

Towards Environmental Sustainability: Transformation of Indah Water Konsortium (IWK) Biosolids

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ABSTRACT

Biosolids are nutrient-rich organic materials derived from domestic wastewater treatment plants, which have gained increasing recognition as valuable resources due to their diverse organic and inorganic constituents. These constituents find beneficial applications across agriculture, civil engineering and energy recovery sectors. Since the late 1990s, Indah Water Konsortium (IWK) has led research and innovation in converting sewage sludge into nutrient-rich biosolids. These biosolids serve as effective fertilisers, significantly enhancing agricultural productivity and soil health while minimizing reliance on chemical fertilisers thereby promoting environmental conservation through the reuse and recycling of organic waste. Over the years, the generation of sewage sludge has increased alongside urbanisation and population growth, posing challenges for traditional disposal methods. IWK has responded with advancements in biosolids management, offering a sustainable solution by transforming this waste into a valuable resource. Addressing challenges in biosolids management, including public perception, is crucial for the widespread adoption of these sustainable practices. Ongoing research and development by IWK play a crucial role in optimising biosolids applications and expanding their benefits. Innovations in treatment processes ensure biosolids meet stringent regulatory standards for safe agricultural and other beneficial uses, safeguarding public health and the environment. By transforming waste into a valuable resource, IWK's initiatives demonstrate substantial progress in sustainable waste management, the circular economy and environmental stewardship. Biosolids contribute to a circular economy by closing the nutrient cycle and reducing dependency on finite resources. It enhances soil fertility and contributes to environmental resilience, promoting sustainable agricultural practices.

Keywords: Biosolids; waste management; reuse; nutrient; circular economy

INTRODUCTION

Malaysia's wastewater industry has evolved significantly from septic tank treatments to advanced mechanised treatment plants, driven by technological advances, growing environmental awareness, and concerns for public health. Despite these advancements, the sewerage industry still faces significant environmental challenges that must be tackled to ensure sustainable operations and minimise ecological impact. These challenges may include in addressing waste management issues, sewage flooding which can lead to waterborne diseases and mitigating soil and groundwater contamination which may be due to the improper disposal practice (Sridhar & Parimalarenganayaki 2024), (Regitano et al. 2022). Furthermore, sewerage

industry also must address its contribution to global warming and climate change due to the greenhouse gas emission from the wastewater treatment facilities and activities (Lambiasi et al. 2024). Addressing these issues requires a comprehensive approach that integrates innovative technologies, stringent regulatory frameworks, and public education to promote sustainable practices. By overcoming these challenges, Malaysia can not only achieve environmental sustainability but also safeguard public health, setting a benchmark for sewerage systems globally. The objective of this paper was to explore how IWK's biosolids management practices can be transformed to align with environmental sustainability principles, including resource recovery, reduction of environmental footprints, and mitigation of climate impacts.

SEWERAGE EVOLUTION IN MALAYSIA

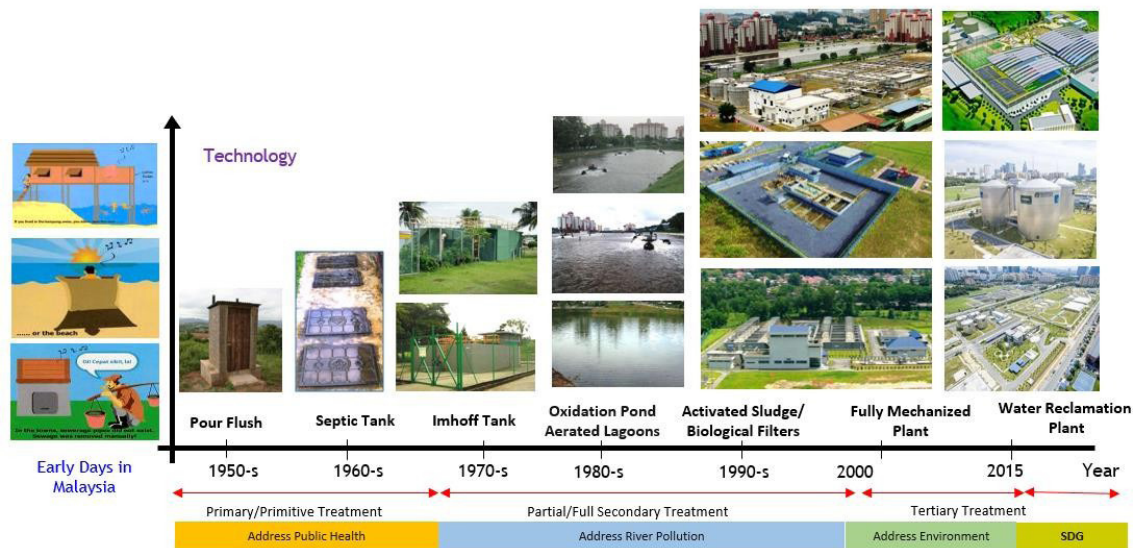


FIGURE 1. Sewerage evolution in Malaysia

Indah Water Konsortium Sdn Bhd (IWK) is Malaysia's a national sewerage company which has played a key role in managing and maintaining the sewerage system for over three decades. Since its establishment, IWK has been responsible to operate and maintain more than 7,000 public sewage treatment plants (STPs) to serve a population equivalent (PE) of 31.7 million and over 21,000 km of sewerage pipeline nationwide (Mohd Taufik, 2024). IWK is committed to ensure that the sewage that made up mainly from kitchen, toilet and bathroom is being treated to meet stringent environmental standards before being discharged into water bodies. Through continuous improvements and the adoption of advanced technologies, IWK remains dedicated in providing effective sewerage services in order to address immediate environmental challenges but also supports the long-term sustainability and resilience of Malaysia's ecosystems and communities.

Figure 2 illustrates a typical sewage treatment system, starting with primary treatment to screen out sand and debris. The secondary treatment typically utilise biological processes where the microorganism will degrade and breakdown the organic matters and further decrease the pollutants. While clear water (treated water) and sludge will be separated from the wastewater at the clarifier before the treated water or known as bioeffluent is released into the water bodies. Excess sludge from this process is thickened, anaerobically digested to reduce volume and produce biogas, and finally dewatered to generate biosolids. These biosolids consist mainly of beneficial microorganisms and organic matter, typically in a semisolid form where presently are being disposed at landfill sites

(Sonia et al. 2020). However, biosolids are nutrient-rich organic materials that can be recycled and reused for various applications. They can be beneficially repurposed as soil conditioners, used in land reclamation projects, and applied for forestry and landscaping purposes (Elgarahy et al. 2024), (Mabrouk et al. 2023). These diverse applications highlight the versatility and environmental benefits of effectively managing and utilizing biosolids from sewage treatment processes. By transforming waste into valuable resources, this approach aligns with the principles of a circular economy, promoting resource efficiency and reducing the environmental footprint of waste management practices (Amorim et al. 2022), (Hadad et

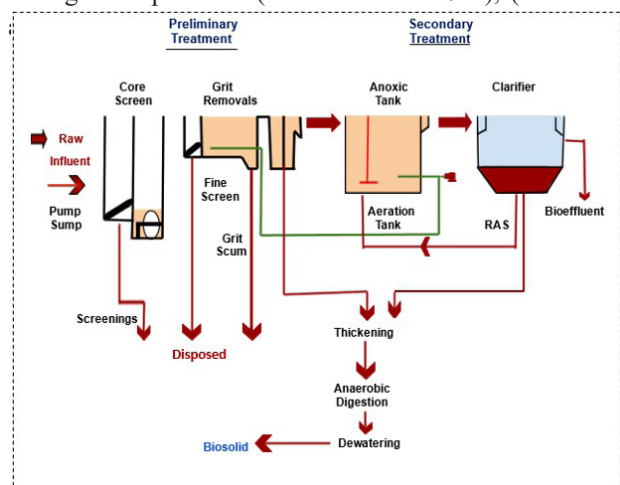


FIGURE 2. Typical sewage treatment system

METHOD OF BIOSOLIDS TREATMENT

Biosolids treatment encompasses various methods aimed to manage and reuse the organic materials recovered from the sewage treatment plants (STPs) (World Health Organization 2006). Each method serves to stabilise, reduce volume, and ensure the safe disposal or beneficial use of biosolids. In biological treatment methods such as digestion use microorganisms to break down organic matter within the biosolids (Wenhui et al. 2025). The digestion process can be either aerobic or anaerobic. Aerobic digestion occurs in the presence of oxygen, where microorganisms break down organic matter to produce carbon dioxide and water (Steven & Qi 2014). While this method effectively reduces the volume of biosolids and stabilises them, it requires a continuous supply of oxygen and energy. In contrast, anaerobic digestion takes place in the absence of oxygen, resulting in the production of biogas mainly composed of methane and carbon dioxide, and stabilized biosolids (Deshai & Rune 2011). Anaerobic digestion is often preferred as one of the most effective and sustainable biosolids treatment technologies due to its dual environmental and energy recovery benefits. Through metabolic activity of anaerobic microorganism, the organic matter is degraded biologically in the absence of oxygen resulting in production of biogas which can be harness as renewable energy. In addition to energy generation, the process allow the sludge stabilisation making the biosolids safer to be reuse (Lise et al. 2008) (Chen et al. 2008).

Physical treatment methods involving thickening processes such as gravity thickening increase the concentration of solids by removing excess water (Tan et al. 2023). Furthermore, dewatering techniques will further reduce moisture content, employing equipment like centrifuges, belt filter presses, screw presses as well as drying beds to produce a denser, more manageable material. Centrifugation employs centrifugal force to separate water from solids, while belt filter presses squeeze water out using rollers. Screw presses work by compressing the biosolids to expel water and drying beds rely on natural evaporation to reduce moisture content (Shilin 2023).

Chemical treatment methods enhance biosolids stabilisation and safety through chemical additives such as lime or alkaline agent alter the pH or interact with biosolids components, improving stabilisation and reducing odor (Ella 2024). Pathogen reduction in biosolids is achieved through chemical treatments to meet U.S. Environmental Protection Agency (EPA) Class A standard to ensure biosolids meet safety standards for various uses (Eliza 2020).

Finally, thermal treatment methods apply heat to the biosolids to further reduce its volume and potentially

generate energy. Incineration involves burning biosolids at high temperatures, which not only reduces the material to ash but also produces heat that can be used for energy (Savankumar et al. 2026). Heat drying uses direct or indirect heat to evaporate moisture from biosolids, resulting in a dry, stable product that is easier to handle and transport. Based on Metcalf and Eddy (2014), the end product is a pathogen-free, odourless, and manageable form of biosolids that can be used as soil amendments or fertilisers, contributing to sustainable waste management practices.

EVOLUTION R&D ON BIOSOLIDS APPLICATION IN IWK

Presently, domestic sewage treatment facilities in Malaysia generate approximately 100,000 tons annually in 2023 (Indah Water Konsortium Sdn Bhd 2024). The rate is anticipated to increase in tandem with the increasing of population equivalent growth. Currently, almost all of the biosolids are disposed of at approved landfill or IWK trenching sites, which are designated remote location for sludge disposal and regularly monitored by IWK to ensure that the disposal activities are properly managed. Biosolids disposal to landfill would not be an environmentally sustainable solution in a long term due to limited landfill space, the potential for leachate generation, and the significant release of methane, a greenhouse gas that contributes to climate change (Shilin 2023), (Hailey & Simeng 2024), (Magdalena 2019). In response to these concerns, IWK has been actively involved in conducting various research and innovation (R&D) in providing scientific data to further explore various reuse potentials of biosolids since the late 1990s. Thus, a narrative literature review was conducted covering studies published between the late 1990s and 2022 focusing on biosolids treatment, reuse technologies, heavy metal assessment, and regulatory frameworks to examine technological developments, environmental risks and regulatory evolution prior to commercial-scale implementation. The R&D comprises characterising the biosolids generated from IWK's STPs which involving chemical and physical properties of the biosolids to understand their nutrient content. Additionally, field studies are conducted to assess the effect of biosolids application soil health, plant growth, and crop yields, ensuring that their use is safe and beneficial for agriculture. Furthermore, innovative technologies are explored to transform biosolids into marketable products, such as organic fertilisers, soil amendment or construction materials such as bricks, which offer a sustainable alternative to traditional building materials.

CHARACTERISTIC OF BIOSOLIDS

From the characterisation study, biosolids typical moisture content ranges from 80-85% with solids comprising between 20% and 15% using the gravimetric method in accordance with Standard Methods for the Examination of Water and Wastewater (Wójcik & Stachowicz 2018), (Zhenyu Chen 2014). These solids are primarily composed of organic microbial organisms including biomass from dead cell, extracellular polymeric substances and residual organic matter that play a vital role in enhancing soil structure and stimulating microbial ecology. Research has shown that the proportion of nitrogen (N) which was analysed using the Kjeldahl method ranges from 2 to 8 % whilst organic matter constitutes more than 50 % (Kanteraki et al. 2022). In addition to nitrogen, biosolids are rich in macronutrients (i.e. phosphorus, potassium, calcium and magnesium) and micronutrients (i.e. iron, zinc, and copper) that essential for promoting plant growth and development (Dede et al. 2010). While trace amounts of heavy metals and other contaminants (i.e. cadmium, lead and nickel) are present, it generally within the permissible limits established by U.S. Environmental Protection Agency (EPA), potentially attributable to the use of household products like detergents, shampoos and illegal industry discharge when appropriately managed (Jianting et al. 2023). In Malaysia, the Suruhanjaya Perkhidmatan Air Negara (SPAN) has published technical standards for the use of biosolids which specify conditions for non-food applications, ensuring that biosolids are applied safely and in compliance with environmental requirements prior to reuse (Suruhanjaya Perkhidmatan Air Negara (SPAN) 2020).

STABILISATION OF BIOSOLIDS

The stabilisation methods for enhancing the beneficial value of biosolids were explored, ranging from traditional composting to vermicomposting, a biological process in which earthworms, break down the organic materials, accelerating decomposition and transforming the biosolids into nutrient-rich, stable organic fertiliser. Research conducted by Universiti Putra Malaysia (UPM) found that compost made from sewage sludge was comparable to commercial compost and the planting performance was satisfactory (Dzulkurnain et al. 2017).

Whilst research by the Malaysian Agricultural Research and Development Institute (MARDI) demonstrated that vermicomposting using earthworm effectively transform sewage sludge into a stable and valuable by-product. The study highlighted that vermicomposting is particularly effective in preserving the

available organic nutrients within the biosolids, making them more beneficial for use in various applications (Masduki 2017).

BIOSOLIDS APPLICATION AS FERTILISER

Field trials conducted in collaboration with UPM on a diverse range of timber species, such as meranti tembaga, jelutong, acacia, kayu manis, and merawan have shown remarkable results. These trials demonstrated significant growth in terms of height and basal diameter of the trees (Nik 2005). Finding also indicated a marked improvement in soil quality specifically in soil's Cation Exchange Capacity (CEC). The CEC was found to increase to 22meq/100g soil compared to 7.4meq/100g soil at the control plot. This enhancement reflects the soil ability to retain and exchange nutrients which is essential for plant health and productivity.

Study on rubber trees with UPM and Rubber Research Institute of Malaysia (RRIM) also showed the promising results. The study demonstrated that the application of biosolids significantly increased the growth rate of rubber trees (Karim 2008). The study also revealed that the use of biosolids not only accelerated the growth of these trees but also showed the potential to increase the wood yield. Additionally, UPM found no significant difference in the mineral content of latex produced with biosolids compared to without sludge treatment (Karim 2008). This indicates that biosolids can enhance tree growth and yield without affecting the latex quality.

Biosolids have good potential for reuse as fertiliser but may require easier handling for end users. Through collaboration with UPM, biosolids were successfully converted into biopellets addressing handling and transportation issues and making it more acceptable to end users. This study developed standard operating procedures for converting biosolids into compressed fertiliser pellets, reducing their volume and improving transportation, handling, and storage efficiency (Mohd 2017).

BIOSOLIDS AS BRICK

In addition to nutrient recovery, IWK in collaboration with UPM to investigate the potential of using sewage sludge as a clay amendment for brick production. The study assessed various proportions of sludge-clay mixtures for their physical appearance, mechanical properties, and chemical properties. The findings revealed that the final product had a light red colour and was odourless (Azni 2002). With a mixture containing 20% sludge, the comprehensive strength of the sludge-amended bricks conformed to the minimum load-bearing capacity specified in MS 7.6:1972

(Specification for Bricks and Blocks of Fired Brickearth, Clay or Shale) (Liew et al. 2004). Additionally, the analysis of soluble salt content classified the bricks as 'Low Level' grade according to BS3921:1985, where acceptable minimal salt levels and resulting in minimal white deposits on the brick surface. This research suggests that sewage sludge can be effectively incorporated into brick making, with extreme firing temperatures sterilizing the sludge.

ENERGY RECOVERY FROM BIOSOLIDS

Sewage sludge also can be converted into an energy source. Energy recovery methods include anaerobic digestion to produce biogas (Rafaela et al. 2017), biofuel conversion using various technologies such as pyrolysis and gasification to produce syngas (Li et al. 2024). At IWK, the biogas generated from the anaerobic digester has a methane content range about 55-65% which means generation of electricity from sewage is possible. Therefore, the potential for green energy development in this area should be further explored through feasibility studies and pilot projects

PERCEPTION AND ACCEPTANCE TOWARDS BY-PRODUCT REUSE

Despite scientific research highlighting the benefits of biosolids, the commercial viability of biosolids reuse may depend on public perception and acceptance. For this reason, a collaborative R&D study between IWK and Universiti Kebangsaan Malaysia (UKM) was carried out to gauge public perception towards biosolids reuse through social perception survey forms investigating the respondent's background, general understanding on sewerage treatments and acceptance towards applications of biosolids. The study adopted the Education, Proof, and Persuasion (EPP) framework as the primary intervention mechanism to assess the public perception where a total of 200 respondents participated in the survey. The instrument was designed to evaluate key parameters including public awareness, perceived risks, acceptance levels, and the influence of socio-demographic factors on attitudes toward biosolids reuse within the Malaysian context (Indah Water Konsortium Sdn Bhd 2010). Statistical analysis of public acceptance towards various biosolids reuse applications showed that 90% of respondents agree with the use of biosolids as fertilisers/soil conditioner for non-food crops such as rubber plantation, horticulture, landscaping and gardening as well as processing into building material (Farina 2010). This acceptance rate could be enhanced with educational and awareness tools to inform the public about the importance of environmental

conservation and sustainability through the continued reuse of biosolids. This intervention approach able to increase respondent's acceptance while lowering respondent's uncertainty as well as rejection in regard to biosolids reuse.

CIRCULAR ECONOMY FOR BIOSOLIDS MANAGEMENT

A circular economy for biosolids management focuses on reusing and recycling biosolids to create sustainable and economically viable products, minimizing waste and closing the loop on resource use (Collivignarelli et al. 2019). This approach involves several key concepts, such as resource recovery, product development, sustainable practices and economic viability. Resource recovery entails extracting valuable nutrients like nitrogen and organic matter, as well as energy in the form of biogas from biosolids. These resources can then be used to develop products such as fertilisers, soil conditioners and construction materials (Mukesh et al. 2023). Sustainable practices are implemented to treat and reuse biosolids in environmentally friendly ways reducing the reliance on the landfills (Braine et al. 2024). To achieve a circular economy in biosolids management, the process begins with the effective treatment of sewage sludge to recover valuable resources and ensure safe, sustainable reuse.

Nutrient recovery is a primary goal where biosolids can be applied to agricultural land as fertiliser, enriching soil with essential nutrients and reducing reliance on chemical fertiliser (Ahmed et al. 2024). Anaerobic digestion of biosolids produces biogas, a renewable energy source that can power wastewater treatment plants or be supplied to the grid, thus reducing greenhouse gas emissions and fossil fuel dependence (Derick et al. 2023). Biosolids also serve as soil amendments in land reclamation projects, restoring degraded lands and promoting vegetation growth, which supports ecosystem restoration and biodiversity (Sánchez et al. 2004). Composting biosolids with other organic materials creates a high-quality soil amendment for landscaping and horticulture, diverting organic waste from landfills and mitigating greenhouse gas emissions (Sarah et al. 2023). Integrating these practices into a circular economy framework transforms biosolids from waste into valuable resources, promoting resource efficiency, reducing environmental impact, and supporting sustainable development. In 2022, IWK with the collaborative partner has initiate a pre-commercialisation research study in converting biosolids into organic fertilisers to assess the feasibility of large-scale production by evaluating the technical and commercial viability of the process, as well as ensuring market acceptance and effectiveness. The benefits of this approach include

environmental protection through lower greenhouse gas emissions and reduced landfill use, alongside resource efficiency by maximising the use of nutrients and organic matter from biosolids. Implementing a circular economy for biosolids management offers a sustainable and economically viable solution for wastewater treatment facilities, aligning with global goals for resource efficiency and environmental protection by turning waste into valuable resources.

However, implementing a circular economy for biosolids management may presents several challenges that need to be addressed for widespread adoption and success. The technical complexity of converting biosolids into valuable products may requires advanced technologies and infrastructure such as drying, pyrolysis which can be costly, safely, effective and may need to meet the environment regulatory requirement (Vincenzo et al. 2024). Developing efficient processes for nutrient recovery, energy generation and the production of bio-based materials often involves significant research and development investments. Additionally, ensuring the consistent quality and safety of these products, such as fertilisers, can be technically challenging due to the variability in sewage sludge composition (Vaithyanathan 2021). Stringent regulations governing the reuse of biosolids can vary significantly between regions, creating a complex regulatory. In some cases, existing regulations may not adequately support innovative circular economy practices, necessitating updates or new policies to facilitate their adoption. Navigating this regulatory environment requires significant expertise and resources (Bakan et al. 2021). Social challenges involve public perception and acceptance of products derived from biosolids, with concerns about safety and potential contamination hindering market acceptance (Hannah et al. 2022). Educating stakeholders about the benefits and safety of these products is crucial for overcoming these barriers. Addressing these challenges requires a multi-faceted approach, including investing in research, fostering partnerships, updating regulatory frameworks, and engaging in public education to achieve a sustainable and economically viable circular economy for biosolids management.

CHALLENGES IN COMMERCIALISING BIOSOLIDS REUSE IN MALAYSIA

Despite positive outcomes from past research highlighting the benefits and potential of biosolids reuse, the impact on actual commercial implementation remains limited. One major limiting factor is the scale of study, as many research study have been conducted on a small or pilot scale which

do not translate effectively to large-scale commercial applications. This increases the risk for potential commercial off-takers and hinders the initiative to commercialise biosolids reuse projects. Additionally, there are currently no recycling plants in Malaysia to process biosolids into various valuable products, resulting in a lack of commercial-scale data for benchmarking. This gap has made it challenging to gather operational data and performance needed to demonstrate economic viability and effectiveness thus creating a significant barrier for investors and stakeholders. Moreover, uncertain market penetration strategies pose significant challenges such as difficulties in identifying and reaching target markets, understanding consumer preferences and establishing effective distribution networks. These uncertainties and challenges create a major hurdle for investors and stakeholders, who may be reluctant to commit to biosolids recycling projects. Addressing these issues is crucial to overcoming barriers and moving towards successful commercialisation.

FUTURE OF BIOSOLIDS REUSE

In line with the Government Green Technology Master Plan (GTMP) which targets zero biosolids disposal by 2030, advancing the future of biosolid reuse requires strategic actions. Establishing dedicated recycling facilities in Malaysia is essential to process biosolids into valuable products and generate the commercial-scale data needed for effective benchmarking. Therefore, IWK is seeking funding from government agencies and private investors to establish these facilities to initiate the first commercial scale recycling plant, thereby bridging the data or infrastructure gap and demonstrating the feasibility of sustainable biosolids reuse. Comprehensive market research will help identify target markets, understand consumer needs, and develop robust market entry and distribution strategies. Increasing public awareness and education about biosolids reuse benefits will foster greater acceptance and demand. Supportive policies and financial incentives are crucial to encourage investment and growth in this sector. Addressing these areas will help to overcome existing challenges, align with the GTMP's goal of achieving zero biosolids disposal by 2030 and support the realisation of significant environmental and economic benefits. By implementing effective recycling practices and leveraging supportive policies, the potential for sustainable biosolid reuse can be achieved, contributing to a greener and more resource-efficient future.

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DECLARATION OF COMPETING INTEREST

None.

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