Journal of Basic and Applied Engineering Research
p-ISSN: 2350-0077; e-ISSN: 2350-0255; Volume 8, Issue 4; October-December, 2022, pp. 21-34
© Krishi Sanskriti Publications
https://www.krishisanskriti.org

Multi-stage Device for Purification of Agricultural Runoff (MDPAR)

Adhi Daiv

Class 12
The Shri Ram School, Moulsari, Gurgaon-122002(Haryana)
Mail id:-Adhidaiv204@gmail.com

Abstract — It is vital to note that land-based sources such as agricultural runoff contribute towards approximately 80% of water pollution, globally. This can lead to contamination of fresh/sea water affecting aquatic life adversely. Therefore, a solution to this problem would help us take a green step towards a more sustainable future.

Our device looks into one of the various branches of problems created as a result of agriculture, that is, agricultural runoff. Agricultural runoff refers to the water from the farm fields. Now, the water can come from multiple sources: Groundwater, rain, and snow. This water is rich in substances that it absorbs from the fields, which primarily includes soil particles and chemicals. It has complex pollutant compositions such as nitrates, phosphates, and organic pollutants. This heavily polluted water is termed as "runoff" as it then flows into water bodies causing water pollution.

Our multi-stage device will help us take us a step towards eradicating the problem of agricultural runoff.

The device has been designed keeping in mind minimal energy utilisation. In fact, it does not rely on electricity for its operations. It is done to ensure the device's easy and cheap installation even in the most remote areas. It carries out multiple processes such as sedimentation, filtration, and desalination. By the end of the process, one will receive water out of the agricultural runoff, which may then be discharged into streams and be reused for agricultural purposes. Another factor kept in mind while designing it was the materials used. Cheap and readily available materials have been used to make this device. This will make sure that the device is accessible by all.

Introduction

Approximately 38% of Earth’s land surface area, that is 5 billion hectares, is used for agricultural purposes. Furthermore, 33% of this land area is used for growing crops[1]. The current world population is 7.99 billion. By 2050, this number is projected to rise to 9.7 billion.

The arithmetically growing agricultural produce will certainly face several hindrances to provide enough resources for this exponentially growing population. Had it not been for the Green Revolution, it indeed would have been difficult to support the current population size. Occurring in 1950s and 1960s, Green Revolution is referred to a time post the Industrial Revolution when farming became mechanized. It also led to the introduction of chemical fertilizers and pesticides, which resulted in a massive growth in farm yields and irrigation across the world. Fertilizers refer to chemicals that increase the growth and overall productivity of crops. Whereas, pesticides aid in destroying insects and other organisms that are harmful to crops.

After the period of innovation, farmers around the world became extremely dependent on these chemicals to ensure maximum total output of food. In fact, if we were to completely stop using fertilizers and pesticides, the total food production in the world would suffer a tremendous drop of approximately 40%. This is essentially because they significantly reduce the number of crops lost to fungi, insects, and other pests. Hence, this explains why 2.54 billion kilograms of pesticides alone are used all over the world each year (a number that has almost tripled since the 1970s).

Such heavy utilization of chemicals of course has its demerits. When fields are watered, the water leaches out the chemicals from the top soil. The polluted water can then make its way into streams, rivers, and other water bodies in the form of agricultural runoff. Agricultural runoff refers to the excess water (resultant of irrigation, rain, or snow) that is drained from farm fields. It contains pesticides, sediments, and other pollutants.

This warm, nutrient-rich water does not mix well with the colder water bodies leading to eutrophication. Eutrophication occurs when warm, nutrient-rich water results in immense growth of algae (algal bloom). The zooplankton experience a burst in population as they feed on the algae and phytoplankton.

Further, when they both die (zooplankton and phytoplankton), the bacteria metabolizes the present DO (Dissolved Oxygen) as they decompose them. This concludes in the formation of a dead/hypoxic zone due to a lack of oxygen. The above phenomenon is exacerbated from the fact that saturated DO is a function of temperature. For example, at 0 ^{0}C, saturated DO is 14.6 mg/L, but is 8.4 mg/L at 25 ^{0}C. Hence, mixing of warm water in cold water directly results in a loss of DO and therefore easier creation of dead zones.

Different regions of the world emit different levels of nutrients. Human activities emit twice as many nutrients (such as nitrogen and phosphorous) than natural sources. Even developed countries, such as the United States and the nations of the United Kingdom, use major amounts of industrial fertilizers and animal manure which lead to eutrophication. In the 1970s, one of the first dead zones was identified in the Chesapeake Bay, which lies on the east coast of the United States. The Chesapeake's high levels of nitrogen are chiefly caused due to agricultural practices in the region (up to 2/3rd of the nitrogen discharged).

The Chesabeake Bay Foundation was founded in 1967, which focused on improving the bay's water quality and curbing the polluted runoff. However, to this date, there still lies a dead zone in the bay, which varies in size with the season and weather.

Agricultural runoff introduces toxins into water bodies that are consumed by aqueous organisms. The accumulation of toxins in successively higher trophic levels (from primary to tertiary consumers) leads to the phenomenon of biomagnification. Tertiary consumers, such as the humans, are ones who are not just the first to be affected by these environmental problems, but also the ones who are the most critically affected. For example, PCB (Poly-Chlorinated Biphenyls) biomagnification is 2.85 ppb for the primary producers (such as phytoplanktons), but is 11,400 to 17,300 ppb for tertiary consumers.

The Minamata disease is a well known example of the phenomenon of biomagnification. The disease was first discovered in May, 1956 in Minamata City, which lies south-west of Japan's

Kyushu Island. It was caused due to the consumption marine products in the bay, which showed high levels of mercury (Hg) contamination (5.61 to 35.7 ppm). This contamination was a result of the methyl mercury (MeHg) discharged in wastewater from a chemical plant (Chisso Co. Ltd.), which was ingested by fishes, shellfish and other marine organisms.

Since we are not purifying the water 100%, we are also relying on the self-purification of the water bodies, which is dependent on factors such as rate of oxidation, sunlight, temperature, current and dilution.

The aim is not to purify water completely as it is simply impractical. In fact, even post the industrial treatment, water is partially purified. More will be explained on the same in the literature review a little later.

There are two primary ways to deal with water pollution. First is the removal of source (such as the industries releasing untreated sewage wastewater) itself while the second involves treatment of the water to remove pollutants to render it harmless to water bodies. The first method is not only incredibly difficult to achieve, but also extremely impractical. Therefore, I have tried to come up with a solution through the second method, that is, purifying the agricultural runoff to a point where it is not only harmless to the water bodies, but can also be reused for agricultural and drinking purposes.

I will also make sure that the device designed does not utilize energy and is constructed of cheap materials. This will be done keeping in mind the fact that the device should be accessible even in the remote, rural communities.

Literature Review

Motivation for an Alternative: -

While the industrial process for purification of water is extremely effective, it does have its own social and economic demerits. The various processes require lots of energy to execute. In the United States alone, municipal water treatment plants are estimated to be using 30×10^{12}W of electricity, which results in approximately $ 2 billion of annual electricity costs. Furthermore, their energy consumption accounts for 1% to 3% of the global energy output.

Not only this, but constructing these treatment plants requires a huge investment. The facilities they use make sure that they can only be constructed near industrial centers such as metropolitan cities, resulting in isolation of rural populations. Hence, I have researched to create an optimal, energy efficient and economical water purification model which can operate even when isolated from energy centers. Therefore, it can solve various problems such as that of agricultural runoff, which is the motivation behind writing this research paper. Here on, I will be discussing various aspects of water purification in my literature review, which can be implemented in creating this optimal device.

❖ Current Solution: -

A pre-existing solution does exist for the purification of water. This method is known as the industrial method for purification of water. It has primarily four stages: -

1.) Screening: It is the first step of purification. The water, either from a natural or industrial source, passes through a screen when entering the industrial filtration system. It acts as a membrane that removes some of the macro-particles such as sticks and trash, which can otherwise clog the pipes and hinder the purification process.
2.) Coagulation/Flocculation: This step refers to the addition of chemicals to the water. The addition of these chemicals results in the formation of tiny, but sticky particles known as floc. The floc grows and grows in size, attracting other particles. The floc, now greater in size, begins to sink to the bottom of the tank. The water is then moved for the next stage of purification leaving the floc behind. This stage is a modification of the sedimentation process, which refers to the natural settling or deposition of sediments in a tank. The addition of chemicals merely speeds up the same process.
3.) Filtration: This is probably the most important part of the industrial method of purification. The water, when it moves into this stage, is passed through several different kinds of filters to remove the finer particles present in it. The filters can be made of different materials such as BWS (Black Walnut Shell) or even cloth and sand.
4.) Disinfection: This is the last stage of the process where the water is moved into a closed tank. Here, disinfecting chemicals such as chlorine are mixed in the water to destroy microorganisms such as bacteria, which may survive post the filtration process.

There are several other adaptations of the same process. For example, ultrafiltration, ultraviolet light, or reverse osmosis/RO (used commonly in households).

I will be trying to create a device that efficiently purifies agricultural runoff by using the industrial method of treatment of water as my source of inspiration. I will be attempting to incorporate the same processes using different methods to ensure that the resultant model does not require any energy to operate, is extremely economical and easy to build. Some of the alternative processes are discussed here in the literature review.

1 - Removal of Fertilizers/Pesticides: -

1.1 - Adsorption of low cost and locally available organic substances to remove pesticides from aqueous solutions: Sorption appeared to be related to the pesticide's physiochemical properties. Trifuralin ($C_{13}H_{16}F_3N_3O_4$) and chlorpyrifos ($C_9H_{11}Cl_3NO_3PS$) displayed the fastest sorption kinetics among the four pesticides used. Rice husk was the best adsorbent for simazine ($C_7H_{12}ClN_5$) and chlorfenvinphos ($C_{12}H_{14}Cl_3O_4P$) had comparable adsorbent level for all sorbents (materials which portray sorption: adsorption and absorption as a single process).

1.2 – Removing organochlorine pesticides using chitosan loaded with silver oxide (AgO) nanoparticles from water: The characteristics of chitosan-AgO nanoparticles (CS-AgONPs) were studied using different means such as infrared sprectroscopy (FTIR), X-ray diffraction, and scanning electron microscopy. Then, CS-AgONPs were modified to remove maximum pesticides from an aqueous solution of permethrin ($C_{21}H_{20}Cl_2O_3$). Various parameters were also considered such as pH, amount of sorbent, agitating time, and initial concentration of the model pesticide. Under certain specific conditions, such as maintaining room temperature and pH as 7, CS-AgONPs were able to remove 99% of the permethrin from the aqueous solution (0.1 mg L^{-1}). Their efficiency was 49% greater relative to pure chitosan (a form of sugar/fibrous compound which comes from the shell of crustaceans).

1.3 – Using biopolymer-nanocomposite hybrid materials as a potential solution: Nanostructured polymeric hybrid materials have recently emerged as revolutionary adsorbents for removal of pesticides. This is essentially because they portray properties such as easy recovery, regeneration, and reusability, which makes them optimal for treatment of aqueous solutions. Even though their use on a large scale is under development, interdisciplinary approach will help overcome several obstacles. Polymeric nanostructured hybrid materials could very well transform into a safe, effective, and economical solution in the future. Some examples of these nanocomposite materials are β-cyclodextryn, MMT/CuO/CS, zeolitic MOF, along with many others.

1.4 – Usage of post-graphene 2-D materials for detection and removal of pesticides: A study was conducted to test post-graphene materials (pg-2DMs), such as layered double hydroxides and transition metal dichalcogenides, in the removal of pesticides due to their unique physiochemical characteristics. Some of these characteristics are high photocatalytic activity and large specific surface area. Pg-2DMs were efficient in the detection and removal of pesticides such as thiobencarb, paraquat, and methyl parathion. However, these materials are still under development for large scale use.

1.5 – Some chemical methods for removal of pesticide: -

1.5.1 – Iron Enhanced Sand Filters (IESFs): IESFs consist of sand filters with a concentration of approximately 5% iron filings. The removal rate of contaminants varies from 26% to 100%. However, for hydrophobic pesticides, the removal rate is merely 10% to 30%. Therefore, IESFs are not a promising method when it comes to the filtration of pesticides.

1.5.2 – Advanced Oxidation Processes (AOPs): Some of the AOPs are discussed as follows.

1.5.2.1 – Free Radicals: Sodium persulfate ($Na_2S_2O_8$) as an oxidizing species is used to remove 17 different pesticides with an initial concentration of 0.02 to 1.17 mg/L. Persulfate is activated to form sulfate radicals, which have a longer lifetime than OH_- allowing them to stay connected to the organic contaminants for a longer period. Persulfate can be activated using ultraviolet rays or sunlight (for feasibility and economical causes). Photolysis of persulfate leads to the formation of sulfate radicals (SO_4-) which mineralize pesticides into CO_2 and H_2O. Furthermore, the results displayed that dissolved organic carbon (DOC) was reduced by approximately 87%. Hence, although really promising as a method, oxidation through sulfate radicals needs some research for its implementation.

1.5.2.2 – Photochemical degradation: Ultraviolet light is used for the photodegradation of various contaminants in water. Even though it is currently used for killing micro-organisms in water, it can be used to remove other contaminants as well through utilization of its different wavelengths. UV light is divided into four categories: UV-A (315-415 nm), UV-B (2880-315 nm), UV-C (180-280 nm), and UV-D (10-180 nm). The smaller the wavelength, the more effective it is. However, one major setback of this method is that it has to be used along with other methods for efficient degradation of contaminants such as pesticides.

1.5.2.3 – Ozonation: Ozonation refers to the process of removal of contaminants either by direct effects or through indirect effects of ozone molecules (by oxidation effect of free radicals). Removal of four different pesticides was tested in a study using ozonation. The results were that 70% of isoproturon ($C_{12}H_{18}N_2O$), 75% of diuron ($C_9H_{10}Cl_2N_2O$) and parathion methyl ($C_8H_{10}NO_5PS$) along with 50% of atrazine were removed. This treatment was then modified with the addition of activated carbon and 20 mg Al/L, which resulted in 90% removal of atrazine and 100% removal of the other three pesticides.

1.5.2.4 – Fenton: It is one of the most efficient oxidation methods for the decontamination of organic pesticides. Its reagents are the combination of hydrogen peroxide solution and ferrous iron sulfate, which result in a redox reaction during Fenton's treatment. Fenton technology has been able to successfully remove 988.5% to 100% of fenitrothion ($C_9H_{12}NO_5PS$), which is an insecticide. It has also removed 97.1% to 100% of chlorfenvinphos. Hence, it is extremely efficient in the removal of various pesticides.

1.6 – Some biological methods for the removal of pesticides:

1.6.1 – Treatment using bio-augmented activated sludge: Development of activated sludge using 2,4-Dichlorophenol is a bio-augmentation of the sludge. It increased the removal efficiency of sludge to 88% when the initial concentration was between 10 to 100 mg/L. It was tested with fluoxil, a herbicide, with an initial concentration of 85 to 500 mg/L. Even though it was not completely removed, removal rate of herbicide reached up to 80% post 70 hours of exposure.

1.6.2 – In-vitro treatment with microbial consortium: Submerged biological aerated filter (SBAF) consisting of adapting bacteria was able to remove atrazine from wastewater with an efficiency of 97.9%. Degradation percentage after 72 hours was 99.9% for linuron, 92.3% for diuron, and 96.3% for chlorturon ($C_{10}H_{13}ClN_2O$) showing great efficiency.

1.6.3 – Pressurized activated sludge: This method is relatively more environment friendly when compared to chlorination and more economical than advanced oxidation processes. However, it does require a disposal area for sludge and skilled labor for maintenance. One of the limitations of activated sludge is COD (Chemical Oxygen Demand). Treating water with high COD in great volumes can be difficult due to lack of dissolved oxygen under atmospheric pressure. Increasing aeration time, sludge concentration, and pressure helps increase efficiency. At 0.2 MPa and aeration time of 6 hours, COD removal of concentration between 2500 to 5000 mg/L was 92.5%.

1.6.4 – Aerobic-Anaerobic biological treatment: Effectiveness of bioremediation was tested through purification of triadimenol ($C_{14}H_{18}ClN_3O_2$), a fungicide, from water. In an aerobic bioreactor, 96% triadimenol was removed at 22 $_{o}$C after 172 days. In an anaerobic bioreactor, the same was removed at 30 $_{o}$C after 230 days. On further investigation, it was revealed that 12 hours of anaerobic treatment followed thereon by aerobic treatment was the most efficient combination for treating wastewater containing triadimenol.

1.7 – Using charcoal filtration for removal of pesticides: Charcoal (graphite carbon) has a great potential for removing agricultural contaminants from aqueous solutions due to its electrochemical surface properties. The amount of charcoal required essentially depends upon the concentration of contaminants in water. For assured safety, the ratio should be 5 grams of charcoal to 1 liter of water. Taking the EPA recommended daily water intake as the requirement (2.5 liters/person/day), around 4.5 kilogram is required to provide safe drinking water to one person for 1 year. The amount increases linearly for each additional increase in people. For example, 9 kilogram of charcoal will be required per year for two people to provide clean drinking water.

2 – Removal of bacteria: -

2.1 – Cellulose based water purification using paper filters modified with polyelectrolyte multilayers to remove bacteria from water through electrostatic interactions: Cellulose filters are brilliant options for the removal of particles, but bacterial removal depends on various other factor and cannot simply be removed through size exclusion. Paper filters were given a positive net charge to trap bacteria. They were also modified with cationic polyelectrolyte polyvinylamine polymer (1 liter) in multilayers along with anionic polyelectrolyte polyacrylic acid (3 to 5 liters) using a water dependent process at room temperature. This modification can remove 99.9% of E. Coli. from water. The bacteria can be further reduced with increase in the number of layers.

2.2 – Disinfection of water through chitosan-modified clay composite adsorbent: Hybrid clay particles were produced using Kaolinite clay and Carica papaya seeds through surface modification of chitosan. The adsorbent had a maximum adsorption removal value of 4.07×10^6 cfu/ml for V. Cholerae after 120 minutes, 1.95×10^6 cfu/ml for E. Coli. after 180 minutes, and 3.25×10^6 cfu/ml for S. Typhi. after 270 minutes.

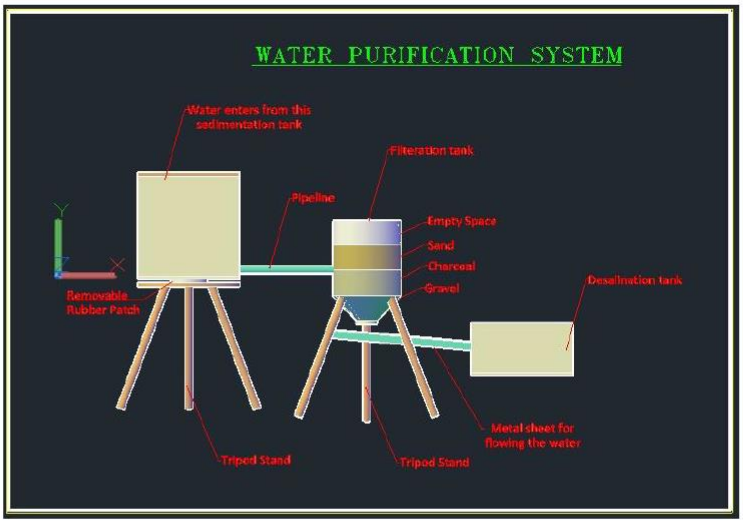
3 – Removal of salts (desalination) and other micro-particles: -

3.1 – Ultrahigh-efficiency desalination through a thermally-localized multistage solar still (TMSS): The TMSS is a passive solar desalination device that combines interfacial solar heating and recycling of vaporization enthalpy through a capillary-fed multistage structure. A record solar to vapor conversion efficiency of 385% was achieved along with a production rate of 5.78 L m^{-2} h^{-1} through one sun illumination. In this device, more than 75% of the total production was received through condensation. Therefore, TMSS can serve as a portable and affordable desalination system. Its only demerit is that its design was created to handle minimal quantities of salt as it primarily works towards desalination of seawater, which has approximately 3.5% of its composition as salt.

3.2 – Highly efficient and salt rejecting solar evaporation through a wick-free confined layer: It works on the principle of salt transport and provides a low cost strategy for high-performance solar evaporation. This device demonstrates a high solar to vapour conversion efficiency (>80%) and has a high salt rejecting ability (20% weight). The device is engineered in such a way that natural convection can be triggered through a wick-free confined water layer. There exists an arrangement through which simultaneous thermal localization and salt rejection can be enabled while inducing negligible heat loss. Furthermore, the model reported an improved efficiency when integrated with a recently developed contactless solar evaporator.

As part of the experiments conducted, various configurations are set up. The set ups and results for the three configurations are discussed in great detail. Out of all three, configuration-1 (C-1) portrays the highest solar to vapour conversion rate (91%). Its rate of evaporation was approximately 1.36 L m^{-2} h_{-1}. Furthermore, C-1 maintains a high evaporation rate even during brine evaporation. For example, for 20% weight brine, the solar to vapour conversion efficiency was still higher than 80%.

Device Overview



Main Body

The multi-stage device for purification of agricultural runoff (MDPAR) is divided into multiple stages to conduct a systematic process of purification of agricultural runoff. The goal is to not only receive water that can be safely deposited into streams and other water bodies, but to receive water that can be used for drinking purposes.

The dimensions of the various stages were difficult to decipher on mere approximation. Therefore, I have taken Mawsynram as the base for the model's dimensions. Mawsynram is a town on the east Khasi hills of Meghalaya, India. It is not only the wettest place in India, but also one of the wettest places in the world.

Agricultural runoff could be the result of various factors such as groundwater and snowfall. However, I have based the dimensions of MDPAR on the rainfall received by Mawsynram. As Mawsynram is an extreme example of an agricultural runoff scenario, the model achieved will be implementable in all regions of the world.

The dimensions of the device are calculated so as to purify the agricultural runoff received from 1 m^2 of Masynram on an average. The volume of water received per meter sq. has been calculated and shown: -

Average annual rainfall received by Mawsynram = 11802.4 mm (average between 1974 to 2022)

Average annual rainfall (in meters) = 11.8024 m

Average daily rainfall (taking 365.25 days in a year) = 0.0323 m

Average hourly rainfall = 0.0013 m

According to definition, volume of rainfall accumulated in 1 meter sq. area per hour = 0.0013 m^3 OR 1.300 liters

Keeping the above mentioned data in mind, the different stages of purification in MMPAR are discussed below.

1 – Screening: -

The first step in the process of purification is screening. Screening refers to the process of removal of macro-particles and coarse solids. This prevents these particles from slowing down or hindering the process by blocking the pipes and restricting the flow of water.

To carry out this process, a mesh is used. It is placed on top of the sedimentation tank. It is fitted in such a way that it is convenient to move it for removing the solids accumulated on it.

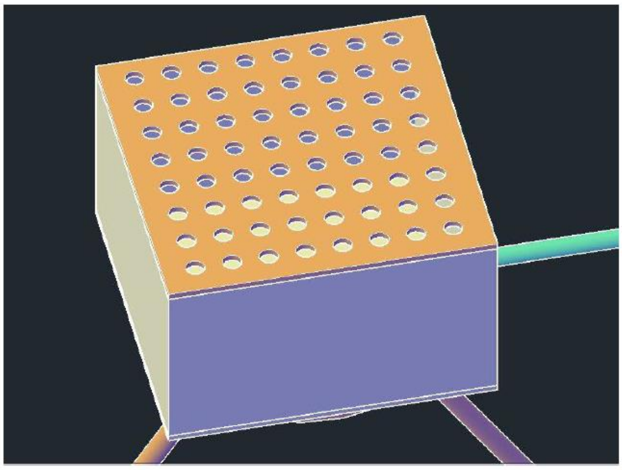
The holes of the mesh are circular in shape. They have a radius of 5 mm and a radius of 10 mm. The holes are not kept too small to ensure that all the water that falls on the mesh enters the sedimentation tank. In the first step, we can expect the removal of various objects such as sticks, leaves, larger insects, and certain soil particles. We can expect the removal of certain soil particles as the maximum size of a soil particle is 63 mm (gravel soil). Whereas, the minimum size is 0.001 mm (clay soil). Therefore, we can expect most of the gravel soil particles to be screened out of the aqueous solution. However, sand, silt, and clay particles will not be removed via this process.

Dimensions of the mesh:

· Length = 0.16 m/160 cm ; Breadth = 0.145 m/145 cm

· Area = Length × Breadth = 0.0232 m^2

The length and breadth is different from the base of the tank keeping in mind the detachable property of the mesh. Furthermore, this is a pre-treatment process whose aim is to make the process smoother to conduct. After the solution is screened, the water enters the sedimentation tank.



2 – Sedimentation: -

Post the screening process, the water enters the sedimentation tank. As the name of the tank suggests, the purpose of this tank is to carry out the sedimentation process. Sedimentation refers to the process in which particles are suspended in an aqueous medium for a given period of time. The heavier particles settle at the bottom. These settled particles are called sludge. In the industrial process of treatment of water, coagulants are added to the solution to speed up the process. However, no coagulants will be used in the MDPAR as the aim behind creating such a device is to purify agricultural runoff in an extremely economical manner.

In the calculations shown earlier, it is clear that 1.3 L/h of rainfall is received per meter sq. of area. A per hour data is important as it tracks the hourly rate of purification of device. It also helps as the last stage of the MDPAR works on an hourly output of purified water.

The dimensions are as follows:

· Length = 0.15 m/150 cm ; Breadth = 0.15 m/150 cm ; Height = 0.1 m/10 cm

· Capacity/volume of tank = Length × Breadth × Height = 0.00225 m^3 OR 2.25 L

· Base area = 0.0225 m^2

There is a removable patch attached to the base of the sedimentation tank. This is placed in order to easily remove the sludge accumulated at the bottom once the water moves onto the next stage of purification of water. The rubber patch is placed at the center of the base. It is circular in shape and its radius is 1/3rd the length of the tank. Hence:

· Radius = 0.05 m/50 cm ; Diameter = 100 cm

· Area occupied by the detachable rubber patch = $\pi \times r^2$ = 0.0075 m^2

The volume of the sedimentation tank has been decided by keeping approximately a 73% margin for error (it is 1.73 times the required capacity). This is done keeping in mind the fact that rainfall, as a weather phenomenon, is unpredictable in nature.

What remains now is calculating the time allowed for the particles to settle at the bottom of the tank. The same has been evaluated below:

- t (sedimentation time) = L/U

L: Height of the sedimentation tank; U: Velocity of the particle during sedimentation

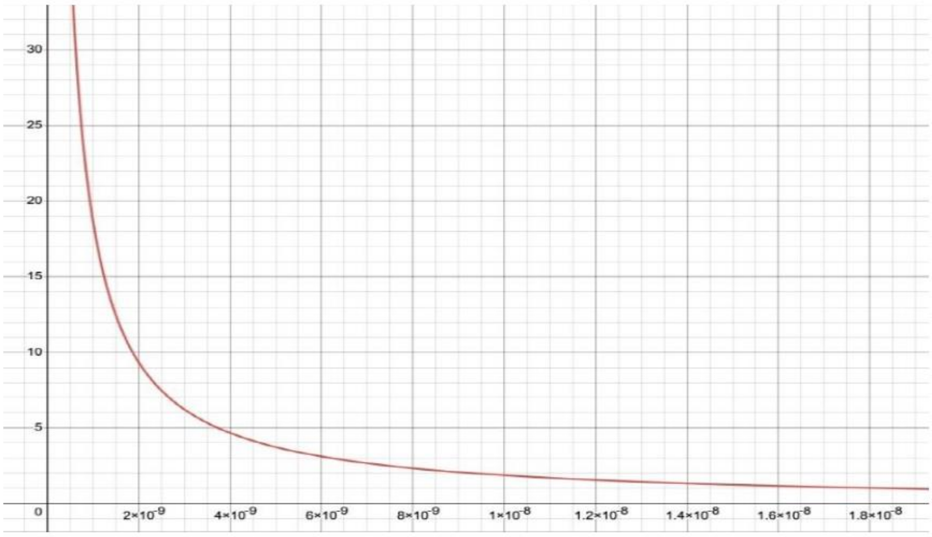
- $U = R^2 (\rho - \rho_f) g$

R: Radius of particle; ρ: Density of the particle; ρ_f: Density of the surrounding fluid;

g: Acceleration due to gravity

- Sedimentation in liquids is modeled using the balance established between the gravity force and force due to viscosity of the liquid. The above mentioned equation is applicable only for spherical particles.
- We can use the following curve to determine the average settling time that should be allowed for the average volume of water flowing in per hour (1.3 L). The line is plotted given the relation that t is inversely proportional to the square of the size of the particle R^2.

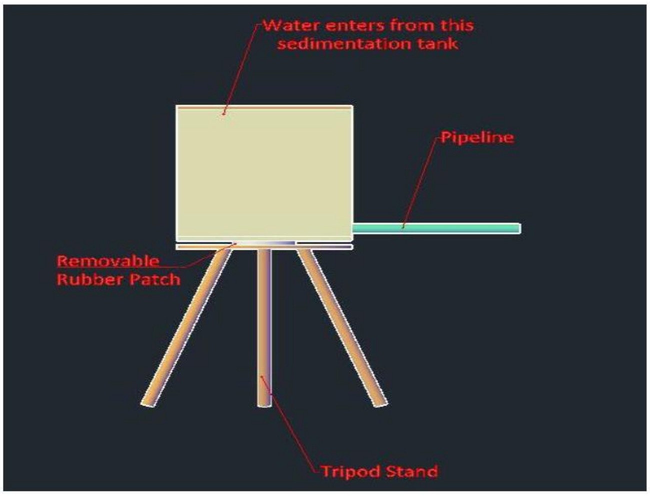
The minimum R value taken is 0.001 mm/ 1×10^{-6} m and the maximum value taken is 10 mm/ 0.001 m (diameter of the mesh). Based on this, we can keep the average settling time to be 10 minutes. Post this, the stopper placed on the open end of the tank can be removed allowing the water to pass on to the next stage. The pipe which serves as the outlet for the water is placed 0.005 m/5 cm above the bottom of the tank, preventing most of the settled sludge from moving to the next stage of purification.



The above attached graph is plotted using the equation: $1867 \times 10^{-11} \times X^{-1}$

The Y-axis represents the sedimentation time t and the X-axis represents R^2 (square of the particle's radius). Since the minimum size of particle is 10^{-6} m, we are providing a settling time of 10 minutes. At y=10 (settling time in minutes), the R^2 value is 1.86×10^{-9} m. Therefore, the particle radius R will be: 4.31×10^{-5} m.

Therefore, we can safely assume that on providing 10 minutes of settling time, particles with a size greater than 10^{-4} m will be filtered out through the process of sedimentation before the water flows into the next tank. I have kept the assumption of the filtered particle size as $>10^{-4}$ m to keep in mind the scope for error: with the water moving through the connected pipe to the next time, certain settled particles may flow with the water into the filtration tank



3 – Filtration: -

Filtration refers to the process in which an aqueous solution containing various particles is passed through a filter medium. When passed through it, the medium retains certain particles (mostly only solids) and allows the fluid to pass through.

I have discussed various methods of removing pesticides from aqueous solutions in the literature review. However, I have implemented solution 1.7 from the literature review in MDPAR ("Using charcoal filtration for the removal of pesticides"). This is because it is relatively much easier to construct, which is important for its application in rural areas. Furthermore, it comprises substances that are not only cheap, but are readily available as they are mainly labor materials that can be sourced locally. This makes 1.7 a much better fit for the process of filtration of solid particles and pesticides present in the agricultural runoff.

The conical structure represented as the filtration tank consists of sand, pulverized charcoal, and gravel. There is also a cotton plug present at the bottom end of the conical tank, which acts as a semi-permeable membrane for the solid particles present in the runoff. The filtration tank will essentially serve as an inexpensive system for the removal of pesticides and other chemical contaminants from the runoff.

The charcoal present in the tank will primarily serve to remove the agrochemical compounds. It is able to do so due to its electrochemical surface properties. While charcoal is chiefly produced through an industrial process, it is also possible to prepare the same through earthen kilns to ensure that the supply of the material is sustainable. An adobe kiln can also be made to ensure a continuous supply of pulverized charcoal. In fact, approximately 50 kilogram/110 lbs of charcoal can be prepared per batch of 80 bricks. These bricks are stacked in a beehive shape during preparation with an inner diameter of 1 meter. The composition of these bricks is 80% sand and 20% clay. A mixture of mud and straw is applied to the outer portion of the kiln to hold the shape and provide the kiln with greater insulation. Smoke generated from heating the adobe kilns is condensed in the chimney to form wood vinegar, which is a natural pesticide. Once the charcoal is prepared, it is passed through a 3 mm fine sieve to pulverize it. Pulverizing it increases the charcoal's surface area, leading to greater contaminant absorption.

Amount of charcoal required depends upon the concentration of the contaminants in the water. An estimate is taken based on the scientific literature of these terms. It is observed that the ratio of 5 grams of charcoal to 1 liter of water suffices the requirements of MDPAR. Around 4.5 kilograms of charcoal is needed annually to purify 2.5 liters of water per day, which is the recommended daily water intake. This ratio increases linearly with an increase in the number of people. For example, if we were to purify the recommended daily water intake for two people, we would need 9 kilograms of charcoal annually to purify 5 liters of water per day. Keeping this statistic in mind, we can find the charcoal required for the MDPAR.

- Water intake of MDPAR per day = 0.0323 $m^3 \times 1000$ = 32.3 L
- Charcoal required annually = $2.5/4.5 \times 32.3$ = 17.944 kg OR approx. 18 kg

As seen above, 18 kg of charcoal is sufficient for filtration of 32.3 L of daily water intake. A batch of 80 bricks can produce 50 kg of charcoal, which will be enough for more than 2.5 years of filtration of the runoff produced per meter sq. of area.

While the charcoal is crucial for filtration, the tank also comprises of sand and gravel. Sand here acts as a pre-filter and the gravel acts as a layer which prevents movement of the above two soil layers towards the cotton plug. Therefore, it not only holds the structural integrity together, but increases the life span of the cotton plug by reducing the concentration of particles borne by it. If there is no gravel, the cotton plug would be directly placed below the charcoal, which on becoming wet can put excessive load on the cotton plug. Following is the thickness/height of each of the individual layers of the filtration tank in systematic order:

· Sand layer: 0.45 m/45 cm

· Charcoal: 0.45 m/45 cm

· Gravel: 0.18 m/18 cm

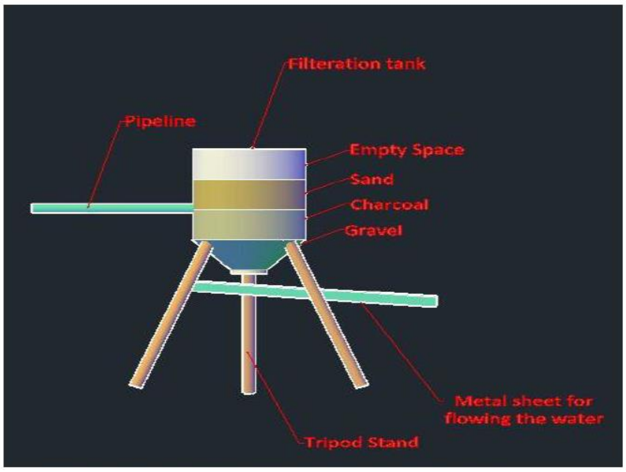
In the paper, which talks about this model, it is mentioned that 50 cm of sand is used for purifying 2.5 liters of water per day. Therefore, by simply unitary method, we can calculate that to purify 2.25 liters of water 0.45 m of sand will be used and 0.18 m of gravel will be used. For maximum purification, 0.45 m is established as the width of the charcoal layer. The tank will have a relatively greater height than width. The dimensions of the tank are as follows:

· Height (h) = 0.45 + 0.45 + 0.18 (+ 0.02) = 1.10 m/110 cm (0.02 m/2 cm have been added to the height keeping in mind the surge of water that will be coming once the water is released from the sedimentation tank

· Radius (r) = 0.2 m/20 cm

· Volume/Intake capacity (Cylindrical tank) = $\pi \times r^2 \times h = \pi \times (0.3)^2 \times (0.07) = 0.002512$ m^3 OR approx. 2.512 L (Height is taken as 0.02 m/2 cm giving thought to the fact that the water may be accumulated first before it starts to be filtered due to the high flow-rate of water flowing in from the outlet of sedimentation tank).

Keeping the above conditions and dimensions in mind, the tank is shaped like a cylinder with a conically shaped bottom. The conically shaped bottom comprises gravel and the opening has a cotton plug wrapped around it, acting as a semi-permeable membrane. Post the filtration process, almost all, if not all, pesticides and macro-particles will be removed from the aqueous solution. However, the water that passes on to the next stage will still contain dissolved micro-particles such as salts and micro-organisms such as bacteria and may even contain minute traces of pesticides even after filtration.

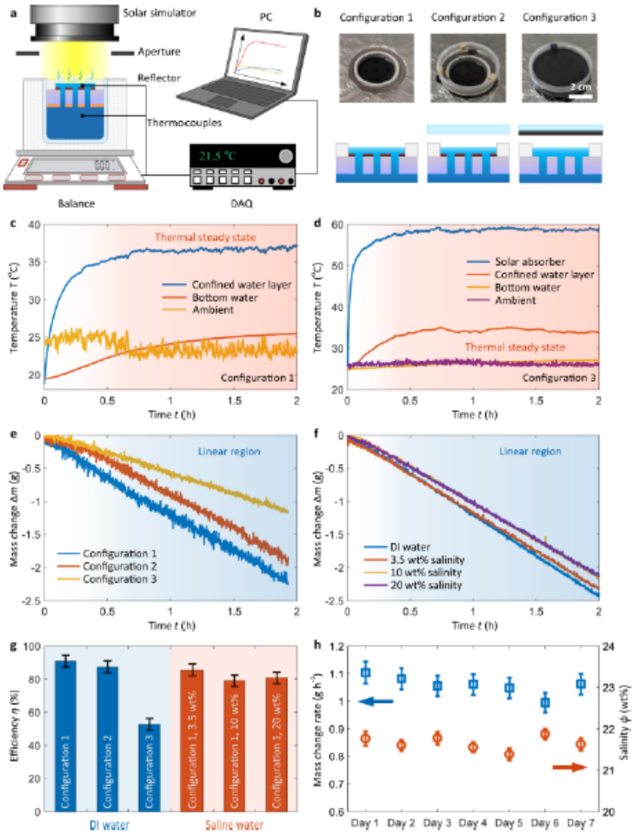


solution number 3.2 in the MDPAR ("Highly efficient and salt rejecting solar evaporation through a wick-free confined layer"). For convenience, I shall be referring to this device as WCL (Wick-free Confined Layer).

The reason I have chosen WCL over solution 3.1 [Ultrahigh-efficiency desalination through a thermally-localized multistage solar still (TMSS)] is because TMSS can desalinate seawater efficiently. The percentage of salt by weight in seawater is 3.5%. Whereas, WCL can desalinate even 20% salt weight percent.

This shows that WCL has a greater capacity for the removal of micro-particles from water in comparison to the TMSS. Hence, I have chosen to install WCL in place of the TMSS as part of MDPAR. The purpose of WCL is essentially to remove micro-particles/micro-organisms such as germs, bacteria, and salt. Therefore, it becomes even more essential that the efficiency of removal of foreign substances be high.

The following diagrams and graphs display the setup of the three configurations (a). It also shows the difference in the efficiency between the configurations 1, 2, and 3. The primary reason behind the difference in the efficiency between these configurations is the way they have been set up. Otherwise, their confined layer water structures are practically the same. I will be discussing configuration-1 (C-1) as it portrays the greatest efficiency of purification (as shown by g). Hence, I will be installing WCL using C-1.



It is demonstrated that a high evaporation rate can be maintained even during brine evaporation. Figure 'f' shows the mass change of the reservoir with different salinities (3.5 wt%, 10 wt%, and 20 wt%). No salt crystallization was noticed during the tests conducted. However, with an increase in salinity, there was a decrease in the evaporation rate. This is essentially because of the reduced water activity of salt solutions.

Nevertheless, for the 20 wt% brine solution, the solar-to-vapour conversion efficiency was higher than 80%. A 6 hour continuous solar evaporation of 25% brine is conducted to test the limit of the confined water layer. Still, no salt crystallization is observed and a solar-to-vapour conversion efficiency of 67% is noted. The summary of the solar-to-vapour conversion efficiencies and salinities is in fact shown by figure 'g'.

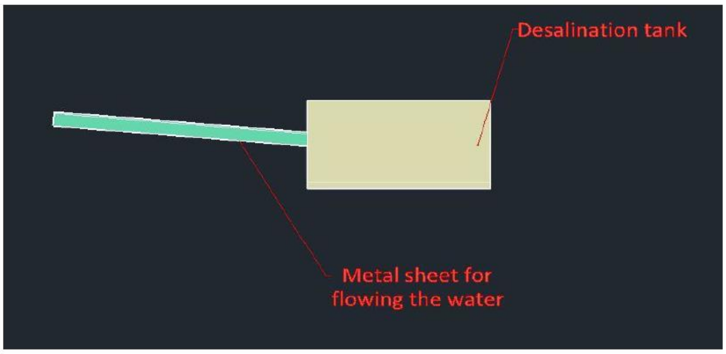
The C-1 of WCL purifies 1.36 L m^{-2} h^{-1}.

Set up for C-1: -

- A circular polyurethane foam is used as the floating thermal insulation: 36 mm diameter and 25 mm thickness.
- An insulating ring of polystyrene foam is attached on top of this thermal insulation: 36 mm external diameter, 31 mm internal diameter, and 6 mm height.
- Black paint is sprayed uniformly on top of the thermal insulation layer (creates a 31 mm diameter for solar absorption): 245198, Rust-Oleum.
- Five 2.5 mm diameter macro-channels are drilled through the thermal insulation. Only one of these channels is in the center while the rest are in the four vertices of a square, which are 9 mm away from the central macro-channel.
- The convection cover comprises of glass slides (45 mm diameter and 2 mm thickness) and an air gap (5 mm thickness). The solar absorber for the contactless mode is a double-sided black-painted aluminium plate, which is attached to the back side of the convection cover.

It is shown that WCL structure provides a simple and low-cost approach to receive a highly efficient and salt rejecting solar evaporation. This is the last stage of the multiple stage layout of the MDPAR. The input to this stage is water that consists of micro-contaminants such as bacteria and salt. They are removed from the water through the process of evaporation and condensation.

Since there are other stages before this one, I have ensured that there is not too much load on the WCL. This ensures that the overall efficiency of purification of WCL increases, resulting in a clean and drinkable water output from a toxic input in the form of agricultural runoff.



Results

I have constructed the MDPAR based on the case study of Mawsynram, which receives the highest rainfall in India. In fact, it receives one of the greatest amount of rainfall in the world. I used Mawsynram as the case study as it is an extreme case of rainfall in a region. When the device is built to handle extreme situations such as this one, it becomes applicable for implementation in other parts of the world.

I have made sure that the process is very structured and efficient for maximum convenience and efficiency of purification.

The MDPAR discussed in this paper can purify up to 1.36 L m^{-2} h^{-1} of water (based on the purification rate of WCL).

Some important demerits: -

- We will have to install multiple devices for a greater area of land to handle larger volumes of water.
- We can also increase the number of WCLs installed in the device and simultaneously increase the proportions of other stages of the device to handle greater volumes of water.

- We will have to change materials like sand, charcoal, gravel, and cotton whenever they become saturated or highly contaminated.

Some important advantages: -

- The MDPAR does not utilize any external energy such as electricity and relies solely on principles of mechanics for its operations.
- The device is composed of cheap and readily available materials, making it affordable and accessible for the people living in remote, rural areas.
- The MDPAR is a multiple stage device, making the process of purifying agricultural runoff highly efficient and convenient.

Conclusion

Agricultural runoff is one of the world's leading causes of water pollution. Over the past 50 years, the number of dead zones around the world have increased dramatically from 10 documented cases in 1960 to a total of 415 dead zones around the world in 2016. It is interesting to note that the number of dead zones have increased along with the human population. The human population was 3 billion in 1960. The current human population has surpassed 7.5 billion.

If we were to try to make a sense out of this data, we would understand that the proportional relation established between the dead zones and the human population is due to the increasing agricultural practice all over the world.

With increasing agricultural practices and innovations in farming, the agricultural runoff has also become more toxic over the past few decades.

Dead zones are merely the tip of the iceberg as far as the harmful impacts of agricultural runoff are concerned. Hence, it becomes even more important that agricultural runoff is purified before it is allowed to enter rivers, streams, and other water bodies.

In an attempt to tackle this issue, I have come up with the ideation of MDPAR. The purpose of MDPAR is to purify the agricultural runoff before it is passed on to the water bodies. The aim is to not only render agricultural runoff harmless to the environment, but it is also to make it so pure that it can be reused for farming or drinking purposes.

Keeping this in mind, I researched extensively. I broke down the device into multiple stages to ensure a structured and smooth process. As shown in the results earlier, the device is extremely efficient in removing foreign particles from agricultural runoff. Any and all parameters possible have been kept in mind while constructing MDPAR.

At the same time, however, MDPAR has various flaws. Its primary flaw being that currently it is a theoretical model that is yet to be tested experimentally. While the data provided for the various stages has been found experimentally, the overall efficiency of MDPAR as a multi-stage device for purification of agricultural runoff remains to be tested.

Another setback of MDPAR is the fact that while the device may efficiently purify water, it is not capable of purifying large volumes of water productively. In fact, 1 MDPAR can currently only purify the agricultural runoff of 1 m^2 area of land. To handle the runoff for a much larger area of land, one of two options can be implemented: Either the number of MDPARs can be increased or the proportions of the materials in the device can be altered to support the given volume of water.

Therefore, owing to the above two reasons, the MDPAR is currently impractical to implement as a model. However, there is no doubt that further research into the components of the device can see its efficiency and water capacity to increase exponentially.

Nonetheless, the MDPAR does have many advantages. The first of its most important advantages is that the MDPAR is built of cheap and readily available materials only. Therefore, the device becomes affordable to construct for people living in remote, rural areas. The device has multiple stages so that it is easy to build for everyone. Another reason that makes the device so unique is that it operates on the basic principles of mechanics and that it does not depend on electricity or any external source of energy such as electricity for its operations.

I would like to conclude by saying that the MDPAR is a one of a kind device. In all the research conducted by me, I have not come across a device that tackles the problem of agricultural runoff directly. While it may not reverse the effects of agricultural runoff, it can certainly help by preventing further damage from happening to the environment. A device like the MDPAR has the potential to create a better world not just for ourselves, but for the future generations to come.

Acknowledgements

I would like to thank Shaumik Verma for his valuable insights and constant support and guidance from the beginning till the end of this research paper. I would also like to express my gratitude to the members of the Polygence organization for offering me a scholarship to conduct my research with them.

Bibliography

Alavanja, Michael C R. “Introduction: Pesticides Use and Exposure Extensive Worldwide.” Reviews on Environmental Health, vol. 24, no. 4, 2009, pp. 303–9, www.ncbi.nlm.nih.gov/pmc/articles/PMC2946087/.

Busch Systems. “What Is Agricultural Runoff?” Buschsystems.com, 2016, www.buschsystems.com/resource-center/knowledgeBase/glossary/what-is-agricultural-runoff.

countrymeters.info. “World Population 2019 | Population Clock Live.” Countrymeters.info, 2017, countrymeters.info/en/World.

“Detail.” Food and Agriculture Organization of the United Nations, 7 May 2020, www.fao.org/sustainability/news/detail/en/c/1274219/#:~:text=Globally%20agricultural%20land%20area%20is.

Team, TIAL WIZARDS. “Self Purification of Streams and Oxygen Sag Curve - TIAL WIZARDS.” TIAL WIZARDS, www.tialwizards.in/2021/07/self-purification-oxygen-sag-curve.html. Accessed 17 Oct. 2022.

United Nations. “Growing at a Slower Pace, World Population Is Expected to Reach 9.7 Billion in 2050 and Could Peak at Nearly 11 Billion around 2100 | UN DESA | United Nations Department of Economic and Social Affairs.” UN DESA | United Nations Department of Economic and Social Affairs, 2019, www.un.org/development/desa/en/news/population/world-population-prospects-2019.html.

Baigorria, Estefanía, and Leonardo F. Fraceto. “Biopolymer-Nanocomposite Hybrid Materials as Potential Strategy to Remove Pesticides in Water: Occurrence and Perspectives.” Advanced Sustainable Systems, vol. 6, no. 1, 7 Oct. 2021, p. 2100243, 10.1002/adsu.202100243. Accessed 17 Oct. 2022.

“Circular Economy: Tapping the Power of Wastewater.” International Water Association, iwa-network.org/learn/circular-economy-tapping-the-power-of-wastewater/.

Energy Data Management Manual for the Wastewater Treatment Sector Authors and Acknowledgements. 2017.

Lanfair, Jordan K, and Archis Ambulkar. “Water Purification | Description, Processes, & Importance.” Encyclopædia Britannica, 18 June 2018, www.britannica.com/topic/water-purification.

Ottenhall, Anna, et al. “Cellulose-Based Water Purification Using Paper Filters Modified with Polyelectrolyte Multilayers to Remove Bacteria from Water through Electrostatic Interactions.” Environmental Science: Water Research & Technology, vol. 4, no. 12, 22 Nov. 2018, pp. 2070–2079, pubs.rsc.org/en/content/articlelanding/2018/ew/c8ew00514a#, 10.1039/C8EW00514A. Accessed 29 Oct. 2020.

Rahmanifar, Bahar, and Shahram Moradi Dehaghi. “Removal of Organochlorine Pesticides by Chitosan Loaded with Silver Oxide Nanoparticles from Water.” Clean Technologies and Environmental Policy, vol. 16, no. 8, 23 Nov. 2013, pp. 1781–1786, 10.1007/s10098-013-0692-5. Accessed 17 Oct. 2022.

Rojas, Raquel, et al. “Adsorption Study of Low-Cost and Locally Available Organic Substances and a Soil to Remove Pesticides from Aqueous Solutions.” Journal of Hydrology, vol. 520, 1 Jan. 2015, pp. 461–472, www.sciencedirect.com/science/article/abs/pii/S0022169414008415, 10.1016/j.jhydrol.2014.10.046. Accessed 17 Oct. 2022.

Saleh, Iman A., et al. “Removal of Pesticides from Water and Wastewater: Chemical, Physical and Biological Treatment Approaches.” Environmental Technology & Innovation, vol. 19, Aug. 2020, p. 101026, 10.1016/j.eti.2020.101026.

“Sedimentation - an Overview | ScienceDirect Topics.” Www.sciencedirect.com, www.sciencedirect.com/topics/chemistry/sedimentation#:~:text=Thus%2C%20sedimentation%20time%20t%20%3D%20L. Accessed 17 Oct. 2022.

Systems, Filtra. “4 Steps in Industrial Water Purification | Filtra Systems.” Www.filtrasystems.com, www.filtrasystems.com/blog/4-steps-in-industrial-water-purification/. Accessed 17 Oct. 2022.

Unuabonah, Emmanuel I., et al. “Disinfection of Water with New Chitosan-Modified Hybrid Clay Composite Adsorbent.” Heliyon, vol. 3, no. 8, Aug. 2017, p. e00379, 10.1016/j.heliyon.2017.e00379. Accessed 9 Feb. 2022.

“What Is Chitosan? Uses, Benefits, Side Effects, and Dosage.” Healthline, 7 Sept. 2021, www.healthline.com/nutrition/chitosan-supplements.

Xu, Zhenyuan, et al. “Ultrahigh-Efficiency Desalination via a Thermally-Localized Multistage Solar Still.” Energy & Environmental Science, vol. 13, no. 3, 2020, pp. 830–839, 10.1039/c9ee04122b. Accessed 22 May 2021.

Yang, Qi, et al. “Using Post-Graphene 2D Materials to Detect and Remove Pesticides: Recent Advances and Future Recommendations.” Bulletin of Environmental Contamination and Toxicology, vol. 107, no. 2, 20 May 2020, pp. 185–193, 10.1007/s00128-020-02868-z. Accessed 17 Oct. 2022.

Zhang, Lenan, et al. “Highly Efficient and Salt Rejecting Solar Evaporation via a Wick-Free Confined Water Layer.” Nature Communications, vol. 13, no. 1, 14 Feb. 2022, p. 849, www.nature.com/articles/s41467-022-28457-8, 10.1038/s41467-022-28457-8.

“Mawsynram Sets New June Rainfall Record at 1003 Mm in 24 Hours.” The Indian Express, 17 June 2022, indianexpress.com/article/weather/cherrapunji-972-mm-rain-24-hrs-third-wettest-june-day-122-years-7975357/. Accessed 17 Oct. 2022.

“Sedimentation - an Overview | ScienceDirect Topics.” Www.sciencedirect.com, www.sciencedirect.com/topics/chemistry/sedimentation#:~:text=Thus%2C%20sedimentation%20time%20t%20%3D%20L.

“Step-By-Step Guide for Grain Size Analysis.” Www.geoengineer.org, www.geoengineer.org/education/laboratory-testing/step-by-step-guide-for-grain-size-analysis.

“WDI - a Changing World Population.” *Datatopics.worldbank.org*, datatopics.worldbank.org/world-development-indicators/stories/a-changing-world-population.html#:~:text=There%20were%203%20billion%20people.

“Dead Zone | National Geographic Society.” *Education.nationalgeographic.org*, education.nationalgeographic.org/resource/dead-zone.