HY-04 Where the waste goes: latrines, composting, night soil and the diseases of bad sanitation

HEALING after the FALL, research library, HY-04

Researched 10 October 2026 by Claude Opus agent for THRIVING after the FALL, Book Four. Library document, unverified.

Findings by section

This report asks four questions. Which diseases does sanitation prevent, and by how much? How far from water and how deep should a latrine be, and how is it kept safe? At what temperature and for how long must human waste be held before it can go back on the land? And what did the large modern trials that found no effect actually teach? Where a figure comes only from an abstract or a secondary summary the reference says so. Unchecked figures and my own inferences carry [VERIFY].

1. The diseases at stake

Human faeces carry bacteria, viruses, protozoa and worm eggs, which differ in infective dose, survival outside the body and what kills them. That difference drives every rule below.

Disease	Agent	How it spreads from faeces	Why it matters after the Fall
Cholera	*Vibrio cholerae* bacterium	Water, food, hands	Can kill within hours. Case fatality up to 50% where no one knows rehydration, under 1% where they do (WHO 2023a)
Typhoid	*Salmonella* Typhi	Water, food, carriers' hands	Untreated case fatality about 10 to 20%, under 1% with antibiotics (UKHSA 2020). Chronic carriers seed outbreaks for years
Shigellosis (bacillary dysentery)	*Shigella* species	Hands, flies, food	As few as 10 to 100 organisms infect, and stool carries 100,000 to 100 million per gram (CDPH n.d.).

Disease	Agent	How it spreads from faeces	Why it matters after the Fall
Hepatitis A	Hepatitis A virus	Hands, food, water	Mostly silent in under-fives (80 to 95% have no symptoms) but 70 to 95% of infected adults fall ill (PHAC 2023)
Polio	Poliovirus	Faecal-oral	About 1 in 200 infections paralyses, and 5 to 10% of the paralysed die (WHO 2023b). Only vaccine stops it
Roundworm	*Ascaris lumbricoides*	Eggs in soil, on vegetables, on hands	Eggs survive years in soil. Heavy loads stunt children and can block the gut
Whipworm	*Trichuris trichiura*	Eggs in soil	Chronic dysentery and rectal prolapse in heavy infection
Hookworm	*Necator*, *Ancylostoma*	Larvae in soil enter bare skin	Blood loss and iron-deficiency anaemia. Shoes matter as much as latrines

Soil-transmitted worms infected about 1.5 billion people in 2023 (WHO 2023c). Roundworm and whipworm eggs must ripen in soil for some weeks before they become infective. Hookworm eggs hatch in soil and the larvae wait in moist, shaded earth for a bare foot. So worms respond to where faeces are put, while bacteria and viruses respond as much to hands, food and water.

Environmental enteric dysfunction was proposed by Humphrey (2009), who noted that about 32% of the world's 555 million preschool children were stunted and argued that a gut constantly inflamed by faecal bacteria absorbs food poorly. A later review found the biomarker evidence mixed (Harper et al. 2018). The idea helped justify the growth trials of the 2010s, whose null results bear on it.

2. What sanitation prevents: the reviews

The largest review, Freeman et al. (2017), pooled 171 studies.

Diarrhoea. Across 27 studies, sanitation was associated with an odds ratio of 0.88 (0.83 to 0.92), with very high heterogeneity (I^2 79%). Restricting to the 16 intervention studies gave 0.77 (0.66 to 0.91), with GRADE certainty rated low. Any sanitation compared with none gave 0.76 (0.64 to 0.91, four studies). Moving from an unimproved to an improved facility gave almost nothing, 0.96 (0.92 to 0.99). The effect was seen in children under five (0.91) but not in adults (1.03, not significant). Of nine household studies that reported how many households actually had and used sanitation, only three found an effect, and two of those three were sewerage studies (Freeman et al. 2017).

Wolf et al. (2022) agreed that sanitation interventions reduced diarrhoea by about a quarter (RR 0.76, 0.61 to 0.94). Sewer connection compared with unimproved sanitation gave a much larger effect, RR 0.53 (0.30 to 0.93), from only five studies. In the same review, handwashing with soap gave about 0.70 and household water filtration about 0.50

(Wolf et al. 2022, read via secondary summary). Two errata were later published, and I have not checked whether they changed these figures [VERIFY].

Worms. Freeman et al. (2017) found sanitation associated with less roundworm (OR 0.73, 0.61 to 0.86, 39 studies), less hookworm (0.65, 0.53 to 0.78, 42 studies), less *Strongyloides* (0.48, 0.36 to 0.65, nine studies) and probably less whipworm (0.80, 0.63 to 1.03, 34 studies). In intervention studies alone, the hookworm effect vanished (0.94, 0.76 to 1.15, seven studies) and the whipworm estimates scattered from 0.37 to 2.69. Strunz et al. (2014), pooling 94 mostly observational studies, found sanitation access associated with an odds ratio of 0.66 for any soil-transmitted helminth, 0.62 for roundworm and 0.61 for whipworm, but only 0.80 (0.61 to 1.06) for hookworm. Wearing shoes was associated with an odds ratio of 0.29 for hookworm. For hookworm, footwear is the stronger observed barrier.

Intervention studies show less than observational ones partly because families with latrines tend to be better off, and partly because of time. Twelve months after deworming, roundworm prevalence had returned to 94% of its pre-treatment level, whipworm to 82% and hookworm to 57% (Jia et al. 2012). A one- or two-year latrine trial is fighting eggs already in the soil, which survive for years (Section 7).

Trachoma and schistosomiasis. Sanitation was associated with less active trachoma (intervention studies OR 0.51, 0.29 to 0.90, four studies) and less schistosomiasis (*S. mansoni* 0.61, *S. haematobium* 0.69) (Freeman et al. 2017). Keeping excreta out of ponds and streams directly prevents schistosomiasis.

Growth. The mean height-for-age difference was only 0.08 SD (0.00 to 0.16, nine studies, very low certainty) (Freeman et al. 2017).

3. The modern trials and what the null results taught

Between 2010 and 2019 a series of large randomised trials tested rural sanitation. Most found little or nothing.

India's Total Sanitation Campaign, Odisha. Clasen et al. (2014) randomised 100 villages. Latrine coverage rose from 9% to 63% against 8% to 12% in controls. Diarrhoea prevalence was 8.8% against 9.1% (PR 0.97, 0.83 to 1.12). Worms, weight and mortality did not change. Many latrines went unused.

Madhya Pradesh. Patil et al. (2014) randomised 80 villages with 5,209 children. Improved sanitation rose to 41% against 22%, but adult open defecation only fell to 73% against 84%. No health effect was detected.

Community-led total sanitation in Mali. Pickering et al. (2015) randomised 121 villages. Private latrine access reached 65% against 35%, and adult open defecation fell from about a third to about a tenth. Diarrhoea did not change (PR 0.93, 0.76 to 1.14), but children were taller (height-for-age +0.18 SD, 0.03 to 0.32) and fewer were stunted (35% against 41%).

WASH Benefits Bangladesh. Luby et al. (2018) enrolled 5,551 pregnant women. The sanitation arm (dual-pit latrines, child potties, faeces scoops) reduced diarrhoea in their children (PR 0.61, 0.46 to 0.81) but did not change length (THRIVING library, HY-01). A longer follow-up reported a weaker effect, about PR 0.81 (0.66 to 1.00), found only in a secondary summary [VERIFY]. Promoters visited six times a month, which the trialists judged not possible at scale (Pickering et al. 2019, read via secondary summary).

WASH Benefits Kenya and SHINE Zimbabwe. Null et al. (2018) found no effect of sanitation, water or handwashing on diarrhoea or growth in Kenya (THRIVING library, HY-01). SHINE (Humphrey et al. 2019) gave households a ventilated improved pit latrine, handwashing stations and water treatment in 211 clusters and found no effect on stunting or diarrhoea, while its infant feeding arm did raise length. I did not retrieve SHINE's exact WASH estimates [VERIFY].

What the null trials taught. The lessons, from the trialists' consensus statement (Cumming et al. 2019) and my reading of the data, are these.

1. **Coverage and use, not construction.** Cameron et al. (2022) pooled trials in India, Indonesia, Mali and Tanzania and found that child height gains appeared only when village coverage reached about 50 to 75%, worth roughly 0.3 SD, and that full coverage was worth about 0.43 SD. What matters is the amount of open defecation in the community. Harris et al. (2017) found in Mali that each 10% rise in coverage within 200 m added about 0.03 SD of height for children in households with no latrine, while owning a latrine showed no association. Fuller et al. (2016) found similar herd protection in Ecuador.
2. **The interventions were too narrow.** A latrine leaves the other routes open: animal faeces, stored water, soil eaten by crawling infants, flies and food (THRIVING library, HY-01, citing Swarthout et al. 2024). The consensus statement called for "transformative WASH" that clears faecal contamination from the child's whole environment (Cumming et al. 2019).
3. **Growth is not driven by sanitation alone.** SHINE's feeding arm worked where its WASH arm did not.

I partly disagree with one reading of HY-01, which rightly records SHINE's latrine package as giving no effect. SHINE's latrine was one household's VIP among contaminated neighbours, animals and soil. The lesson is not that latrines fail but that one family's latrine does not protect that family. After the Fall the unit of sanitation is the settlement.

Why latrines go unused. Spears estimated from India's Total Sanitation Campaign that average programme intensity reduced infant mortality by about 4 per 1,000 and increased child height by about 0.2 SD (work by Spears summarised in Coffey and Spears 2017 [VERIFY]). Coffey and Spears (2017) then showed that purity and caste norms made emptying a pit unthinkable for many rural Indian households. About 40% of households with a working latrine had at least one member who still defecated in the open. Every community has its own version of such norms, and they decide whether the latrine is used.

4. The Victorian revolution and the McKeown debate

Chadwick. Edwin Chadwick's *Report on the Sanitary Condition of the Labouring Population* (1842) set out the mortality gap between town and country and between classes. His most quoted figures were average ages at death of 15 or 17 for Manchester labourers' families (the figure depends on the reading) against 38 for labourers in rural Rutland and 52 for the Rutland gentry (Chadwick 1842, with the discrepancy discussed in Hanley 2002). Infant deaths drag these averages down. Chadwick's theory of disease (miasma, bad air) was wrong but his remedies, clean water in and waste out, were right. The Public Health Act of 1848 followed.

Snow. In 1854 John Snow compared households supplied by the Southwark and Vauxhall Company, which drew from the Thames below the sewer outfalls, with those of the Lambeth Company, which had moved its intake upstream. In the first seven weeks, deaths per 10,000 houses were 315 for Southwark and Vauxhall, 37 for Lambeth and 59 for the rest of London: 1,263 deaths among 40,046 houses against 98 among Lambeth's 26,107 [VERIFY the Lambeth house count] (Snow 1855). His Broad Street investigation led the parish to remove the pump handle on 8 September 1854. Sources give different totals for that outbreak, from about 500 to over 600 deaths, and I could not settle it [VERIFY]. The epidemic was already declining when the handle came off, as Snow acknowledged.

Bazalgette. After the "Great Stink" of 1858, Joseph Bazalgette built intercepting sewers (1859 to the mid-1870s) that carried London's sewage east to outfalls below the city. The 1866 cholera epidemic, which killed about 5,500 people, mostly in the East End, struck the district not yet connected, which was supplied with unfiltered water by the East London Water Company (Farr's report of 1868, read via secondary sources [VERIFY]). It was London's last major cholera epidemic.

Typhoid. Secondary sources give England and Wales typhoid death rates of about 320 per million in the 1870s falling to about 110 per million in 1901 to 1905, with unchanged case fatality, which implies fewer infections rather than better treatment [VERIFY]. Hinde and Harris (2019) found that waterborne disease deaths fell most between the 1860s and the 1880s, and that typhoid fell in parallel in towns and countryside, which complicates any simple story

that sewers alone did it.

The McKeown debate. Thomas McKeown argued that the nineteenth-century fall in mortality came mainly from better nutrition and living standards (McKeown and Record 1962). Simon Szreter (1988) replied that McKeown underrated municipal water and sewerage, paid for by loans that rose after the 1870s, and later reviewed the debate (Szreter 2002). Chapman (2019) estimated from town data for 1861 to 1900 that infrastructure investment explained about 30% of the urban mortality decline in fixed-effects models and up to about 60% in instrumented models. American estimates point the same way, though their size was revised down (THRIVING library, HY-02, on Cutler and Miller and its correction).

My reading is that nutrition decides how well a child survives an infection and sanitation decides how many infections there are. A settlement needs both, and sanitation is the one no household can achieve alone.

5. The hookworm campaigns of the American South

The Rockefeller Sanitary Commission began in October 1909 with one million dollars and worked in eleven southern states (Elman et al. 2014). Surveys found roughly 40% of those examined infected, with a mean county rate of 38.4%. In 1910 alone the campaign recorded 42,946 positive examinations and treated about 14,400 people with thymol. Before the campaign only about a third of farmhouses had any privy. In one North Carolina survey, 6 of 238 white schools and none of 20 Black schools had a sanitary privy.

Charles Wardell Stiles gave privies more weight than treatment, but in practice the travelling dispensaries dominated. The International Health Board later admitted that the dispensaries had not led to lasting prevention, and the declaration of eradication in the late 1920s was not quite true (Elman et al. 2014). Hookworm declined in the South over decades as shoes, privies, schooling and incomes spread together.

Bleakley (2007) found that areas with more hookworm before the campaign gained more school enrolment, attendance and literacy afterwards, and that adult earnings rose for those exposed as children. Roodman (2017) argued that the causal evidence was weaker than claimed. I did not read Ettling's social history, *The Germ of Laziness* (1981).

The lessons are that treatment without privies and shoes buys only months (Jia et al. 2012), and that dispensaries are easier to count than privy use. Engel and Susilo (2014) traced a line from Rockefeller hookworm work in colonial Java in the 1920s to modern sanitation shaming.

6. The night-soil record

In China night soil was a common fertiliser by the Song dynasty, and in Edo-period Japan it was bought and sold. In Osaka the faeces of a house belonged to its owner and the urine to the tenants, and buyers paid in silver for the output of each household (Hanley 1987, read via secondary summary). Press coverage of Japanese historians gives Edo's output as about 500,000 tonnes of fertiliser a year from a city of about a million [VERIFY].

The cost was worms. In 1949, 62.9% of Japanese people of all ages carried roundworm. By 1973 it was 0.6% (Hasegawa et al. 2020). The decline followed the Parasitosis Prevention Law of 1931 (abolished only in 1994), mass screening and treatment, and chemical fertiliser replacing night soil, after wartime shortages had brought raw night soil back into wide use. A molecular survey of 682 Japanese children in 2017 to 2018 found no infections at all (Hasegawa et al. 2020).

The Asian record proves that excreta can feed fields for centuries, and also that untreated night soil kept most of the population wormy. Japan's escape combined treating people with controlling what went on the fields.

The European record says the same. Jenkins reports that in post-war Germany in 1949, untreated sewage used to irrigate vegetables carried about 540 roundworm eggs per 100 ml and infected over 90% of the population (Jenkins 2005, citing older sources [VERIFY]).

7. How long pathogens survive

These figures come from Feachem et al. (1983), which I read only through two summaries (Schönning and Stenström 2004, Jenkins 2005).

In faeces held at 20 to 30 °C (Schönning and Stenström 2004):

Group	Survival
Faecal coliform bacteria	Under 90 days, usually under 50
Salmonella	Under 60 days, usually under 30
Viruses (enteroviruses)	Under 100 days, usually under 20
Hepatitis A	Reported at 20 to 50 days [VERIFY]
Protozoan cysts	Under 30 days, usually under 15
Roundworm eggs	Several months

In soil (Schönning and Stenström 2004, after Feachem): bacteria normally up to 2 months with an absolute maximum of 1 year. Viruses normally up to 3 months with a maximum of 1 year. Worm eggs normally up to 2 years with a maximum of about 7 years. Jenkins cites reports of roundworm eggs surviving up to 10 years in soil (Jenkins 2005). Cholera vibrios last a week or less in soil and hookworm larvae up to about 20 weeks (Jenkins 2005, after Feachem).

On crops. Bacteria and viruses on leaves usually die within a month in sun and dry air. Roundworm eggs on tomatoes and lettuce fell by 99% in 19 days and disappeared in four weeks in one study cited by Jenkins (2005). Direct sunlight kills exposed roundworm eggs in about 15 hours, but eggs shaded in soil or in a fold of a leaf last far longer.

In water. Survival varies with temperature and sunlight, and norovirus can persist in surface water for more than 70 days (Sosah et al. 2025). Any well or stream within reach of faeces must be presumed contaminated.

In sludge. After six months of anaerobic digestion about 10% of roundworm eggs may still be viable (Jenkins 2005, after Feachem).

Bacteria and viruses die in weeks to months. Roundworm eggs need heat or very long storage, so every safe-use rule is written for them: if they are dead, everything else almost certainly is.

8. Killing pathogens: heat, time, dryness and alkalinity

Heat. The kill curve for roundworm eggs (Jenkins 2005, after Feachem) is the most useful single table in this report:

Temperature	Roundworm eggs killed in about	Other organisms
55 °C	2 hours	*Shigella* in 1 hour
50 °C	20 hours	Hookworm in 5 minutes
45 °C	200 hours (8 days)	

Jenkins gives the safe zone as 62 °C for one hour, 50 °C for a day, 46 °C for a week or 43 °C for a month (Jenkins 2005). Haug's figures, quoted by EcoSanRes, say 55 to 60 °C for one to two days kills essentially all pathogens (Schönning and Stenström 2004).

Composting standards. These build in different safety margins.

- EcoSanRes: above 50 °C for at least one week throughout all the material, as a minimum (Schönning and Stenström 2004).

- WHO 1989, quoted by EcoSanRes: 50 °C for 14 days, or aerated composting at 55 to 60 °C for one month plus two to four months of maturation (Schönning and Stenström 2004).
- WHO 2006 Volume 4: above 50 °C for at least one week, according to secondary sources. I could not download the document [VERIFY].
- US EPA (40 CFR 503): aerated static pile or in-vessel at 55 °C or more for 3 days, or windrow at 55 °C or more for 15 days with at least five turnings.
- Niwagaba et al. (2009), bench trials with human faeces: above 50 °C for at least two weeks.

EcoSanRes and the EPA differ in time by a factor of two to five. The difference lies in the word "throughout". The outside of a pile never gets hot, so the EPA requires turning and EcoSanRes requires that all the material reach temperature. My conservative rule, derived from both, is at least 55 °C for at least two weeks with at least three turnings, then at least six months of maturing [VERIFY, my inference].

The field reality. Hot composting of human waste works at scale with trained people and often fails in household toilets.

- At the SOIL site in Port-au-Prince, Haiti, large bins with sugarcane bagasse reached over 58 °C in the centre, with corners 10 to 20 °C cooler. *E. coli* became undetectable after 16 weeks and roundworm egg viability reached zero after six weeks (Berendes et al. 2015). The study's CDC and Emory authors later objected to SOIL's description of the results as showing acceptable *E. coli* levels [VERIFY the exact content of the exchange].
- Household composting toilets in Denmark and Sweden rarely reached thermophilic temperatures (Tønner-Klank et al. 2007, read via secondary summary).
- Uninsulated piles of faeces stayed within about 15 °C of ambient, and moisture above 60% soured the material (pH below 6) and slowed it (Niwagaba et al. 2009).

A household batch of a few buckets a week does not reliably heat. A community pile with plenty of carbon material and a person whose job it is to turn it can.

Time alone (cold storage). Where heat cannot be guaranteed, time does the work, slowly.

Condition	Storage needed
Dry faeces, ambient 2 to 20 °C	1.5 to 2 years
Dry faeces, ambient 20 to 35 °C	Over 1 year
Strauss and Blumenthal, warm and cool climates	1 year at 28 to 30 °C, 18 months at 17 to 20 °C
With ash or lime raising pH above 9	Over 6 months

All figures are from Schönning and Stenström (2004), which quotes Strauss and Blumenthal. A Danish risk model there puts the chance of roundworm infection from handling stored faeces at near 100% for fresh material, about 10% after six months and about 1 in 1,000 after twelve months. Jenkins' claim that a few months kills nearly all pathogens (Section 12) is not supported for roundworm by these figures.

Dryness and alkalinity. Drying below about 20 to 25% moisture speeds die-off, and wood ash (pH about 9.4) and lime (pH about 10.5) raise the pH. But in El Salvador, in vaults where pH stayed below 9, faecal coliforms survived over 1,000 days and roundworm eggs about 600. Even above pH 11, roundworm eggs survived about 450 days. Rewetting can let *Salmonella* and *E. coli* grow again (Schönning and Stenström 2004). Ash and lime help but do not replace time.

9. The pit latrine: siting, depth, building and filling

How far from water? Conventions vary, as Graham and Polizzotto (2013) showed in a review of groundwater near latrines used by 1.77 billion people. Older engineering texts ask 15 m (Franceys et al. 1992), Sphere, MSF and Haiti 30 m, WaterAid 50 m and South Africa 75 m. The furthest observed travel was about 25 m for bacteria, 50 m for viruses and 26 m for nitrate, with most studies showing under half those distances. In fissured rock and coarse gravel, contamination travels much further and faster (Graham and Polizzotto 2013).

How far above the water table? Older guidance asked for more than 2 m of fine soil under the pit (Franceys et al. 1992). Sphere asks that the pit bottom be at least 1.5 m above the highest water table (Sphere via RCRC n.d.). Kligler, in 1921, recommended 3 to 4.5 m (Graham and Polizzotto 2013).

The library's earlier report gave 30 m and 1.5 m as the convention and warned about fissured rock (THRIVING library, HY-02). I agree, and add three points. Judge the water table at its wettest season, not at a dry-season dig. In sand over gravel or cracked rock no distance is safe, and the answer is a raised or sealed system such as a UDDT. And put the latrine downhill and down the groundwater flow from the well, which slope usually shows [VERIFY].

Nitrate is a separate risk. The drinking-water guideline is 50 mg per litre, and wells near dense latrines have exceeded 100 mg per litre (Graham and Polizzotto 2013). High nitrate in water for infant feeds can cause methaemoglobinaemia ("blue baby"). In a dense settlement, many pits add up even if each is far enough from the well.

Distance from homes. Sphere asks that toilets be at least 6 m and no more than 50 m from dwellings, with 20 people per toilet as the standard and 50 in the first days of an emergency (Sphere via RCRC n.d.).

How deep and how big? Pits are commonly 2.5 to 4 m deep and 1 to 1.5 m across. A pit 3 m deep and 1.5 m square lasts a family of six about 15 years (Reed n.d.). Franceys et al. (1992, via Practical Action) gave sludge accumulation in litres per person per year: wet pits 40 with degradable cleansing material and 60 with rubbish, dry pits 60 and 90. Field measurements ranged from 18 to 81. Size a pit as people × rate × years, plus half a metre of free depth. Six people in a dry pit fill 360 litres a year, so a 1.5 × 1.5 × 3 m pit with 0.5 m left free (about 5.6 m^3 usable) lasts roughly 15 years, matching WEDC's figure.

Building. Line at least the top metre (the whole pit in sand), raise the slab about 15 cm with a soil mound to shed rain, test it with four adults standing on it, and fit a tight lid that keeps flies in and children out (Reed n.d.). The SanPlat, a small domed concrete slab a village mason can cast, is a cheaper alternative.

Full pits. A pit is full when contents come within 0.5 m of the surface. Fill the rest with soil and dig a new pit (Reed n.d.). A sealed pit left at least two years can be dug out as soil (Schönning and Stenström 2004).

Hazards of the pit itself. Pits collapse, often in heavy rain or when unlined (Reed n.d.). Pits hold methane, carbon dioxide and hydrogen sulphide, so no one climbs in, and anyone who must is roped from above with a second person standing by [VERIFY]. Children fall in. Five-year-old Michael Komape drowned in a school pit latrine in Limpopo, South Africa, in January 2014, and Lumka Mkhethwa, also five, in 2018. No national count of such deaths exists (Africa Check 2018). Every drop hole children use must be too small to swallow a child, and every pit covered when not in use.

10. The ventilated improved pit latrine

The VIP latrine adds a vent pipe from the pit to above the roof, with a fly screen on top, and keeps the shelter dark. Air moves up the pipe, carrying smell away. Flies hatching in the pit fly towards the light at the top, hit the screen and die, while flies outside are drawn to the smell at the screen rather than the dark doorway.

Feature	Tilley et al. 2014	Other guidance
Vent pipe diameter	At least 110 mm	150 mm in many designs [VERIFY the second source]
Height above roof	Over 300 mm	500 mm in South African guidance [VERIFY]
Fly screen	Corrosion-resistant mesh	Apertures about 1.2 × 1.5 mm, aluminium or stainless

Screens rust and clog, and a broken screen turns the vent into a fly exit. SHINE's VIP latrines gave no health effect (Section 3): a good household latrine is not a public health programme.

11. Arborloo, fossa alterna, urine diversion and urine use

Arborloo. A shallow unlined pit about 1 to 1.5 m deep with a portable slab and shelter. Soil and ash go in after each use. When the pit is nearly full, typically in 6 to 12 months for a family, the slab and shelter move. The old pit is topped with about 15 cm of soil and planted with a tree such as banana, papaya or guava (Tilley et al. 2014 [VERIFY the depths]). The waste stays well above most water tables and is never handled.

Fossa alterna. Two shallow lined pits, each no deeper than about 1.5 m, used in turn with soil, ash and leaves. The closed pit is emptied after resting at least a year, when the other is full (Tilley et al. 2014). The EcoSanRes figures (Section 8) argue for longer in cool climates.

Urine-diverting dry toilet (UDDT). The seat or squat plate sends urine forward to a pipe and faeces back to a dry vault, covered after each use with ash, lime, soil or sawdust. Two vaults are used in turn, and no water enters the faeces vault (Tilley et al. 2014). EcoSanRes recommends 200 to 500 ml (one to two cups) of ash or lime after each defecation and storage of at least six months with it, or without it at least a year above 20 °C and 1.5 to 2 years in cooler climates (Schönning and Stenström 2004). The UDDT suits high groundwater and shallow rock, because the vault is above ground.

Urine. Urine from healthy people is nearly sterile. Its risk comes from faecal cross-contamination, and typhoid passing in urine is unusual (Schönning and Stenström 2004).

- A household may use its own urine on its own crops, stopping at least one month before harvest.
- Shared systems should store urine at least one month at about 20 °C before use on processed or cooked crops, and six months before use on all crops. Stored urine reaches about pH 9, which itself kills many organisms (Schönning and Stenström 2004, consistent with WHO 2006 as reported in secondary sources [VERIFY]).
- Apply close to the ground, not over leaves.
- Never let urine reach fresh water where urinary schistosomiasis occurs.

Faeces on food crops. Not on vegetables eaten raw or on root crops. Fruit trees are acceptable. Stop at least one month before harvest (Schönning and Stenström 2004).

12. Composting toilets and the humanure argument

Jenkins' *Humanure Handbook* (2005) is the most influential guide to composting one's own excreta. Its method is a bucket toilet with sawdust cover and an outdoor bin where toilet waste is mixed with kitchen and garden waste, left to heat and aged for a year. Jenkins argues, correctly, that a well-built hot pile kills pathogens.

Where the book understates risk is persistence. It treats two years of retention as obsessive and states that a few months kill nearly all pathogens (Jenkins 2005). Three facts weigh against that. First, small domestic piles often do not reach thermophilic temperatures throughout (Section 8). Second, the outside and corners of a pile, where

temperatures may be 10 to 20 °C lower than the centre, are exactly where fresh material sits (Berendes et al. 2015). Third, roundworm eggs survive months to years at moderate temperatures (Sections 7 and 8). EcoSanRes asks for longer storage (Schönning and Stenström 2004).

The humanure method can be safe if three conditions hold. The material is held for at least a year after the last fresh addition. The compost goes to fruit trees, ornamentals and field crops, not to salad or root vegetables. And whoever turns and handles it washes hands and tools. After the Fall, with no testing available, two years is the margin I would recommend, as Jenkins himself allows for the cautious [VERIFY, my inference].

13. Children's faeces and animal faeces

Children's faeces are often thought harmless. They are not. Young children carry more enteric pathogens than adults, because they are infected more often, and they pass them where other children crawl and play [VERIFY: I found no direct comparison of pathogen loads]. More than half of households in low- and middle-income countries dispose of children's faeces unsafely, rising to over 80% in India, and many do so even when the household has a latrine [VERIFY: figures from secondary summaries of UNICEF and World Bank surveys]. One Bangladeshi study found that unsafe disposal was associated with about five times the odds of pathogenic *E. coli* in the soil where children played [VERIFY]. A Cochrane review of interventions to improve disposal of children's faeces found the evidence of health effects mixed and of very low to moderate quality (Majorin et al. 2019).

The practical rules are in Protocol 8. WASH Benefits Bangladesh included potties and faeces scoops in its sanitation arm, one of the few to reduce diarrhoea (Luby et al. 2018).

Animal faeces carry *Campylobacter*, some *E. coli* strains, *Cryptosporidium* and *Giardia*, and animals in the compound raise contamination of stored water (THRIVING library, HY-01). Penning animals is a sanitation measure too.

14. Flies

Flies breed in exposed faeces and carry pathogens to food and children's eyes.

- In The Gambia, insecticide spraying cut fly numbers by about 75%, fly-eye contacts by more than 95% and trachoma by about 75% (RR about 0.25) (Emerson et al. 1999). The same trial reported less diarrhoea in the dry season, a figure I could not check [VERIFY].
- In a larger follow-up, latrine provision without spraying cut flies landing on children's eyes by about 30% (7 to 52%), and the reduction in trachoma was about 30% but not significant. Spraying gave 88% fewer eye flies and 56% less trachoma (Emerson et al. 2004).
- In Pakistan, spraying reduced childhood diarrhoea by about 23% during the fly season (Chavasse et al. 1999, read via secondary summary).
- Esrey et al. (1991) reported a median 40% reduction in diarrhoea from fly-related interventions, but from poor-quality studies before 1960.

After the Fall, without insecticide, the defence is to deny flies a breeding place (Protocol 8).

15. Excreta in a cholera outbreak

MSF's guidance for cholera treatment centres asks for separate latrines for patients and staff, pits sited at least 30 m from any water source and with the bottom at least 1.5 m above the water table, and a dedicated pit for liquid excreta and vomit near the treatment area, roughly 90 cm to 1.5 m deep and at least 5 m from other facilities (MSF n.d.). Buckets of stool and vomit are disinfected with chlorine solution before emptying. The concentration should come from the library's disinfection report [VERIFY, see HY-05].

Evidence grades

Claim	Grade	Basis
Sanitation reduces childhood diarrhoea by about 10 to 25%	A (low certainty)	Systematic reviews (Freeman et al. 2017, Wolf et al. 2022)
Sewerage reduces diarrhoea more than on-site latrines	A (low) and B	Wolf et al. 2022, five studies, and the Victorian record
Building latrines without near-universal use has no detectable health effect	A	Odisha, Madhya Pradesh, Kenya and SHINE trials
Child growth improves only when community coverage passes about 50 to 75%	A to B	Pooled trial data (Cameron et al. 2022), Mali (Harris et al. 2017)
Sanitation reduces roundworm and whipworm	B	Mostly observational reviews (Strunz et al. 2014, Freeman et al. 2017)
Footwear reduces hookworm more than latrines do	B	Strunz et al. 2014
Deworming without sanitation buys only months	A	Jia et al. 2012
Fly control reduces trachoma	A	Emerson et al. 1999, 2004
Fly control reduces diarrhoea	B	Chavasse et al. 1999, older studies
Water and sewers drove much of the Victorian urban mortality fall	B	Chapman 2019, Szreter 1988, Snow 1855, contested
Composting at 50 to 55 °C throughout for one to two weeks kills pathogens	B	Kill curves and standards bodies
Household compost toilets reach these temperatures	X	Tønner-Klank et al. 2007, Niwagaba et al. 2009
Dry storage for 1 to 2 years makes faeces safe to handle	B	EcoSanRes risk model and field data
Ash or lime alone sterilises faeces quickly	X	El Salvador vault data (Schönning and Stenström 2004)
30 m from water and 1.5 m above the water table protects groundwater	B in fine soil, X in fissured rock	Graham and Polizzotto 2013
Raw night soil on fields is safe because East Asia did it for centuries	X	Japan 62.9% roundworm in 1949 (Hasegawa et al. 2020)
Children's faeces are harmless	X	Majorin et al. 2019 and pathogen biology
Environmental enteric dysfunction links faecal exposure to stunting	C	Plausible mechanism, mixed biomarker evidence (Harper et al. 2018)

The tradition (night soil, pits, ash in the privy) says excreta are a resource and a nuisance. The record (Japan, the American South, Victorian London) shows they kill unless managed. The science infers that the danger lies chiefly in worm eggs and community-wide exposure, controlled by time, heat and coverage.

Means ledger

Rung	What is possible	What it buys
Hands and knowledge alone	Cat holes about 15 to 20 cm deep, covered [VERIFY], defecation areas downhill and 30 m from water, shoes, handwashing with ash	Most of the benefit of ending open defecation near water and paths, if everyone does it
Hearth, garden and still	Ash from the hearth for cover, arborloo with a tree, urine for the garden after one month, fly control by covering, pole and thatch shelters	Safe household sanitation without any built material beyond wood
Village dispensary (300 people)	Lined pits with log or SanPlat slabs, VIP pipes of bamboo or clay with fine mesh, UDDTs where water is high, a sanitation steward and a map of wells and latrines	50 to 75% coverage or better, the threshold for child growth
District infirmary (3,000 people)	Community compost site with staff and thermometer, cement, a pit-emptying service with protective gear, cholera excreta pits, water tests if a laboratory survives, deworming	Safe reuse of excreta at scale, outbreak response
Pre-Fall hospital (reference)	Sewers, treatment works, chlorinated piped water, vaccines for typhoid, hepatitis A, polio and cholera, antibiotics, faecal testing	The 50% drop in diarrhoea seen with sewerage and the near-elimination of cholera and typhoid

The step that matters most is the one from household to village. A latrine is a household good. Sanitation is a public good.

Harm test

How sanitation measures can harm. - Latrines too close to wells, in fissured rock or over high water tables put faecal organisms and nitrate into drinking water (Graham and Polizzotto 2013). - Pits collapse, drown children and hold gases that can suffocate anyone who climbs in (Reed n.d., Africa Check 2018). - Night soil or under-treated compost on vegetables spreads worms and bacteria, as in Japan before 1950 and Germany in 1949 (Hasegawa et al. 2020, Jenkins 2005). - Emptying fresh pits by hand exposes workers to the highest pathogen loads in the system. - Lime and strong ash can burn skin and eyes [VERIFY]. - Shaming campaigns can humiliate and coerce the poor (Bartram et al. 2012, Engel and Susilo 2014).

Who must never be exposed. Children must never handle fresh excreta or play near pits, compost or fields fertilised in the past month. Pregnant women should not handle fresh excreta [VERIFY: my inference from hepatitis E risk, outside this brief]. Nobody enters a pit. Untreated or partly treated material never goes on anything eaten raw.

Warning signs. Diarrhoea clustering in households sharing one well. Watery diarrhoea with rapid dehydration in an adult (suspect cholera). Children passing worms or pale and breathless (hookworm). More flies around latrines. Smell or cloudiness in a well after rain. A cracking or sinking slab or subsiding ground round a pit. Wet, stinking, cold compost.

What to do. Stop using a suspect well and treat all water (THRIVING library, HY-02). Find and close the source.

Re-site pits, cover drop holes and rebuild sagging slabs before they fall. Re-pile compost that has not heated with more carbon material and restart the timing.

Historical cases. Broad Street 1854, East London 1866, Germany 1949, Japanese wartime night soil, and the Komape death in 2014.

Red flags

Red flag	Why it matters	Honest comfort
Many people with sudden, profuse watery diarrhoea, especially adults	Possible cholera. Untreated, half may die	With oral rehydration started early, almost all survive (WHO 2023a). The treatment is water, salt and sugar, and a carer who keeps giving it
High fever lasting a week, slow pulse, abdominal pain, confusion	Possible typhoid. 10 to 20% die without antibiotics	Most people recover even untreated, and good nursing, fluids and food improve the odds
Bloody diarrhoea with fever in a child	Shigella dysentery, spreads fast in households	Usually self-limiting within a week. Fluids and continued feeding matter most
Yellow eyes and skin after a week of malaise	Hepatitis A	Almost everyone recovers fully, and one attack gives lifelong immunity
A child who suddenly cannot move a leg after a fever	Possible polio	Most paralysis improves partly, and most infected children never become paralysed
A child passing a worm	Roundworm	Uncomfortable, common, rarely dangerous, and treatable if any vermifuge survives
Pale, breathless child who eats soil	Hookworm anaemia	Iron-rich food and shoes reverse it slowly
A child near an open pit	Drowning	One lid and one rule prevent it entirely

The case against

Against expecting health gains from latrines. The Odisha, Madhya Pradesh, Kenya and SHINE trials found little or no effect on diarrhoea or growth (Clasen et al. 2014, Patil et al. 2014, Null et al. 2018, Humphrey et al. 2019). Critics of sanitation-first policy argue that the money would do more in nutrition or vaccination. The trialists' answer is that the interventions were too weak and too narrow, not that sanitation is useless (Cumming et al. 2019). Both readings fit the data. After the Fall there are no vaccines to buy instead.

Against coercion. Bartram et al. (2012) warned that community-led total sanitation can use public shaming, fines and denial of services that violate individual rights. Engel and Susilo (2014) traced its methods to colonial hygiene campaigns, and later work by Bateman and Engel, which I did not read, extended the critique [VERIFY]. Venkataramanan et al. (2018) found the CLTS evidence weak and of low quality. The coverage data say the whole community must comply, which is a reason for persuasion and fair shared work, not for humiliation.

Against the sanitary story of Victorian health. McKeown credited nutrition (McKeown and Record 1962). Hinde and Harris (2019) showed typhoid falling in parallel in towns and countryside, where sewers were rare. Szreter

(1988) and Chapman (2019) answered that infrastructure explains a large share. The debate is not closed.

Against the hookworm success story. Roodman (2017) questioned Bleakley's (2007) estimates of the economic benefit. Elman et al. (2014) showed that dispensaries, not privies, dominated the campaign and that eradication was declared prematurely.

Against long retention. Jenkins (2005) argues that two-year storage is excessive. If he is right, the protocols here waste space and time. I keep the longer figure because heating is rarely verified without a thermometer and the cost of being wrong is a wormy village.

Against reuse at all. Some engineers argue that excreta should be contained and never reused, because reuse needs a discipline communities rarely sustain. After the Fall the nitrogen and phosphorus in excreta may be a community's most important fertiliser, so containment alone carries a cost in food.

10-line summary

1. Sanitation cuts childhood diarrhoea by roughly 10 to 25%, sewers by more, and reduces roundworm, whipworm, trachoma and schistosomiasis.
2. Hookworm responds more to shoes than to latrines.
3. Latrines protect the community, not the household. Gains appear when 50 to 75% of a village stops open defecation.
4. The null trials built latrines that went unused and left other routes open.
5. Site pits at least 30 m from water, downhill, 1.5 m above the wettest-season water table, further in sand or cracked rock.
6. Line the top metre, raise the slab, cover the hole, close at 0.5 m from full, never enter.
7. Worm eggs are the hardest target: 50 to 55 °C throughout for one to two weeks, or one to two years of dry storage.
8. Household compost rarely heats enough. Trust time over temperature unless you measure.
9. Urine is near sterile: store a month, apply to soil, keep out of water where schistosomiasis occurs.
10. Children's faeces are dangerous, flies carry, and untreated night soil means a wormy population.

Open questions

- What distance protects groundwater in each local soil? Simple dye or salt tracer tests might answer it [VERIFY whether a field method is published].
- Can a community compost be trusted without a thermometer? Could a wax or fat that melts at a known temperature serve as an indicator? [VERIFY, my inference]
- Does ash at 200 to 500 ml per use shorten safe storage in cool climates, given the El Salvador results?
- What is the health cost of night-soil use after one year of storage, compared with containment? No trial exists.
- What persuades a whole community to give up open defecation without shaming?
- Does WHO 2006 Volume 4 match the EcoSanRes figures used here? I could not read the WHO text.

Sources to read in full

1. WHO (2006), *Guidelines for the safe use of wastewater, excreta and greywater*, Volume 4. The standard, not read directly.
2. Feachem RG et al. (1983), *Sanitation and Disease*. The source of most survival figures, read only through summaries.
3. Franceys R, Pickford J, Reed R (1992), *A Guide to the Development of On-site Sanitation*. WHO.
4. Schönning C, Stenström TA (2004), the EcoSanRes guidelines. The backbone of this report.
5. Tilley E et al. (2014), *Compendium of Sanitation Systems and Technologies*. Eawag.

6. Coffey D, Spears D (2017), *Where India Goes*.
7. Ettling J (1981), *The Germ of Laziness*. Not read.
8. Snow J (1855), *On the Mode of Communication of Cholera*.
9. Cumming O et al. (2019), the consensus statement on the WASH trials.
10. Jenkins J (2005), *The Humanure Handbook*, read alongside EcoSanRes.

At the bedside after the Fall

A person with diarrhoea is a source of infection for the whole household.

- Give a covered bucket for stool and vomit with a little ash or soil in the bottom. Empty it into the latrine or a deep pit after each use, never onto open ground or near water.
- Wash hands with soap or ash and water after every contact with the patient, bucket or bedding, and before touching food or water. Keep to one carer where possible.
- Keep the patient's cup separate and the water covered and treated (THRIVING library, HY-02).
- Wash soiled bedding away from the water source, pour the wash water into the latrine and dry the bedding in sun.
- Cover the patient's food, the bucket and the drop hole against flies.
- Give fluids and food. Rehydration saves the dying (THRIVING library, HY-01).
- For suspected cholera, disinfect buckets with strong chlorine solution if available [VERIFY, see HY-05], dig a separate deep pit at least 30 m from water, and tell the sanitation steward at once.
- For a child with worms, find the route: where the child plays, whether the family's faeces are contained, whether the child wears shoes.
- After a death from cholera or typhoid, handle the body with gloves or cloths that are then burned or washed, and bury promptly, far from water [VERIFY].

Protocols

Protocol 1. Siting a pit latrine - [ ] At least 30 m from any well, spring or stream. Further (50 m) in sand or gravel. No pit at all in cracked rock or limestone. - [ ] Downhill from the water source. - [ ] Pit bottom at least 1.5 m above the highest water table, judged at the end of the wet season or from nearby wells at that time. - [ ] Wet-season water within 2.5 m of the surface: build a UDDT, arborloo or fossa alterna instead. - [ ] At least 6 m and at most 50 m from dwellings. At most 20 people per latrine. - Tolerance: distances are minimums.

Protocol 2. Digging and building - [ ] Volume: people × 60 litres × years, plus 0.5 m free depth. Six people for 15 years: about 1.5 × 1.5 m and 3 m deep. - [ ] Line at least the top 1 m with stone, brick, logs or woven poles, the whole pit in sand. - [ ] Slab raised about 15 cm with a soil mound. Test with four adults standing on it. - [ ] Drop hole too small for a child to fall through, with a tight lid. - [ ] Handwashing point with soap or ash at the door. - [ ] Only excreta and degradable cleansing material in the pit.

Protocol 3. Closing a pit or arborloo - [ ] Close at 0.5 m from the top. Fill with soil, compact and mark it. - [ ] Plant a fruit tree on an arborloo, not vegetables. - [ ] Leave a closed lined pit at least 2 years before digging it out, with gloves and tools.

Protocol 4. VIP latrine - [ ] Vent pipe at least 110 mm, preferably about 150 mm across, its top at least 300 to 500 mm above the roof, on the sunny side. - [ ] Rust-proof fly screen with holes no larger than about 1.2 × 1.5 mm. - [ ] Shelter dark inside, no lid on the drop hole. Check the screen monthly.

Protocol 5. Urine-diverting dry toilet - [ ] After each use, cover faeces with 200 to 500 ml (1 to 2 cups) of dry ash, lime or soil. - [ ] No water or urine in the faeces vault. Anal washing water to a separate soak pit. - [ ] When a vault is full, seal it, date it and use the other. - [ ] Store at least 6 months with ash or lime (pH above 9). Without it, at least

1 year above 20 °C and 1.5 to 2 years in cooler climates. Material that gets wet starts its count again. - [ ] Empty with gloves and a dedicated shovel. Use on fruit trees and non-food crops, or compost again.

Protocol 6. Thermophilic community compost - [ ] Mix excreta with at least an equal volume of carbon material. Damp as a wrung sponge. - [ ] Pile at least 1 m^3, insulated with straw or soil. - [ ] Hold the core at 55 °C or more for at least 2 weeks with at least 3 turnings bringing the outside to the middle. Restart the count if the core falls below 50 °C [VERIFY, my inference combining EcoSanRes, WHO and EPA]. - [ ] Then mature at least 6 months with no fresh additions. - [ ] Use on fruit trees and field crops, never salads or roots, stopping 1 month before harvest. - Tolerance: no thermometer means treat it as cold storage (Protocol 5 times).

Protocol 7. Urine - [ ] Own household: apply to the soil, not leaves, stopping 1 month before harvest. Dilute about 1 part to 3 to 5 parts water if plants scorch [VERIFY the dilution]. - [ ] Shared systems: store closed for 1 month before use on cooked crops and 6 months before use on all crops. - [ ] Never near fresh water where schistosomiasis (blood in urine) occurs.

Protocol 8. Children's faeces and flies - [ ] Every child's faeces into the latrine the same day, by potty or scoop. Wash hands after. - [ ] Sweep the play area daily. Pen animals away from crawling infants. - [ ] Wash nappies away from wells and pour the water into the latrine. - [ ] Cover every drop hole and every dry-toilet deposit. Bury or cover animal dung within a few days. Cover food.

Protocol 9. Cholera excreta - [ ] Separate latrines for the sick. - [ ] A covered excreta pit for stool and vomit, about 1 to 1.5 m deep, at least 30 m from water, 5 m from beds and 1.5 m above the water table. - [ ] Disinfect buckets with strong chlorine solution, or lime if none [VERIFY, see HY-05]. - [ ] Handwashing at every latrine exit.

Protocol 10. Ending open defecation - [ ] Map every household, well, latrine and defecation area. - [ ] Aim for at least 75% of households using a latrine within a season and all within a year, sharing where needed. - [ ] Appoint a sanitation steward and make latrine building shared work. - [ ] Persuade through example and children's health, not humiliation. - [ ] Walk the paths and field edges monthly to check use, not construction.

Numbers to carry

1. **30 m** from any water source to a pit, downhill, more in sand, no pit in cracked rock (Sphere, Graham and Polizzotto 2013).
2. **1.5 m** of dry soil between the pit bottom and the wettest-season water table (Sphere).
3. **0.5 m** from the top is when a pit is full. Line the top **1 m**.
4. **60 litres** per person per year of pit filling, dry pit (Franceys et al. 1992).
5. **55 °C for 2 weeks** throughout with turning, then **6 months** maturing, for compost (my rule from EcoSanRes and EPA).
6. **1.5 to 2 years** of dry storage in cool climates, **1 year** in warm ones, **6 months** with ash or lime above pH 9 (Schönning and Stenström 2004).
7. **1 month** withholding before harvest after applying urine or treated faeces.
8. **50 to 75%** community coverage before child growth improves (Cameron et al. 2022).
9. **200 to 500 ml** of ash per use in a dry toilet (Schönning and Stenström 2004).
10. **Roundworm eggs** survive in soil normally for 2 years and up to 7 or more (Schönning and Stenström 2004, Jenkins 2005).

References

1. Africa Check (2018). Reports on deaths of children in school pit latrines in South Africa, including the cases of Michael Komape and Lumka Mkhethwa. Africa Check. https://africacheck.org (read via secondary summary and search results, exact article URL not recorded).

2. Bartram J, Charles K, Evans B, O'Hanlon L, Pedley S (2012). Commentary on community-led total sanitation and human rights: should the right to community-wide health be won at the cost of individual rights? Journal of Water and Health 10(4):499 to 503. https://doi.org/10.2166/wh.2012.205 (abstract only).
3. Berendes D, Levy K, Knee J, Handzel T, Hill VR (2015). Ascaris and Escherichia coli inactivation in an ecological sanitation system in Port-au-Prince, Haiti. PLoS ONE 10(5):e0125336. https://doi.org/10.1371/journal.pone.0125336 (abstract and secondary summaries read, including notes on the authors' objection to SOIL's account).
4. Bleakley H (2007). Disease and development: evidence from hookworm eradication in the American South. Quarterly Journal of Economics 122(1):73 to 117. https://doi.org/10.1162/qjec.121.1.73 (read via secondary summary and Elman et al. 2014).
5. Cameron L, Gertler P, Shah M, Alzua ML, Martinez S, Patil S (2022). The dirty business of eliminating open defecation: the effect of village sanitation on child height from field experiments in four countries. Journal of Development Economics 159:102990. https://doi.org/10.1016/j.jdeveco.2022.102990 (abstract and secondary summary).
6. CDPH (n.d.). Shigellosis. California Department of Public Health. https://www.cdph.ca.gov/Programs/CID/DCDC/Pages/Shigellosis.aspx (read via search summary, with a Louisiana Department of Health fact sheet giving the same figures).
7. Chadwick E (1842). Report on the Sanitary Condition of the Labouring Population of Great Britain. London: W Clowes for HMSO. https://archive.org/search?query=sanitary+condition+labouring+population+chadwick (read via secondary summaries, not the original).
8. Chapman J (2019). The contribution of infrastructure investment to Britain's urban mortality decline, 1861 to 1900. Economic History Review 72(1):233 to 259. https://onlinelibrary.wiley.com/journal/14680289 (abstract only, article DOI not recorded).
9. Chavasse DC, Shier RP, Murphy OA, Huttly SR, Cousens SN, Akhtar T (1999). Impact of fly control on childhood diarrhoea in Pakistan: community-randomised trial. The Lancet 353(9146):22 to 25. https://doi.org/10.1016/S0140-6736(98)03366-2 (read via a Cochrane review summary).
10. Clasen T, Boisson S, Routray P, et al. (2014). Effectiveness of a rural sanitation programme on diarrhoea, soil-transmitted helminth infection, and child malnutrition in Odisha, India: a cluster-randomised trial. Lancet Global Health 2(11):e645 to e653. https://doi.org/10.1016/S2214-109X(14)70307-9 (abstract and secondary summary).
11. Coffey D, Spears D (2017). Where India Goes: Abandoned Toilets, Stunted Development and the Costs of Caste. Noida: HarperCollins India. https://riceinstitute.org (read via secondary summaries and reviews).
12. Cumming O, Arnold BF, Ban R, et al. (2019). The implications of three major new trials for the effect of water, sanitation and hygiene on childhood diarrhea and stunting: a consensus statement. BMC Medicine 17:173. https://doi.org/10.1186/s12916-019-1410-x (abstract and secondary summary).
13. Elman C, McGuire RA, Wittman B (2014). Extending public health: the Rockefeller Sanitary Commission and hookworm in the American South. American Journal of Public Health 104(1):47 to 58. https://doi.org/10.2105/AJPH.2013.301472 (read in substantial part).
14. Emerson PM, Lindsay SW, Alexander N, et al. (2004). Role of flies and provision of latrines in trachoma control: cluster-randomised controlled trial. The Lancet 363(9415):1093 to 1098. https://doi.org/10.1016/S0140-6736(04)15891-1 (abstract only).
15. Emerson PM, Lindsay SW, Walraven GE, et al. (1999). Effect of fly control on trachoma and diarrhoea. The Lancet 353(9162):1401 to 1403. https://doi.org/10.1016/S0140-6736(98)09158-2 (abstract only).
16. Engel S, Susilo A (2014). Shaming and sanitation in Indonesia: a return to colonial public health practices? Development and Change 45(1):157 to 178. https://doi.org/10.1111/dech.12075 (abstract only).
17. Esrey SA, Potash JB, Roberts L, Shiff C (1991). Effects of improved water supply and sanitation on ascariasis, diarrhoea, dracunculiasis, hookworm infection, schistosomiasis, and trachoma. Bulletin of the World Health

Organization 69(5):609 to 621. https://apps.who.int/iris/ (read via secondary summary).
18. Feachem RG, Bradley DJ, Garelick H, Mara DD (1983). Sanitation and Disease: Health Aspects of Excreta and Wastewater Management. Chichester: John Wiley and Sons for the World Bank. https://documents.worldbank.org (not read, figures taken via Schönning and Stenström 2004 and Jenkins 2005).
19. Franceys R, Pickford J, Reed R (1992). A Guide to the Development of On-site Sanitation. Geneva: World Health Organization. https://apps.who.int/iris/handle/10665/39313 (read via Practical Action and Graham and Polizzotto 2013, not the original).
20. Freeman MC, Garn JV, Sclar GD, et al. (2017). The impact of sanitation on infectious disease and nutritional status: a systematic review and meta-analysis. International Journal of Hygiene and Environmental Health 220(6):928 to 949. https://doi.org/10.1016/j.ijheh.2017.05.007 (read in full text).
21. Fuller JA, Villamor E, Cevallos W, Trostle J, Eisenberg JN (2016). I get height with a little help from my friends: herd protection from sanitation on child growth in rural Ecuador. International Journal of Epidemiology 45(2):460 to 469. https://doi.org/10.1093/ije/dyv368 (read via secondary summary).
22. Graham JP, Polizzotto ML (2013). Pit latrines and their impacts on groundwater quality: a systematic review. Environmental Health Perspectives 121(5):521 to 530. https://doi.org/10.1289/ehp.1206028 (read in full text).
23. Hanley JG (2002). Edwin Chadwick and the poverty of statistics. Medical History 46(1):21 to 40. https://www.ncbi.nlm.nih.gov/pmc/ (read via secondary summary, exact PMC URL not recorded).
24. Hanley SB (1987). Urban sanitation in preindustrial Japan. Journal of Interdisciplinary History 18(1):1 to 26. https://www.jstor.org/journal/jinterdischist (read via secondary summary).
25. Harper KM, Mutasa M, Prendergast AJ, Humphrey J, Manges AR (2018). Environmental enteric dysfunction pathways and child stunting: a systematic review. PLoS Neglected Tropical Diseases 12(1):e0006205. https://doi.org/10.1371/journal.pntd.0006205 (abstract only).
26. Harris M, Alzua ML, Osbert N, Pickering A (2017). Community-level sanitation coverage more strongly associated with child growth and household drinking water quality than access to a private toilet in rural Mali. Environmental Science and Technology 51(12):7219 to 7227. https://doi.org/10.1021/acs.est.7b00178 (abstract only).
27. Hasegawa M, Pilotte N, Kikuchi M, et al. (2020). What does soil-transmitted helminth elimination look like? Results from a targeted molecular detection survey in Japan. Parasites and Vectors 13:6. https://doi.org/10.1186/s13071-019-3875-z (read in full text via PMC6950881).
28. Hinde A, Harris B (2019). Mortality decline by cause in urban and rural England and Wales, 1851 to 1910. The History of the Family 24(2):377 to 403. https://www.tandfonline.com/journals/rhof20 (abstract and secondary summary, DOI not recorded).
29. Humphrey JH (2009). Child undernutrition, tropical enteropathy, toilets, and handwashing. The Lancet 374(9694):1032 to 1035. https://doi.org/10.1016/S0140-6736(09)60950-8 (abstract only).
30. Humphrey JH, Mbuya MNN, Ntozini R, et al. (2019). Independent and combined effects of improved water, sanitation, and hygiene, and improved complementary feeding, on child stunting and anaemia in rural Zimbabwe: a cluster-randomised trial. Lancet Global Health 7(1):e132 to e147. https://doi.org/10.1016/S2214-109X(18)30374-7 (abstract and secondary summary).
31. Jenkins J (2005). The Humanure Handbook: A Guide to Composting Human Manure. 3rd edition. Grove City, Pennsylvania: Joseph Jenkins Inc. https://humanurehandbook.com (chapters on pathogens read online, with Feachem figures cited second-hand).
32. Jia TW, Melville S, Utzinger J, King CH, Zhou XN (2012). Soil-transmitted helminth reinfection after drug treatment: a systematic review and meta-analysis. PLoS Neglected Tropical Diseases 6(5):e1621. https://doi.org/10.1371/journal.pntd.0001621 (abstract only).
33. Luby SP, Rahman M, Arnold BF, et al. (2018). Effects of water quality, sanitation, handwashing, and nutritional interventions on diarrhoea and child growth in rural Bangladesh: a cluster randomised controlled trial.

Lancet Global Health 6(3):e302 to e315. https://doi.org/10.1016/S2214-109X(17)30490-4 (abstract and the summary in THRIVING library HY-01).

34. Majorin F, Torondel B, Ka Seen Chan G, Clasen T (2019). Interventions to improve disposal of child faeces for preventing diarrhoea and soil-transmitted helminth infection. Cochrane Database of Systematic Reviews CD011055. https://doi.org/10.1002/14651858.CD011055.pub2 (abstract only).
35. McKeown T, Record RG (1962). Reasons for the decline of mortality in England and Wales during the nineteenth century. Population Studies 16(2):94 to 122. https://doi.org/10.1080/00324728.1962.10414870 (read via Szreter and secondary summaries).
36. MSF (n.d.). Management of a cholera epidemic. Médecins Sans Frontières medical guidelines. https://medicalguidelines.msf.org (read via secondary summary of the excreta pit specifications).
37. Niwagaba C, Nalubega M, Vinnerås B, Sundberg C, Jönsson H (2009). Bench-scale composting of source-separated human faeces for sanitation. Waste Management 29(2):585 to 589. https://doi.org/10.1016/j.wasman.2008.06.022 (abstract and secondary summary).
38. Null C, Stewart CP, Pickering AJ, et al. (2018). Effects of water quality, sanitation, handwashing, and nutritional interventions on diarrhoea and child growth in rural Kenya: a cluster-randomised controlled trial. Lancet Global Health 6(3):e316 to e329. https://doi.org/10.1016/S2214-109X(18)30005-6 (abstract and the summary in THRIVING library HY-01).
39. Patil SR, Arnold BF, Salvatore AL, et al. (2014). The effect of India's Total Sanitation Campaign on defecation behaviors and child health in rural Madhya Pradesh: a cluster randomized controlled trial. PLoS Medicine 11(8):e1001709. https://doi.org/10.1371/journal.pmed.1001709 (abstract).
40. PHAC (2023). Hepatitis A vaccine: Canadian Immunization Guide, with the National Advisory Committee on Immunization statement. Public Health Agency of Canada. https://www.canada.ca/en/public-health/services/publications/healthy-living/canadian-immunization-guide-part-4-active-vaccines/page-6-hepatitis-a-vaccine.html (read via search summary, figures confirmed against a second clinical summary).
41. Pickering AJ, Djebbari H, Lopez C, Coulibaly M, Alzua ML (2015). Effect of a community-led sanitation intervention on child diarrhoea and child growth in rural Mali: a cluster-randomised controlled trial. Lancet Global Health 3(11):e701 to e711. https://doi.org/10.1016/S2214-109X(15)00144-8 (abstract and secondary summary).
42. Pickering AJ, Null C, Winch PJ, et al. (2019). The WASH Benefits and SHINE trials: interpretation of WASH intervention effects on linear growth and diarrhoea. Lancet Global Health 7(8):e1139 to e1146. https://doi.org/10.1016/S2214-109X(19)30268-2 (read via an Emergency Nutrition Network summary).
43. Reed B (n.d.). Mobile Note 21: Pit latrines. Water, Engineering and Development Centre, Loughborough University. https://wedc-knowledge.lboro.ac.uk (read in full).
44. Roodman D (2017). The impacts of hookworm eradication in the American South: a replication study of Bleakley (2007). https://davidroodman.com (read via secondary summary).
45. Schönning C, Stenström TA (2004). Guidelines on the Safe Use of Urine and Faeces in Ecological Sanitation Systems. EcoSanRes Publications Series 2004-1. Stockholm: Stockholm Environment Institute. https://susana.org/downloads?documentID=149 (read in full).
46. Snow J (1855). On the Mode of Communication of Cholera. 2nd edition. London: John Churchill. https://www.ph.ucla.edu/epi/snow/snowbook.html (read via the UCLA edition and secondary summaries).
47. Sosah et al. (2025). Review of enteric pathogen persistence in water environments. Frontiers in Microbiology 16:1654785. https://doi.org/10.3389/fmicb.2025.1654785 (abstract only, full author list and title not recorded).
48. Sphere via RCRC (n.d.). Sphere Handbook excreta management standards, as presented in a Red Cross Red Crescent training slide deck. https://spherestandards.org/handbook/ (the Sphere Handbook itself was not read).
49. Strunz EC, Addiss DG, Stocks ME, Ogden S, Utzinger J, Freeman MC (2014). Water, sanitation, hygiene, and soil-transmitted helminth infection: a systematic review and meta-analysis. PLoS Medicine 11(3):e1001620.

https://doi.org/10.1371/journal.pmed.1001620 (abstract and results summary).
50. Szreter S (1988). The importance of social intervention in Britain's mortality decline c.1850 to 1914: a re-interpretation of the role of public health. Social History of Medicine 1(1):1 to 38. https://doi.org/10.1093/shm/1.1.1 (abstract only).
51. Szreter S (2002). Rethinking McKeown: the relationship between public health and social change. American Journal of Public Health 92(5):722 to 725. https://doi.org/10.2105/AJPH.92.5.722 (abstract only).
52. Tilley E, Ulrich L, Lüthi C, Reymond P, Zurbrügg C (2014). Compendium of Sanitation Systems and Technologies. 2nd revised edition. Dübendorf: Swiss Federal Institute of Aquatic Science and Technology (Eawag). https://www.eawag.ch/en/department/sandec/publications/compendium/ (read via secondary summaries of the VIP, arborloo, fossa alterna and UDDT sheets).
53. Tønner-Klank L, Møller J, Forslund A, Dalsgaard A (2007). Microbiological assessments of compost toilets: in situ measurements and laboratory studies on the survival of fecal microbial indicators using sentinel chambers. Waste Management 27(9):1144 to 1154. https://doi.org/10.1016/j.wasman.2006.04.022 (read via secondary summary).
54. UKHSA (2020). Typhoid: the green book, chapter 33. UK Health Security Agency. https://www.gov.uk/government/publications/typhoid-the-green-book-chapter-33 (read via search summary, with a Manitoba Health fact sheet giving the same case fatality).
55. US EPA (40 CFR 503). Standards for the Use or Disposal of Sewage Sludge, Appendix B, Processes to Further Reduce Pathogens. https://www.ecfr.gov/current/title-40/chapter-I/subchapter-O/part-503 (read via secondary summary).
56. Venkataramanan V, Crocker J, Karon A, Bartram J (2018). Community-led total sanitation: a mixed-methods systematic review of evidence and its quality. Environmental Health Perspectives 126(2):026001. https://doi.org/10.1289/EHP1965 (abstract only).
57. WHO (2006). Guidelines for the Safe Use of Wastewater, Excreta and Greywater. Volume 4: Excreta and Greywater Use in Agriculture. Geneva: World Health Organization. https://www.who.int/publications/i/item/9241546859 (not read directly, figures confirmed only through secondary sources).
58. WHO (2023a). Cholera fact sheet. World Health Organization. https://www.who.int/news-room/fact-sheets/detail/cholera
59. WHO (2023b). Poliomyelitis fact sheet. World Health Organization. https://www.who.int/news-room/fact-sheets/detail/poliomyelitis
60. WHO (2023c). Soil-transmitted helminth infections fact sheet. World Health Organization. https://www.who.int/news-room/fact-sheets/detail/soil-transmitted-helminth-infections
61. Wolf J, Hubbard S, Brauer M, et al. (2022). Effectiveness of interventions to improve drinking water, sanitation, and handwashing with soap on risk of diarrhoeal disease in children in low-income and middle-income settings: a systematic review and meta-analysis. The Lancet 400(10345):48 to 59. https://doi.org/10.1016/S0140-6736(22)00937-0 (read via secondary summary).
62. THRIVING library, HY-01 (2026). Clean hands: Semmelweis, Nightingale and the quantified effect of handwashing and soap. THRIVING after the FALL, Book Four, library document, file research/out/HY-01.md (sections read).
63. THRIVING library, HY-02 (2026). Safe water without a utility: boiling, solar disinfection, sand filters, chlorine and the evidence for each. THRIVING after the FALL, Book Four, library document, file research/out/HY-02.md (sections read).