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XENOBOTS: A Sustainable System of Water Treatment

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ABSTRACT

Water is a resource imperative for survival; however, a large percentage of people globally suffer from limited access to safe, clean water. In order for it to be securely administered for domestic use, water must first undergo a series of treatment processes before people can access it. These processes can often be expensive, significantly energy consumptive, and potentially harmful to human health as a long-term means for purification. A proposed alternative solution harnesses the potential of an emerging article of biotechnology: xenobots. Xenobots are programmable, organic 'bio-bots' engineered from stem cells. They possess the capacity for movement, molecular memory, kinematic self-replication, and self-repairment as well as the ability to collect and distribute rogue matter. They are also completely biodegradable, hence having little to no environmental footprint or posing as a health hazard. In applying xenobots in the water treatment process, they can be deployed to extract biological, chemical, radiological, and minuscule physical contaminants from the water supply thus eliminating the need for more inexpedient procedures. Though there are some ethical concerns in regards to employing living, conscious organisms as a means to service human enterprises and possible risks pertaining to the development of xenobots as living organisms which can be potentially disruptive to the natural order or concerning the exploitation of this technology for violent purposes, these can be circumvented if the technology is handled with the immense care and responsibility required to operate it safely. Therefore, a more efficient, cost-effective and environmentally sustainable system of water treatment can be composed.

Keywords: ***xenobots, water treatment, sustainability, biotechnology, science***

Subject: Science and Technology

INTRODUCTION

More than 71% of the earth's surface is covered with water, but only 0.5% of clean drinkable water is available for direct consumption to sustain life (USBR, 2020). Safe, clean water is an essential resource that over 2.2 billion people do not have regular access to, most of whom belong to developing countries (Healing Waters, 2021). Clean water that *is* available to the masses is oftentimes contaminated by various substances that must be removed for the water to be deemed safe for consumption.

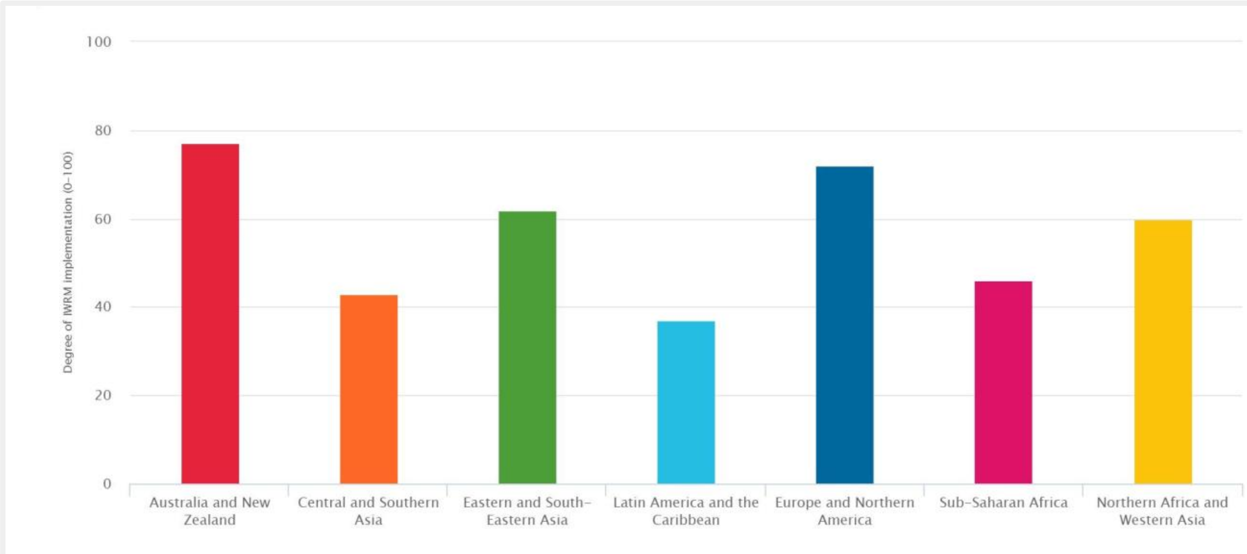

Figure 1: Status of integrated water resource management implementation in different SDG regions.
Source: UN Water (2020)

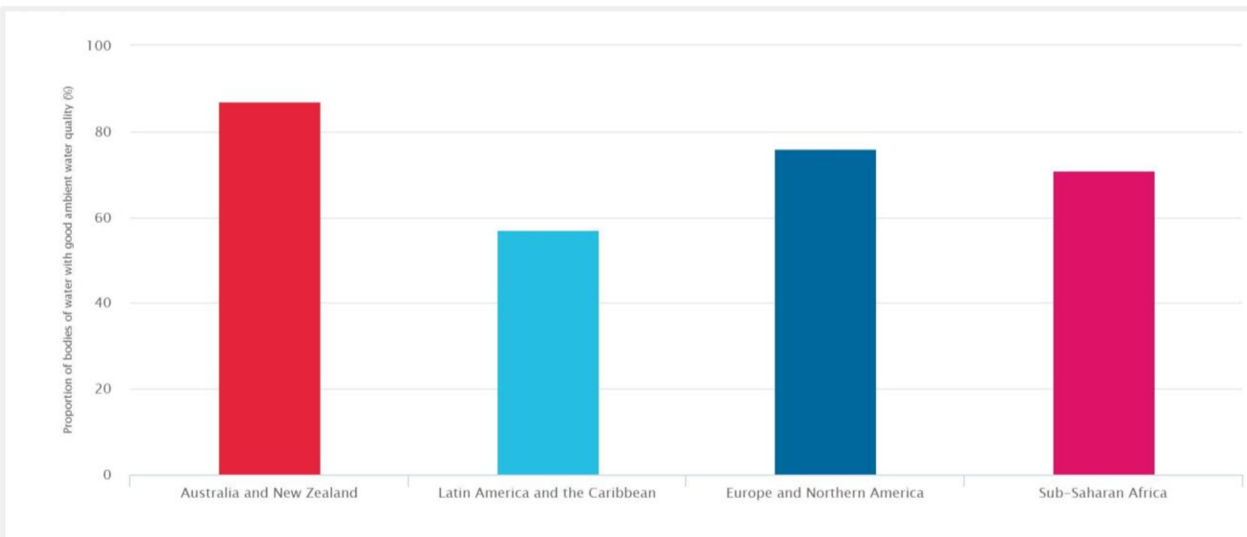

Figure 2: Status of the proportion of bodies of water with good ambient water quality in different SDG regions.
Source: UN Water (2020)

Common water contaminants can be categorized under four headings (EPA, 2022):

1. Physical contaminants: these may be sediments, large debris, microplastics or organic material suspended in the water.
2. Chemical contaminants: these are inorganic contaminants, for example, nitrogen, arsenic, etc.
3. Biological contaminants: these are living organisms that can also be referred to as microbiological contaminants, for example, bacteria, viruses, parasites, etc.
4. Radiological contaminants: these are radiation-emitting chemical elements such as radium, cesium, etc.

Chemical contaminants find their way into the water supply as a natural occurrence or by consequence of climate change, industrialization, and residential and commercial use of chemical substances (EPA, 2021). These have been associated with a plethora of adverse health effects including cancer, cardiovascular disease, neurological disorders, etc (Barret, 2014). Water that is microbiologically contaminated can transmit diseases such as diarrhoea, cholera, and polio and is estimated to cause 485,000 diarrhoeal deaths each year (WHO, 2022). If the water consumed is left untreated for radiological contaminants, a build-up of radionuclides can eventually result in radiation damage, bone-marrow fatality, cancer, hereditary disorders and myriad other diseases (US National Research Council Safe Drinking Water Committee, 1977).

Current water treatment systems produce a large environmental footprint, are relatively expensive and therefore, difficult to maintain in poverty-stricken regions, and are unsustainable as a long-term solution for water purification (Gallego-Valero et al, 2021; CleanTeq Water, 2021). Naturally-sourced water undergoes various treatment processes including filtration, reverse osmosis and chlorination. Reverse osmosis, in particular, is an expensive procedure that consumes large amounts of energy to function (Gude et al., 2013). Chlorination is a process that removes microbiological contaminants from water; however, chlorine can combine with naturally occurring organic matter in the water to form compounds called disinfection byproducts (DBPs) which can cause negative health effects after regular exposure (Government of Canada, 2019).

In order to find an effective solution to these problems, one must look towards recent advancements in technology. Xenobots are an emerging piece of biotechnology presently being developed that operates under the field of nanotechnology. They are programmable bio-robots created from stem cells enabling them to self-duplicate, are capable of collecting and transporting matter, survive particularly well in an aqueous environment, and have little to no consequence on the environment making them perhaps an ideal fix to the world's water crisis in the near future (Ballard, 2021).

MATERIALS AND METHODS

This research was conducted by reviewing the qualitative data provided by both primary sources and secondary sources; the primary sources were the papers published in scientific journals by the institutions responsible for the creation of xenobots. Given that this paper was written in pursuit of expanding on sustainable practices, 'sustainability' remained amongst the core keywords used throughout the research process. In reviewing the current applications of xenobots while recognizing recent technological developments, a new application was conceptualized based on utilizing the abilities that xenobots already possess.

RESULTS

Xenobots are organic 'robots' created from the skin and heart stem cells belonging to the embryos of the *Xenopus laevis*, more commonly known as the African clawed frog. These cells are not genetically modified but are synthesized in different shapes after being cultured in salt water to create programmable xenobots that can be used to collect and transport piles of micro-matter. They develop cilia along their surface which sanction linear propulsion and rotary motion in aqueous environments (Neuman, 2021). After first undergoing a filtration process to remove large physical contaminants, by releasing xenobots into the water supply at water-treatment plants, most chemical, biological, and radiological contaminants can be collected to eliminate the risks perpetuated by more traditional methods.

By employing the use of artificial intelligence-driven computer simulations, scientists analysed different arrangements to manipulate the xenobots in order to find the ideal shape for them to collect large quantities of matter systematically. Eventually, a C-shape was conceptualized which was found to be impressively efficient in corralling matter into large piles (Hunt, 2021). This coupled with the xenobots' capacity for movement makes them the perfect vessel to aggregate minuscule water contaminants into extractable masses. Xenobots also carries the unique ability to communicate with each other in order to create a functioning hive mind despite them not possessing any nerve cells. Adhesive proteins within facilitate their ability to attach to one another and to sense mechanical forces and deformations. This enables them to work together in swarms to transport debris (Silver, 2021).

Recently, scientists have designed xenobots with the capacity to record memory; these were engineered with a read/write capability to record one bit of information by integrating within their biological configuration a fluorescent reporter protein called EosFP, which normally glows green but if exposed to the light of 390 nm, emits red light instead. Ten bots were then allowed to swim around a surface on which one spot is illuminated with a beam of 390nm light. After two hours, it was found that two of the ten bots emitted red light while the others retained their green hue. This demonstrates an effective recording of the 'travel history of the xenobots (Silver, 2021). In the near future, this proof of the principle of molecular memory could be extended in the future to detect and record the presence of radioactive contamination, chemical pollutants, and biological contaminants within the water supply to allow for a comprehensive purification system. Furthermore, advanced engineering could also allow xenobots to develop the potential to react upon sensation of stimuli by altering their behaviour or releasing compounds to address the presence of any contaminants (Silver, 2021).

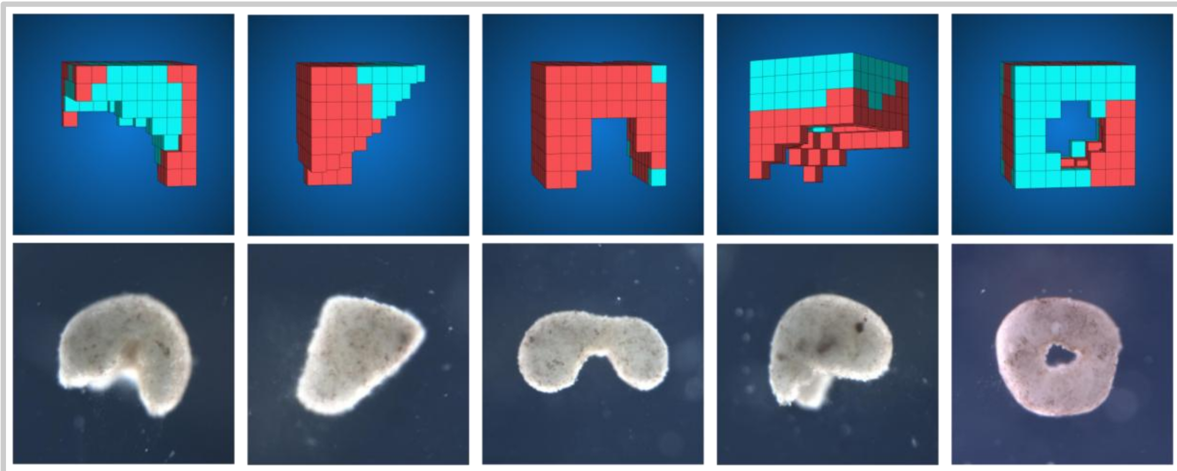

Figure 3: Artificial Intelligence employed to simulate different structural shapes (top row). Utilizing a cell-based construction toolkit, the designs are then realized in living systems (bottom row).
Source: Kriegman et al. (2019)

Similar to other living organisms, xenobots can reproduce; however, their method of reproduction is unlike the natural process commonly observed in most species. Instead, xenobots observe a process known as kinematic self-replication - this is a process in which organisms move within their environment while simultaneously moving and compressing dissociated cells into clusters that form functioning self-copies (Brown, 2021). Moreover, when scientists sliced xenobots in half, they found that the bots were able to stitch themselves back to their original form and carry on functioning as they normally would (Brown, 2020). The ability to readily procreate and self-repair grants xenobots increased durability that would aid them in decontaminating the water supply which would not be available to classical technologies.

The natural lifespan of a xenobot is 7-10 days after which they break apart. Since xenobots are entirely composed of organic matter, they are biodegradable; hence they are environmentally friendly and of no harm to humans (Brown, 2020). Therefore, if perchance the xenobots were to be left unremoved from the water supply, they would naturally disintegrate, causing no harm. This is in direct contrast to the energy-consumptive processes and usage of potentially harmful chemicals such as chlorine in traditional water treatment facilities.

DISCUSSIONS

Despite their salient benefits, the engineering of xenobots has raised a number of ethical questions and concerns about potential risks. First and foremost, it is fundamental to address the fact that in introducing man-made organisms into the ecosystem, the natural order designed to sustain mostly naturally-occurring species of flora and fauna can be adversely affected in unprecedented ways (Kumari, 2021). Another plausible risk is in regards to the misuse of this technology. Biobots could become valuable assets in propagating warfare and violence; in the hands of those with immoral intentions, these bots could be manipulated to carry and administer virulent agents in order to harm human life (Chandler, 2020). Lastly, the creation of xenobots has led to the realization of a rational fear of biobots achieving sentience. Scientists continue to make advancements in biotechnology and xenobots might be the first piece of technology in a long line of prospective intelligent biobots. The notion of humans being governed by sentient robots of their own creation has long been content of dystopian science-fiction. However, with the invention of xenobots, this reality seems to appear more and more plausible. If this technology were to continue developing to the extent where it transcends the limit of human control, it would yield substantial consequences. Further establishing on the idea of sentient biobots, one could argue that employing the use of living, possessing-of-will-and-conscious organisms to facilitate human endeavours would be inhumane. These issues consolidate the need to responsibly govern the use of xenobots and other biobots of the future to prevent the abuse of a technology that, if handled with the right care and caution, could be of significant value to the human race (Coghlan & Leins, 2020).

CONCLUSION

Xenobots are an emerging piece of biotechnology and as a consequence of their novelty, their potential applications have not yet been thoroughly explored. In proposing a utilisation of this technology in the field of water treatment, this report has sought to expand upon our knowledge on the practical uses of xenobots and proffer an idea that could make water treatment systems more sustainable. Furthermore, the research conducted on utilising xenobots for this purpose could potentially lead to breakthroughs in the expansion of the applications of xenobots. By replacing traditional water treatment methods with xenobots, a cleaner and more efficient treatment system is formulated. Post the filtration to remove larger debris, xenobots can be added to the water supply for further, more intensive decontamination. Xenobots' ability to detect contaminants and collectively transport matter through aqueous substances would allow them to accumulate then transport debris to a designated extraction point. This system would occupy less land area and reduce construction costs for facilities required by conventional processes, thus, reducing the long-term cost in operating a water treatment plant. Xenobots having been composed of entirely organic, biodegradable matter, they are entirely non-toxic to all living organisms. For the same reason, they reduce the environmental footprint created by traditional facilities by a large factor. These qualities make xenobots a more serviceable water treatment facility for poverty-stricken communities, granting them regular access to safe water.

There are several aspects of the utilization of xenobots in water treatment that require further research, for example: ensuring that large scale systems are possible; checking if there are certain contaminants that are incompatible with the system; or determining if there are any external environmental factors that could impede the process. Though it is difficult to account for these facets now, as the technology evolves, so will our knowledge of it, and given that, the system can be fine-tuned to perfectly accommodate for any potential shortcomings.

REFERENCES

[1]. Akanksha Kumari. (2021). Xenobots. *The Treatise.* Available at: https://medium.com/the-treatise/xenobots-a80941add037
[2]. Barclay Ballard. (2021). Using 'Living Robots' to Remove Microplastics from The Ocean. *The Oxygen Project. Available at:* https://www.theoxygenproject.com/post/using-living-robots-to-remove-microplastics-from-the-ocean/
[3]. CleanTeq Water. (2021). *Low Carbon Discharge Water Treatment.* https://www.cleanteqwater.com/water-treatment/low-carbon-water-treatment/
[4]. Gallego-Valero, L.; Moral-Parajes, E.; Román-Sánchez, I.M. (2021). *Wastewater Treatment Costs.*
[5]. Government of Canada. (2019). *Disinfection by-products in drinking water.* https://www.sac-isc.gc.ca/eng/1563307885242/1563307933110
[6]. Gude, Veera Gnaneswar & Khandan, Nirmal & Deng, Shuguang & Maganti, Anand. (2013). Energy consumption and recovery in reverse osmosis. *Desalination and Water Treatment.*
[7]. Healing Waters. (2021). *How Do Developing Countries Get Clean Water?* Available at: https://healingwaters.org/how-do-developing-countries-get-clean-water/
[8]. Joshua Brown. (2020). Team Builds the First Living Robots. *The University of Vermont.* Available at: https://www.uvm.edu/news/story/team-builds-first-living-robots
[9]. Joshua Brown. (2021). Team Builds the First Living Robots—that can reproduce. *Wyss Institute.*
[10]. https://wyss.harvard.edu/news/team-builds-first-living-robots-that-can-reproduce/
[11]. Julia R. Barret. (2014). Chemical Contaminants in Drinking Water: Where Do We Go from Here? *National Centre for Biotechnology Information.* Available at: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3948028/
[12]. Katie Hunt. (2021). World's first living robots can now reproduce. *CNN.*
[13]. https://edition.cnn.com/2021/11/29/americas/xenobots-self-replicating-robots-scn/index.html#:~:text=The%20supercomputer%20came%20up%20with,of%20cells%20became%20new%20xenobots.
[14]. Mike Silver. (2021). Scientists Create the Next Generation of Living Robots. *TUFTS.* https://now.tufts.edu/2021/03/31/scientists-create-next-generation-living-robots
[15]. National Research Council (US) Safe Drinking Water Committee. (1977). *Drinking Water and Health: Volume 1.* https://www.ncbi.nlm.nih.gov/books/NBK234160/
[16]. Sam Kriegman, Douglas Blackiston,, Michael Levin, and Josh Bongard. (2019). A scalable pipeline for designing reconfigurable organisms. *PNAS.*https://www.pnas.org/doi/pdf/10.1073/pnas.1910837117
[17]. Simon Chander. (2020). World's First 'Living Robot' Invites New Opportunities And Risks. Forbes. Available at: https://www.forbes.com/sites/simonchandler/2020/01/14/worlds-first-living-robot-invites-new-opportunities-and-risks/?sh=580aa6893caf
[18]. Simon Coughlan and Kobi Leins. (2020). "Living robots": Ethical Questions About Xenobots. *Bioethics Today.* Available at: https://bioethicstoday.org/blog/living-robots-ethical-questions-about-xenobots/
[19]. Scott Neuman. (2021). Living robots made in a lab have found a new way to self-replicate. *NPR.* Available at: https://www.npr.org/2021/12/01/1060027395/robots-xenobots-living-self-replicating-copy
[20]. United States Bureau of Reclamation. (2020). *Water Facts - Worldwide Water Supply.* Available at: https://www.usbr.gov/mp/arwec/water-facts-ww-water-sup.html

[21]. United States Environmental Protection Agency. (2022). *Groundwater Contamination.* https://www.epa.gov/sites/default/files/2015-08/documents/mgwc-gwc1.pdf
[22]. United States Environmental Protection Agency. (2022). *Types of Drinking Water Contaminants.* https://www.epa.gov/ccl/types-drinking-water-contaminants#:~:text=The%20Safe%20Drinking%20Water%20Act,substance%20or%20matter%20in%20water.
[23]. World Health Organisation. (2022). *Drinking Water.* https://www.who.int/news-room/fact-sheets/detail/drinking-water