TECHNIQUES TO DECREASE THE SANITATION RISKS ASSOCIATED WITH WASTEWATER IRRIGATION

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The recycling of wastewater has been practiced for over 3 millennia in order to irrigate or fertilize crops.[1] Over the past 20 years, the practice of wastewater recycling has become much more common as society seeks to solve the issue of water-scarcity, a problem partly attributed to lack of freshwater as well as the contamination of some freshwater sources due to the rapid growth of urban areas.[2] When the need for freshwater becomes too great, authorities would rather direct the freshwater resources to urban centers that have more economic value than toward rural agricultural pursuits which may not be as lucrative. Today, the use of wastewater for irrigation has become a viable alternative that not only allows the urban areas to have enough freshwater but also provides agricultural communities with a water source for irrigation.

Over time, various treatment techniques have been devised in order to protect citizens from the harmful elements within wastewater, but in some parts of the world this technology has either gone unused or has only been partially implemented.[3] Because of the

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[1] Liqa Raschid-Sally, "The Role and Place of Global Surveys for Assessing Wastewater Irrigation," *Irrigation and Drainage Systems* 24, no. 1 (2010): 6.

[2] J. Winpenny, I. Heinz, and S. Koo-Oshima, “The Wealth in Waste-The economics of wastewater use in agriculture,” In FAO Water Report 35 (WHO, FAO, and IDRC, 2010), 2.

[3] T. Rutkowski, L. Raschid-Sally, and S. Buechler, "Wastewater Irrigation in the Developing World--Two Case Studies from the

varying degree of water treatment, there are different wastewater typologies throughout the world.[4] In most developed countries, direct use of treated wastewater is extremely common. In this case, the water is treated in a plant and transported to a collection area in order to be used for irrigation.[5] In other contexts, the treated wastewater is not sent from a treatment plant but instead taken from a body of water where treated wastewater has been deposited. Because of this, the water source contains a diluted amount of the purified wastewater and is considered indirect wastewater use. In such situations, the wastewater is diluted in the water sources while the contamination of the water resources is still detectable. In less developed countries, it is more common to see direct use of untreated water. This is usually due to lack of water treatment infrastructure or an overflow of wastewater that cannot be managed by existing treatment systems. Additionally, indirect use of untreated water is seen when farmers utilize public waterways that have been contaminated by drainage of untreated wastewater originating from large urban centers.[6] In many cases, farmers in these regions have no other choice than to use contaminated sources, and in some situations, are even highly appreciative of the perennial source of water in climates that prevent natural, permanent waterflows.[7] In this analysis, I will focus on the last two cases of wastewater use as they are most common in developing countries, those in most need of water scarcity solutions.

While wastewater irrigation has helped to solve the lack of freshwater in unindustrialized countries, it has also created new concerns related to the health of both the farmers and consumers. Qadir et al. enumerate the difficulties that are associated with

Kathmandu Valley in Nepal," *Agricultural Water Management* 88 (2007): 1.

[4] Raschid-Sally, "Global Surveys for Assessing Wastewater Irrigation," 7.

[5] Raschid-Sally, 8.

[6] Raschid-Sally, 9.

[7] Rutkowski, Raschid-Sally, and Buechler, "Wastewater Irrigation in the Developing World," 1.

wastewater use in developing countries.[8] Because of deficient infrastructure and improper treatment methods, the public is often exposed to water contaminants of two varieties. The first category includes fecal pathogens such as parasitic worms, bacteria, and viruses within the water which can cause infection in the farmers as well as the consumers. The second category consists of organic and inorganic compounds contained in industrial effluent or chemical runoff which can be toxic at high concentrations when the irrigated crop is consumed.[9] These toxic compounds can cause a variety of symptoms such as anemia, vomiting, diarrhea, and fever in addition to many others. Untreated or partially treated water has varying degrees of such contamination, and in some cases becomes a health risk to the farmers as well as the individuals who consume the agricultural products.[10] Qadir et al. also identify the fact that women are often significantly more affected by the contamination due to the nature of their household labor and food preparation. Hanjra et al. have attempted to summarize both the positive and negative aspects of wastewater use in addition to detailing ideas for future policy changes.[11] These sources and others have written of the negative effects of untreated wastewater, but few have considered the

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[8] M Qadir et al., "The Challenges of Wastewater Irrigation in Developing Countries," *Agricultural Water Management* 97, no. 4 (2010): 562.
[9] Qadir et al., "The Challenges of Wastewater Irrigation," 563.
[10] Isaac Dennis Amoah et al., "Contribution of Wastewater Irrigation to Soil Transmitted Helminths Infection among Vegetable Farmers in Kumasi, Ghana," *PLoS Neglected Tropical Diseases* 10, no. 12 (2016): 9; Enrique Cifuentes, "The Epidemiology of Enteric Infections in Agricultural Communities Exposed to Wastewater Irrigation: Perspectives for Risk Control," *International Journal of Environmental Health Research* 8, no. 3 (1998): 203; N. Gupta, D.K. Khan, and S.C. Santra, "Prevalence of Intestinal Helminth Eggs on Vegetables Grown in Wastewater-irrigated Areas of Titagarh, West Bengal, India," *Food Control* 20, no. 10 (2009): 943.
[11] Munir A. Hanjra et al., "Wastewater Irrigation and Environmental Health: Implications for Water Governance and Public Policy," *International Journal of Hygiene and Environmental Health* 215, no. 3 (2012): 257, 265.

sanitation issues and offered a double-pronged comprehensive solution. This solution includes not only sanitation programming for the individuals involved but also implementation of GMOs which would lessen exposure to harmful wastewater components through selected survival traits. Because freshwater sources are in most cases decreasing, water-scarcity and the use of wastewater will only become more important as time goes on. A 2010 information kit published by the World Health Organization, the Food and Agriculture Organization, and the International Development Research Center stated that there is a need for non-treatment based solutions in regions where water treatment is impossible or simply not feasible.[12] Additionally, within the kit there was a call for support of a manual that outlined Sanitation Safety Plans.[13] As water-scarcity becomes more widespread and increases the need for wastewater irrigation, it is imperative that concrete solutions are developed to combat the health risks associated with reuse of wastewater.

As mentioned earlier, there are certain health risks to the farmers that utilize the untreated wastewater, and these risks mainly consist of exposure to parasitic worms and other harmful microbes. Though the untreated wastewater may contain toxic industrial metals and organic substances, the farmers themselves are for the most part unaffected as dangerous exposure to these elements mainly occurs due to ingestion.[14] One of the most pervasive problems throughout wastewater irrigation communities is the higher than usual incidence of helminths infections, or those associated with parasitic worms

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[12] Mark Redwood, Javier MateoSangasta, and Robert Bos, “Lessons learned and recommendations based in pilot research in Jordan, Ghana, and Senegal 2006-2010,” In *Using human waste safely for livelihoods, food production and health,* (WHO, FAO, and IDRC, 2010): 4.
[13] Robert Bos “A call for the contributions to the development of a Manual on Sanitation Safety Plans,” In *Using human waste safely for livelihoods, food production and health,* (World Health Organization, 2010): 1.
[14] Lian Chen et al., "Heavy Metals in Food Crops, Soil, and Water in the Lihe River Watershed of the Taihu Region and Their Potential Health Risks When Ingested," *Science of the Total Environment* 615 (2018): 142.

contained in unsafe water.[15] These parasites are especially dangerous as they can survive under unfavorable conditions for a significant amount of time, which in turn results in a higher chance of infection. Researchers conducted a study in Kumasi, Ghana where not only the soil and water was tested for these parasites but also the farmers themselves. The individuals were tested by the quantification of helminth ova, or eggs, in the farmers' stool.[16] A control group was tested as well that coexisted in the same community, where the individuals used the same resources but did not participate in any of the farming which utilized untreated wastewater. Through the course of the study, the researchers found that the farmers that dealt with the wastewater were three times more likely to contract a helminths infection.[17] Although the wastewater attempts to solve one problem, that of freshwater-scarcity, it also risks the farmers' health by exposing the vulnerable population to wastewater pathogens. In order to solve the water problems for the cities, the health and wellbeing of farmers in rural areas is potentially sacrificed. The intention to help may be there, but it is vital that sanitation practices are utilized on the farms that use untreated wastewater in order to protect the workers from exposure to the contaminated water. Sanitation programming sponsored by the government or foreign aid groups would mitigate the health risks for these farmers in areas where it is simply not feasible to treat the water before it is utilized. The morphology of such programming will be detailed later on in this analysis.

In addition to the farmers and those that work in the fields irrigated by untreated wastewater, other members of these communities can be adversely affected by the microbial contaminants as well as possible toxic industrial compounds in the water.[18] In another study conducted throughout the Mezquital valley in central Mexico, three test groups from three different communities were surveyed and sampled, each utilizing different water sources. One group used untreated wastewater, another drew from industrial

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[15] Amoah et al., "Contribution of Wastewater Irrigation to Soil Transmitted Helminths," 2.

[16] Amoah et al., 1.

[17] Amoah et al., 9.

[18] Cifuentes, "Epidemiology of Enteric Infections," 203.

effluent reservoirs, and a third collected natural rainwater for irrigation.[19] Similar to the study in Ghana, the fecal matter of the test subjects was collected, while the respondents in this study also completed surveys detailing various questions about lifestyle. In this case, the researchers tested for both helminths parasites and fecal coliforms, microbes which can cause enteric diseases or diarrheal infections.[20] The results of the study revealed that children under five in households exposed to either untreated wastewater or reservoir effluent are often at much greater risk for diarrhea than those in communities that make use of rainwater for irrigation.[21] A child in an untreated wastewater household had a 33% higher chance of experiencing bouts of diarrhea compared to those in rainwater households.[22] Additionally, there is some risk to consumers as the researchers associated some of the incidence of infection with consumption of foodstuffs that were grown and/or washed with contaminated water.[23] In another study, vegetables grown in wastewater had an 83% chance of testing positive for helminth eggs.[24] Industrial heavy metals can also leech into crops irrigated by untreated effluent, posing a risk to consumers. One study performed in China found every sample collected of both wheat and rice contained a concentration of lead higher than standard limits.[25] The researchers also observed serious contamination levels of cadmium, nickel, and zinc, each posing serious health risks to rice and wheat consumers.[26] This, in turn, reveals that not only are the farmers and their families at risk but other members of the community that purchase and ingest the food are also exposed to the waterborne pathogens and industrial effluent materials. Again, although there are advantages to using wastewater in place of the depleted freshwater supply, there are serious health risks to both the individuals directly

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[19] Cifuentes, 204.
[20] Cifuentes, 206.
[21] Cifuentes, 212.
[22] Cifuentes, 208.
[23] Cifuentes, 212.
[24] Gupta, Khan, and Santra, “Prevalence of Intestinal Helminth Eggs,” 943.
[25] Chen et al., "Heavy Metals in Food Crops," 145.
[26] Chen et al., 148.

participating in the agricultural activities as well as those who consume the food products. In an attempt to decrease or curb these risks, public health programing should be put in place to provide awareness within the local population as well as to supply the farmers with methods of sanitation such as water filters or gloves. In doing this, one of the disadvantages of untreated wastewater could be avoided without disrupting the freshwater-untreated water balance.

One way to decrease microbial risks to farmers is to employ carefully created GMOs, or genetically modified organisms, that are resistant to drought or need less water than other varieties of the crop. This can be accomplished using different strategies. Selective breeding is one particular method for preparing drought resistant plant varieties, or more specifically called a cultivar in the case of selective breeding. Scientists begin this process by first identifying plant species that already seem to thrive in low water conditions. Once this has been accomplished, scientists attempt to pinpoint the traits that enable the plant to perform better and use this information to breed new varieties of the crop with even better ability to thrive in drought.[27] This method is particularly lengthy and can have insufficient effect on desired crop performance due to different soil and geographical characteristics.[28] These drawbacks can be avoided through the use of crop models that predict future yield changes due to selective breeding. Such modeling technologies are specifically tailored to the conditions of a crop's region and allow researchers to produce efficient and accurate crop data before even beginning a long-winded selective breeding study. In one study conducted in Brazil, the traits that were thought to contribute to drought resistance in soybeans were tested using modeling technology to understand which were most helpful in drought-like conditions.[29] In the study, it seemed that plants bred with a combination of certain drought resistant traits, rather than just possessing one, would perform the best after selective breeding.[30] The helpful traits for this particular

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[27] Rafael Battisti et al., "Assessment of Soybean Yield with Altered Water-related Genetic Improvement Traits under Climate Change in Southern Brazil," *European Journal of Agronomy* 83 (2017): 1.
[28] Battisti et al., "Assessment of Soybean Yield," 2.
[29] Battisti et al., 4.
[30] Battisti et al., 12.

cultivar of soybean were deeper roots, limit of transpiration by vapor pressure deficit, and reduction of grain filling in response to lack of sufficient water. Now, these traits are specific to this soybean cultivar, but the ability to quickly model the yield of a crop cultivar is important to better ensure the success of that future crop variety before selectively breeding for those traits. Another faster alternative to traditional selective breeding is the use of gene editing tools, each employing a different type of site specific nucleases, or SSNs.[31] These nucleases are enzymes capable of cutting DNA sequences in order to directly edit the target gene sequences of a specific plant genome. The most popular gene editing technologies are meganucleases, zinc-finger nucleases (ZFNs), transcription activator-like effector nucleases (TALENs), and type II clustered regularly interspaced short palindromic repeat/CRISPR-associated protein 9 (CRISPR-Cas9). The CRISPR-Cas9 system is not only the most site-specific gene editing technique but it is also relatively easy to use and involves less expensive materials than its alternatives.[32]. If the gene sequence of a desired trait is already known, CRISPR-Cas9 allows for more rapid manipulation of a plant's traits compared to traditional selective breeding.[33] In one study, a CRISPR-Cas9 genome edited maize cultivar produced five more bushels per acre of land than its wildtype counterpart under drought-like conditions.[34] Each of these techniques make it possible to isolate and breed for certain traits of a plant that decrease its need for water, and this, in turn, has the power to reduce the water need for agriculture on a global scale.[35] Genetically modified drought resistant crops could also be used in situations where untreated wastewater is the only water source available. Because the plants themselves have a lesser need for water in general, it would follow that farmers' risk of infection would decrease as they

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[31] Leena Arora and Alka Narula, "Gene Editing and Crop Improvement Using CRISPR-Cas9 System," *Frontiers in Plant Science* 8 (2017): 1.
[32] Arora and Narula, "Gene Editing and Crop Improvement," 16.
[33] Jinrui Shi et al., "ARGOS8 Variants Generated by CRISPR-Cas9 Improve Maize Grain Yield under Field Drought Stress Conditions," *Plant Biotechnology Journal* 15, no. 2 (2017): 207.
[34] Shi et al., "ARGOS8 Variants Generated by CRISPR-Cas9," 210.
[35] Battisti et al., "Assessment of Soybean Yield," 1.

would need to use less water to keep the crops alive. In this way, the farmers would have a lesser threat of infection without disrupting the freshwater-conserving routine they have developed.

Traits that support drought resistance are not the only ones that agricultural scientists selectively breed for, and they are not the only traits that could be beneficial to farmers or communities forced to use wastewater to irrigate. Recently, there has been a great push in the energy and agricultural industries for the production of biofuels, or those created through the degradation of biological matter of plant or animal origin.[36] These fuels are desired, because they are environmentally conscious alternatives to the decreasing supply of fossil fuels. Desire for biofuels and biomass, the energy containing biological matter itself, has prompted the scientific agricultural community to genetically modify crops in order to create cultivars that are more suitable for use in the production of biofuels.[37] Liquid biofuels such as biodiesel and bioethanol are particularly desirable in the energy sector.[38] Biodiesel is produced from vegetable oils, while ethanol is synthesized using fermented sugar from plant species.[39] Due to the diverse nature of biofuels, I will focus on ethanol in particular here to demonstrate the nature of the genetic work performed on crops in order to produce better biomass and consequently more biofuel. Corn and maize are two of the main crops used to synthesize ethanol; the abundant sugar stores in the kernels are fermented in order to manufacture the ethanol product. Multiple projects have been conducted to generate a cultivar of corn that is better suited for biofuel synthesis. In one study, the amount of lignin in the plant was reduced in order to decrease the amount or concentration of chemical treatment needed to ready the corn for

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[36] John Ruane, Andrea Sonnino, and Astrid Agostini. "Bioenergy and the Potential Contribution of Agricultural Biotechnologies in Developing Countries," *Biomass and Bioenergy* 34, no. 10 (2010): 1427-28.

[37] Mariam Sticklen, "Plant genetic engineering to improve biomass characteristics for Biofuels," *Current Opinion in Biotechnology* 17, no. 3 (June 2006): 315, https://doi:10.1016/j.copbio.2006.05.003.

[38] Ruane, "Bioenergy and the Potential Contribution," 1430.

[39] Ruane, 1429.

fermentation.[40] Additionally, the enzymes intended for cellulose degradation have been increased in some varieties of corn. During fermentation, it is necessary that cellulose degrades into sucrose, a simple sugar. When the enzymes for the degradation of glucose are present in higher quantities, it is easier and quicker for the fermentation process to occur, thereby making the cultivar a more efficient candidate for ethanol production. These two genetic modifications number among the many strategies that food scientists have used to create efficient, high-energy biomass that can be converted into fuel. The utilization of these GMOs is another way to protect the community, namely those that consume the foodstuffs, where untreated wastewater is used. Because the crops would not be consumed but instead broken down in order to produce fuels, the community would not be threatened by food-based pathogenic risk from the untreated wastewater. By using these plant varieties modified for the effective use of bio-energy, health risk to consumers is avoided without the need to utilize more of the ever-scarce sources of freshwater. It warrants mentioning that the widespread conversion of food crops to bio-energy crops can deplete local food supply, and so it is with careful consideration of local environmental and economic climate that those forced to use untreated wastewater should make the shift to biomass production.[41] Not all food crop production should transition toward biofuel generation as it is necessary to find a responsible balance that not only considers the benefits of safer use of wastewater but also the nutritional needs of the local population. This balance is specific to the needs of the region, and this emphasizes the importance of generating crops that maximize biomass production per hectare, leaving enough arable land for edible crop growth. With this, the suggested education programming should also include a component that explains the need for discretion when transitioning to biofuel crops.

The aforementioned educational programming will decrease the prevalence of disease due to the contaminated water by creating awareness in the local population of the health risks associated with wastewater irrigation in addition to introducing and explaining the option of GMOs. Many of the farmers, families, and consumers are

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40 Sticklen, "Plant genetic engineering," 315.

41 Ruane, "Bioenergy and the Potential Contribution," 1436.

not aware of the severity of the health risks associated with the use of untreated wastewater.[42] In order for the farmers to implement changes in sanitation habits, they must first know that there is a problem. This awareness would likely encourage the application of improved sanitation practices, as it would be in the better interest of the workers' families and community to be more sanitation conscious. This increased awareness in farmers could be accomplished by educational programming, which would be sponsored by local or international organizations with ties to agriculture in developing countries.[43] These organizations would also introduce concrete sanitation techniques meant to substantially decrease the threat of infections.[44] The methods of sanitation would be simple, such as wearing gloves or handwashing with spare amounts of freshwater, but small efforts like these can make a marked difference in communities that lacked the measures previously.[45] Distribution and utilization of filters can also be effective for point-of-use filtration of both microbes and toxic trace elements.[46] Additionally, drip-irrigation

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[42] Qadir et al., "The Challenges of Wastewater Irrigation," 563; Bernard Keraita et al., "Harnessing Farmers' Knowledge and Perceptions for Health-Risk Reduction in Wastewater-Irrigated Agriculture." In *Wastewater Irrigation and Health: Assessing and Mitigating Risk in Low-income Countries,* ed. Pay Drechsel et al. (London, UK: Earthscan; Ottawa, Canada: IWMI; Colombo, Sri Lanka: IDRC, 2009), 339.

[43] Pay Drechsel et al., eds., *Wastewater Irrigation and Health: Assessing and Mitigating Risk in Low-income Countries* (London, UK: Earthscan; Ottawa, Canada: IWMI; Colombo, Sri Lanka: IDRC, 2009), 43.

[44] Bernard Keraita, Fleming Konradsen, and Pay Drechsel. "Farm-Based Measures for Reducing Microbiological Health Risks for Consumers from Informal Wastewater-Irrigated." In *Wastewater Irrigation and Health: Assessing and Mitigating Risk in Low-income Countries,* ed. Drechsel et al. (London, UK: Earthscan; Ottawa, Canada: IWMI; Colombo, Sri Lanka: IDRC, 2009), 202.

[45] Qadir et al., "The Challenges of Wastewater Irrigation," 563; Chen et al., "Heavy Metals in Food Crops," 147.

[46] Anna S Brady-Estévez, et al., "SWNT-MWNT Hybrid Filter Attains High Viral Removal and Bacterial Inactivation," *Langmuir: The ACS Journal of Surfaces and Colloids* 26, no. 24 (2010): 19157; L. Groendijk,

techniques have been proven to limit the pathogen transfer to farmers, because the water is applied more locally to the plant itself.[47] This reduces the contact between the farmers and the contaminated water, in turn restricting the water's pathogenic ability. To address the health risks for those consuming the produce, the sanitation programming should also suggest cooking the food product before consumption; in cases where the food is eaten raw, the outer part of the produce should be peeled or removed to reduce pathogenicity.[48] Such seemingly small suggestions are not only effective for minimizing health risks, but farmers are also more likely to be receptive to these methods as they necessitate little to no effort or monetary investment.[49] In order for the GMO technology to be implemented, the educational programming should also suggest the use of GMOs as well as explain the benefits that such technologies can have for the health of the farmer and their community. Additionally, it is imperative that officials work with the farmers to implement these technologies while keeping in mind the necessity for the continued growth of sufficient food crops. While it remains the farmer's choice which crops to grow, the programming should help the individuals to learn about responsible biofuel cultivation and its impact on the food supply of the community. After these public health programs are implemented, the farmers, their families, and the community will not only understand the risks of wastewater irrigation but will also be equipped with low-effort techniques to decrease those risks. This

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and H.E De Vries, "Development of a Mobile Water Maker, a Sustainable Way to Produce Safe Drinking Water in Developing Countries," *Desalination* 248, no. 1-3 (2009): 122.

[47] Keraita, Konradsen, and Drechsel. "Farm-Based Measures," 198.

[48] Qadir et al., "The Challenges of Wastewater Irrigation," 563.

[49] Bernard Keraita, Pay Drechsel, and Flemming Konradsen, "Perceptions of Farmers on Health Risks and Risk Reduction Measures in Wastewater-irrigated Urban Vegetable Farming in Ghana," *Journal of Risk Research* 11, no. 8 (2008): 1053.

allows the wastewater to still be utilized without sacrificing the health of the local population.

The use of wastewater for irrigation seems like an environmentally astute answer to the water-scarcity problem that is only becoming more and more serious in our world. Although it does decrease some of the need for freshwater, it too is accompanied by its own drawbacks. I have focused here on the pathogenic risk that is incurred when untreated wastewater is used in developing countries, a phenomenon that occurs as a result of insufficient or non-existent water treatment capabilities. The farmers themselves are at risk for helminth infections as well as fecal coliforms due to their close interaction with the contaminated water and insufficient sanitation practices. In addition to the farmers, their families and communities are at risk when the unhygienic, contaminated produce is sold and consumed without proper treatment. In order to protect the farmers, their families, and the community in general I argue that it is beneficial to employ various genetically modified crop varieties that lessen the farmer's and community's exposure to harmful pathogens of untreated wastewater. On one hand, scientists have been able to create cultivars considered to be drought resistant. These crop varieties require less water to thrive, and therefore the total amount of irrigation water needed is decreased. A lesser quantity of wastewater in general limits the farmers' exposure to the contaminants. On the other hand, the farmer that uses untreated wastewater can also opt to grow genetically modified plants that are especially suited to be used in biofuel production. By growing crops that will not be consumed, the risk due to ingesting contaminated food is avoided; the farmers do not lose income, and the public is protected. In addition to increasing the use of GMOs, it is also important to sponsor public health programs led by agricultural organizations. These would greatly decrease the chance of infection by raising awareness of the risks as well as providing concrete ways to curb the pathogenic power of wastewater in crop cultivation. The use of wastewater is an ingenious solution to freshwater-scarcity in our current world, although it is necessary to consider the pathogenicity of untreated wastewater that is often used extensively in developing countries. By employing sanitation education programs, farm-based sanitation practices, and GMOs to decrease exposure to untreated wastewater, the pathogenic dangers of wastewater irrigation can be diminished. The issue remains vastly important as the use of wastewater becomes more prevalent, and it is imperative that the health risks and health needs of those in developing countries are not forgotten or neglected in favor of protecting urban based capital.

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