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Solutions for urban sanitation: A case study of Imhoff tank technology in Bandung, Dutch East Indies (1917–1938)

Abstract. *This research investigates how municipalities managed wastewater in the Dutch East Indies in the early 20th century. We focus on Bandung, one of the most important cities in the Dutch East Indies, which transformed into a modern residential area, economic center, and seat of government. This research combines primary data from written sources and field observations using historical-archaeological methods. The written sources include official reports from the Public Works Department, Civil Health Department, Bandung City Council, old maps, sewer network designs, environmental engineering journals, and newspapers published from 1909 to 1941. Using the techno-environmental approach introduced by Martin V. Melosi, this study considers urban technology as a strategic response by decision-makers to address the challenges faced by developing cities in the early 20th century. The study reveals that*

Bandung City faced environmental problems, such as the natives' habit of defecating in rivers and open spaces, spreading diseases, and potentially polluting river water. These problems arose due to the lack of sanitation facilities and the densely populated settlements, especially in the native and Chinese residential areas. To address these challenges, policymakers, environmental engineers, and researchers initiated the design and implementation of sewers, public toilets, and wastewater treatment plants in 1917. The Municipality integrated sewers with the Imhoff Tank sewage treatment technology developed by researchers and engineers from 1932 to 1938 to introduce circular sewage treatment. Imhoff Tanks was a significant technological innovation in the Dutch East Indies. In the early 20th century, only a handful of cities in the Dutch East Indies, including Bandung, Medan, and Yogyakarta, had integrated sewer networks. Among the cities that did have sewer networks, Bandung pioneered the implementation of the Imhoff Tank. As a result, it emerged as an important laboratory and development center for Bandung and the entire Dutch East Indies. The Imhoff Tank treatment process, which produces clean water, fertilizer, and methane gas that can be used as vehicle fuel, was part of a proactive strategy pioneered by policymakers in Bandung in the early 20th century, reflecting their vision to create a healthy and sustainable city.
***Keywords**: public health; open defecation; sewage; Imhoff tank; urban technology*

Introduction.

Ensuring a healthy environment stands as an imperative for human well-being. The allure and grandeur of an urban setting hold significance only when underpinned by a healthy living environment. Studies indicate an unhealthy environment amplifies residents' mortality risk (Sun & Shang, 2015). Sanitation systems have historically been a cornerstone of healthy environments and are considered pivotal in advancing civilizations, evident in ancient societies such as the Indus River Valley, Mesopotamia, and Rome (Colman, 1995; Cosgrove, 1909). As elucidated by Melosi (2008), an optimal sanitation infrastructure comprises three key elements: a robust provision of clean water, a mechanism for the disposal of waste, refuse, excreta, and a system designed to safeguard public health. The advent of capitalism and industrialization during the 19th century in Europe exacerbated challenges related to inadequate sanitation infrastructure. The notorious episode of the Great Stink in London, England, vividly exemplifies the dire state of sanitation during that period (Halliday & Hart-Davis, 2001).

Throughout history, concerns regarding hygiene, environmental health, and the prevalence of epidemics have persisted in tropical regions like Southeast Asia. The advent of colonialism in the Dutch East Indies (Indonesia) brought challenges for the Dutch East India Company (*Vereenigde Oostindische Compagnie*) in contending with swampy environmental conditions and the looming threat of a malaria outbreak in Batavia, one of the region's major trading hubs (van den Brug, 1997). These issues began to be addressed in the early 19th century when Governor General H. W. Daendels relocated the governmental center from Old Batavia to Weltevreden.

Until the early 20th century, public health and environmental hygiene posed significant challenges in the Dutch East Indies. The emergence of new cities in the region exacerbated urban issues like overcrowding, dense slum settlements, inadequate drainage and sewage systems, limited access to clean water, and a conducive tropical climate that facilitated the spread of diseases (Jaelani, 2018; Reerink, 2015; Tillema, 1915, 1919). Major cities like Surabaya, Semarang, and Batavia experienced cholera, malaria, typhoid, and dysentery outbreaks. Health professionals and sanitarians attributed these outbreaks to poor living conditions in the slums and the lack of hygiene practices among the native population (Gemeente Semarang, 1931; Tillema, 1919). The threat of diseases and low hygiene standards posed potential impediments to the rapid economic growth of the Dutch East Indies.

The less favorable health conditions in Batavia, compounded by its hot climate, prompted the proposition of relocating the center of the Dutch East Indies government from Batavia to Bandung. Renowned environmental health expert H. F. Tillema highlighted Bandung's potential for enhanced work productivity, cool weather, and a healthier living environment for the European population ("Gezond Bandoeng," 1922; Reitsma & Hoogland, 1927). With its advanced transportation networks, modern European districts, and commercial hubs, Bandung was conceived as an ideal settlement and administrative center for Europeans (Fakih, 2023). Simultaneously, it attracted native populations seeking employment opportunities (Himpoenan Soedara, 1936; Reerink, 2015). Governor General Paul van Limburg Stirum (1916–1921) was compelled by this vision of Bandung as an exemplary city, leading to the relocation of the central government offices to this city.

Despite its advantages, Bandung faced some challenges in terms of public health. The City Council (*Gemeente Bandoeng*) grappled with environmental issues rooted in poor sanitation practices during the colonial era. Despite ample clean water and a mild mountainous climate conducive to productivity, Bandung's native residents maintained notably low hygiene standards. Native inhabitants would defecate in the river and along major sewer lines, leading to contamination of these water sources with feces and pollutants. Moreover, these sewers were utilized for various purposes, including washing vegetables and clothes, bathing, and cleaning teeth (Tillema, 1915, 1916). In areas facing water scarcity, people resorted to using open latrines–holes dug in the ground–to meet their sanitation needs (Tillema, 1913).

In the late 19th century, the City Council and municipal government embarked on several initiatives to enhance the city. They undertook efforts to reclaim damp and swampy areas, rehabilitated villages inhabited by native populations, and initiated the paving of city streets (Kunto, 1984). The municipal administration implemented cutting-edge infrastructure and public services to address the impending challenges associated with waste management and the prevalent practice of open defecation among natives. This condition involved installing sewage pipes, establishing public toilets, and constructing a sewage treatment plant recognized as the Imhoff Tank Technologies (P. Thijsse Jr., 1934, p. 139). These facilities were designed to segregate solid and liquid components of sewage, mitigating organic matter and pathogens within it. Notably, the gas produced from the sewage treatment plant found utility as a fuel for vehicles, a technology previously adopted in Germany and France before World War II ("Methaangas in Plaats van Benzine Voor Auto's," 1937).

Based on the historical background described above, this research aims to investigate two main issues: (1) colonial urban environmental issues in the Dutch East Indies, mainly related to public health and wastewater management in residential settlements; (2) how the city government addressed these environmental issues through the development of infrastructure, city services, and the latest technological innovations in the early 20th century. The wastewater examined in this study pertains to domestic sources, encompassing household effluents such as fecal sludge.

We chose Bandung as the subject of this research due to its distinctive spatial and social structures during the colonial era. Like other early modern cities in the Dutch East Indies, Bandung's city in the early 20th century was segregated along class and race lines (Kusno, 2014; Roosmalen, 2008; Tunas, 2007). Bandung's significance for study lies in its developmental blueprint, which was shaped by envisioning a modern European city necessitating hygiene, economic prosperity, social cohesion, and cultural viability (Fakih, 2023).

To address the problem in this study, we employ the techno-environmental approach introduced by Melosi (1990). This perspective asserts that the integration of urban technologies was not spontaneous but rather a deliberate strategy by decision-makers to tackle the challenges faced by burgeoning cities during the 19th and 20th centuries (Melosi, 1990, p. 51). This approach examines how diverse technical systems, such as urban infrastructure and services, significantly contribute to the physical expansion of cities. In this research, we analyze sewer systems' design, implementation, and upgrading to achieve a sustainable urban environment. We initially mapped population distribution and density to commence this analysis while identifying prevalent health issues within the settlement.

The techno-environmental approach to studying urban environmental history is not a recent development. It gained prominence in America during the 1990s, primarily pioneered by Joel A. Tarr et al. (1984; 1996). Tarr meticulously traced the evolution of diverse technologies and waste disposal systems in the United States, notably addressing concerns about water pollution stemming from industrialization. Donald Worster (1992) significantly expanded the purview of environmental studies by delving into water management, irrigation, and landscape alterations in the American West. Martin V. Melosi (2008) offered a comprehensive perspective, examining sanitation issues, the evolution of infrastructure, and public health concerns in America from the colonial era to contemporary times.

Historical studies of urban environments in South Asia, particularly cities under British colonialism like Bombay and New Delhi, focus on issues such as hygiene, slums (Kidambi, 2001), water (Sharan, 2011), and sewage systems (Prashad, 2001). Within Southeast Asia, post-colonial countries' studies emphasize public health and infrastructure. The research investigates clean water supply in cities like Singapore (Otaki, Y., Otaki, M., & Sakura, 2007; Yeoh, 1993), Jakarta (Batavia) (Kooy & Bakker, 2014), Yogyakarta, Surakarta (Primaditya, 2022), and Bandung (Budiman, Ariwibowo, Saptono, Widyastuti, & Nurani, 2023). Several scholars have explored waste management historically in several cities in Indonesia: Malang (Hudiyanto, 2012), Medan (Affandi, Agustono, & Zuska, 2022), Surabaya (Husain, Indiyanto, & Sugiarti, 2023), and Cirebon (Mutawally, Zakaria, & Falah, 2024). Budiman's (2022) work touches on the history of sanitation in Bandung City but needs in-depth observations on infrastructure design patterns and sewage treatment technology. Therefore, this study addresses this gap by discussing Bandung's early 20th-century sewerage design and sewage treatment technology upgrades.

Research Methods.

This research adopts a historical archaeology method, emphasizing the complementary nature of archaeological and historical data as mutually reinforcing sources of evidence (Orser & Fagan, 1995). This approach is essential as reliance solely on archaeological data may provide an incomplete depiction of past human life (Sharer & Ashmore, 1979). Primary historical data were collected from early 20th-century publications, including official reports from the Bandung City Council (*Gemeente Bandoeng*), records from the Public Works Department (*Burgerlijke Openbare Werken*), documents from the Civil Health Department (*Dienst der Volkgezonheid*), a report from Civil Construction and Irrigation Department (*Civiele Gebouw en Waterstaat*), old maps of Bandung, engineering and scientific journals such as *De Ingenieur* and *Natuurwetenschappelijk Tijdschrift*, field notes by H. F. Tillema (*Kromoblanda, Kampongwee*), blueprints detailing Bandung's sewers and the Imhoff Tank installation, as well as publications from magazines and newspapers (*Preangerbode, Groot Bandoeng, Bataviaasch Nieuwsblad, De Locomotif*). Most primary sources we accessed were from the National Archives of the Republic of Indonesia (ANRI), The Royal Library of the Netherlands (*Koninklijke Bibliotheek*), and Leiden University Libraries Digital Collections. Supplementary to primary sources, recent research findings published in international journals serve as secondary sources to fortify the study. The archaeological data employed in this research encompasses the physical structure of the Imhoff Tank installation situated on Pelindung Hewan Street, Tegallega, Bandung City, along with the discernible remnants of the sewer infrastructure within the operations of the Tirta Wening Regional Company nowadays.

This research was carried out through a sequential approach comprising four key stages. It began by gathering historical records and on-site assessments of sewer infrastructure and the Imhoff Tank. Subsequent stages involved data categorization, verification for accuracy, and analysis using Melosi's (1990) techno-environmental approach. This comprehensive analysis included scrutinizing historical maps, demographic distributions, sewer designs, and details of the Imhoff Tank technology. Ultimately, findings were interpreted and systematically structured into three pivotal subchapters: outlining environmental problems, environmental countermeasures, and sewage treatment technology.

Results and Discussion.

During the late colonial period, Bandung, a city in the Dutch East Indies (Indonesia), underwent a significant transformation process, evolving from a traditional town (*dayeuh*) situated in the interior of West Java to a modern urban center (Lombard, 1996; Wertheim et al., 1958). This transformation was part of the broader urbanization process that occurred in other Dutch East Indies cities like Batavia, Surabaya, Semarang, and Medan, all influenced by the agrarian capitalism policies that the Dutch East Indies government implemented under the Ethical Policy era (Naas, 2007). The Dutch East Indies government made Bandung a hub for commerce and governance, exploiting its fertile soil, abundant water sources, and temperate climate due to its mountainous terrain (Bemmelen, 1934; Coolsma, 1881). Bandung's transformation significantly impacted its society and culture, such as the emergence of new social classes, ethnic groups, and lifestyles.

Bandung's transformation into a modern city was intricately linked to its designation as a municipality (*gemeente*) in 1906. Following this status change, Bandung entered a significant 'boom town' phase, during which the Dutch East Indies government inaugurated crucial government offices in the city, such as the War Department (1917), the Communications Department (1923), and the headquarters of the train service (1923–1924). The construction of these offices was facilitated by the existing transportation infrastructure dating back to the 19th century, including the main thoroughfare known as Post Road (*De Groot Postweg*) and the western railway line (Reitsma, 1928; Roosmalen, 2008). Concurrently, the mountainous regions surrounding Bandung developed into industrial hubs for private plantations cultivating commodities such as quinine, tea, coffee, and rubber. Bandung's transformation had significant implications for the city and the region, as it increased the population, economic activity, and political influence of Bandung in the Dutch East Indies (Naas, 2012; Nurwulandari & Kurniawan, 2020)

The city's rapid urban development attracted diverse communities, such as European colonizers, Chinese merchants, Arab traders, and Sundanese peasants, who sought livelihoods in Bandung. Residents from Priangan and Java regions also migrated to Bandung, drawn by opportunities in railway work, heavy industry, trade, and plantation labor (Himpoenan Soedara, 1936; Reerink, 2015). However, this population increase also brought about urban challenges such as slums, disease outbreaks, inadequate sanitation, and high mortality rates among both native and Chinese residents (Brand, 1958), as shown in Tables 1 and 2. These elevated mortality rates were strongly linked to socioeconomic factors such as poverty, substandard housing conditions, and poor hygiene standards (Brand, 1958; Tillema, 1915).

Table 1. Population Growth in Bandung 1906–1930 (Brand, 1958, p. 231)

Years	Population Groups				
	European	Chinese	Native	Arabs & other	Total
1906	2.199	3.704	41.393	45	47.391
1920	9.043	6.495	79.017	245	94.800
1930	19.650	16.657	130.028	480	166.815

Table 2. Mortality per Thousand (/1000) of Mid Year Population per Per Population Grup, Bandung, 1921–1926 (Brand, 1958, p. 233)

Years	Population groups		
	European	Chinese	Native
1921	12	6.5	21
1922	7	15	17.5
1923	7.5	15	16
1924	6.5	15	14.5
1925	6.5	15	15
1926	7	15.5	18

Urban Environmental problems in Bandung.

Despite the advantages of clean water sources, a cool climate, and fertile soil, Tillema, a sanitarian and urban ethnographer, noted a significant concern: the local population in Bandung still had a habit of defecating in public places. Despite being contaminated with fecal matter, they often used the Cikapundung River and the large gutters for multiple purposes, such as washing, bathing, and brushing teeth (Tillema, 1915, 1916). For those facing water scarcity, open latrines were utilized – a type of hole dug in the ground and covered with a bamboo booth for sanitation purposes (Tillema, 1913).

In rural settings, the native Sundanese community traditionally used *pacilingan*, specific areas built above fish ponds with bamboo booths and sticks as sanitation walls

(Rosidi, 2000). These simple disposal systems were located away from residences and on lower terrain to prevent the contamination of water sources and paddy fields (Prestasi & Kim, 2020; Sasmita, 2022). The *pacilingan* disposal system allows for the natural decomposition of human waste in fish ponds through anaerobic mechanisms. However, such systems were complex to adopt in urban contexts due to the higher population density, limited water availability, and the lack of fish ponds that were common in rural areas. As a result, '*poep maar-raak*' or open defecation became widespread in urban areas.

The poor hygiene practices of the native population were associated with the outbreaks of cholera, typhoid, and dysentery by Dutch doctors and sanitarians (Tillema, 1919; Tuyter, 1930). The bacterial contamination of food and drinking water caused these diseases. The sources of bacterial transmission included insufficient handwashing, ingestion of contaminated food and beverages, and dirty feet from contact with soils (Longhem, 1920; Tuyter, 1930). Moreover, the situation was aggravated by poorly lit and overcrowded houses and inadequate drainage and sewage systems (Bandoeng, 1929; Tillema, 1919). The housing conditions of the native population differed markedly from those of the Dutch and European residents, who lived in houses with solid walls, sufficient lighting, ventilation, and toilets that met the health standards suitable for the tropical climate (Bergmans, 1909; Taylor, 2013).

These issues were prevalent in the natives's settlements, known as *kampung*, and the Chinese settlements, referred to as *Chineesche Kamp*, were acknowledged by the Bandung municipality (Bandoeng, 1929; Kunto, 1986; Wertheim et al., 1958). The government considered both these settlements insufficient public health and hygiene standards and characterized them as primitive areas (Wertheim et al., 1958). These *kampungs* and *Chineesche Kamp* were mainly situated in the western and southern parts of Bandung City, adjacent to markets and rice fields (Roosmalen, 2008).

The western area of Bandung was a vibrant center of commerce and social interaction for the native and Chinese populations due to its high concentration of shops and markets (Heetjans, 1925; Kunto, 1986). It was also close to the train station, which connected Bandung with other regions and attracted many passengers (Tunas 2007). Some of the districts in this area, such as Suniaraja, Pasar Baru, Citepus, Cibadak, and Kaum, were densely populated with *kampung* and *Chineesche Kamp* settlements (see Figure 1). The Bandung Municipality reported that the average population density in these districts was 250–350 people per hectare in 1925 (Heetjans, 1925). Population in the district Suniaraja, Pasar Baru, Citepus, Cibadak, and Kaum contrasted with the lower population density in the northern area of Bandung, which ranged from 25–75 people per hectare (Heetjans, 1925).

Figure 1. Native and Chinese settlements densely populate the western part of Bandung (Heetjans, 1925; Topographisch Bureau, 1905).

Environmental challenges, such as inadequate drainage systems and a lack of waste disposal facilities, plague the congested Suniaraja, Pasar Baru, and Citepus districts. The poor sewage infrastructure in these districts increased the risk of gastroenteritis-related diseases, such as cholera, typhoid, and dysentery. News articles from 1909 to 1914 reported sporadic cholera cases in districts like Citepus, Cibadak, and Tegallega ("Cholera," 1914; "Cholera Te Bandoeng," 1913; "De Cholera Te Bandoeng," 1910). These outbreaks were linked to the local population's lack of proper sanitation facilities. According to a report by *Gemeente Bandung* (Heetjans, 1925), septic tank systems were impractical in densely populated areas like Suniaraja, Pasar Baru, and Citepus due to the proximity of houses. Moreover, septic tanks could contaminate groundwater sources in these areas (Heetjans, 1925).

Bandung City lacked a comprehensive sewage system until 1916. The existing sewers were poorly constructed and planned, and they mainly discharged sewage into nearby rivers (Gemeente Bandoeng, 1919). This substandard sewage and drainage infrastructure caused frequent flooding during the rainy season (Gemeente Bandoeng, 1919). These problems affected the native or Chinese neighborhoods and the northern area where the European population lived. However, the north area had better health protection as the European population used septic tanks.

In response to these challenges, the Bandung Gemeente Public Works Office recognized the need for an integrated drainage and sewage system. Therefore, in 1917, the Public Works Department, led by Heetjans, began planning to construct integrated drainage and sewage channels (Gemeente Bandoeng, 1919). The western region was prioritized, especially the densely populated Pasar Baru, Suniaradja, and Citepus, as it urgently needed a sewer network. The Municipal Public Works Department also designed toilets, clean hydrants, and public washing facilities for Bandung's villages (Bandoeng, 1929; "Kampong Toestanden," 1925).

Environmental Countermeasures: Sewerages (*rioleering*) and Public Toilets.

The Bandung City Government acknowledged the need for a systematic approach to address the sewerage problems that exceeded the individual residents' capacity. Therefore, the city engaged engineers and health experts to develop a comprehensive sewage management system. This initiative, which commenced in 1917, involved key figures such as Heetjans, the Director of Public Works; J. J. van Lonkhuijzen, the Inspector of the Civil Health Service of West Java; and C.A.E. Van Leeuwen, the Engineer of the Public Works Repair Bureau. The design of the sewer and drainage system, which cost 1,000,000 guilders, received a 50% subsidy from the central government (Rioleering van Bandoeng, 1926a). The plan, submitted by *Gemeente Bandung*, obtained the approval of the central government, with the endorsement of Perelaer, the Head of the Public Works Department, and De Vogel, the Head of the Civil Medical Service.

The Bandung City Works Department developed a 15-year plan for constructing the sewers (Rioleering van Bandoeng, 1926b). The sewer construction commenced in 1919 and underwent refinement in 1925, eventually completing the entire sewer network by 1938. During this period, the city also implemented various improvements in the *kampung* (*kampong verbetering*) alongside the extensive drainage and sewerage network construction. These improvements comprised road repairs, stormwater drainage system installations, house-to-house clean water supply pipe installations, the closure of old wells, and even the provision of electricity (Bandoeng, 1929; P. Thijsse Jr., 1934).

According to the reports compiled by *Gemeente Bandung* in 1919 and 1925, Bandung had two types of sewers. The first type of sewer was designed to collect rainwater, feces, urine, and kitchen waste. These were open concrete channels measuring 3 meters in width initially implemented in East Bandung, especially around the War Department and government offices (Bandoeng, 1929; Heetjans, 1925). However, these combined sewerages posed health concerns due to their open structure, which could facilitate bacterial transmission. Moreover, residents often used these open channels to dispose of garbage and even for defecation (Bandoeng, 1929; P. Thijsse Jr., 1934). The technical condition of the combined sewerages increased the risk of disease transmission and escalated maintenance costs.

The second type consisted of sewers (*riol*) intended to collect feces, urine, and kitchen waste, deemed safer from a health perspective by experts such as J. J. Van Lonkhuijzen and C.A.E. Van Leeuwen. These sewers were constructed below ground level, made of concrete, and measured 90 cm in diameter (see Figure 2) (*De Koerir* 9 Maret 1938; KITLV, 1930). The price per meter of concrete sewers for this size was 21 guilders (Gemeente Bandoeng, 1919, p. 52). The sewer system, mainly established in West Bandung and covering about 135 hectares, including densely populated villages, was initiated in 1925 (Dienst der Volksgezondheid, 1936; P. Thijsse Jr., 1934, p. 139). The sewer network, comprising four main channels, followed specific routes: three ran from west to east, and one from north to South, namely: (1) Dunguslaja-Kebonjukut, (2) Sukahaji-Ciateul Kulon, (3) Ciparay-Sindangpalay, and (4) Kebonjukut-Tegallega, aligning with the course of the Cikapundung River (see Figure 3) (Heetjans, 1925).

Figure 2. The installation of sewer pipes and the construction of concrete joints for sewerage in Bandung took place between 1929 and 1930 (KITLV 157009, KITLV 157013).

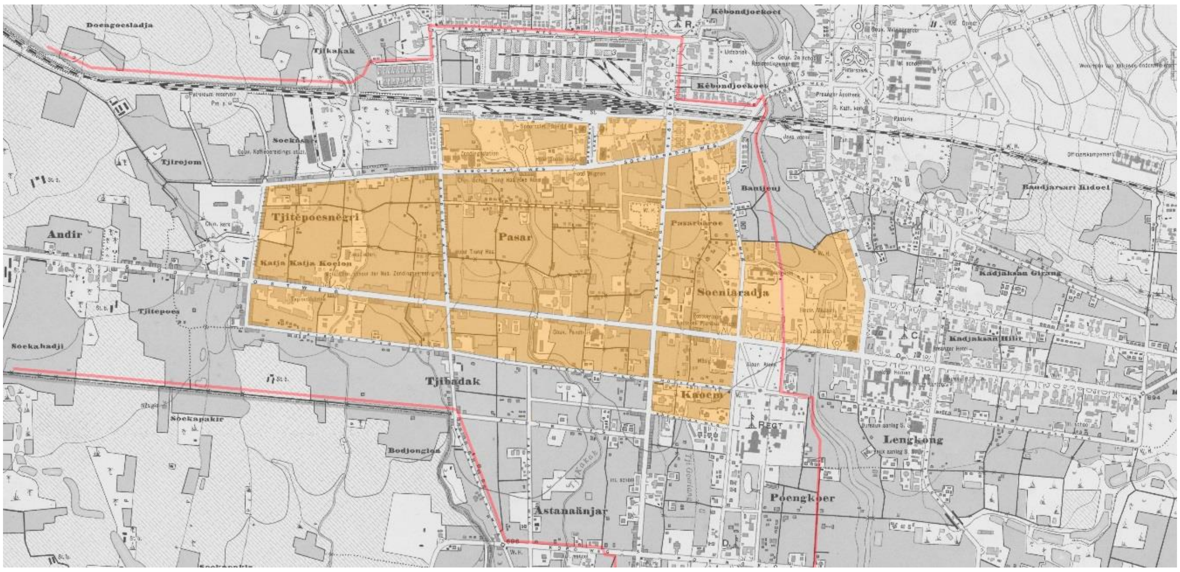

Figure 3. The reconstruction of the sewer network in western Bandung in 1925 was based on the report Sewerage and Drainage Plan 1925 of Bandung and the Bandung Guide Map 1946. (Red lines indicate the sewer network; orange shading indicates dense residential areas) (Heetjans, 1925, pp. 45–47; AFNEI Headquarters Survey Department, 1946).

The *kampungs* in Bandung were equipped with a main sewer network that efficiently collected and distributed sewage and waste through pipes that connected houses, toilets, and public washing stations (Bandoeng, 1929; P. Thijsse Jr., 1934). This sewer system was supplemented by 70 public toilets, 70 public bathrooms, and 70 public washing stations distributed across the *kampungs* by the 1930s (Gemeente Bandoeng, 1924; Thijsse, 1935). Some of the *kampungs* that benefited from the improved public toilet facilities were Babatan, Cipurut, Gempol, Astana Anyar, Ciateul, and Rasamala (see Figure 4) ("Kampong Toestanden," 1925; Reerink, 2015). According to the Bataviaasch Niuewsblad newspaper ("Kampong Toestanden," 1925), the villagers had adopted these public toilet facilities and appreciated their convenience and hygiene.

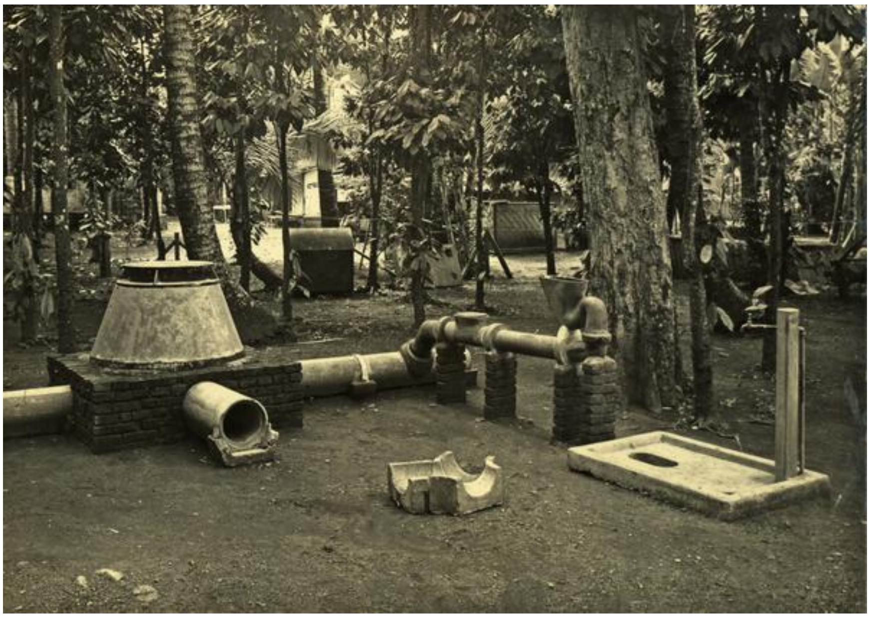

Figure 4. Public toilet and washing facilities built in the *kampungs* (KITLV 157053).

This sewerage network has its final discharge point in the Tegallega area of South Bandung, where the last effluent undergoes treatment using the activated sludge method (Gemeente Bandoeng, 1919). After treatment, the processed sewage is discharged into the Citepus Hilir River. This closed sewer system relies on the *spoilwater* (rinse water) from the Cikapayang and Leuwilimus Rivers, which have a flow rate of 818 liters per second (Gemeente Bandoeng, 1919; Heetjans, 1925). The success of Bandung's sewer system can be attributed to the city's sloping landscape in the South, which facilitates the gravitational flow of sewage and wastewater toward the city's southern region. This area, which consists mainly of rice fields with few residential zones, reduces the risk of pollution and bacterial transmission, enabling optimal sewage management (Heetjans, 1925).

Heetjans, the City Public Works Department head, devised the sewer design with foresight, considering Bandung's expected population growth and expansion. Heetjans planned an additional network that would span from Cibuntu in the west to Binong in the east, envisaged for the future when Bandung's population was projected to reach 378,000 by 1965. The elaborate design included the locations of sewage collection and treatment plants (Heetjans, 1925). Researchers continually pursued advancements in the final treatment station to secure a fitting, cost-effective treatment method.

The Bandung Municipality initiated the construction of a modern wastewater treatment plant using Imhoff or Emscher tank technology in 1932. The Municipality appointed Ir. L. W. Hofland led this plant's research and implementation. The primary goal of establishing the Imhoff Tank was not solely to prevent environmental pollution but also to harness the methane gas generated from the septage. According to the calculations by the Public Health Department, the Imhoff Tank in Bandung had the potential to produce 320 m^3 of methane gas, envisaged for use as motor vehicle fuel (Dienst der Volksgezondheid, 1936). This project's approach to utilizing methane gas drew inspiration from successful implementations in Germany and France before World War II ("Methaangas in Plaats van Benzine Voor Auto's," 1937). To ensure the project's success, the Bandung City Government engaged engineers from *Technische Hoogeschool* Bandoeng, including Professor C. P. Mom and Ir. Baumgarten ("Methaangas Voor Auto's Belangwekkende Demonstratie Door Gemeentedienst Te Bandoeng," 1937; Mom, 1941).

Imhoff Tank and Methane gas utilization.

The Imhoff Tank, also known as the Emscher Tank, is a sludge treatment technique initially developed by Karl Imhoff in the Essen District of North Germany in 1907 (Kinnicutt, Winslow, & Winthrop Pratt, 1919). Functioning on a principle akin to a septic tank, the Imhoff Tank is a primary treatment facility to separate solids and water in wastewater and treat settling solids (sludge). Notably, Imhoff Tanks can precisely capture the gas produced by fecal sludge for use as fuel, a feature not present in conventional septic tanks. Initially employed in Germany, England, and America, this technology can reduce suspended sludge solids by 50–70% and lower chemical oxygen demand by 25–50% (Hoffman, Platzer, Winker, & von Muench, 2011; Mom, 1941).

In the context of initiatives to enhance urban environmental conditions and public health, adopting Imhoff Tanks represented a crucial technological innovation in the Dutch East Indies. During the early 20th century, only a handful of cities in the Dutch East Indies, including Bandung, Medan, and Yogyakarta, boasted integrated sewer networks (Dienst der Volksgezondheid, 1936). Surabaya and Batavia, the most densely populated centers, could not complete integrated sewer networks due to the economic crisis that struck the Dutch East Indies. Among the cities with sewer networks, Bandung pioneered the implementation of Imhoff Tanks. Consequently, the application of Imhoff Tanks in the Tegallega area of Bandung emerged as a crucial laboratory and development center, not only for Bandung itself but for the entire Dutch East Indies. The system's development involved consultations with the water purification laboratory in Manggarai, and the trials received full support from the Dutch East Indies Association for the Promotion of Hygiene (*Nederlandsch-Indische Vereeniging ter bevordering der Hygiëne*) (P. Thijsse Jr., 1934, p. 139). The government, particularly the Public Health Service, strategically planned the success of the Imhoff Tank project as a pilot system that could be replicated in other cities across the Dutch East Indies in the future (see Figure 5).

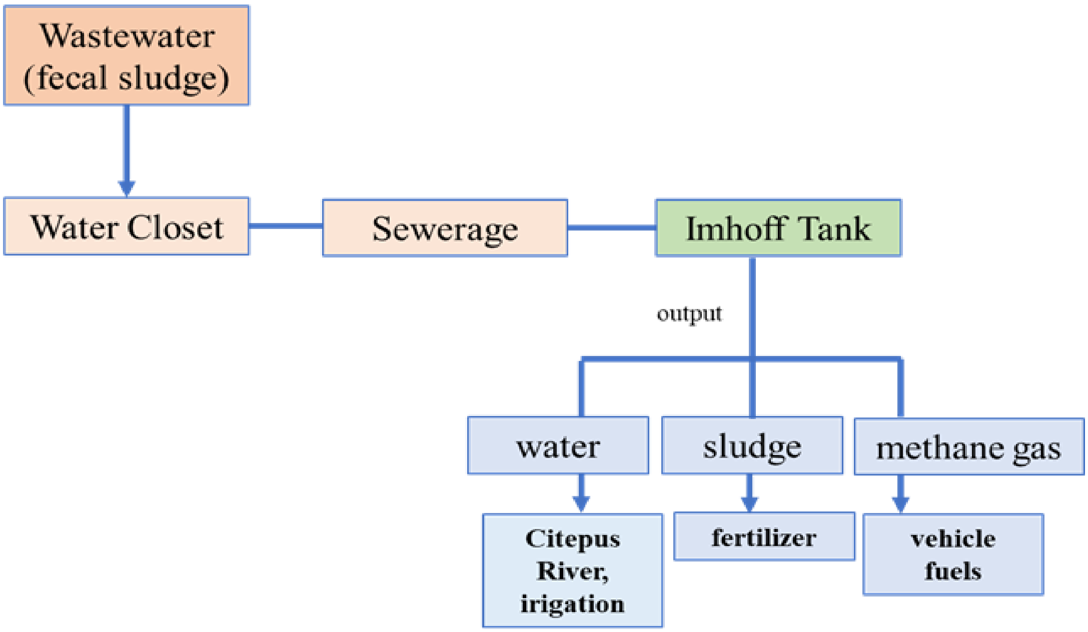

Figure 5. Wastewater management scheme in Bandung in the early 20th century.

With a development and research duration of approximately seven years, by 1938, the Imhoff Tank sewage treatment plant could effectively manage wastewater from 160 hectares of sewers in Bandung City (*Het nieuws van den dag voor Nederlandsch-Indië* 9 Maret 1938). According to a report by Ir. L. W. Hofland, this sewer network was projected to gradually expand to cover 598 hectares, encompassing the built-up area of Bandung City (Hofland, 1936). The Imhoff Tank Installation played a crucial role in collecting and treating wastewater primarily originating from the western and southern areas of Bandung, including densely populated districts like Suniaraja, Banceui, Landraad, and Alun-alun ("Bandoeng's Rioleering," 1938). The wastewater conveyed through the sewer network underwent treatment at the Imhoff Tank installation in the southern part of the city, near the Citepus River. The treated water from the Imhoff Tank, exhibiting significantly improved cleanliness, was discharged into the Citepus River. Subsequently, the water from the Citepus River served to irrigate the rice fields of residents scattered in the southern part of the city. Simultaneously, the sludge separated from the Imhoff Tank was found to be applicable as fertilizer for plantations.

The Imhoff Tank design comprises two vertically arranged compartments: the upper compartment for solid particle separation and the lower compartment for the anaerobic digestion of settled sludge. The Imhoff Tank, owned by the Bandung City government, was constructed below ground level, featuring a compartment structure depth of 11.15 meters and a compartment surface width of 13.7 meters (Figure 6). With these dimensions, the Bandung municipality established a pair of Imhoff Tank installations: the upper compartment's width was 5.7 meters, the lower compartment's width was 3.95 meters, and four gas storage tubes with a diameter of 4 meters (Hofland, 1936; Mom, 1941). The Imhoff Tank installation (see Figure 7) was additionally equipped with a pumping machine for sludge removal and a laboratory room (Mom, 1941; Nauta, 1937). To actualize the Imhoff Tank installation, the Public Health Service Departement and the Bandung City Government allocated a budget of 82.360.58 guilders, covering the expenses for constructing the Imhoff Tank, pump house, pump and mixing installation, and other supporting costs (Dienst der Volksgezondheid, 1936).

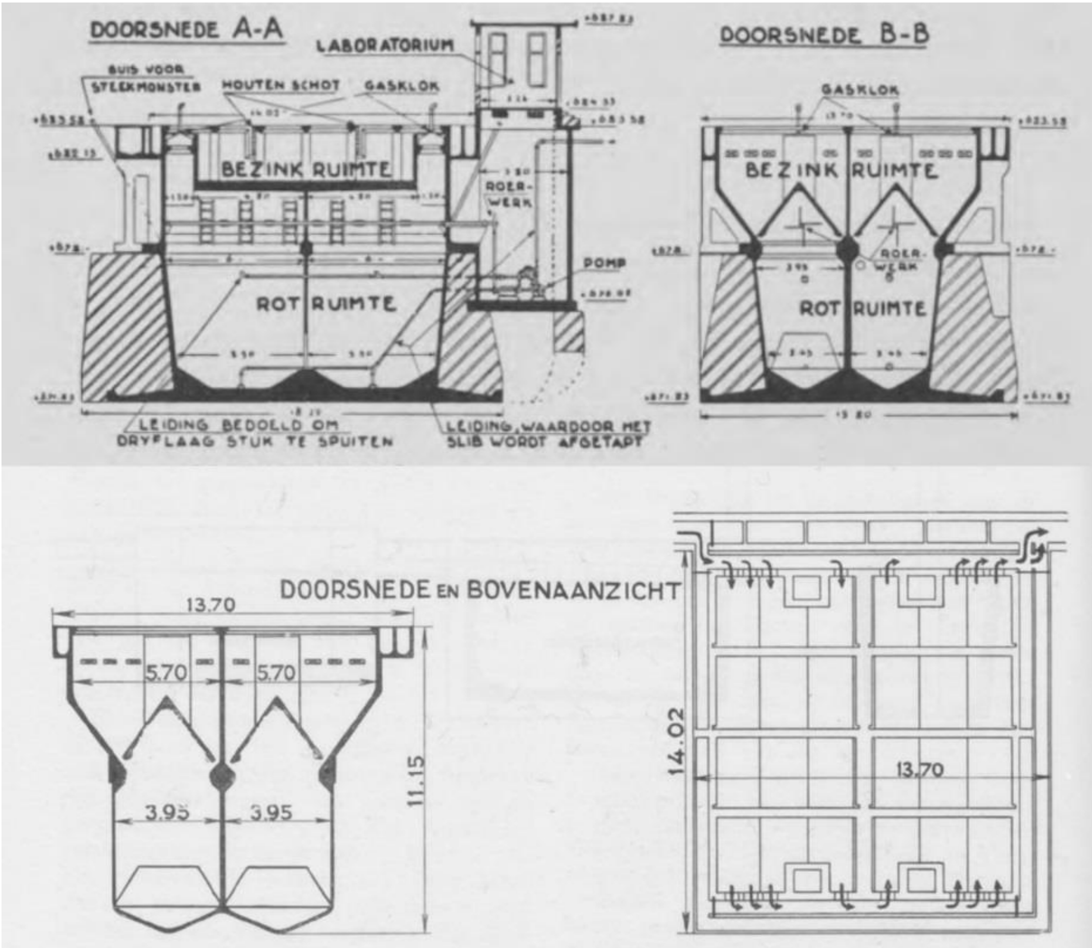

Figure 6. Imhoff Tank installation design (Nauta, 1937; Mom, 1941).

Figure 7. The sewage treatment plant, Imhoff Tank, in Tegallega, Bandung. Number 1 shows the laboratory room, and number 2 shows the methane gas collection tube (Mom, 1941, p. 163; personal documentation, 2023).

The wastewater treatment mechanism of the Imhoff Tank involves seven stages. Initially, wastewater or septage enters the upper compartment, which is larger and open, facilitating the easy inflow of raw wastewater. The wastewater is retained in this compartment for a specific period, allowing solid particles to settle and descend to the lower compartment. Subsequently, heavier solids like sludge and other particles settle in the lower compartment, marking the second stage, primary sedimentation. The third stage involves liquid and solid phase separation, employing a pyramid or inverted pyramid-shaped sludge hopper between the upper and lower compartments to let the clean liquid flow out while retaining sludge or other solids in the lower compartment. The fourth stage entails anaerobic digestion of sludge in the lower compartment. During this stage, anaerobic bacteria decompose the organic matter of the sludge, reducing its volume, stabilizing the organic content, and generating biogas, including methane (CH_4) and carbon dioxide (CO_2). In the fifth stage, the gas produced from sludge digestion accumulates in the upper compartment and can be discharged or collected through a gas pipe into a unique tube. The sixth stage involves the dehydration and volume reduction of the settled sludge in the lower compartment. Finally, in the seventh stage, the remaining sludge in the lower compartment is discharged through a pipe.

In the context of the Imhoff Tank application in Bandung, the methane gas produced underwent testing for powering the city's cleaning service trucks ("Methaangas in Plaats van Benzine Voor Auto's," 1937). Ir. Baumgarten, alongside Dr. C. O. Schaeffer, conducted mechanical developments to purify the carbon dioxide (CO_2) content to harness the methane gas from the Imhoff Tank treatment.

Additionally, they worked on the advancement of gas carburetors for vehicles, enabling the conversion of energy from methane (CH_4) into a usable fuel source (Figure 8) (Mom, 1941).

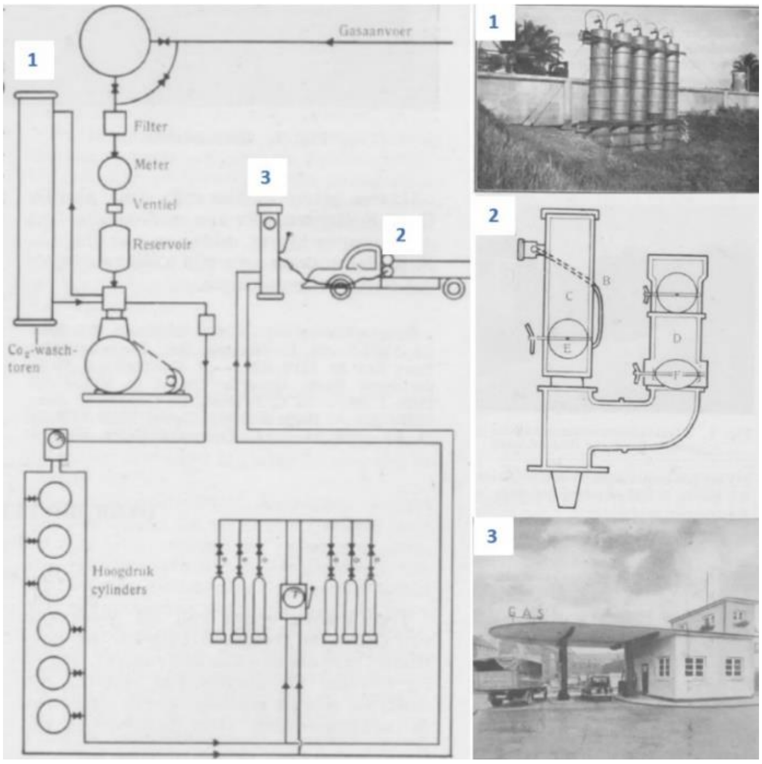

Figure 8. Flow of methane gas utilization for vehicle fuel. Number 1 indicates methane gas collection toren; number 2 indicates a combination of gas carburetor and gasoline carburetor; and number 3 indicates a gas filling station (Mom, 1941, p. 163).

Based on a report by Ir. L. W. Hofland, overseeing the development and research of the Imhoff Tank, the sludge decomposition process in tropical areas with a temperature of 26 °C, such as Bandung, occurs more rapidly than in subtropical regions like Europe (Hofland, 1936). These conditions create a more favorable environment for generating methane gas abundantly and quickly from sludge decomposition. The gas composition from the Imhoff Tank includes methane (CH_4) at 71.4%, hydrogen (H_2) at 3.5%, carbon dioxide (CO_2) at 21.3%, Nitrogen (N_2) at 2.5%, and oxygen (O_2) at 1.3%. The average calorie production from the gas composition is 6,500 Calories/m^3, and the daily gas supply reaches 320 m^3. They calculate the daily calories, which results in 320 m^3 × 6,500 Cal = 2,000,000 calories. Using 1 HP/hour = 630 calories, so 2,000,000 calories can be translated to 3,300 HP/hour, equivalent to 3,346.8 HP/hour (Hofland, 1936).

With such energy potential, a research and development team composed of Ir. L. W. Hofland, Professor C. P. Mom, and Ir. Baumgarten explored various options for methane gas utilization, including applications in industries and commercial enterprises such as welding, water refinement, processing of mining products, coal companies, and gas companies (Hofland, 1936). However, commercial enterprises tended to find methane gas less economical and efficient among the considered options. One contributing factor was the perceived distance of the methane gas plant (Imhoff Tank) from the city center, coupled with the availability of cheaper alternatives like cokes (Hofland, 1936). In light of this assessment, Ir. L. W. Hofland proposed that the methane gas produced from the Imhoff Tank could be more effectively employed for internal purposes within the Bandung Municipality. Internal purposes included providing energy for the Imhoff plant itself and fueling the garbage trucks of the Municipal Cleaning Service Department. The research team ultimately opted for the second alternative, utilizing methane gas as fuel for waste collection vehicles. The effectiveness of methane gas utilization was tested publicly by Professor C. P. Mom, A. W. Allirol, and Ir. Baumgarten on October 12, 1939 ("Lezing Di Gemeente," 1939). The trial received a positive response from city officials and journalists at the demonstration. Unfortunately, the onset of World War II, which also impacted the Dutch East Indies, likely impeded further development and utilization of this technology. Post-World War II, following the end of Dutch colonial rule in Indonesia, the Imhoff Tank installation in Bandung has yet to be fully utilized and today stands as an abandoned colonial heritage urban technology.

Conclusions.

This study reveals that the emerging modern cities in the early 20th century in the Dutch East Indies (Indonesia) encountered analogous environmental challenges: densely populated slums, inadequate sewerage systems, restricted access to clean water, and the looming threat of diseases (cholera, malaria, typhoid, dysentery) due to poor hygiene practices among the population. These issues significantly escalated the risk of population mortality. Bandung City, envisioned by the Dutch East Indies government as a modern city suitable for European habitation, grappled with environmental problems that demanded urgent attention. These challenges included the practice of native populations defecating in rivers and open areas, spreading diseases, and potentially polluting river water. Such conditions persisted due to insufficient sanitation facilities, particularly in native (*kampung*) and Chinese (*Chineesche Kamp*) residential areas such as Suniaraja, Pasar Baru, Citepus, and Cibadak districts.

To address the environmental challenges in Bandung, the municipality government, in collaboration with the Public Works Department, engineers, and environmental engineering researchers, initiated the construction of urban infrastructure, facilities, and technology in 1917. Prioritizing public toilets, sewer networks, and sewage treatment plants, the city government adopted a sustainable approach in designing the sewer network, planning its extension until 1965, aligning with the city's developmental potential and anticipated population growth. Environmental engineers and researchers introduced cutting-edge technology known as the Imhoff Tank between 1932 and 1938 to mitigate wastewater pollution proactively. This technology facilitates circular wastewater treatment, separating solid and liquid waste while capturing methane gas. The treated water from the Imhoff Tank is discharged into the river, serving residents in rice fields for irrigation. Simultaneously, the sludge output serves as fertilizer, and the collected methane gas is utilized to fuel vehicles of the Municipal Cleaning Service Department. The implementation of the sewer network and the Imhoff Tank by the Bandung City Government during the early 20th century exemplified their commitment to realizing a vision of a healthy and sustainable city.

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Conflicts of interest.

The authors declare no conflict of interest.

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Рішення для міської санітації: Кейс технології Імхоффа в місті Бандунг, Нідерландської Ост-Індії (1917–1938)

Анотація. *Це дослідження вивчає, як муніципалітети управляли стічними водами в Нідерландській Ост-Індії на початку 20-го століття. Ми зосереджуємося на Бандунгу, одному з найважливіших міст Нідерландської Ост-Індії, яке перетворилося на сучасний житловий район, економічний центр і місце уряду. Це дослідження поєднує первинні дані з письмових джерел і польові спостереження за допомогою історико-археологічних методів. Письмові джерела включають офіційні звіти від Департаменту з будівництва, Департаменту цивільного здоров'я, Міської ради Бандунгу, старих карт, проекти каналізаційної мережі, журнали з екоінжинірінгу та газети, опубліковані з 1909 по 1941 рік. Використовуючи техно-екологічний підхід, запропонований Мартіном В. Мелосі, це дослідження розглядає міську технологію як стратегічну відповідь приймачів рішень на виклики, що стоять перед розвиваючимися містами на початку 20-го століття. Дослідження показує, що Бандунг мав проблеми з навколишнім середовищем, такі як звички місцевих мешканців залишати екскременти у річках та на відкритих територіях, що призводило до поширення хвороб і потенційного забруднення води в річках. Ці проблеми виникли через відсутність санітарних умов та щільне заселення, особливо в місцевих та китайських житлових районах: Кампунг і Китайський Табір. Для вирішення цих викликів політики, екологічні інженери та дослідники ініціювали проектування та впровадження каналізацій, громадських туалетів та очисних споруд для стічних вод у 1917 році. Муніципалітет* *інтегрував каналізаційні системи з технологією очищення стічних вод за допомогою баків Імхоффа, розроблених дослідниками та інженерами з 1932 по 1938 рік, щоб впровадити циклічну очистку стічних вод. Баки Імхоффа стали значущим технологічним вдосконаленням в Нідерландській Ост-Індії. На початку 20-го століття лише декілька міст у Нідерландській Ост-Індії, включаючи Бандунг, Медан та Джок'якарту, мали інтегровані каналізаційні мережі. Серед міст, які мали каналізаційні системи, Бандунг першим застосував впровадження баків Імхоффа. В результаті він виріс у важливий лабораторний і розвитковий центр для Бандунгу і всієї Нідерландської Ост-Індії. Процес очищення за допомогою баків Імхоффа, який виробляє чисту воду, добриво та метановий газ, який може бути використаний як паливо для транспортних засобів, був частиною активної стратегії, впровадженої політиками в Бандунгу на початку 20-го століття, що відображає їхню візію створення здорового та сталого міста.*

Ключові слова: *громадське здоров'я; відкрита дефекація; каналізація; бак Імхоффа; міська технологія*

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