported in his review that the concentrations of atenolol within the influents from Asian countries were significantly higher than those from Europe and North America. They also indicated that the concentrations of atenolol and propranolol in the effluents of WWTPs in some case could have exceeded PNECs to aquatic animals.

The antiepileptic and antipsychotic drugs such as carbamazepine, gapapentin, and sulpiride were the most frequently detected compounds in the influents and effluents of Europe (Kasprzyk-Hordern et al., 2009; Gurke et al., 2015), North America (Writer et al., 2013), Korea (Behera et al., 2011), India (Subedi et al., 2015), China (Sun et al., 2016; Tran and Gin, 2017; Yang et al., 2017). The concentrations of these drugs in the above stated regions were in many cases higher than the PNECs and pose potential risk to aquatic animals.

The presence of estrogens both natural (i.e. estrone and 17-estradiol) and synthetic (17-ethinylestradiol) hormones were reported in WWTPs of Asian (Behera et al., 2011(Korea); Tran and Gin, 2017 (Singapore)), European (Miege et al., 2009; Gabet-Giraud et al., 2010) and North American

(Hedgespeth et al., 2012) countries. The concentrations of these hormones in Asian and European countries in some cases exceed the PNECs.

ECoCs entering wastewater treatment plants can undergo further transformations and can either degrade, persist or convert into by-products which could potentially be more hazardous (Kumar et al., 2022).

In effluent, the levels of most antifungal and antimicrobial agents, are much lower than in the influent (Tran et al., 2018).

3.2 ECoCs in sludge

The concentration of antibiotics, antimicrobials, NSAIDS, betablockers, anti-convulsants, lipid regulators, hormones, and plasticizers in sludge and biosolids around the globe varied from below detection limit to tens of grams per kg of dry sludge (Table 3. 1). From the antibiotic contaminant group, Azithromycin in activated sludge from Switzerland (64±30 mg/kg) had the highest concentration. Trimethoprim, which is the only reported antibiotic from South Africa (1.0 – 50 ng/g dw) had relatively wider range of concentration than those reported from Korea (<LOQ – 6.09 ng/g) and USA (26±21.5 µg/kg dw). From the Antifungal/antimicrobials group, the Triclocarban in various biosolid types from USA (36036±3816 µg/kg dw) had the highest concentration. The concentration of Triclocarban from South African sludges at different process stages (0.1ng/g – 11.8 ng/g) was far lower than those reported for France (78±9 - 486±68 ng/g); China (1130 – 2180 µg/kg dw); India (5570 – 8460 ng/g dw) and Canada (2000 – 11 000 ng/g dw). Similarly, the concentration ranges for Triclosan from South African sludges (0.1 ng/g – 90 ng/g dw) was far lower than those reported for France, USA, China, India, Canada, and USA.

From the NSAIDS group, Salicylic acid in various biosolid types from USA (0.000002 – 13.743 mg/kg dw) had the highest concentration. The concentration of Salicylic acid from an activated sludge as reported by Ademoyegun et al. (2020) (19 – 60 ng/g dw) is in the lower range of what was reported from USA and Poland. From the Beta-blockers group, Propranolol in various sludge types from France (83 - 849±214 ng/g dw) had the highest concentration ranges. From the anticonvulsants group, Carbamazepine in various biosolid types from USA (163±56.4 µg/kg dw) had the highest concentration ranges. The concentration ranges of carbamazepine in an activated sludge from South Africa (9.0ng/g – 59 ng/g dw) was much lower than that of USA but slightly higher than those from China and India. From the lipid regulators group, Gemfibrozil in different sludge types from Australia (<BDL – 1.192 mg/kg dw) had the highest concentration ranges. From the plasticizers group, bisphenol-A in different sludge types from USA (6.5 ng/g – 4700 ng/g) had the highest concentration ranges.

Table 3.1 Concentration of selected emerging contaminants in wastewater sludge from different parts of the world

Contaminant group	Contaminant name	Country	Concentration range	Reference
Antibiotics	Azithromycin	France	MQL – 666 ng/g dw (various sludge types)	Peysson and Vulliet (2013)
		Switzerland	64 ± 30 mg/kg dw (activated sludge)	Gobel et al. (2005)
		USA	0.008 – 5.21 mg/kg dw (various sludge types)	US EPA (2009)
		USA	838±224 µg/kg dw (various biosolid types)	McClellan and Halde (2010)
		Canada	81 – 850 ng/g dw (digested)	Guerra et al. (2014)
	Chlortetracycline	Canada	4-Epianhydrochlortetracycline = 57-260 ng/g dw 4-Epianhydrotetracycline = 40 – 100 ng/g dw 4-Epitetracycline = 74 – 1700 ng/g dw Anhydrochlortetracycline = 28 – 350 ng/g dw Anhydrotetracycline = 35 – 104 ng/g dw Chlortetracycline = 11 – 12 ng/g dw (digested)	Guerra et al. (2014)
		USA	23.4 ±16.9 µg/kg dw (various biosolid types)	McClellan and Halden (2010)
		Spain	Oxytetracycline = <MDL – 742.5±1.5 ng/g dw Dioxycycline = 23±18 – 1222.5±0.6 ng/g dw Chlortetracycline = <MDL – 106.75±3.7 ng/g dw	Pamreddy et al. (2013)
		Korea	Chlortetracycline = 0.184 - 1.908 mg/kg dw Oxytetracycline = 1.667 – 35.50 mg/kg dw	Ekperghere et al. (2017)
	Ciprofloxacin	USA	6858±2348 µg/kg dw (various biosolid types)	McClellan and Halden (2010)
		Canada	1780-16000 ng/g dw (digested)	Guerra et al. (2014)
		Switzerland	1.40±0.12 – 2.42±0.06 mg/kg dw	Golet et al. (2002)
		Brazil	10.9 – 158.4 µg/kg dw	Santana et al. (2021)
	Clarithromycin	USA	66.2±25.5 µg/kg dw (various biosolid types)	McClellan and Halden (2010)
		Canada	4.6-580 ng/g dw (digested)	Guerra et al. (2014)
		Spain	MDL – 256 ng/g dw (different sludge types)	Barreirs et al. (2022)
		France	Not detected - <MQL	Peysson and Vulliet (2013)
	Enrofloxacin	Korea	0.065-11.56 mg/kg dw	Ekperghere et al. (2017)
		China	7.60-26.8 µg/kg dw	Sun et al. (2016)
		Brazil	BLD-45 mg/kg	Kumar et al. (2022)
	Erythromycin	Korea	0.006-0.050 mg/kg dw	Ekperghere et al. (2017)
		Japan	110-158 µg/kg dw	Narumiya et al. (2013)
		USA	81.5±52.3 µg/kg dw (various biosolid types)	McClellan and Halden (2010)
	Lincomycin	Korea	0.053-4.977 mg/kg dw 4.95–11.1 ng/g dw	Ekperghere et al. (2017) Subedi et al. (2014)
		India	0.85-47.3 ng/g dw	Subedi et al. (2015)

Contaminant group	Contaminant name	Country	Concentration range	Reference
	Minocycline	USA	1884±939 µg/kg dw (various biosolid types)	McClellan and Halden (2010)
	Ofloxacin	China	1480-4020 µg/kg dw	Sun et al. (2016)
		Japan	38.6-160.7 µg/kg dw (digested)	Narumiya et al. (2013)
		Sweden	<0.01–2 mg/kg dw	Lindberg et al. (2005)
		USA	5446±1941 µg/kg dw (various biosolid types)	McClellan and Halden (2010)
	Oxytetracycline	China	208-3790 µg/kg dw	Sun et al. (2016)
		USA	87.5±22.2 µg/kg dw (various biosolid types)	McClellan and Halden (2010)
	Sulfamethoxazole	China	BLD-2.90 µg/kg dw	Sun et al. (2016)
		India	LOQ-31.0 ng/g dry wt	Subedi et al. (2015)
	Tetracycline	China	49.8-466 µg/kg dw	Sun et al. (2016)
		Japan	7.1-132.3 µg/kg (liquid phase digested sludge)	Narumiya et al. (2013)
		USA	691±124 µg/kg dw (various biosolid types)	McClellan and Halden (2010)
		USA	0.038-5.27 mg/kg dw	US EPA (2009)
	Trimethoprim	Korea	LOQ–6.09 ng/g dw	Subedi et al. (2014)
		USA	26±21.5 µg/kg dw (various biosolid types)	McClellan and Halden (2010)
		RSA	1.0 – 50 ng/g dw (Activated sludge)	Ademoyegun et al. (2020)
	Tylosin	Korea	0.031-0.139 mg/kg dw	Ekperghere et al. (2017)
Antifungal/antimicrobials	Miconazole	France	n.d. - 200±12 ng/g (different types)	Peysson and Vulliet (2013)
		China	88.3 – 215 µg/kg dw (different types of sludge)	Sun et al. (2016)
		Korea	LOQ – 317 ng/g dw(different sludge types)	Subedi et al. (2014)
		China	40 – 2069 ng/g dw (different sludge types)	Peng et al. (2012)
		Canada	9.4 – 910 ng/g dw (digested)	Guerra et al. (2014)
		USA	777±266 µg/kg dw (various biosolid types)	McClellan and Halden (2010)
	Thiabendazole	China	BLD (below the method detection level.	Sun et al. (2016)
		Korea	LOQ – 17.5 ng/g dw (different sludge types)	Peysson and Vulliet (2013)
		USA	110±131 µg/kg dw dw (various biosolid types)	McClellan and Halden (2010)
	Triclocarban	France	78±9 - 486±68 ng/g (different types)	Peysson and Vulliet (2013)
		China	1130 – 2180 µg/kg dw (different types of sludge)	Sun et al. (2016)
		India	5570 – 8460 ng/g dw (different sludge types)	(Subedi et al., 2015)
		Canada	2000 – 11 000 ng/g dw (digested)	Guerra et al. (2014)
		USA	36036±3816 µg/kg dw (various biosolid types)	McClellan and Halden (2010)
		RSA	3.7 - 11.8 ng/g dw (Raw sludge)	Lehutso et al. (2017)
		RSA	1.2 - 9.2 ng/g dw (Activated sludge)	Lehutso et al. (2017)
		RSA	2.59 - 8.23 ng/g dw (Biosolids)	Lehutso et al. (2017)
		RSA	0.1 - 8.8 ng/g dw (Raw sludge)	Bakare and Adeyinka (2022)
	Triclosan	France	255±51 - 4230±845 ng/g (different types)	Peysson and Vulliet (2013)
		USA	ND – 15.6 mg/kg dw	Harrison et al. (2006)

Contaminant group	Contaminant name	Country	Concentration range	Reference
		China	354 – 608 µg/kg dw (different types of sludge)	Sun et al. (2016)
		India	645 – 1470 ng/g dw (different sludge types)	Subedi et al., (2015)
		Canada	1200 – 8900ng/g dw (digested)	Guerra et al. (2014)
		USA	12640±266 µg/kg dw dw (various biosolid types)	McClellan and Halden (2010)
		RSA	3.7 - 15.0 ng/g dw (Raw sludge)	Lehutso et al. (2017)
		RSA	2.1 - 7.8 ng/g dw (Activated sludge)	Lehutso et al. (2017)
		RSA	2.16 - 13.5 ng/g dw (Biosolids)	Lehutso et al. (2017)
		RSA	0.1 - 2.5 ng/g dw (Raw sludge)	Bakare and Adeyinka (2022)
		RSA	11.0 – 90 ng/g dw (Activated sludge)	Ademoyegun et al. (2020)
NSAIDS	Acetaminophen	France	MQL - 464± ng/g dw (different types)	Peysson and Vulliet (2013)
		USA	0.0000006 – 4.353 mg/kg dw	Harrison et al. (2006)
		China	BLD – 180 µg/kg dw (different types of sludge)	Sun et al. (2016)
		Korea	LOQ – 515 ng/g dw (different sludge types)	Subedi et al. (2014)
		Canada	14 - 150 ng/g dw (digested)	Guerra et al. (2014)
		UK	Nd	Petrie et al. (2015)
		RSA	2.0 - 98.9 ng/g dw (Activated sludge)	Ademoyegun et al. (2020)
	Codeine	China	BLD	Sun et al. (2016)
		India	N.D – 26.6 ng/g (different sludge types)	Subedi et al., (2015)
		France	28±3 - 79±8 ng/g (different types)	Peysson and Vulliet (2013)
		Canada	2.9 - 110 ng/g dw (digested)	Guerra et al. (2014)
		USA	n.d	McClellan and Halden (2010)
		RSA	20 – 43 ng/g dw (Activated sludge)	Ademoyegun et al. (2020)
	Diclofenac	France	35±9 - 133±34 ng/g (different types)	Peysson and Vulliet (2013)
		China	BLD – 14 µg/kg dw (different types of sludge)	Sun et al. (2016)
		UK	70 ng/kg dw (different types)	Petrie et al. (2015)
		Poland	20 ng/g dw	Kumirska et al. (2015)
		RSA	9.0 – 50 ng/g dw (Activated sludge)	Ademoyegun et al. (2020)
	Ibuprofen	USA	0.000006 – 3.988 mg/kg dw	Harrison et al. (2006)
		China	BLD – 30.4 µg/kg dw (different types of sludge)	Sun et al. (2016)
		India	ND – 145 ng/g dw (different sludge types)	Subedi et al., (2015)
		Poland	96 ng/g dw	Kumirska et al. (2015)
		Canada	76 – 200 ng/g dw (digested)	Guerra et al. (2014)
		UK	380 ng/kg dw (different types)	Petrie et al. (2015)
		USA	246±121 µg/kg dw dw (various biosolid types)	McClellan and Halden (2010)
		RSA	11.0 – 97 ng/g dw (Activated sludge)	Ademoyegun et al. (2020)
	Indomethacin	China	BLD - 8µg/kg dw (different types of sludge)	Sun et al. (2016)
	Ketoprofen	China	BLD	Sun et al. (2016)

Contaminant group	Contaminant name	Country	Concentration range	Reference
		India	ND	Subedi et al., 2015)
	Naproxen	USA	0.000001 – 1.022 mg/kg dw	Harrison et al. (2006)
		China	BLD	Sun et al. (2016)
		Poland	10 ng/g dw	Kumirska et al. (2015)
		Canada	2.9 - 150 ng/g dw (digested)	Guerra et al. (2014)
		USA	119±79 µg/kg dw dw (various biosolid types)	McClellan and Halden (2010)
	Salicylic acid	USA	0.000002 – 13.743 mg/kg dw	Harrison et al. (2006)
		Poland	489 ng/g dw	Kumirska et al. (2015)
		RSA	19 – 60 ng/g dw (Activated sludge)	Ademoyegun et al. (2020)
Beta-blockers	Atenolol	Japan	ND - 86 ng/g dw (raw and treatd sludge types)	Matsuo et al. (2011)
		India	ND – 21.1 ng/g dw (different types of sludge)	Subedi et al. (2015)
	Metoprolol	China	BDL – 226 µg/kg dw (different types of sludge)	Sun et al. (2016)
	Propranolol	China	BDL - 29.6 µg/kg dw (different types of sludge)	Sun et al. (2016)
		France	83 - 849±214 ng/g dw (different sludge types)	Peysson and Vulliet (2013)
		India	7.19 – 11.7 ng/g dw 9different sludge types)	Subedi et al. (2015)
Anticonvulsants	Carbamazepine	France	MQL – 50±1 ng/g dw (different sludge types)	Peysson and Vulliet (2013)
		China	BDL – 1.80 µg/kg dw (different types of sludge)	Sun et al. (2016)
		USA	163±56.4 µg/kg dw (various biosolid types)	McClellan and Halden (2010)
		India	3.02 – 18.8 ng/g dw (different sludge types)	Subedi et al. (2015)
		RSA	9.0 – 59 ng/g dw (Activated sludge)	Ademoyegun et al. (2020)
Lipid regulators	Gemfibrozil	USA	152±13.2 µg/kg dw (various biosolid types)	McClellan and Halden (2010)
		Australia	BDL – 1.192 mg/kg dw (different sludge types)	Khan and Ongerth (2002)
Hormones	Estrone	Israel	70±13 - 280±86 ng/g dw (different sludge types)	Shargil et al. (2015)
		Australia	BDL – 33.8±51.3 ng/g dw (different sludge types)	Tan et al (2007)
Plasticizers	Bisphenol-A	Australia	3.1±1.2 – 8.0±4.8 ng/g dw (different sludge types)	Tan et al (2007)
		USA	6.5 – 4700 ng/g dw (different sludge types)	Yu et al. (2015)
		China	BLD – 1830 µg/kg dw (different types of sludge)	Sun et al. (2016)

MDL – Method detection limit; MQL – Method quantification limit;

BLD – Below limit for detection; LOQ – limit of quantification;

ND – not detected; dw – dry weight basis

3.3 Microplastics

Global plastic production exceeded 640 million tons by 2021 (Horton 2022) of which 2.42 million tons are biodegradable plastic polymers and is expected to reach 7.59 million tons by 2026 (European commission 2022). Plastics are broken into small particles (micro and nano plastics) as a result of physical wear, ultraviolet radiation, thermal oxidation, and microbial degradation, which potentially harm the ecosystem and living beings (Guo et al., 2020, Jiang et al., 2022, Sarkar et al., 2021).

Microplastics are plastics with particle sizes smaller than 5 mm while nanoplastics are plastics with particle sizes within the ranges of 1-1000 nm (Zhang and Chen 2020). Due to their smaller size, microplastics are considered as bioavailable to organisms. Microplastics have high specific surface area (Cole et al., 2011) and could act as vector of pharmaceutical drugs from wastewater treatment plants (Wagstaff et al., 2022), carrier for pesticides (Li et al., 2021), vectors for antibiotics, persistent organic pollutants and heavy metals (Zhang et al., 2020; Atugoda et al., 2022) and carrier for waste-water borne pathogenic bacteria in municipal sewage (Lai. et al., 2022).

Microplastics could be of primary or secondary origin (Cole et al., 2011). Primary microplastics are intentionally manufactured to be of microscopic nature for use as facial-cleansers and cosmetics (Zhou et al., 2023), polymer coated slow release fertilizers (Katsumi et al., 2023), as air-blasting technology (Hopewell et al., 2009), in medicine as vector for drugs (Soni and Joseph, 2021), and virgin plastic production pellets (Karlsson et al., 2018). Secondary microplastics are the products of physical, biological and chemical degradation of larger plastic particles (Martinho et al., 2022).

Microplastics in wastewater are reported to have been originated from fibers shed from clothing during laundering and from personal care products (Wagstaff et al., 2022) among others. The dominant microplastics in wastewater are polyethylene, polyamide and polyethylene terephthalate (Sun et al., 2019).

Miranda et al. (2022) reported low to no phytotoxicity from microplastic on the germination and early growth stages of two plant species (*Lepidium sativum and Sinapis alba*) but recommended further studies on the soil-plant system. Atugoda et al. (2022) recommended further studies on the interaction of microplastics with β-blockers, antidepressants, NSAIDs, analgesics, steroidal hormones, antimicrobials, and ultraviolet screening agents. Furthermore, they suggested investigating the effect of pH, salinity, and dissolved organic matter on the kinetics and isotherm sorption behaviors.

Microplastics could have similar effects on lower trophic positioned aquatic biota as macro plastics have on larger animals, such as blockage of feeding appendages and intestinal tracts, stop the secretion of gastric enzymes, and reduce the level of steroid hormones and delay ovulation leading to reproductive failure and significant impacts on offspring (Sussarellu et al., 2016; Guzzetti et al., 2018). Microplastics could enter to the human body system via various sources including food consumption, drinking water, inhalation (Barboza et al., 2018; Eerkes-Medrano et al., 2015), salt extracted from seawater (Seth and

Shriwastav, 2018), and in sugar and honey (Liebezeit and Liebezeit, 2013). As vectors for PAHs, PCBs, phthalates, bisphenols, hormones, pharmaceuticals, and metals microplastics expose humans to physical and chemical toxicities when ingested (Atugoda et al., 2021) causing skin irritation, respiratory problems, cardiovascular diseases, digestive problems, and reproductive issues (Naik et al., 2019). Microplastic contaminated livestock intake by black soldier flies reshaped the microbial community structure by significantly reducing the several organic decomposing bacteria and probiotics while enriching a large number of pathogenic bacteria in feces and black soldier flies gut carrying antibiotic-resistant genes driving the flourishment of antibiotic resistance in transformed fecal piles (Xu et al., 2023). As microbes interact with microplastics, they form plastisphere, which are ideal for biofilm formation (Kaur et al., 2022). As Kaur explains, bacteria in biofilms facilitate the transfer of ARGs via HGT as well as the co-selection of ARGs in microplastic-associated microbial pathogens, leading to the prevalence and spread of AMR. Recent studies by Zhao et al. (2023) indicated that microplastics could be accomplices in the development of inflammatory bowel disease and could cause severe intestinal inflammation. There is currently no single European law that covers microplastics in a comprehensive manner. There are also no economic incentives for businesses to take measures to reduce the presence of microplastics in the environment (European commission, 2023).

Microplastics were detected both in influent, effluent and sewage sludges that had undergone different treatment processes from different regions of the world (Table 3. 2). The reported microplastic concentration range in the influent was 11.1 MPs/L (Spain) to 80.5 MPs/L (Finland). While the concentration of the effluent ranged from 1.1 MPs/L (Finland) to 30.3 MPs/L (China). The decrease in the concentration of microplastics in the effluent indicates the positive role played by wastewater treatment methods in reducing the pollutants. The concentration of microplastics in sludge and biosolids ranged between 4196 MPs/kg (Ireland) to 170 900 MPs/kg (Finland); 1.45 x 10^{-3} mg/g dw (Denmark) to 92.8 mg/g dw (Japan). To date only one publication by Vilakati et al. (2021) was reported from South Africa. The study reported on the major microplastic polymers from one wastewater treatment plant in Gauteng but did not provide quantitative data on the amount of microplastics per unit sludge volume or mass.

Table 3.2 Microplastics in wastewater influent, effluent and sludge from various countries around the globe

Country	Microplastic concentration			Microplastic form	Reference
	Wastewater		Sludge/biosolid		
	Effluent	Influent			
USA	Not reported	Not reported	28 – 12000 µg/g dw	Fibers	Zhang et al. (2019)
Canada	Not reported	Not reported	8.7×10^3 MPs/kg to 1.4×10^4 MPs/ kg	Fibers, fragments, microbeads	Crossman et al. (2020)
Germany	0 to $5x10^1$ m^{-3} MP >500µm (polyethylene) $1x10^1$ to $9x10^3$ m^{-3} MP <500µm (polyethylene) and $9x10^1$ to $1x10^3$ m^{-3} MP (Polyester)	Not reported	Not reported	Polythylene, polyester, fibres	Mintenig et al. (2017)
Spain	2.8 MPs /L	11.1 MPs /L	18000-32070 MPs /kg	Fibers, fragments and film	van den Berg et al. (2020), Bretas Alvim and Bes-Pia. (2020)
Ireland	Not reported	Not reported	4196 to 15385 MPs/kg dw	Fibers, fragments, films spheres, and others	Mahon et al. (2017)
Finland	1.1 MPs/L	57.6 MPs/L	170.9 MPs/g dw	Fibers and particles	Lares et al. (2018)
Denmark	Not reported	Not reported	1.45×10^{-3}g/kg dw	Fibers, fragments	Chand et al. (2021)
Chile	Not reported	Not reported	18-40 MPs/g dw	Fibers, fragments and film	Corradini et al. (2019)
Japan	Not reported	Not reported	0.1-92.8 mg/g dw	-	Ishimura et al. (2021)
China	7.9-30.3 MPs/L	23.3-80.5 MPs/L	2933-5533 MPs/kg dw	Pellets/microbeads, fragments, films, and fibers	Jiang, et al. (2020), Tang et al. (2020)

4. CASE STUDIES ON THE APPLICATION OF WASTEWATR SLUDGE IN A CIRCULAR ECONOMY FOR ENERGY GENERATION, GREENHOUSE GAS REDUCTION AND BIOMASS RECYCLING

The circular economy is a business model which promotes re-use, refurbish, repurpose, re-cycle and recovery in order to achieve a sustainable production, minimizing negative environmental impacts while enhancing economic prosperity and social equality (Van de Westerlo, 2011). The concept of circular economy was first introduced by British economists (Peace and Turner 1989) but better defined by the Ellen MacArthur Foundation (Potocnik, 2013). In a circular economy, waste is the central concept because it provides “sustainable biomass” from which new bio-based products can be generated (Kurnaz et al., 2022).

Sewage sludge accounts for 1-2% of the treated waste water by volume but its disposal is complex and expensive (Durdevic et al., 2022). Sewage sludge treatment and disposal accounts for 20% to 60% of the total wastewater treatment plant operating cost (Andreoli et al., 2007; Guo et al., 2013). The energy content and organic and inorganic substrate resources in a sewage sludge, however, make it technically and economically viable for recycling (Durdevic et al., 2022). Sewage sludge could be used for energy generation, as raw material for the production of various new materials within a biorefinery (Raheem et al., 2018), production of bricks (Taki et al., 2020; Bubalo et al., 2021), biofuel generation or as fuel for energy generation, for the recovery of plant nutrients, heavy metals, proteins, and enzymes (Gherghel et al., 2019; Durdevic et al., 2022). Sludge disposal process accounts for 40% of total greenhouse gas emission from WWTPs, which could be minimized through the application of the circular economy concept (Pilli et al., 2015) by replacing other energy resources thus limiting the associated CO_2 emissions (International Solid Water Association (International Solid Waste Association (ISWA), 2015).

The European Union sewage sludge legislation directive 2000/60/EC (Water Framework Directive – WFD) policy defines sewage sludge as a product of sewage treatment and no longer as a waste material (Werle and Sobek, 2019). The operational document of the WFD (Directive 91/271/EEC) is focused mainly on the reuse of sewage sludge as a valuable material. The key priority of the European Union directive 2008/98/EC, which is responsible for sewage sludge recycling, is prevention of sewage sludge production and the second priority is recycling of sewage sludge for energy production via the Waste-to-Energy model (WtE) (Werle and Sobek, 2019). With the increase in the number of WWTP as a result of an increase in urban population, the WtP model is becoming as one of the attractive models to handle the problem of wastes (Chen et al., 2016), which also provides the opportunity to harness (recovery of) valuable nutrients and metals (Mulchandani and Westerhoff 2016; Donatello and Cheeseman, 2013).

According to Lacroix et al (2014), the energy requirements of wastewater treatment plants could be reduced by up to 35% by coupling anaerobic digestion to biogas production. A Polish case study by Werle and Sobek (2019) on the gasification of sewage sludge for energy generation within a circular economy reported a lower heating gas value of up to 5 MJ m^{-3}. The gasification process from this study generated a valuable phosphorus (P_2O_5) fertilizer resource of 22.06% by mass of the residue (ash), which is close to the natural phosphate rock concentration (28%). Similarly, the ash produced had a high adsorption capacity of 42.22 mg/g, which is close to the adsorption capacity of commercial activated carbon (49.72 mg g^{-1}).

A case study was conducted on the use of sewage sludge for brick production in a circular economy in Croatia (Bubalo et al., 2021). The study found that sewage sludge replaced clay in bricks by 5%wt resulted in higher compressive strength than a control brick. A similar comprehensive case study from Brazil on the use of sewage sludge for brick production indicated that good quality bricks with acceptable linear shrinkage, water absorption, and mechanical strength can be produced by firing at temperatures between 850 and 950 degrees Celsius and replacing clay up to 15%wt with sludge. (Areias et al., 2020).

Several case studies have been conducted to assess the environmental and financial implications of various sewage sludge management practices and sewage sludge treatment processes. A study conducted by Houillon and Jolliet (2005) reported that agricultural use of sludge had the lowest non-renewable primary energy consumption compared with wet oxidation, pyrolysis, incineration in cement kilns, fluidized bed incineration, and landfilling. Based on a comparative study of three sewage sludge treatment scenarios (scenario 1 - anaerobic digestion, mechanical dewatering, and land application; scenario 2 - mechanical dewatering and incineration; scenario 3 - mechanical dewatering, thermal drying, and pyrolysis), Hospido et al. (2005) found the land application of digested sludge to be an acceptable treatment option.

5. MACRO DRIVERS AFFECTING THE USE OF SLUDGE IN A CIRCULAR ECONOMY

The rising solid waste generation due to rising wealth and population dynamics is expected to increase pressure on current waste management systems which will have significant global socioeconomic, environmental, technological, and geopolitical implications (Werle, 2015). Consequently, it is crucial that a Life Cycle Analysis approach (LCA), which takes into consideration a range of factors involved in the entire wastewater sludge generation process, existing and potential alternative technologies for sludge management and reuse, financial drivers and implications, implications to climate change and the circular economy, location, policies, and regulations, as well as public opinion, is used.

Several Life Cycle Analysis studies have been conducted to assess the overall environmental impacts such as sewage sludge treatments methods, management strategies among others. Two of these studies include that of Suh and Rousseaux (2002) and Johansson et al. (2008). Life Cycle Analysis comparison studies conducted by Suh and Rousseaux (2002) of five combination scenarios that included a stabilization process (composting, anaerobic digestion, or lime stabilization), a main process (landfill, incineration, or agricultural application), and sludge transport indicated that the combination of anaerobic digestion and agricultural land application had the lowest energy consumption and greenhouse gas emissions. A comparative LCA study by Johansson et al. (2008) on the environmental impact of four sewage sludge management strategies (restoration of mining areas, composting for use on golf courses, hygienization for agricultural use, and supercritical water oxidation with phosphorus recovery) demonstrated that supercritical water oxidation produced the lowest biogeochemical emissions (the least environmental impacts), largely due to the effective utilization of nutrients and energy recovery from the sludge. Another study by Bertanza et al. (2016) reported that incineration with energy recovery and digestion with application on agricultural soils were effective solutions for sludge disposal from WWTP serving a population of 500 000 and higher.

The variation in the choice of sewage sludge treatment methods and management practices reported above indicate that the choice of a sludge treatment and management practice depends on several factors including but not limited to the sludge quantity, properties and composition, heavy metals and pathogens, energy and material reuse, location, policies and regulations, and public opinion (Durdevic et al., 2022). In order to assist with the selection of the most effective technologies and solutions for sewage sludge treatment, the qualitative PROMETHEE method, which involves multicriteria decisions based on quantitative and qualitative data is currently being considered (Brans and Mareschal, 2005). This model offers two types of ranking systems based on the chosen priorities: partial ranking (PROMETHEE I) and complete ranking (PROMETHEE II). The options are ranked from the best to the worst (Durdevic et al., 2022).

6. CONCLUSIONS AND RECOMMENDATIONS

The existing South African criteria for pathogenic organisms and stability are up to date with existing guidelines. It is, however, proposed that updating the ceiling concentration of heavy metals in the current South African sludge guideline taking into consideration the background concentration of heavy metal around the various provinces could enhance the sustainable use of sludge in South African agricultural lands.

Existing sludge guidelines in both developed and developing countries have not yet set criteria on emerging contaminants of concern which include pharmaceuticals, personal care products, flame retardants, artificial sweeteners, nanomaterials, and their transformation products due to the absence of sufficient scientific information. Hence, local studies on the fate of emerging contaminants from sludge applied to agricultural lands should be conducted.

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APPENDIX B: Stakeholder consultation

by

HG Snyman & JE Herselman

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1 INTRODUCTION AND OBJECTIVES

The WRC invested a significant portion of funding to develop the South African sludge guidelines from 2000 to 2009 and published a set of 5 Volumes each focussing on the management of different use and disposal options:

- Volume 1: Selection of management options (Snyman and Herselman, 2006 a, TT261/06);
- Volume 2: Requirements for the agricultural use of sludge (Snyman and Herselman, 2006 b; TT262/06);
- Volume 3: Requirements for the on-site and off-site disposal of sludge (Herselman and Snyman, 2009, TT349/09);
- Volume 4: Requirements for the beneficial use of sludge (Herselman and Moodley, 2009, TT350/09); and,
- Volume 5: Requirements for the thermal sludge management practices and for commercial products containing sludge (Herselman et al., 2009, TT351/09).

Currently, sludge is classified in three main categories in a decreasing quality order of metal content, potential to cause odour nuisances and fly-breeding as well as to transmit pathogenic organisms to the environment. These documents have steadily been adopted by the local authorities as the guidelines are currently referred to in all Water Use Licences (WUL) issued by the Department of Water and Sanitation (DWS) responsible for water to stipulate the regulatory requirements for sludge management.

While the guidelines were developed with the best available knowledge at the time to guide the South African water sector towards the beneficial use of wastewater sludge and more responsible disposal, there has been significant progress in water, sanitation and environmental legislation, policy and guidelines as well as in research, development and innovation over the years. Therefore, a revision of the Sludge Management Guidelines is necessary to take into account developments since 2009, including circular economy principles, emerging contaminants and SABS for non-sewered systems. The revision and update of the guidelines will provide improved long-term sustainability planning and management approaches. The first step in the process is the development of a framework for the revision of guidelines and in doing so, describe a way forward for and identify key theme areas which would be defined through stakeholder engagement. The framework will outline the vision, narrative and key themes and strategy for the revised guidelines.

2 APPROACH

2.1 Draft Framework

The Draft Framework was based on the team's broad sector experience and assisted in framing the agenda for the consultation with national and local government and the water sector. The project team have been working with local government, regulators and the research community assisting in developing sludge management plans, audits, sludge classification, waste classification, training and research since the Guidelines were published in 2006 and 2009. There have also been numerous discussions with the DFFE and DWS regarding the legislative requirements especially related to regulations published under the National Environmental Management: Waste Act (NEMWA) 59 of 2008 for the classification and assessment of waste: (1) SANS 10234 waste classification as detailed in the Waste Classification and Management Regulations of 23 August 2013 (GN R.634 of 2013); and (2) Waste assessment according to the National Norms and standards for the assessment of waste for landfill disposal (GN R.635 of 2013). The DFFE also developed an enabling mechanism (Waste Exclusion Regulations, GN. 715 of 2018) to exclude a waste from the definition of waste if the intended use of such waste is proven to be beneficial.

2.2 Literature Review

A post graduate student of the Department of Plant and Soil Sciences at the University of Pretoria is undertaking a comprehensive literature review guided by the senior project team members. The literature review will include, but is not limited to the following aspects: (1) The South African legislative environment and regulations pertaining to the management of sludge and faecal sludge; (2) International regulatory trends in sludge and faecal sludge management including the underlying motivation for adopting such regulations; (3) International standards and limits based including the scientific rationale; (4) Emerging technological trends for sludge and faecal sludge stabilization, beneficiation and management; (5) Risk assessment trends and emerging risk factors such as persistent pollutants, micro plastics, endocrine disrupting compounds, microbiological agents; (6) Case studies on the application of the circular economy, energy generation, greenhouse gas reduction or offsetting etc.; and (7) Macro drivers such as development, finance and impact of climate change.

2.3 Stakeholder consultation (this document)

Face-to-face stakeholder consultation as well as on-line workshops were conducted to seek input from Local Government and wastewater treatment service providers, consultants, laboratories and researchers. The workshops to gain the input from the Regulators at local and national level will be conducted a later stage to communicate the information gathered by the first set of workshops and to get clarity on certain aspects.

2.4 Final Framework

The final framework including the vision, narrative and key themes and strategy for the revised guidelines will be presented for consideration by the WRC appointed Reference Group. It is envisaged that the framework will also be able to include early wins such as clarity on the regulations and confirmation on interim arrangements as agreed with the regulators.

The narrative will include clear terms of reference for the different role players as agreed with the WRC, the regulators and the sector. This could include, but is not limited to terms of reference related to:

(1) Research projects needed to fill knowledge gaps with a separate memorandum on indicative costs
(2) Update of the sludge guidelines addressing each of the Volumes separately and adding Volumes if needed. This will include timing for the updates as some uses might require research input or regulatory changes before it can be developed and published

(3) Policy and regulation changes needed to achieve certain agreed goals aligned with Government priorities
(4) Training needs for the sector to improve sludge and faecal sludge management and promote beneficiation and beneficial use of sludge
(5) Best practice guidance for the interim (if required)

3 METHODOLOGY

The draft framework including the vision, narrative and key themes and strategy for the revised guidelines were presented and each of these aspects discussed to obtain input from various perspectives. The following workshops/consultations were conducted:

(1) On-line opportunity #1 on 21 February 2023;
(2) Gqeberha (Eastern Cape) on 23 February 2023;
(3) Tshwane (Gauteng) on 27 February 2023;
(4) Cape Town (Western Cape) on 1 March 2023;
(5) eThekwini (Kwa-Zulu Natal) on 3 March 2023; and
(6) On-line opportunity #2 on 7 March 2023.

The project team also reached out to the municipality and authorities in Mangaung (Free State) to host a workshop, but were not successful.

The Green Drop audits revealed that sludge management is limited in the smaller municipalities and representatives from these municipalities were invited to attend an on-line workshop or alternatively a workshop at the Metropolitan Municipality closest to them. The regional offices of the DWS, DFFE, Department of Agriculture (DoA), Public Works and the Department of Mineral and Energy (DME) were also invited to attend the face-to-face or on-line workshops.

A separate face-to-face consultation session with the national offices of the DWS, DFFE, Department of Agriculture (DoA) and Department of Public Works will be conducted during May 2023. The focus of these discussions will be to share concerns and constraints reported by local government and to develop solutions within the current regulatory framework. Contradicting and complementary pieces of legislation will also be discussed. This feedback will give Government an opportunity to address low hanging fruit in amending regulations to support Local Government to fulfil its mandate.

The presentation used for the workshops were included in previous deliverables to the WRC. A series of questions were included to get feedback from stakeholders on:

- Current sludge management practices and use of Sludge Guidelines;
- Critical appraisal of the Sludge Guidelines;
- Stumbling blocks experienced in implementation of the Sludge Guidelines; and
- Envisioning and local nuances.

The attendance registers of the workshops were passed to the WRC together with a compilation of the feedback received.

Figure 1 Tshwane attendees

Figure 2 eThekwini attendees

Figure 3 Cape Town attendees

Figure 4 Attendee responses Tshwane

Figure 5 Attendee responses Cape Town

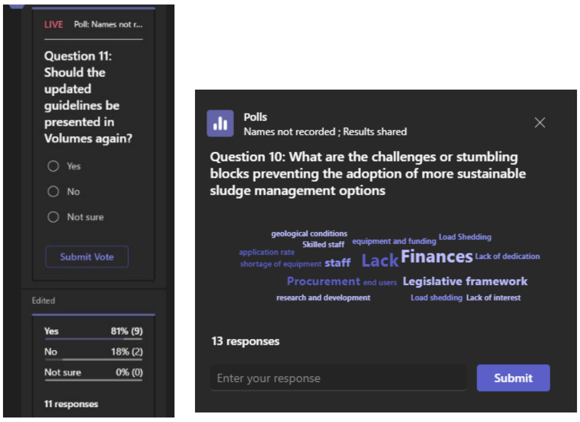

Figure 6 On-line responses with Polls

4 RESPONSES AND OUTCOME FROM WORKSHOPS

The summarised responses and key outcomes for each question obtained during the workshops will be discussed in this section.

4.1 Question 1: Is Volume 1 been used to characterise and classify wastewater sludge in your municipality or municipalities you are involved with?

The majority of municipalities use the Sludge Guidelines for classification, but a number of attendees had no knowledge of the guidelines and how it should be used. There are WWTWs where sludge is not classified and therefore the quality is not monitored.

4.2 Question 2: Is the sludge classification used to determine beneficial uses as intended in Volume 1?

Beneficial use options are identified after classification, but not necessarily implemented.

4.3 Question 3: Which of the Sludge Guideline Volumes 2- 5 are applied in your municipality or municipalities you are involved with?

Volumes 2 and 3 are used by most municipalities, while Volume 4 is used mainly in eThekwini, Gauteng (ERWAT and Mogale City) and Cape Town. Volume 5 is used in Gqeberha where brick making is the beneficial use option of choice. Other municipalities indicated that Volume 5 is mainly used as reference when additional options are investigated. The composting section of Volume 5 has historically been used in eThekwini but currently all sludge is disposed (no beneficial use).

4.4 Question 4: Environmental authorisation of WWTWs (permit, Water Use License (WUL), General Authorisation (GA), Coastal discharge permit (CDP))

The majority of WWTWs are authorised by WULs or GAs for smaller works. In the coastal areas CDPs are also applicable to some WWTWs. Clarity from authorities required on when CDP is required and is both required?

4.5 Question 5: Additional environmental authorization not normally associated with WWTWs (Waste Management License (WML), Air Emission License (AEL), Exclusion from definition of waste)

eThekwini municipality has WML for waste piles on some WWTWs. The rest of respondents indicated that WMLs were required during the construction phase of new infrastructure but not for operations. WMLs are held by managers of industrial water treatment works. AELs are only applicable for incinerators, but none are active at the moment (eThekwini).

Umgeni water is in the process of application for exclusion from the definition of waste (GNR 715).

4.6 Question 6: The sludge generated from the WWTW's in your municipality or municipalities you are involved in is characterized, classified and assessed in terms of which guideline/regulations:

Classification according to Sludge Guidelines are used by the majority of municipalities, while some indicated that they also use GNR 634 and 635 (3 classifications). For industrial sludges only GNR 634 and 635 are used.

4.7 Question 7: The estimated percentage of wastewater sludge used beneficially in your municipality or the municipality you are involved with:

Respondents at all workshops indicated that 25 – 75% of sludge is used beneficially in their areas. eThekwini municipality is the exception as all sludge are disposed since 2020 due to natural disasters (Covid and flooding) as well as the looting in July 2021.

4.8 Question 8: The following sustainable management options are applied in your municipality or municipality you are involved with:

- Agriculture;
- Rehabilitation;
- Brick manufacturing;
- Turf grass/instant lawn;
- Composting;
- Golf courses; and
- Landfill cover

4.9 Question 9: The following sustainable management options could be applied in your municipality or municipality you are involved with:

- Composting;
- Fertilizer production;
- Biosolids beneficiation;
- Bio-diesel;
- Animal feed
- Electricity generation;
- Phosphate recovery;
- Activated carbon recovery;
- Pelletisation;
- Landfill cover; and
- Rehabilitation.

4.10 Question 10: What are the challenges or stumbling blocks preventing the adoption of more sustainable sludge management options

Numerous challenges/stumbling block have been identified by respondents, but the following ones are universal:

- Finances: Income is not ring-fenced for O&M at WWTWs;
- MFMA and SCM: Public-private-partnerships (PPPs) is the only way to adjudicate long term contracts for O&M and these take a long time to be realised. Procurement departments and Bid Committees are not knowledgeable on requirements and best practice;

- Legislative framework and red-tape: Clarity required regarding which authorisations are required for which beneficial use option. Ideally, one department should handle all authorisations related to wastewater sludge. Authorisations often hamper implementation of beneficial use options;
- Skilled staff/labour: Training of staff on sludge management is lacking, the main focus is on water quality.
- Political will: WWTWs and sludge is the last thing politicians care about;
- Training and public acceptance: Training and education is required to ensure public acceptance of sludge. Incentives should be considered to promote beneficial use.

4.11 Question 11: Is agricultural use still the most appropriate sustainable use option?

The majority of respondents agreed that agricultural use (including composting and instants lawn) is still the best option, but some concerns were also raised:

- Emerging constituents of concern (ECoCs) and its prevalence in sludge;
- Interaction between ECoCs, crops, soil and water in agriculture (is it taken up by plants, will it leach to groundwater etc.); and
- The metal content in sludge from WWTWs receiving industrial effluent is increasing due to the fine balance between economic growth and fining industries for polluting.

4.12 Question 12: Should the updated guidelines be presented in Volumes again?

Respondents were divided on whether the guidelines should be published as one comprehensive book rather that different volumes. However, ≈75% of attendees agreed on a single volume with different chapters/sections. The applicable legislation could be a separate volume to make updates easier as legislation changes.

4.13 Question 13: Should the volumes be condensed?

The majority of respondents indicated that the guidelines should not be condensed as it is easier when all relative information is in the same document. As stated in question 12, the legislation section could be a separate volume.

4.14 Question 14: Should we do away with the sludge specific classification system?

All respondents agreed that wastewater sludge is different from other wastes and that the specific classification system must remain.

4.15 Question 15: Is the wastewater sludge classification system appropriate for all or some uses?

There was agreement that the classification system is appropriate for all beneficial uses but that disposal need additional classification according to GNR 635.

4.16 Question 16: Are we ready to adopt a 2x3 tier classification system?

The consensus was that the 3x3 classification system should remain.

4.17 Question 17: Are the microbiological class limits still appropriate?

The following concerns were raised regarding the microbiological class:

- Prevalence and survival of viruses must be investigated;
- New research on helminth ova methodology should be considered (Dr Colleen Archer, UKZN);
- Link tests to risk abatement plans (RAPs);
- National audit on sludge microbiological quality required.

4.18 Question 18: Are the stability class criteria appropriate?

Simplification of the stability class criteria should be considered, i.e. specific VS content, specific WAS sludge age, operations that will produce stable sludge, etc. The effectiveness of cell lyses on sludge stability should also be investigated and considered as an option.

4.19 Question 19: Are the pollutant class limits and constituents still appropriate?

The following responses were received regarding the pollutant class constituents:

- National audit on metals and ECoCs in sludge;
- Research on prevalence of ECoCs in sludge and its impact on environment (soil and water);
- Omit benchmark metals as it causes confusion;
- Align constituents and limits with GNR 635 to avoid duplication in analyses; and
- Investigate analytical capabilities of municipal laboratories.

4.20 Question 20 - 24: What would you like to see changed in the different Volumes?

Volume 1:

- Simplify the beneficial use option selection tables;
- Update Helminth ova method;
- Fix VSS calculation;
- Expand on sampling procedures and methods (specific samples for specific analyses);
- Check on most recent analytical methods (i.e. aqua regia vs microwave digestion)

- Specify that classification is based on the average of 3 samples (where 3 samples are analysed). Revision of the requirement for 3 samples should be considered due to cost implications;
- Reduce re-classification frequency to align with WUL renewal periods.

Volume 2:

- Add an example of legal contract with farmers;
- Who should be informed when sludge are transported from one municipality to users in a different municipality (if required)?

Volume 3:

- Update legislation section;
- Generic design specifications for waste piles according to DWS and DFFE checklists;

Volume 5 is not used often but the options should remain in the guidelines.

4.21 Question 25: Should we include guidance on other aspects in the sludge management guidelines?

Guidance on the following should be considered for inclusion in the updated guidelines:

- Bylaws to improve sludge quality and management;
- Sludge minimisation;
- Sludge stabilisation;
- Transport;
- Sludge Master plan example;
- Sludge Management plan examples;
- Public information posters and flyers;
- Handling of faecal and septic tank sludges;
- Disposal of primary sludge;
- Handling of package plant sludge;
- Generic SANS 10234 classification and SDS for sludge;
- Guidance on volumes of sludge wasted;
- Guidance on handling of industrial sludge.

4.22 Envisioning and open discussion

The key theme taken from the envisioning of attendees were centralisation of wastewater and/or sludge treatment. This investment in sludge treatment will ensure better quality sludge for beneficial use which could bring revenue to the municipalities. If the definition of sludge can be changed from 'waste' to resource public perception might change (through GNR 715 exclusion process).

Another important theme is electricity generation at WWTWs to reduce operational cost and get revenue through surplus electricity generation.

Other themes included:

- Education, awareness and capacity building:
    - Start separating waste at source to prevent foreign objects from reaching the WWTWs;
    - Change the public perception by educating kids from ECD stage as well as the general public on the value of 'biosolids';
    - Best practise guideline for sludge management;
    - Separate guideline for general public on sludge use;
    - Dedicate a volume of 'Water Wheel' to sludge management (annual);
- Political:
    - Create Council-level understanding on benefit of investment in WWTW O&M and potential return on investment;
    - Declare WWTWs as National key-points to reduce loadshedding and increase security;
- Finances & procurement:
    - Revenue generation from selling A1a sludge/compost could off-set capital investment;
    - Explain 'Cradle to grave' concept to economic sector;
    - Define 'circular economy' for WWTWs;
    - PPP contracts are specialised skill which is a barrier to implementation of beneficial use options;
    - Ringfencing income and funding for WWTW O&M;
    - Simplify procurement systems;
    - Allocate funding towards sludge treatment and handling and not only effluent;
    - Environmental, social, and corporate governance (ESG);
    - Life-cycle cost calculations;
    - Carbon footprint calculators;
- Enforcement and monitoring of bylaws:
    - Extended producer responsibility;
    - Build capacity for monitoring and fining of perpetrators (industries discharging bad quality wastewater);
    - Hold individuals and companies accountable;
    - Criminal charges to Executives if non-compliant;
- Research and development:
    - Feeding of fly larvae, especially with primary sludge;
    - National audit on sludge quality to determine progress since 2003;
    - Research into micro-plastics, PFAS & PFOS, lifecycle and consequence of emerging CoCs;
    - Survival of viruses;

- Effectiveness of cell lyses on stability of sludge.

5 KEY QUESTIONS FOR AUTHORITIES

All respondents indicated that uncertainties regarding authorisations hamper the implementation of beneficial use. During the consultation with the Authorities, clarity will be requested regarding the following:

- Is DWS still the lead authority for sludge management?
- When does CDP apply? Indications are that discharge above the estuary need a WUL (DWS) but discharge into the estuary is authorised by DFFE (CDP).
- Will the WUL be replaced by CDP where coastal discharge is applied for or are both required?
- There is no timeline for the GNR 715 Exclusion process resulting in uncertainty on beneficial use;
- Are pre-2006 authorisations to bury sludge on site still legal?
- It seems like construction and expansion of facilities at a WWTW require a WML. When is a WML triggered for operations and when does it revert to WUL 21G authorisation?
- Simplify authorisation for sludge management and beneficial use;

6 CONCLUSIONS

Workshop attendees and respondents indicated that the Sludge Guidelines, especially Volume 1, are widely used by municipalities and WWTW operators and managers. Agricultural use is still the most popular sludge management option. Other popular options include instant lawn/turf grass, composting and brick manufacturing. Majority of municipalities indicated that electricity generation is an option that need investigation due to the current electricity crisis in SA.

Training of staff on the use of the Sludge Guidelines is lacking at most municipalities and periodic training courses are required (every 2 – 5 years). Similarly, education of the general public and children on the benefits of sludge is required to get public acceptance and promote beneficial use.

The main stumbling blocks experienced regarding implementation of beneficial use of sludge include:

- Authorisations and red-tape;
- Finances and procurement processes (MFMA and SCM);
- Political will;
- Skilled staff; and
- Public perception and fear regarding public health unknown.

Most municipalities indicated that establishment of centralised high COD/BOD treatment plants is an opportunity that is investigated. Exclusion of sludge from the definition of waste (GNR 715 application) will promote beneficial use and ease authorisation.