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# ASSESSMENT OF LANDFILL PROTECTION SYSTEMS IN JAPAN – A CASE STUDY

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## ABSTRACT

Landfilling of untreated waste is still seen as an acceptable practice in many developed countries. Sanitary landfills are facilities for the disposal of untreated mixed municipal solid waste as a major waste stream. The Waste Management and Public Cleansing Act of 1970 is the main waste legislation in Japan. Waste management methods differ in Japan from the European Union and other countries. As waste incineration is prevalent in Japan, the final waste disposal rate in landfills is extremely low, occupying less than 5% of the waste generated. In Japan, there are obligatory barrier systems, treatment facilities for leachate and concrete structures for major facilities (waste storage structures, barriers, and leachate treatment facilities), landfill operations (dumping and soil covering) and management facilities (weighing and monitoring equipment) which are identified in the Guideline Manual of Landfill Site. This work examines the landfill protection systems in Japan based on two case studies from selected research facilities.

**Key words:** Japan, waste management, sanitary landfill, sealing systems

## INTRODUCTION

Over the past decade, the constantly growing industrial production and trade in many countries of the world have accompanied a rapid increase in the production of municipal solid waste (MSW) (Vaverková, 2019). Around the world, waste management (WM) seems to be a challenging task with serious implications for the health, conservation of natural resources, stability, and sustainable wealth of a nation (Yaashikaa et al., 2022). Landfilling of untreated MSW is still seen as an acceptable practice in many developed countries if highly sophisticated facilities are utilised to fulfil the purpose (Madon, Drev & Likar, 2019). Sanitary landfills are facilities for the disposal of untreated mixed MSW as a major waste stream. Landfills for the disposal of mechanically-biologically-treated residual MSW or for the disposal of waste-to-energy bottom ash do not meet such a definition (Madon, Drev & Likar, 2020). Sanitary landfills can be described as a place where controlled waste disposal is carried out in an environmentally responsible manner. In 1937, the Fresno municipal sanitary landfill opened in Fresno, California. It is considered to be the first modern sanitary landfill in the USA, innovating in the techniques of trenching, compacting and daily covering of waste with soil (Ireaja, Okeke & Opara, 2018). Modern sanitary landfills are designed as sealed facilities that isolate the buried waste from the surrounding environment indefinitely. As such, the design focuses

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on landfill lining systems, associated construction quality control and management of safety assurance during the pre-operational and closure phases of the landfill (Rowe, 2012; Madon et al., 2019). Nevertheless, due to different regulations, sealing and reclamation landfill methods vary worldwide.

Japan's WM system is characterised by the existence of two independent basic acts on WM and material recycling, under which laws on the recycling of specific items are determined (Sakai et al., 2011; Ishimura & Takeuchi, 2019). The Waste Management and Public Cleansing Act is the main WM legislation in Japan (Ishimura & Takeuchi, 2019; Katsumi et al., 2021). The Act classifies waste into MSW (household waste) and industrial waste (business waste) (Ishimura & Takeuchi, 2019). The legal framework is similar to that of the European Union (EU) and Korea (Sakai et al., 2011). However, it should be highlighted that Japan participates in the realisation of the sustainable development goals (SDGs) established by the United Nations in 2016 (United Nations, 2022). In 2018, the incineration of MSW in Japan accounted for ~80% of all municipal waste (Katsumi et al., 2021; Klein, 2022), whereby the recycling rate was ~19% (Ministry of Environment of Japan, 2020; Honma & Hu, 2021; Klein, 2022) and landfilling ~1% (Ministry of Environment of Japan, 2020; Klein, 2022). Compared to 2014, the amount of waste landfilled decreased by 9% (Amemiya, 2018). By 2020, there were about 1,600 final waste disposal facilities in Japan, but that number has been steadily declining over the past decade (Klein, 2022).

Moreover, due to strict government regulations and very limited land availability, newer technologies have been developed here. Japan can be considered a leader in developing and implementing traditional and cutting-edge waste-to-energy (WtE) technologies, such as thermal treatment plants (Themelis & Mussche, 2013).

Japan's population is extremely dense, and its land resources are scarce (Ishimura & Takeuchi, 2019). Due to the securing of landfill sites, it is difficult to find a new inland location for the construction of landfills (Weng et al., 2015). This led to the creation in 1970 of a legal system that allows for coastal and/or offshore landfilling based on the concept of creating new land by remediating waste for ports, harbours, and other investments (Katsumi et al., 2021). According to Asakura, Matsuto and Inoue (2010), the first landfill-related regulation (1971) stated that measures to prevent the pollution of surface and groundwater for public use by leachate from landfill sites should be taken but did not indicate the required equipment and performance definitively. In 1977 according to the "Instructions for technical standards on landfill facility for municipal and industrial solid waste" the setting up of barrier systems and treatment facilities for leachate became obligatory. In 1989, concrete structures became a requirement for major facilities (waste storage structures, barriers, and leachate treatment facilities) and landfill operations (dumping and soil covering) and management facilities (weighing and monitoring equipment) were finally specified in the "Guideline manual of landfill site" (Tanaka, Tojo & Matsuto, 2005; Asakura et al., 2010). Because the construction regulations and sealing systems used for landfills in Japan differ from European standards, it was decided to analyse them in more detail.

The following paper presents an assessment and review of the sealing systems of two different municipal and industrial landfills located in Okayama Prefecture, Japan.

## MATERIAL AND METHODS

### Types of landfills and sealing systems in Japan

In Japan, waste landfills are divided into three categories: (i) inert waste landfills, accepting stable industrial waste; (ii) MSW and degradable waste landfills, accepting MSW and perishable, but not hazardous industrial waste; (iii) hazardous waste landfills. The first type of landfill, the inert waste, and stable industrial landfill, accepts, i.e. plastic waste, metal waste, glass, concrete, ceramic, and rubber waste. Because the listed wastes are not degradable, both a liner system and leachate treatment system are not necessary (Fig. 1a). However, if industrial waste does not pass the elution test, which determines the hazardousness of the waste, it is then accepted at hazardous waste landfills. The type of elution test is selected based on Leachate Test No 13 (JLT13) from the Environmental Agency in 1973 (Ministry of the Environment of Japan, 1973) and its updates.

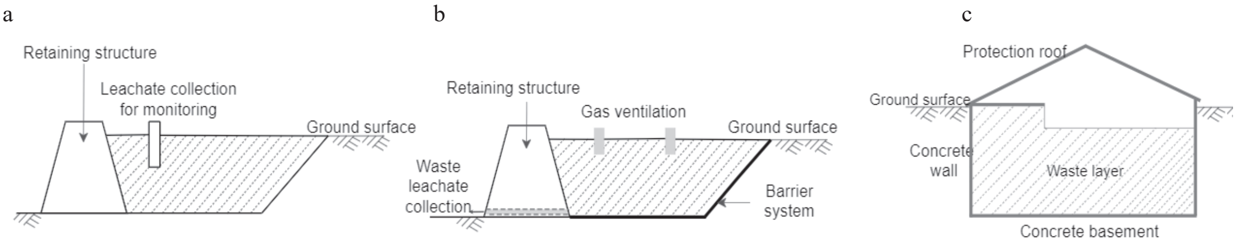



**Fig. 1.** Types of landfills in Japan: a – inert waste landfill; b – municipal solid waste landfills; c – hazardous waste landfills

Source: Katsumi et al. (2021) modified by the authors.

The liquid obtained in the elution test is formed by shaking the liquid and solid fractions, and then after separation, passed through a one-micrometre filter. The chemical composition of the liquid is tested to verify that the concentrations of substances in it have not exceeded the limits of 34 items, including lead, arsenic and selenium, for which a limit standard is 0.3 mg·l$^{-1}$. Trichloroethene, tetrachloroethene and benzene have a limit standard of 0.01 mg·l$^{-1}$ and 0.09 mg·l$^{-1}$ for cadmium has been set (Katsumi et al., 2021).

The second type – MSW landfills accept degradable but non-hazardous waste, with the hazardousness of the waste assessed by whether the concentrations of chemicals in the waste do not exceed the limit values shown above. No matter what guidelines exist in the country, MSW landfills should have a bottom liner, leachate drainage system, retaining structures and a landfill degassing system (Jessberger, 1993; Wysokiński, 2009; Koda, 2011; Fig. 1b). Due to the possibility of infiltration of leachate from biodegradable waste, MSW landfills have strict sealing and soil regulations for the bottom liner, including the permeability coefficient $1 \cdot 10^{-8}$ m·s$^{-1}$, according to Japanese guidelines (Ministry of Health and Welfare of Japan, 2001). However, when the landfill is located on impermeable soil with a thickness of at least 5 m, then the permeability coefficient must equal $1 \cdot 10^{-5}$ m·s$^{-1}$ or less (Ministry of the Environment of Japan, 2012). Bottom barrier systems vary depending on the country's adopted regulations, but nevertheless, systems consisting of natural clay, crack-free natural rock, compacted clay with a geomembrane, a layer of asphalt concrete with a geomembrane or a double geomembrane are commonly used in Japan (Katsumi et al., 2021).

Figure 2 shows the bottom barrier system of MSW landfills that are used worldwide. The graphic is enhanced with Japanese guidelines for the thickness of individual layers, according to Jingging (2014). For Japanese landfills, the hydraulic head of the leachate collection layer ($h_L$) should be ≥ 0.5 m, with the thickness of the high-density polyethylene (HDPE) geomembrane (GM) ≥ 1 mm, the thickness of the compacted clay liner ($h_C$) ≥ 0.5 m and the permeability coefficient ($k_c$) ≤ $1 \cdot 10^{-8}$ m·s$^{-1}$.

Depending on the regulations of the countries, the limit standards of the indicators: $h_L$, $h_G$, $h_C$ and $k_c$ are different. Table 1 shows the limit values of the indicated parameters for Japan, China, the USA, Germany, and

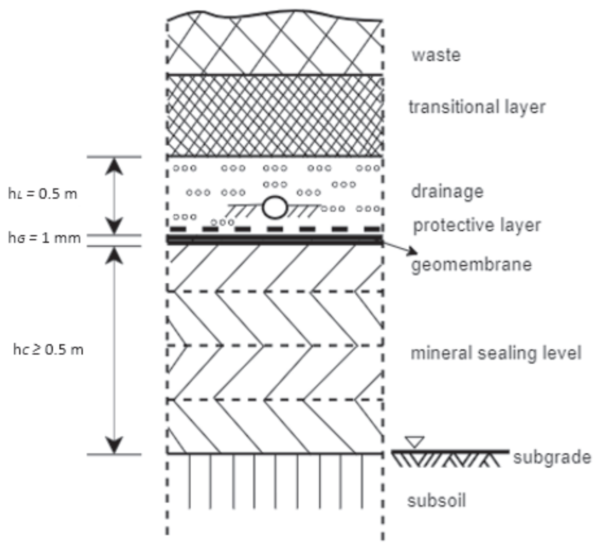



**Fig. 2.** Sealing system of municipal solid waste landfills

Source: Jakimiuk (2022) modified by the authors.

Poland. The most restrictive are German regulations, which establish that the kc has to be $\leq 1 \cdot 10^{-10}$ m·s$^{-1}$, while Japanese landfills assume that the optimal rate will be $\leq 1 \cdot 10^{-8}$ m·s$^{-1}$. Jingging (2014), in his study of the infiltration of pollutants through the liner system found that the concentration of pollutants is lowest for the German barrier system due to the fact that $h_G$ and $h_C$ are the largest and $k_c$ is the smallest, while Japanese standards indicating $h_G$ and $h_C$ with the lowest values and $h_G$ with the largest, are more economical.

**Table 1.** Legal regulations of selected countries on the selection of barrier parameters used for sealing municipal solid waste landfills

| Country | Parameter | | | |
|---|---|---|---|---|
| | $h_L$ [m] | $h_G$ [mm] | $h_C$ [m] | $k_c$ [m·s$^{-1}$] |
| Japan | 0.5 | 1 | 0.5 | $1 \cdot 10^{-8}$ |
| China | 0.3 | 1.5 | 0.75 | $1 \cdot 10^{-9}$ |
| USA | 0.3 | 1.5 | 0.6 | $1 \cdot 10^{-9}$ |
| Germany | 0.3 | 2 | 0.75 | $1 \cdot 10^{-10}$ |
| Poland[a] | 0.5 | 1.5–2[b] | 0.5 | $1 \cdot 10^{-9}$ |

[a]Polish Regulation of the Minister of Environment of 2013 on landfills with amendments (Rozporządzenie Ministra Środowiska z dnia 30 kwietnia 2013 r. w sprawie składowisk odpadów).

[b]Wysokiński (2009).

Source: Jingging (2014) modified by the authors.

The third type of landfill is hazardous waste landfills (Fig. 1c), also known as 'strictly controlled type landfills'. These landfills dispose of hazardous waste that exceeds the leaching criteria for heavy metals. Landfills are required to be constructed with solid concrete walls and a concrete base. The top of the landfill is covered by a concrete structure (Ministry of Environment of Japan, 2012; Tojo, Ikeda, Matsuo & Matsuto, 2020).

## Surveyed landfill sites

This study was conducted on two landfill sites located in Japan: (i) a coastal landfill for industrial waste in Mizushima and (ii) a roofed landfill in Tsuyama. Mizushima is a coastal area located in Kurashiki, which is the second largest city in Okayama prefecture in Japan, with a population of 474,592 inhabitants in 2020 (City Population, 2022). The western part of Kurashiki is a huge concentration of heavy industry built on reclaimed land in the Seto Inland Sea, while the Bikan Historical Area, thanks to a compact, well-preserved Edo-era merchant district called Bikan Chiku (Bikan District), is one of the tourist attractions of Okayama prefecture.

The location of the Mizushima coastal industrial landfill is shown in Figure 3. Landfilling in that place began in 1979, and the area for waste disposal was about 960,000 m$^2$ with a landfill capacity of about

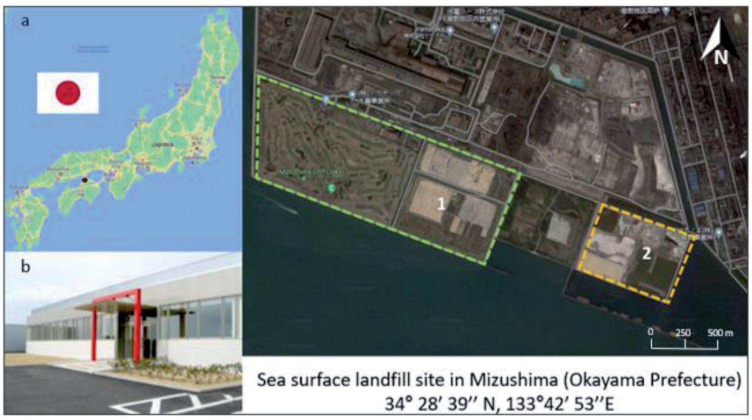



**Fig. 3.** Location of an industrial waste landfill in Mizushima: a – location of landfill on the map; b – recycling facilities; c – site plan of the landfill from above: (1) reclaimed old landfill and existing recycling facilities; (2) active part of the landfill

Source: own work.

13 million m$^3$. Landfill No 1 operated for 34 years and was closed and reclaimed as a water treatment plant and golf course in May 2013, whereas Landfill No 2 started operation in 2009, occupying an area of approx. 230,000 m$^2$ with a capacity of approx. 2.4 million m$^3$ (Okayama Prefectural Environmental Conservation Agency, 2022).

Apart from industrial landfill, environment-related facilities such as the Mizushima Clean Center (incinerating sewage sludge and plastic waste with an energy-generating capacity of 1,200 kWh) and the Kurashiki Recycling Center (sorting fluorescent lamps and bottles with an efficiency of 15 t per 5 h) are being developed on the landfill site. In addition, the Mizushima management office is working on solar power generation, wind power generation, and rooftop greening (Okayama Prefecture Environmental Conservation Foundation, 2022). Mizushima coastal industrial landfill accepts all industrial waste produced from the construction industry and specially controlled industrial waste, which is hazardous to the environment. In 2020, the facility accepted at the landfill: cinders (29,181 Mg·year$^{-1}$), particulate matter (51,440 Mg·year$^{-1}$), dirty mud (61,352 Mg×year$^{-1}$), waste plastics (10,506 Mg·year$^{-1}$), glass, concrete and ceramic waste (17,541 Mg·year$^{-1}$), mines (9.85 Mg·year$^{-1}$), debris (36,901 Mg·year$^{-1}$), scrap metal (68 Mg·year$^{-1}$), automobile and other crushed materials (2,293 Mg·year$^{-1}$), specially controlled industrial waste, e.g. waste asbestos, etc. (208 Mg×year$^{-1}$), mixed waste (2,558 Mg·year$^{-1}$), general waste (300 Mg·year$^{-1}$), disaster waste (71 Mg·year$^{-1}$), which in total gives an amount of 222,269 Mg·year$^{-1}$ (New Disposal Facility Development Project Environmental Management Report, 2020).

The second landfill is the roofed Tsuyama Landfill (Fig. 4). The city of Tsuyama is in the northern part of Okayama Prefecture, Japan, and had a population of 99,937 inhabitants in 2020 (City Population, 2022). The landfill is located in the western suburbs of the city. In the immediate vicinity of the landfill, there are wooded areas along with small bodies of water, and farther away, there is farmland. Tsuyama Area Resource Recycling Facility Association was founded on April 2009 and aims to reduce and recycle waste in Tsuyama and four towns. The Tsuyama Area Clean Center Association, manages and operates a heat recovery facility, a recycling plant, and a landfill since 2016. The daily capability of the heat recovery plant here is estimated at 128 Mg of waste, while the recycling plant facility achieves a capability of 38 Mg·day$^{-1}$. The roofed landfill, which is the third facility located at the Tsuyama Area Clean Center Association, covers an area of 2,530 m$^2$, with a capacity estimated at 30,000 m$^3$ (Tsuyama Area Resource Recycling Facility Association, 2022).

Nevertheless, despite the large area the facility occupies, only waste that cannot be recycled or incinerated

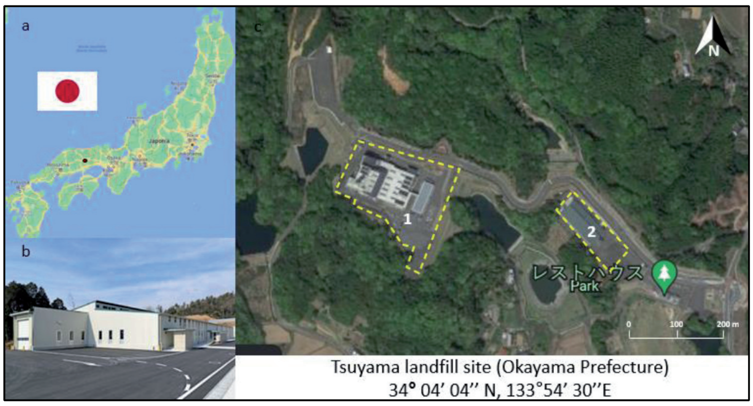



**Fig. 4.** Location of Tsuyama municipal solid waste landfill site: a – location of landfill on the map; b – recycling facilities; c – site plan of the landfill from above: (1) heat recovery/recycling facility; (2) roofed landfill

Source: own work.

(non-combustible residue) is accepted here. The generated leachates are fully and automatically controlled and processed (pH control, sterilisation, and released to sewerage).

## DISCUSSION AND ASSESSMENT

### Selected landfill sealing systems

To protect the areas surrounding the landfill from undesirable negative impacts, Mizushima coastal industrial landfill was properly sealed before receiving waste. Impermeable steel structures were used for the construction of the coastal landfills, along with embankments to prevent water retained inside the landfill from seeping outside. In addition, double steel pipe sheet piles (SPSP) were used to construct the embankment (Fig. 5), giving the effect of providing additional security. For the joints between steel pipe sheet piles, special leak-proof rubber and rubber that swells in contact with water are used to fill the gap between the joints to ensure waterproofness. Bank protection should perform the function of seepage control to protect the environment from uncontrolled leachate from waste containing toxic substances (Inazumi & Kakuda, 2013). To strengthen the SPSP cutoff wall, filling material composed of a sand fraction is often used (Inazumi & Kimura, 2009).

In coastal landfills, the difference in water level between the inside and outside is controlled daily so that it does not exceed 2 m (Inazumi, Ohtsu, Otake, Kimura & Kamon, 2009) to prevent uncontrolled overflow. Figure 6 shows the method of waste deposition at Mizushima coastal landfill. In the area below sea level, the operation of the landfill is carried out using the so-called ‘thin layer method’, in which waste is deposited directly by delivery vehicles from the floating platform. Meanwhile, in land-based areas, waste is deposited by a dozer. Before the waste is placed in the water, it is weighed, and the temperature is checked to prevent fires.

The quality of marine waters bordering the landfill is regularly tested at several points and it is verified that the permissible standards are not exceeded for: (i) public water bodies, (ii) particular water bodies defining their type. In 2020, four control measurements of basic marine water parameters (in the surface layer and medium depth), such as pH, total nitrogen content (*N*), phosphorus content (*P*), chemical oxygen demand (*COD*) and heavy metals content (*HM*), were made at four piezometric points: three of them were sites in the surrounding marine area south of the landfill (A-3, A-4 and A-6) and one point (A-5) where treated leachate was discharged (Fig. 7).

The results of this survey showed that most of the items were in accordance with environmental stan-

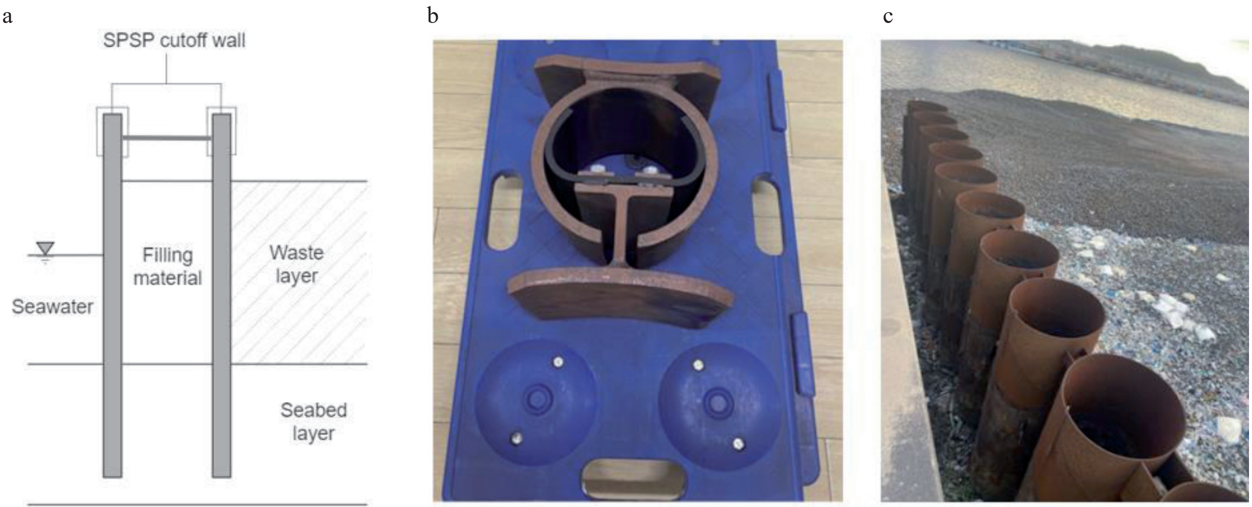



**Fig. 5.** Coastal landfill barrier: a – simplified scheme of double SPSP cutoff walls in Mizushima landfill; b – steel pipe connections; c – cutoff wall steel pipes

Source: own work.

a b

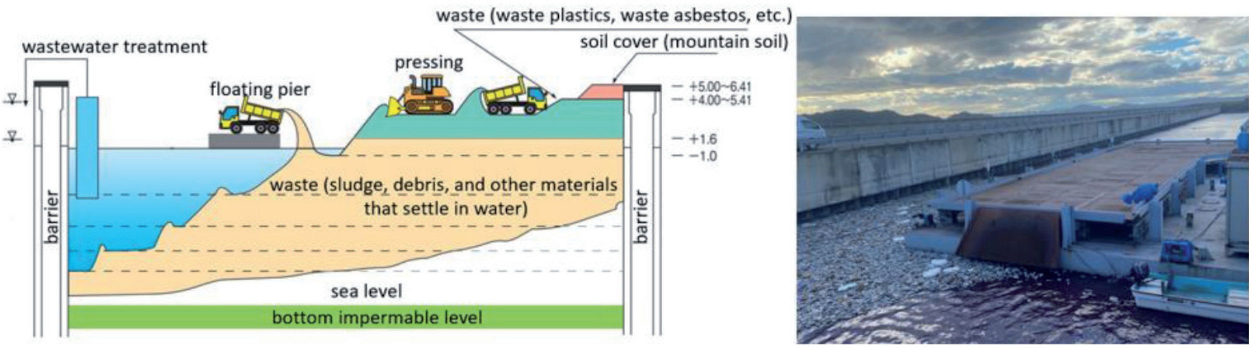



**Fig. 6.** Industrial waste landfill at Mizushima: a – scheme of waste placement; b – waste discharge platforms

Source: [a]Okayama Prefecture Environmental Conservation Foundation (2022); [b]own work.

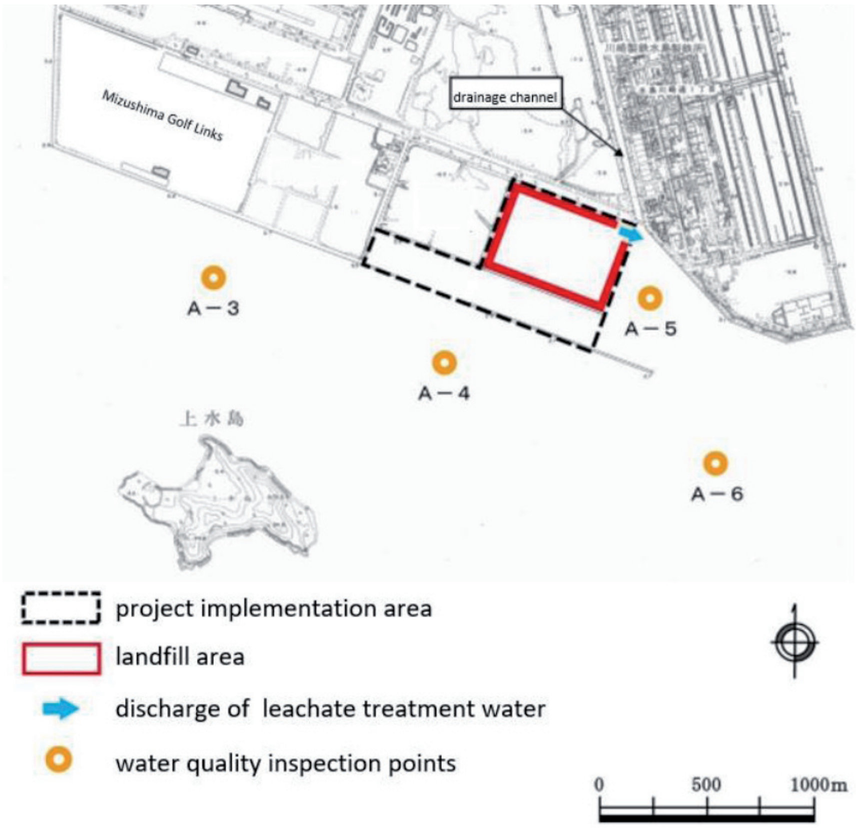



**Fig. 7.** Water intake control points in Mizushima

Source: Okayama Prefecture Environmental Conservation Foundation (2022).

dards. It has been noted that water quality deteriorates after rainfall, and water quality is also affected by other factors, such as fast ocean currents and changes in the flow direction. At point A-5, water quality was greatly affected by runoff from the drainage channel of the Mizushima industrial zone. Although there were some items that did not comply with the standard, the results were compared with the preliminary investigation and the results of monitoring the quality of the discharged water, and no changes in the water quality of the sea area surrounding the landfill area were observed (Okayama Prefectural Environmental Conservation Foundation, 2021).

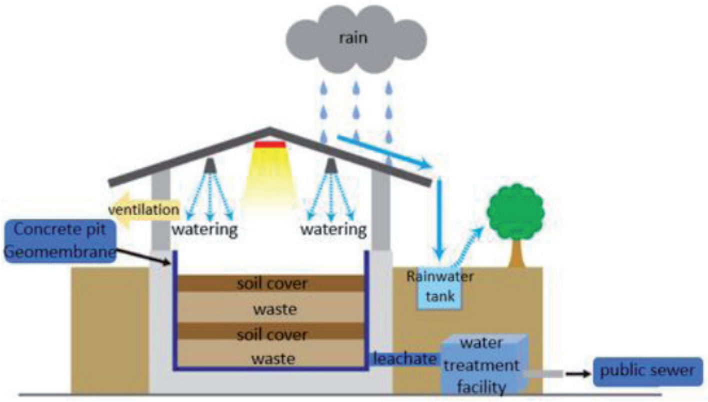
The issue of climate change and rising sea levels is increasingly being addressed in the literature, and thus the risk of environmental contamination through the potential release of liquid and solid waste materials is increasing (Nicholls et al., 2021). Another problem is related to the declining quality of impermeable walls, which could cause large-scale contamination of the marine area. Inazumi, Sekitani, Chae and Shishido (2017) evaluated the risk of leakage of undesirable substances due to the degradation of walls to determine the most optimal repair method. They estimated that there is a 10% probability of uncontrolled leakage after 15 years of use of double steel cutoff walls resulting from technical deterioration. Nevertheless, it has not been proven whether steel walls can adequately retain toxic substances over time. Despite any doubts, steel walls at coastal landfills are very commonly used around the world.

The second facility studied – the Tsuyama landfill – is a roofed landfill. Roofed landfills have gained popularity in Japan nowadays. This is because it reduces the spread of odours, eliminates the visibility of waste and it potentially blowing away as well as because of the so-called syndrome: 'just not in my backyard', which has made the construction of new landfills extremely difficult (Asakura et al., 2009). Due to the high population density, there is also a lack of open space in Japan to build a landfill far enough away from residential areas.

In addition to stopping odour emissions and waste blowing away, roofed landfills also protect against excessive hydration of waste caused by rain, which contributes to the production of toxic leachate. According to Zhang and Matsuto (2013), 11 covered landfills in Japan have a removable roof created from a translucent plastic or steel sheet membrane. According to Weng (2016), the cost per cubic meter of a conventional landfill was estimated at 4,519.70 yen, with the construction of a roofed one at 67,490 yen. Nevertheless, the potential environmental and social benefits exceed the given costs.

A roofed landfill in Tsuyama stores waste that cannot be recycled or incinerated (non-combustible residue). Figure 8 shows a simplified diagram of the landfill, including its sealing. The landfill is sealed with a concrete pit with waterproof sheeting, while leachate is discharged to a wastewater treatment facility at the site and then diverted to a public sewer. The landfill has unloading boxes in which waste is stored. The waste is placed alternately with the soil and is periodically sprinkled and ventilated for stabilisation (Tsuyama Area Environmental Technology Corporation, 2022).

a




b

**Fig. 8.** Roofed Tsuyama landfill site: a – scheme of seal used; b – inside view of the landfill

Source: [a]Tsuyama Area Environmental Technology Corporation (2022); [b]own work.

The use of landfill roofs works well in places where the amount of waste sent to landfills is low and when a country has a different predominant waste management system, and landfilling is only a minor percentage of that. Japan is an example of a country where the percentage of waste transferred to landfills is < 5%. In contrast, in European countries, due to landfill percentages > 10%, roofing is mostly used for hazardous waste landfills. An example is the roofed landfill Pozďátky located in Vysočina, the Czech Republic.

## CONCLUSIONS

- Landfilling of untreated municipal solid waste is still an acceptable practice of waste treatment if highly sophisticated facilities are utilised to fulfil the purpose.
- The sanitary landfill is a land-based waste disposal method designed to minimise its impact on the environment and public health by efficiently utilising engineering skills.
- In Japan, waste management methods differ from those in European and other countries.
- The system is based on waste incineration (approx. 80%), which means that only approx. 1% of waste goes to landfills, thus, there is no need for large-scale landfills, as used in European and other countries.
- Roofed landfills are also used, which is rarely implemented in European and other countries.

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### Authors' contributions

Conceptualisation: A.J., Y.M. and M.D.V.; methodology: A.J., A.P. and M.D.V.; validation: Y.M. and A.P.; formal analysis: A.J., Y.M. and M.D.V.; investigation: A.J., Y.M. and M.D.V.; data curation: A.J., A.P. and M.D.V.; writing – original draft preparation: A.J. and M.D.V.; writing – review and editing: Y.M. and A.P.; visualisation: A.J.; supervision: Y.M. and M.D.V.

All authors have read and agreed to the published version of the manuscript.

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## OCENA SYSTEMÓW OCHRONNYCH SKŁADOWISK ODPADÓW W JAPONII – STUDIUM PRZYPADKU

### STRESZCZENIE

W wielu krajach rozwiniętych składowanie nieprzetworzonych odpadów jest nadal dopuszczalną praktyką. Składowiska sanitarne to obiekty służące do unieszkodliwiania zmieszanych stałych odpadów komunalnych jako głównego strumienia odpadów. W Japonii ustawa o gospodarce odpadami i porządku publicznym to główne prawodawstwo dotyczące odpadów. Metody zarządzania odpadami różnią się w Japonii od tych stosowanych zarówno w Unii Europejskiej, jak i innych krajach. Spalanie odpadów w Japonii jest powszechne, z tego powodu poziom wskaźnika ostatecznego usuwania odpadów na składowiska jest niezwykle niski, stanowiąc mniej niż 5% wytworzonych odpadów. W Japonii obowiązkowo stosuje się systemy barier i konstrukcji betonowych dla obiektów do magazynowania oraz składowania odpadów, a także zakładów przetwarzania odcieków według odpowiednich wytycznych dotyczących składowisk odpadów. W artykule przeanalizowano systemy ochrony składowisk stosowane w Japonii na podstawie dwóch studiów przypadków z wybranych obiektów badawczych.

**Słowa kluczowe:** Japonia, gospodarka odpadami, składowisko odpadów sanitarnych, systemy uszczelnień