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A SUSTAINABLE AND ECONOMICAL APPROACH TO WATER TREATMENT : A REVIEW IN CONTEXT OF INDIA

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ABSTRACT

Recent papers related to the field of water purification, environmental economics and biosorption were studied and are reviewed. Considering the existing economic disparity and sustainability concerns in the developing and under-developed nations and the incapability of the rural people to afford modern fancy water purifiers, we present some economical water treatment processes. All the prescribed methods were also found to be eco-friendly and technically efficient. For reducing the turbidity of water, we discuss the use of Sari and Burlap cloth sheets and *Moringa Oleifera* powder. For improving the aesthetic qualities of water, we have used the sand and gravel filtration approach wherein the water is passed through different layers of sand and gravels before being consumed. For removing disease causing microorganisms from water, use of SODIS technique, copper pots, and biosand filter is advocated. Finally, for the removal of inorganic chemical contaminants and radioactive substances, various biosorbents are discussed.

Key words: Biosand filter, Chemical contaminants, Developing countries, Turbidity, Water treatment, Sustainability, Economical measure, Aesthetic qualities, Heavy metals, Biosorption.

INTRODUCTION

In every developing nation, water contamination is posing serious health problems. Considering the global statistics, around 135 million people will die from water-related diseases by 2020, if no requisite actions are taken. Moreover, even if the Millennium Goals suggested by WHO in 2000 are met, the estimated deaths due to the water-related diseases will be anywhere between 34 and 76 million[1].

As regards India, 85% of the drinking water supply is based on ground water, a large part of which contains chemical contaminants in quantities that exceed the permissible limits suggested by the World Health Organization. For example, around 64,212 habitations face water-related problems due to the presence of excessive iron and nearly 23,107 habitations face the same due to the presence of excessive Fluoride[2]. These issues have not only deteriorated the living conditions of the people but have also given a hard blow to the economic structure of the nation. This is evident from the fact that around 37.7 million Indians are affected by waterborne diseases annually and consequently, around 73 million working days are lost. The economic losses suffered due to this are of the order of Rs. 3300 Crores per year[3].

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Moreover, about 60% of the Indians living in rural areas earn even less than Rs. 35/day[4]. These are the people who are most vulnerable to water-borne diseases because of low level of income, lack of awareness and inadequate provisions of safe drinking water.

Since, the scope of the challenge posed by water contamination is enormously large, individual efforts are greatly required in order to deal with the problems caused by it. We have to create awareness among the people regarding the diseases to which they are exposed and more importantly, teach them how to minimize the risk of getting affected. In this review paper, we discuss:

(i) Various cheap and easily available materials, which can be instrumental in dealing with the problems of water contamination at a personal level, and

(ii) The economic feasibility and the working efficiencies of the prescribed remedial measures.

The Indian Scenario

We will now present a deeper insight into the Indian scenario of water contamination. Out of the total population of 1.2 billion, around 97 million people lack access to safe water. Consequently, around 21% of the country's diseases are water-related. Treatment of these life threatening diseases clearly involves a great deal of time and money. Hence, we need a proper water purification system in place to prevent the risk of getting contaminated. But how can a person living on less than Rs. 35/day afford a water purifier, even the cheapest of which costs around his 7 months' income ?

Even if, the Government steps forward and distribute these water purifiers at zero cost in the rural areas, then also certain factors may restrict the availability and supply of pure water:

(i) Most of the water purifiers require electricity. Since one out of every six villages in India has no access to electricity, installation of water purifiers there will not yield any positive results.

(ii) Unavailability of new parts in these areas to replace the old or damaged ones. Such unavailability may occur due to the remoteness of the rural areas. The continued use of old or damaged parts will greatly decrease the efficiency of the purification system.

It is required that we clean the water filter or replace the filter cartridge periodically for the proper functioning of the equipment. Lack of awareness amongst the rural people will prevent timely cleaning or replacement of the filters which will further make the purification process less efficient.

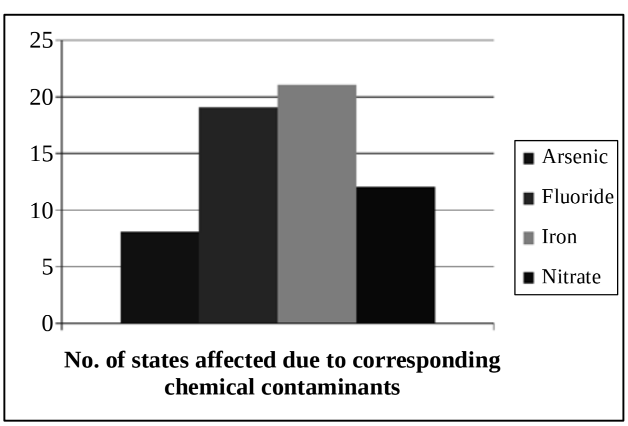

Fig. 1: No. of Indian states affected due to arsenic, fluoride, iron and nitrate[2]

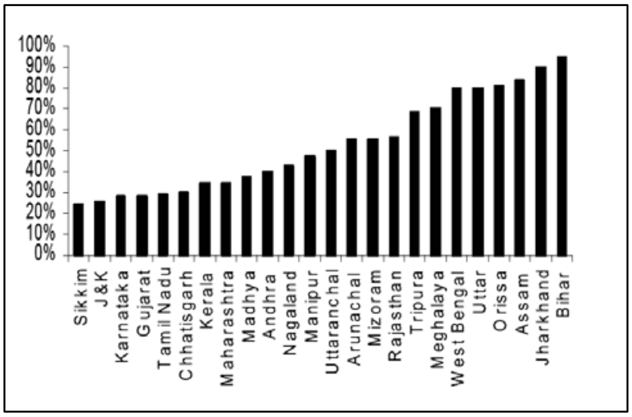

Fig. 2: Un-electrified households (in %) in Indian states[5]

Literature survey

A vast literature related to the field of water purification and biosorption is available for reference. Tammisetti and Padmanabhan[6] have done an extensive research on the effectiveness of various fabrics in removing turbidity from water. They reported Burlap as the most effective fabric while dealing with turbidity. Further, a fact sheet, "colour, taste and odour problems in drinking water", published by the Washington State Dept. of Health in 2011[7] gives detailed information on the aesthetic qualities of water. It gives all the possible variations in the taste, colour and odor of water with their causes.

Lea[8] discusses the working of extract of *Moringa oleifera* seeds with respect to the removal of turbidity from water. He reported that these seed extracts have an efficiency of more than 99% in this turbidity-removal process. The biosand filter construction manual published by the Centre for Affordable Water and Sanitation Technology (CAWST) discusses all the aspects of a biosand filter from its construction to its operation. A biosand filter is highly effective in removing bacteria and other microorganisms from water[9].

Many works have also been done concerning the adsorption of chemical contaminants, especially copper, from water. Hossain et al.[10] reported the usage of banana peels as a biosorbent in order to remove copper and Sethu et al.[11] presented the adsorption thermodynamics of copper ions (Cu^{2+}) from waste water using neem leaf based biosorbents. Chowdhury et al.[12] presented quite a useful insight to the removal of copper (II) from aqueous solution by using Onion and Garlic skin. They also presented equilibrium, thermodynamic and kinetic studies for the same. Kamsonlian et al.[13] also reported the use of banana peels but for the adsorption of Arsenic (As (III)) from contaminated water. Further, Binti et al.[14] proved the efficiency of *Rosa Centifolia* in adsorbing iron and manganese from groundwater and Lam and Ong[15] discussed the removal of nitrate ions from aqueous medium using dried biomass of *Brassica alboglabra*. At the deeper end of biosorption, Shrestha et al.[16] discuss the surface modification of tea leaves based biowaste where they are aminated in order to increase their adsorption capacity while dealing with lead and cadmium.

As regards the economic aspects of our problem statement, the data given in the National Sample Survey (2009-10), "Drinking water quality in rural India: Issues and approaches, Water Aid" by Sen and Khurana and the 12th Five Year Plan of India discuss all the relevant statistical results related to issues of Water contamination in the country[2-4]. Our work summarizes the findings of the researches mentioned above and many other related ones. The various sections of the paper deal with the treatment of water under different conditions and with different contaminant-load. Our work, thus, serves as synopsis to the existing literature in the field of municipal and well-water purification.

Defining the risk

We are concerned with the purification of municipal water in urban areas and ground-water in rural areas. For our entire study, we have used the following notion of impure water:

Impure water can be defined as water which possess high turbidity, bad taste & odour, and/or unclear appearance and is contaminated due to the presence of microorganisms, unwanted chemicals, and/or radioactive substances in quantities that can put the health of an individual at risk, where,

(i) Microorganisms are small organisms that can only be seen under a microscope. These include bacteria (such as *E. coli* and *Salmonella*, etc.), viruses (such as Rotavirus and Norwalk Virus) and protozoans (such as Entamoeba, Cryptosporidium and Giardia)[17].

(ii) Unwanted chemicals include chemicals which may be naturally occurring (such as arsenic, chromium and fluoride), derived from industrial sources & human dwellings (such as cadmium, mercury, benzene and xylenes), from agricultural activities (such as nitrate, nitrite, chlordane, aldrin and cyanazine), from water treatment and materials in contact with drinking water (such as chlorine, monochloramine, bromate, antimony, lead, copper and nickel), and from pesticides used in water for public health (such as DDT and metabolites)[18].

(iii) Radioactive substances refer to the radionuclides that give off radiations that are extremely harmful for living beings. They are of two types; natural and man-made. The radiation doses given by naturally occurring radionuclides in drinking water are usually more than those given by man-made radionuclides. Examples of radioactive substances include uranium-238, uranium-234, lead-210, carbon-14, thorium-228, etc.[18]

Therefore, in order to treat impure water for drinking purposes, we need to get rid of:

(i) High turbidity

(ii) Bad colour, taste & odour

(iii) Disease causing microorganisms

(iv) Excess quantities of unwanted chemicals

(v) Excess quantities of radioactive substances

Removal of high turbidity

Turbidity is a measure of relative clarity of water. Higher the value of turbidity, higher will be the cloudiness in water. Materials that cause water to be turbid include clay, silt, finely divided inorganic and organic matter, algae, soluble coloured organic compounds, and plankton and other microscopic organisms[19,20].

The magnitude of turbidity is measured in Nephelometric Turbidity Units (NTUs). According to the World Health Organization, the turbidity of drinking water should ideally be less than 1 NTU. Water with turbidity more than 1 NTU may be safe for drinking, but the visible cloudiness has a negative impact on consumer acceptability. Moreover, high turbidity in water is a possible source of microbial contamination and it also reduces the efficiency of the water purification systems[18].

One of the cheapest ways of removing turbidity is by filtering the turbid water with cotton or burlap clothes. These fabrics are cheap and readily available, which make them perfect materials for water treatment in rural areas. Tammisetti and Padmanabhan[6] have shown in his research that on passing a water sample through a Burlap Cloth folded over three times (8 layers), the turbidity of that water sample was reduced by 57.28% (from 4.75 NTUs to 2.03 NTUs). When the same experiment was repeated using a cotton cloth folded over 3 times, the observed reduction in turbidity was 48.23%.

Material selection plays an important role in this type of treatment because if we use polyester cloth instead cotton of burlap, then the turbidity of water may even increase. Tammisetti justified this observation by stating that the resultant increase in the turbidity of water in this case was due to the release of cloth fibres into the water. Furthermore, on using tightly woven silk cloth, the time taken for treatment was too much to be of any practical significance and even the magnitude of turbidity reduction was quite small.

In the rural areas, Sari cloth is easily available, which is highly efficient in reducing the turbidity of water. A 3-year study conducted in Matlab, Bangladesh showed that a sari cloth folded at least 4 times removed 99% of the cholera bacteria from water in addition to a significant reduction in turbidity. Moreover, an old sari cloth works better than the new one because after repeated use, the threads of a sari become soft and loose, which reduces the pore size of the fabric. This resulting reduction in the pore size leads to a more efficient water treatment[21].

Flocculation of impurities present in turbid water caused by *M. Oleifera* seed powder is another effective approach used for reduction of turbidity. The dosage of this powder required during the Bioremediation of turbid water varies from 50 mg/L when the turbidity is low (less than 50 NTU) to 400 mg/L when the turbidity is of the order of 250 NTUs or more. Lea[8] also observed that *M. Oleifera* doesn't coagulate the impurities effectively when the turbidity is less than 50 NTUs.

Removal of bad colour, taste & odour

Generally, these aesthetic characteristics of water do not pose any health concern to the people. However, clean water with good taste and odour always has more consumer acceptability. The underlying table gives the sources of variations in these aesthetic properties viz. taste, colour and odour[7].

Table 1: Sources of variations in the aesthetic properties of water

Colour of water	Sources
1. Green/Blue	Corrosion of plumbing metals. Usually, copper
2. Black/Dark brown	Presence of manganese
3. Brown/ Red/Orange/Yellow	Iron rust
4. Milky white/Cloudy	Can be observed in tap water because of the air dissolved in the water supply
Taste	**Sources**
5. Metallic	Leaching of minerals (such as iron or copper) or some metals like zinc and manganese into the water from pipes
6. Salty	High concentration sodium, magnesium and potassium
7. Chlorine, chemical, or medicinal	Use of excessive chlorine for purification purposes

Cont…

Odour	**Sources**
8. Petroleum, gasoline, turpentine, fuel, or solvent	Possible Leakage from an underground storage tank
9. Sulphur or rotten egg	Presence of hydrogen sulphide gas, which can be produced in ground water, by some sulphur bacteria or due to some chemical reactions in the water heater[22].
10. Mouldy, musty, earthy, grassy, or fishy	Due to the bacteria present in sink drain or from the organic matter which is naturally present in the reservoirs

Sand and gravels of specific Grain sizes can be used to reduce bad odour and taste and to improve the appearance of the water[9]. They also filter out the microbial contaminants. A similar concept is used in the biosand filter developed by CAWST Team. Sand and gravel mixture is cheaper compared to the various fancy purification systems and the availability of sand and gravels in rural areas is also relatively higher. Hence, biosand filter approach is discussed in this paper.

The biosand filter uses 4 ways to get rid of the pathogens and dirt present in water[9]:

(i) Pathogens getting trapped into the various sand and gravel layers.

(ii) Pathogens getting adsorbed to the sand.

(iii) Eating of each other by the microbes themselves.

(iv) Natural death of pathogens due to insufficient air and food in the filter.

These pathogens and dirt particles impart typically unpleasing taste, colour and odor to the water. Hence, on removing these tastants and odorants from the water, its aesthetic qualities improve considerably.

Removal of disease causing micro-organisms

The methodologies discussed in the paper for the removal of turbidity, bad taste, colour and odour also work towards the removal of many of the disease causing microorganisms. A biosand filter, if operated carefully, can block most of the pathogens present in water. The following table gives the pathogen or contaminant removing efficiency of a biosand filter[9].

Table 2: Contaminant removing efficiency of biosand filter

Contaminant type	**Treatment efficiency (Based on field tests)**
Bacteria	87.9 to 98.5%
Turbidity	85%
Iron	90-95%
Viruses*	70 to 99%
Protozoa*	Greater than 99.9%

*Based on laboratory tests only

If the water to be used is void of any bad taste, colour and odour, then we can use copper pots to store it in order to get rid of the disease causing microorganisms if its turbidity has been already removed.

A test has revealed that on storing contaminated water in a copper pot, the bacteria present in that sample either died or lost their ability to grow and reproduce. The bacteria incubated in the water sample were: *V. cholerae, S. flexneri*, *Enterotoxigenic Esc-herichia* coli, *Enteropathogenic Escherichia coli, S. enterica Typhi* and *S. Paratyphi A.* When water is kept in copper vessels for longer time durations, some leaching of copper ions into the water may occur. However, even after the 16 hrs incubation of water in copper pots, the copper leached into the water was within the permissible limits of the World Health Organization. The amount of copper leached into water sample was 177 ± 16 ppb. Moreover, no change was observed in the values of TDS, alkalinity, hardness, and contents of chlorides & sulphates after the incubation[23].

Copper vessels (especially copper pots) are generally found in most of the rural Indian households. It finds its use in many religious proceedings making it socially acceptable too. This makes copper vessels another available alternative for water treatment for the rural people.

Furthermore, a greener and a low cost alternative for the removal of high turbidity and disease causing microorganisms from impure water is using Ramachan (*Vettiver zizanoides*), Drumstick Seeds (*Moringa olifera*) or seeds like Kathaka Seeds (*Strychospotatorum*) and Nirmalee[24].

Another approach involves using crushed seed powder from *M. Oleifera* plants, which is a natural flocculating agent. They bind the suspended impurities into flocs which settle down later due to its own weight. These flocs also trap the pathogenic microorganisms present in the water which further reduces the bacterial load over it. The following table gives the efficiency of *M. olifera* seeds in removing turbidity and bacteria[25].

Table 3: Efficiency of *Moringa olifera* seeds

Problem/Contaminant type	Percentage reduction upon water-treatment
Turbidity	80 to 99.5%
Bacteria (*E. Coli*)	90 to 99.99%

Solar Disinfection (SODIS) is another effective way of getting rid of the disease causing microorganisms from water. It is the UV radiations from the Sun that kills the pathogens. It requires only PET bottles and sunlight for the disinfection to take place. SODIS works even when the temperature of air and water is low. Within 6 hrs of exposure to sunlight, the water from the PET bottles becomes safe to drink. SODIS Technology can be enhanced by adding lemon juice/pulp[26], by attaching aluminium foils to the back of the bottles[27], or by using additives such as Titania[28], riboflavin[29], etc.

Removal of excess quantities of unwanted chemicals and radioactive substances

The following Table 4 gives data regarding the permissible limits of various contaminants in water along with the diseases/problems caused if the actual concentration is more than the permissible limit. To present a general idea, we have chosen only the major chemical contaminants for our study.

There many processes, which can be carried out in order to remove harmful chemicals from water but their cost effectiveness is prime cause of worry for the rural people. The order of cost effectiveness of various processes for Water Treatment is as follows[30]:

1. Adsorption
2. Evaporation
3. Aerobic reaction processes
4. Anaerobic reaction processes
5. Ion Exchange
6. Electro-dialysis
7. Micro- and Ultra-filtration
8. Reverse Osmosis
9. Precipitation
10. Distillation
11. Oxidation
12. Solvent extraction

Our main aim to report the most cost effective water-treatment process i.e. adsorption and that too, using only naturally available materials in order to greatly reduce the operation cost of the entire process. For example, adsorption of Copper can be carried out by neem leaves based biosorbents[11], banana peel[10] and carbon black amongst many. Similarly, lead and cadmium can be removed by biowaste with modified surface such as aminated tea leaves[15].

Negi et al.[31] have shown that heavy metals like lead can be removed from water also by using onion and garlic wastes. Moreover, Ngah et al.[32] present the works done in the last ten years on Chitosan composite, a type of biopolymer, for the removal of heavy metals and dyes from water. Unuabonah et al.[33] have developed new hybrid clay based on kaolinite clay and carica papaya seeds which effectively adsorbs Cd^{2+}, Ni^{2+} and Pb^{2+} ions from water. Adsorption of arsenic from its aqueous solution can also be done by biosorbents such as cupressus female cone[34], banana peel, shoreline seaweeds and sea-grasses[35] etc.

Adsorption of fluoride from water can be facilitated by using easily available materials such as red soil, charcoal, fly-ash, serpentine and brick. Among these materials, red lateritic soil is the most efficient in removing fluoride because this type of soil contains oxide of aluminium and iron as its major components[36].

Fresh leaves of *B. alboglabra* shows effective adsorption of nitrates from water but adsorption of the same by dried leaves and stems of *B. alboglabra* is not that efficient[15]. Chatterjee and Woo[37] showed that chitosan hydrogel beads are also highly efficient in adsorbing nitrates from their aqueous solution. Moreover, the spent beads can be reused as desorption ratio of 87% is achieved when the pH of the solution is made alkaline to the order of pH = 12.

Ahalya et al.[38] reported that the husk of Tur dal (*Cajanus cajan*) is an effective biosorbent for adsorbing iron {Fe (III)} and chromium {Cr (IV)}. The adsorption capacity depends on the pH of the solution and its maximum value for Fe (III) was found to be 66.63 mg/g of the biosorbent. For chromium {Cr(IV)}, it has an adsorption capacity of 96.05 mg/g, which is considerably higher than those shown by sawdust[39-41], exhausted coffee, walnut shell, waste tea, nutshell[42], etc.

Table 4: Permissible limits of chemical contaminants

Name of the Contaminant	Permissible Limit as suggested by WHO (mg/L)	Some of the Diseases/Problems Caused (if the actual concentration is more than the permissible limit)
Cadmium	0.003	Kidney dysfunction and lung impairment.
Iron	Not Given	Inflammatory problems, kidney problems, hypertension.
Arsenic	0.01	Black foot disease, arsenicosis.
Lead	0.01	Lead poisoning.
Mercury	0.006	Hydrargyria.
Chlorine	5.0	Possible artery damage, melanoma, and cancers
Nitrate (as nitrate ion)	50.0	Reduction in the oxygen-carrying capacity of blood, blue-baby syndrome
Fluoride	1.5	Dental and skeletal fluorosis
DDT	0.001	Headache, nausea, vomiting, confusion, and tremors.
Uranium	0.03	Nephritis.

Binti et al.[14] reported that pre-treated dried *Rosa centifolia* can adsorb almost 70% of the manganese [Mn(II)] and iron [Fe(II)] from their solutions, provided, contact time is 240 minutes, pH of the solution is 5 and concentration of the solution is 0.05 g/mL. As regards uranium and other radioactive substances, brewery yeast is a fairly good biosorbent. Omar et al.[43] reported that the yeast dry biomass can adsorb as much as 98% of uranium from its 0.1 to 0.5 mol L^{-1} solution provided the pH is suitable. They observed maximum absorption at pH = 4.5. Gloaguen et al.[44] reported that Barks is another suitable biosorbent for removing uranium and common heavy metals. With the maximum adsorption capacity of 145 mg UO_2^{2+}/g it is not only efficient but also an environmental friendly and cost effective alternative.

Khoramzadeh et al.[45] presented the use of dried sugarcane bagasse for the adsorption of mercury ions from its aqueous solution. They reported 97.584% removal of Hg(II) from its solution having a concentration of 76 mg/L at pH = 4. Alomá et al.[46] reported that sugarcane bagasse can also be used for the removal of Ni (II) from its solution. They obtained an adsorption capacity of 2 mg/g for it in a solution of pH 5 kept at 25^0C.

The biggest limitation of using these biosorbents is that most of these biosorbents require surface modification before operation. Some of the surface modification processes are highly particular and therefore, the rural people may not be able to perform them. But, as regards cost, these substances are very much affordable. There are many factors that affect the process of biosorption: temperature of the solution, pH of the solution, contact time with the biosorbents, concentration of the impurities in the solution, shaking speed, type and quantity of then biosorbent used, size of the biosorbent, etc.

Biosorbent pre-treatment and its significance

Before using the biosorbent for the adsorption process, it is generally pre-treated in the following ways:

(i) Cleaning of the surface of the biosorbent.

(ii) Drying of the biosorbent (reducing the water content) in an oven or in similar equipment.

(iii) Pulverization, followed by granular separation

(iv) Surface modification i.e. chemically modifying the surface of the adsorbent.

Pre-treatment of a biosorbent is done majorly to increase the rate of adsorption or to achieve a rate that is closer to the theoretically predicted value. In most of the biosorption processes, the biosorbent is cleaned in order to remove any dust particle that may be present on its surface, before being dried and finally, pulverized. Chowdhury et al.[12], in their experiment of adsorption of Cu^{2+} ions from water, cleaned the onion and garlic skin by warm distilled water to remove dirt. Post washing, the biosorbent was oven-dried at 45^0C. Similarly, Rezaee et al.[47] cleaned the Spirogyra biomass using distilled water and then dried it using a filter paper before using it in the adsorption of Mercury. Lea[8] and Kamsonlian and Balomajumder[13] in their works pre-treated the respective biosorbents in a similar fashion and later carried out pulverization and granular separation, respectively.

All the biosorbents have some functional groups attached to them that facilitate adsorption. Through surface modification, we introduce a chemical change in these functional group which results in an increase in the adsorption capacity of the biosorbent[48]. Different modifiers such as hydrochloric acid (HCl), sodium hydroxide (NaOH), ammonium hydroxide (NH_4OH), zinc chloride ($ZnCl_2$), etc. have different impact on the adsorption capacity of the adsorbent. These modifiers can be classified into 3 types: acids, bases and salts. Owabar et al.[49] reported varying adsorption capacities of a same type of clay that was modified using different chemicals; HCl modified clay had the highest rate of adsorption for naphthalene and $ZnCl_2$ modified clay had the lowest value for the same. Table 5 depicts the work of Yeneneh et al.[48] wherein the workers studied the adsorption of Pb(II) ions by both natural and modified rice husk. The experimental trials were held at pH = 5-5.3 and temperature = 25^oC.

Table 5: Maximum adsorption capacities of differently modified rice husk

S. No.	Rice husk	Adsorption capacity (in mg/g)
1	Raw	53
2	Modified with NaOH 0.5 M	78.9
3	Modified with NaOH 0.6 M	75.8
4	Modified with NaOH 0.8 M	72.8
5	Modified with NaOH and later H_2SO_4	106.3
6	Modified with NaOH and later HNO_3	59.4
7	Modified with NaOH and later acrylic acid	51.3
8	Modified with NaOH and later citric acid	57.9

CONCLUSION

Many works related to the field of water treatment and biosorption are reviewed. Sustainable and economical methods do exist for treating contaminated water: turbidity of water can be brought down by passing it through cotton or burlap cloth (using 8 layers for maximum efficiency[6,20] and aesthetic qualities of water can be improved by using a sand and gravel arrangement and passing the water through the same (Biosand Filter)[9]. As regards dealing with microorganisms present in water, use of *Moringa oleifera* seeds aided coagulation-flocculation treatment can be considered[8,24]. Moreover, storing the water in copper pots[21], filtering it through burlap or cotton cloth[6,20] or use of the SODIS technique[25,27,28] are also found effective. As far as removal of excess quantities of chemicals or radioactive substances is concerned, biosorption has been proved to be quite a reliable and efficient counter-measure[50-52].

Our findings show that the discussed methods are reliable and significantly efficient apart from being greatly affordable for and accessible to the rural communities of India or any other developing nation but they require a considerable amount of time for yielding any positive results. Significant amount of time-consumption outweighs the affordability and accessibility of many of the discussed methods but an appropriately planned water treatment framework will be fruitful for the rural people i.e. by setting up the purification processes 7-8 hours in advance before the requirement of water arises.

Another important aspect of our approach is its independence from any chemical substance. This is a great advantage, since problems related to the mishandling and mis-measuring of chemicals are removed from consideration. Furthermore, the methods discussed are quite sustainable, since the approach is dependent on waste materials such as used cotton or burlap cloth, onion and garlic waste, sugarcane bagasse, etc.

Research gaps and future perspectives

Research related to the identification of surface modifiers of natural origin can contribute a lot to the mankind. This identification makes the technique of biosorption quite approachable for those living in rural areas, which will consequently result in the improved health of this population.

It is without a doubt a difficult task to develop cheap and reliable water purifiers, but speeding up the purification process without losing the required efficiency poses an even greater challenge, and will involve a great deal of time and money. However, in the near future it will be a necessity to have quicker purification techniques, and now is the time to develop these.

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