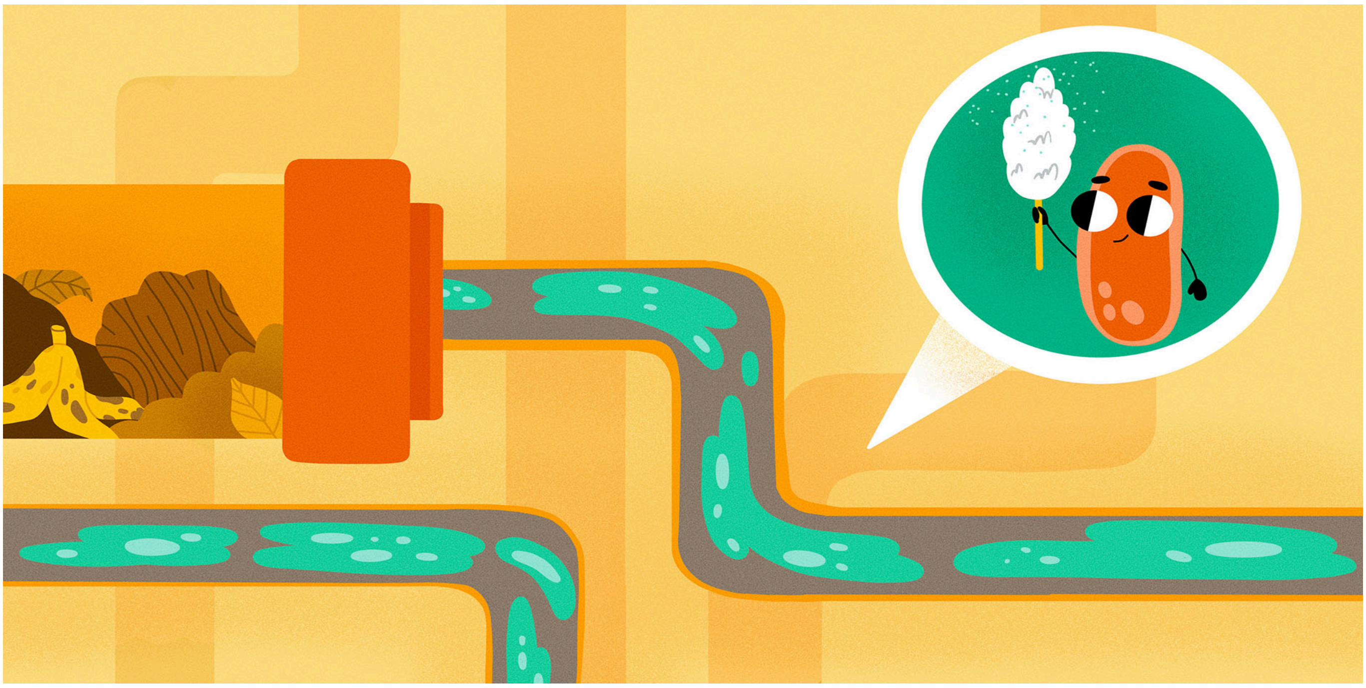
frontiers | Frontiers for Young Minds

EARTH SCIENCES
Published: 16 October 2023
doi: 10.3389/frym.2023.1140996



MICROBIAL "JANITORS" CLEAN UP OUR LIQUID WASTE

Clarence Bo Wen Sim [1†], ***Edric Shao Zhe Sim*** [1†], ***Elton Wenxiong Lim*** [1†], ***Su Xuan Gan*** [1†] ***and Adriana Lopes dos Santos*** [2,3*]

[1] *Singapore Centre for Environmental Life Sciences Engineering, Nanyang Technological University, Singapore, Singapore*
[2] *Asian School of the Environment, Nanyang Technological University, Singapore, Singapore*
[3] *Department of Biosciences, University of Oslo, Oslo, Norway*

YOUNG REVIEWERS:

ANTONIO
AGE: 10

CELINE
AGE: 13

Have you wondered what happens to our pee and poop after we flush the toilet bowl? What about food bits and soapy water from sinks and dishwashers? The liquid waste we all produce when using the toilet, having a bath or shower, or washing our clothes and dishes is called sewage. Sewage also includes rainwater running from the streets and liquid waste from factories. This liquid waste flows in hidden pipes called sewers, to sewage treatment facilities. Sewage treatment facilities are designed such that numerous microbes help to clean our waste so that it does not harm people, rivers, and oceans. In this article, we will explore how microbes are the super cleaners behind sewage treatment and why these microbes are beneficial to us.

WHAT IS SEWAGE AND WHY DO WE NEED TO TREAT IT?

Sewage is liquid waste produced by everyone when using the toilet, having a bath or shower, and washing our clothes and dishes. Liquid waste from factories and shopping malls, as well as rainwater from the streets containing leaves, branches, and anything else that is on the street, are also part of city sewage. This liquid waste travels through a giant, hidden web of pipes called the sewage system to sewage treatment facilities that are centers built to treat this liquid waste before releasing it back into the environment.

Even though sewage consists mostly of what *we* think of as waste, it is rich in nutrients from our poop and leftover food, for example. What we consider waste can be food to other organisms. If released into lakes, rivers, and oceans without treatment, the nutrients in sewage can lead to a rapid growth of algae—a process known as **eutrophication**. During an eutrophication event, the excessive growth of algae blocks the sunlight entering the water, killing other aquatic plants. Once all the nutrients are consumed, the algae die and are decomposed by aquatic microbes. As these microbes break down dead algae, they use up all the available oxygen and create "dead zones" where fish and other animals die from lack of oxygen (for more information about problems caused an excess of nutrients, see this Frontiers for Young Minds article). Sewage treatment is the process of reducing the nutrients in sewage so that it does not cause harm to aquatic ecosystems [1].

EUTROPHICATION

A change in an environment's nutrient status by an increase of nutrients brought by waterways (lakes, rivers, or oceans). One major consequence is the loss of aquatic life due to the rapid growth of plants and algae.

There are many kinds of microbes in sewage, from the environment, rainwater, or our homes. These microbes can break down and consume nutrients. At sewage treatment facilities, these microbes are stimulated to grow and use up the nutrients available in the sewage. Our waste is their food! With the help of microbes, the treated sewage, also called **effluent**, can then be released into the environment without causing eutrophication and other pollution problems.

EFFLUENT

Water or gas outflowing from a structure such as a sewage treatment facilities or pipes to another structure (for example tanks) or to natural body of water (lakes, rivers, or ocean).

WHAT HAPPENS TO THE SEWAGE IN TREATMENT FACILITIES?

When sewage arrives at sewage treatment facilities, it passes through many stages before it is released as effluent (Figure 1A). First, larger objects, such as tree branches or plastic bags, are removed using a screening gate consisting of parallel bars or wire mesh, which prevents large objects from passing through (Figure 1B).

The sewage then flows into a tank where it stays until small solids fall to the bottom. Think of pulpy orange juice: the heavy pulp sinks quickly on its own, while the lighter pieces float for a long time. In the tank, heavy solids such as human waste or sand sink to the bottom. Chemicals are added to make lighter suspended solids stick together,

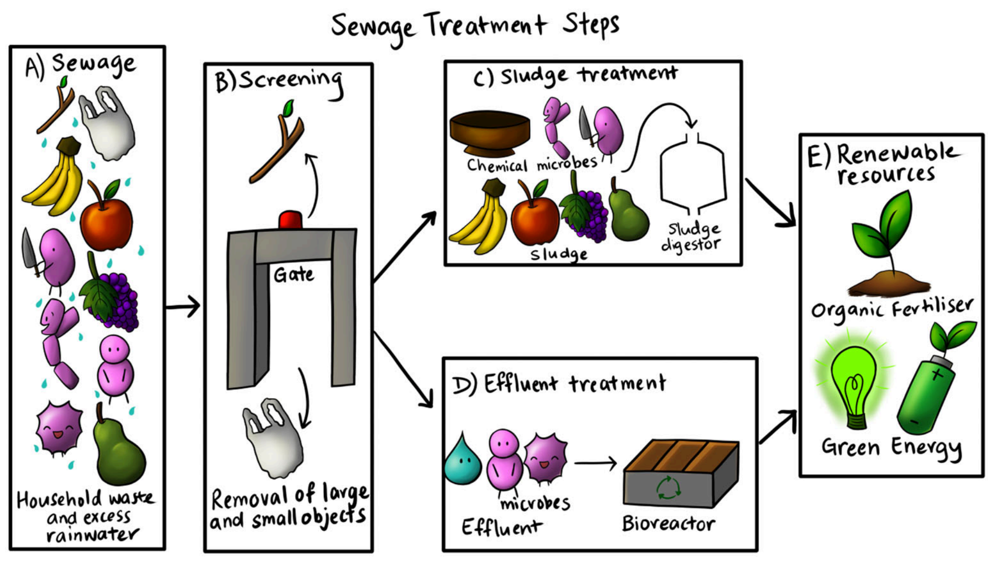


Figure 1

Figure 1

(A) Sewage contains solid waste, which is full of nutrients, and environmental microbes that can consume those nutrients. **(B)** Large solids in sewage are removed by a screening gate. **(C)** Chemicals are added to sewage to make small solids stick together so that they sink to the bottom as sludge. **(D)** The effluent, or liquid part of the sewage, is sent to a bioreactor for further treatment. **(E)** Sewage treatment can produce renewable resources like organic fertilizer and "green" energy. Fruits in A and C represent solid waste like rest of food and poop. The brown tray represents chemicals added to make the light solid waste to sink.

resulting in bigger, heavier chunks that quickly sink to the bottom, too. The solids that settle at the bottom of the tank are a thick, muddy mixture called sludge—made up of nutrients, microbes, and small solids—which gets processed in a sludge digestor (Figure 1C).

The remaining liquid waste, the effluent, is also rich in nutrients and microbes. The effluent is piped away for further treatment in **bioreactors** (Figure 1D), which we will describe in more detail below [1]. Treatment of sludge and effluent produces fertilizer and biogas, a form of "green" energy that does not pollute the Earth (Figure 1E). The treated effluent is then disinfected to remove potentially harmful microbes and then either discharged into the environment or recycled into the water supply.

BIOREACTOR

A container in which chemical processes are carried out by living organisms, like microbes.

ROLE OF MICROBES IN SLUDGE DIGESTERS

Remember the environmental microbes present in sewage? Inside sludge digesters, some of these microbes consume the nutrients present in muddy sludge. This process is called **anaerobic digestion**. Anaerobic digestion involves breaking down nutrients without using oxygen, in a multistep process—like cutting up an apple into bite-sized pieces (Figures 2A, B).

ANAEROBIC DIGESTION

A collection of processes by which microbes break down food to obtain energy and grow in the absence of oxygen (air).

Some sludge microbes break food into simpler molecules, making the nutrients more accessible to other microbes. The most important product of anaerobic digestion is acetic acid, also known as vinegar. Yes, like the vinegar you probably have in your kitchen! Acetic acid feeds the most important group of sludge microbes, the **methanogens**. When they consume acetic acid, methanogens produce an environmentally friendly energy source called biogas,

METHANOGEN

Microbes that produce a specific type of biogas called methane.

which mainly consists of two gases, methane (CH_4) and carbon dioxide (CO_2) (Figure 2C) [2]. Biogas can be harvested and used to generate electricity and to heat our homes. Any remaining undigested sludge can be dried and used as fertilizer (Figure 2C).

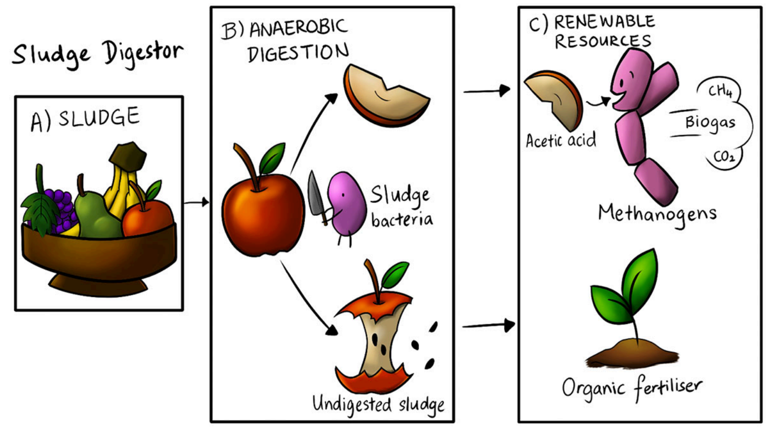


Figure 2

Figure 2

(A) Sludge is a thick, muddy mixture formed from the solids that fall to the bottom of the tank. **(B)** Certain microbes can digest sludge in the absence of oxygen, producing a substance called acetic acid (vinegar) in the process. **(C)** Acetic acid is converted into biogas by other microbes called methanogens, while the remaining undigested sludge can be dried and used as organic fertilizer. Fruits represent solid waste like rest of food and poop that have been sunk to form the sludge.

EFFLUENT: REMOVAL OF NUTRIENTS BY MICROBES IN BIOREACTORS

Now we know what happens to the sludge, but what happens to the effluent? As we mentioned earlier, effluent treatment occurs in bioreactors, where two important nutrients are removed: nitrogen and phosphorus. Effluent microbes are grown in specific conditions to maximize their ability to remove these nutrients from the effluent. These microbes are like "Lego" builders, removing and adding blocks to molecules (Figure 3A).

Microbes in the effluent remove nitrogen from molecules through two processes: **nitrification** and **denitrification**, which are part of the nitrogen cycle (for more information about the nitrogen cycle, see this Frontiers for Young Minds article). During nitrification, ammonia (NH_4^+) is converted into nitrite (NO_2^-) by certain microbes. These microbes remove hydrogen "blocks," transforming ammonia molecules into nitrite molecules. Then, other microbes change nitrite (NO_2^-) to nitrate (NO_3^-) through the addition of oxygen "blocks" (Figure 3A). Other microbes remove the oxygen blocks, converting nitrate (NO_3^-) into nitrogen gas (N_2). Nitrogen gas is released into the air (Figure 3A).

Phosphorus removal is carried out by other microbes, called **polyphosphate-accumulating organisms (PAOs)** [3]. Like all living things, PAOs need energy to grow, and they contain a compound called polyphosphate that acts like a rechargeable battery. Polyphosphate, which is built from several molecules of phosphate (PO_4), is used by PAOs as an energy source. This battery is "recharged" when

NITRIFICATION

A process carried out by microbes that transform ammonia (one form of nitrogen) into nitrates (a different form of nitrogen).

DENITRIFICATION

A process carried out by microbes that transform nitrates into nitrogen gas, which is released into the atmosphere.

POLYPHOSPHATE-ACCUMULATING ORGANISMS

A group of microbes that facilitate the removal of nutrient phosphorus from the environment.

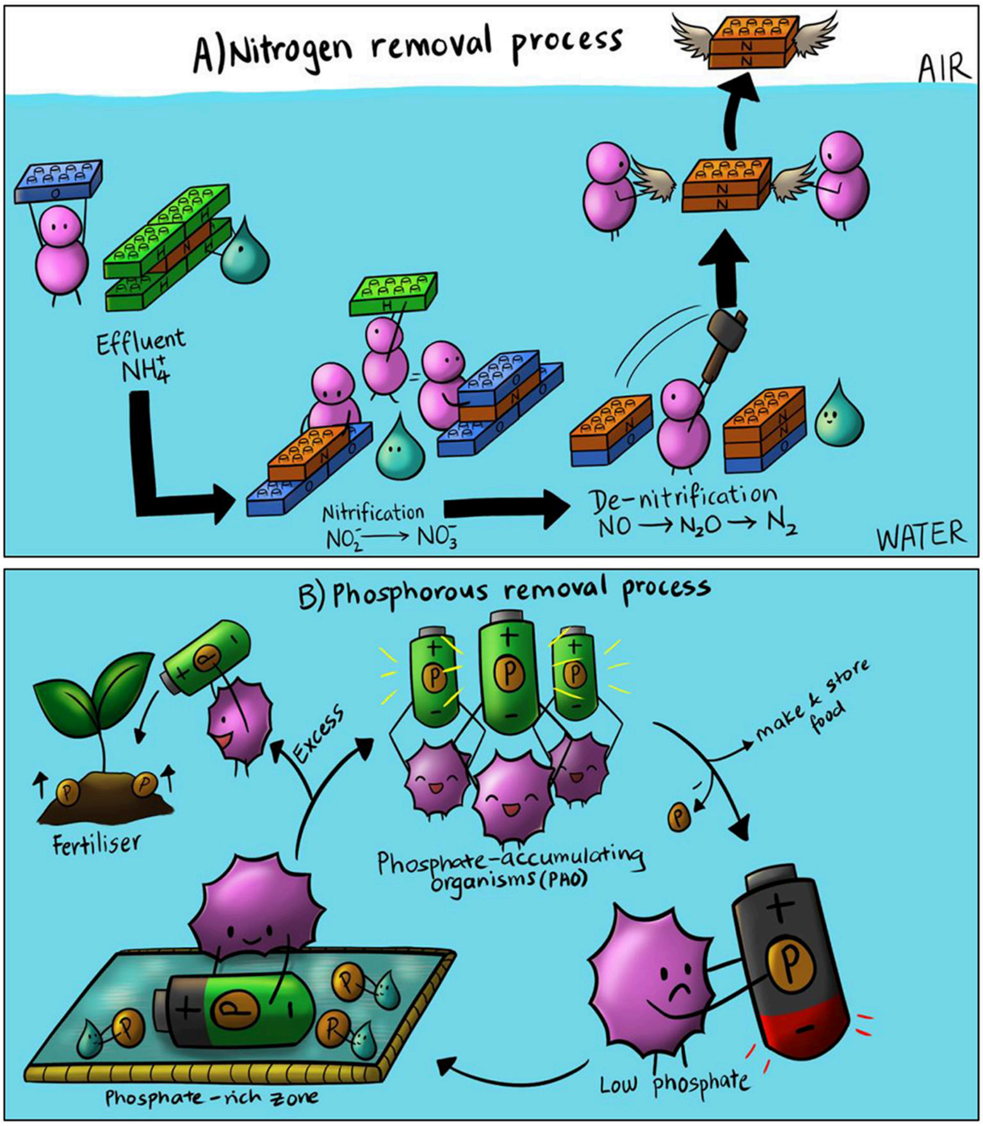


Figure 3

Figure 3

(A) Removal of nitrogen from effluent *via* nitrification and denitrification. Nitrogen removal from effluent is performed by microbes that convert nitrogen in the form of ammonium (NH_4^+) into nitrogen gas (N_2). The letters on the building blocks represent elements: oxygen (blue); hydrogen (green); nitrogen (orange). **(B)** PAOs are microbes used to remove phosphorous from effluent. PAOs use energy from their polyphosphate "batteries" and "recharge" them by taking phosphate from the effluent. Excess PAOs are harvested for use as fertilizer.

PAOs collect phosphates from the effluent to replace what they used (Figure 3B). The process removes phosphorus from the effluent and stores it away in PAOs. PAOs are eventually collected and used as fertilizer.

IMPORTANCE OF MICROBES IN WASTEWATER TREATMENT

Thanks to the unseen microbes from the environment that help us process sewage, we can make sure that the treated water released back into the environment is safe. Research on sewage treatment processes is investigating new types of bioreactor setups and biological treatment processes using different types of microbes that can increase the efficiency of sewage treatment facilities. Treating sewage is very important for protecting the environment and our water resources. Sewage microbes do all the hard work, helping to keep our environment safe, kind of like school janitors. What is more, these microbes provide us with useful products like fertilizer and biogas. What a great deal!

REFERENCES

1. Kesari, K. K., Soni, R., Jamal, Q. M. S., Tripathi, P., Lal, J. A., Jha, N. K., et al. 2021. Wastewater treatment and reuse: a review of its applications and health implications. *Water Air Soil Pollut.* 232:208. doi: 10.1007/s11270-021-05154-8
2. Enzmann, F., Mayer, F., Rother, M., and Holtmann, D. 2018. Methanogens: biochemical background and biotechnological applications. *AMB Express* 8:1. doi: 10.1186/s13568-017-0531x
3. Bunce, J. T., Ndam, E., Ofiteru, I. D., Moore, A., and Graham, D. W. 2018. A review of phosphorus removal technologies and their applicability to small-scale domestic wastewater treatment systems [review]. *Front. Environ. Sci.* 6:8. doi: 10.3389/fenvs.2018.00008

SUBMITTED: 20 February 2023; **ACCEPTED:** 29 September 2023; **PUBLISHED ONLINE:** 16 October 2023.

EDITOR: Leonardo Fernandes Fraceto, São Paulo State University, Brazil

SCIENCE MENTORS: Jacqueline C. Y. Lai and Kellie Aldi

CITATION: Sim CBW, Sim ESZ, Lim EW, Gan SX and Lopes dos Santos A (2023) Microbial "Janitors" Clean Up Our Liquid Waste. Front. Young Minds 11:1140996. doi: 10.3389/frym.2023.1140996

CONFLICT OF INTEREST: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

YOUNG REVIEWERS

ANTONIO, AGE: 10

Antonio is 10 years old. He is an avid bird watcher and gardener, and as a cub scout, is excited to get out into nature. He also really loves reading about new topics in science.

CELINE, AGE: 13

Hi, my name is Celine and I am a high school student from Vancouver BC. I really enjoy studying chemistry and biology on my own time. Also, I like to play sports outside with my friends for fun. My other hobbies are reading, drawing, and scrolling on the internet.

AUTHORS

CLARENCE BO WEN SIM

I am a Ph.D. student at the Singapore Center for Environmental Life Sciences Engineering at Nanyang Technological University, Singapore. My research focuses on the interactions between marine bacteria in their natural habitat and their potential for causing human disease. I enjoy cooking and eating good food, occasionally incorporating what I learn from my bacterial research to make my own (safely) fermented foods.

EDRIC SHAO ZHE SIM

I am a Ph.D. student at the Singapore Centre for Environmental Life Sciences Engineering at Nanyang Technological University, Singapore. My research involves understanding how bacteria from food wastewater could have beneficial effects for fishes, and translating such knowledge in the aquaculture industry in Singapore. Outside of my research, I enjoy spending time connecting with my friends, taking a slow and relaxing hike, playing sports, and listening to music.

ELTON WENXIONG LIM

I am a Ph.D. student at the Singapore Centre for Environmental Life Sciences Engineering at Nanyang Technological University, Singapore. My research focuses on sediment-based biofilms using flume experiments, and on the isolation of fish pathogens from coastal sediments. I love traveling around the world and exploring the wonders of the oceans *via* diving. In my free time, I like to create handicrafts with my nephews and niece.

SU XUAN GAN

I am a research assistant at the Singapore Centre for Environmental Life Sciences Engineering at Nanyang Technological University, Singapore. My work aims to use microalgae as an alternative nutrition source. To do so, I perform extensive screenings of microalgae for metabolites of interest and try to understand their optimal growth conditions and production during interactions with various strains of bacteria from the Roseobacteraceae family. I also draw and dabble in various other creative endeavors.

ADRIANA LOPES DOS SANTOS

As a child, I loved to learn about the creatures I found in my grandpa's garden. Together, we would spend hours trying to discover which species they were and how they grow, what they eat, and how they live. Not surprisingly, I chose to become a biologist. While studying, I became fascinated with the invisible microbial world and its infinitely variable forms and lifestyles, especially those drifting in the ocean, called plankton. My work today involves naming and describing plankton creatures and understanding their ecological roles in the world's oceans. The study of plankton

has taken me around the globe, from the Arctic to the Antarctic. Today I am also a professor at the University of Oslo, teaching marine microbiology and hoping to inspire the next generation of microbiologists to continue uncovering the wonders of the invisible world. *lopesas.ufrj@gmail.com

†These authors have contributed equally to this work