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EVALUATION OF THE EFFICACY OF BIOSAND FILTER FOR POLLUTED SURFACE WATER TREATMENTS IN HOMES OF RURAL AND URBAN COMMUNITIES

[1]SALAUDEEN, S., [1]AZEEZ, M.O., [2]ASIMI, M.A., [3]ASHIRU, A. R., [2]MUIDEEN, R. A., AND [3]OLANITE, W. A.,

[1]Department of Civil Engineering, The Oke-Ogun Polytechnic, Saki. [2]Department of Agricultural and Bio-Environmental Engnr, The Oke-Ogun Polytechnic, Saki. [3]Department of Mechanical Engineering, The Oke-Ogun Polytechnic, Saki.

ABSTRACT

Foofo River receives fetchers from far and near the site every day for various domestic use without considering the possibility of the water being contaminated as well as humans being affected by the water. This study investigates the suitability of the water for the various uses, likely contaminants and the treatment with locally constructed and

Introduction

Globally, the need to use water have increased exponentially in recent years due to population growth and an increase per capital consumption. The need to feed the teeming population requires growing more food which cannot be naturally sustained unless supplemented or totally dependent on irrigation in most places. Irrigation consumes about 70% of the water while 22% is used industrially and 8% for domestic purposes, although there is considerable regional variations. Water is not scarce globally, as there are abundant water in most places based on their regional or continental inclination. Nevertheless, 31% of the global population have been estimated to live in a water scarce nations that have less than 1000 m^3 of fresh

loaded biosand filter (BSF) materials indigenous to our local environment. Raw water samples S1 and S2 collected at mid and downstream respectively indicates that the water has been contaminated. The BSF was used to treat the water and compared with WHO, (2022) guideline values. The BSF was able to eliminate all the harmful substances in the samples except ammonia whose reduction was still slightly above the stipulated limit though 76.8 % and 98.7% removal was achieved respectively. Consuming ammonia in water does not pose any serious health challenges except when the consumption becomes prolonged at higher quantity. The biosand filter raises the DO level from 2.00 to 11.20mg/l and 3.00 to 12.00mg/l at S1 respectively which is an indication of improved freshness and quality of the water. The E-coli was 100% removed in S1 but in S2, it was reduced from a huge amount of $3x10^3$mg/l to a paltry 4.00mg/l which was approximately 99.90% removal. The sources of ammonia and fecal inputs should be traced and prevented from entering the water body.

Keywords: Biosand filter, River, Contamination, Water Treatment, Filter Bed, Flow Rate.

water per person per year by 2025. Water becomes unsafe to drink when polluted and may renders the water unsafe for other purposes. The resulting water shortages have been the cause of major international disputes, (The Open University).

Water scarcity is a common term majorly referring to the availability of clean, potable and drinking water but in a small and inadequate quantity. Here, drinking is used as an indicator to represent all state of water since water that is drinkable will certainly be useful for other purposes. Water scarcity may also be said to occur even if there is abundant availability of water but not suitable for drinking. This so called scarcity of water could be caused by factors like; natural phenomenon which includes aridity or drought in some places, or hydrogeology and so on. It can also be as a result of human factors like absence of water supply infrastructures, or mismanagement of water resources and the related facilities and funds or failed government policies etc. Water scarcity affects all the arms that needs the water for a particular purpose or well-being such as; domestic, agriculture, industrial and so on, (WWC, 2021).

Rivers are the most important freshwater resource for man. Apart from its function as a source of freshwater for drinking, domestic and industrial uses; freshwater resources serve multiple functions most of them being critical to human settlement and survival. Adequate supply of safe and sanitized freshwater is an inevitable factor for human and economic development. Access to good water conditions the progress that any nation can achieve towards the targets of sustainable development and good governance. It is also a key dimension to measure poverty alleviation because poor accessibility to water and sanitation is not a crisis of physical availability, but has been related to deprivation and inequalities of power and resources allocation, (UNDP, 2006). The common sources of water that are available to local communities in Nigeria are fast being severed by a number of anthropogenic factors causing pollution and remains the most dominant problem. Water abstraction for domestic use, agricultural production, mining, industrial production, power generation, and forestry practices can lead to deterioration in water quality and quantity that impact not only the aquatic ecosystem, but also the availability of safe water for human consumption (UNEP, 2006).

Polluted water is an important vehicle for the spread of diseases with many consequences; this is why FAO reported that water related diseases had been interfering with basic human development in African countries, particularly Nigeria, (FAO, 2007). The lack of safe water creates a tremendous burden of diarrheal disease and other debilitating, life-threatening illnesses for people in the developing world. That is why among the top 19 solutions to water crisis enumerated by J. Carl Ganter for Circle of blue, includes remediation of polluted water, (CB, 2022). Point-of-use (POU) water treatment technology has emerged as an approach that empowers people and communities without access to safe water to improve water quality by treating it in their homes without any chemical input. Several POU technologies are available, but, except for boiling, none have achieved sustained, large-scale use. Sustained use is essential if household water treatment technology (HWT) is to provide continued protection, but it is mostly difficult to achieve. The most effective, widely promoted and used POU HWTs are critically examined according to specified criteria for performance and sustainability. Ceramic and biosand household water filters are identified as most effective according to the evaluation criteria applied and as having the greatest potential to become widely used and sustainable for improving household water quality to reduce waterborne disease and death. Hence, there is need to evaluate the options applicable on the household scale to the developing community.

Academic research that provides a greater understanding of the current and potential water demand and consumption pattern and other environmental inputs which will enable decisions to be made with greater confidence in the region is rare. Aware of lack of comprehensive data regarding water demand and consumption under different social economic scenario in Nigeria and in particular this study area, the need for this study is established and will go a long way in providing reasonable water treatment and consumption guides for inhabitants and policy makers and thus, improve the health of individuals.

Review of Common Household Water Treatment Options

Apart from multi-stage, multiple barrier approach, which uses several treatments, (Nath *et al.*, 2009) which is usually community or regional based water treatment plants, several methods has been used in-homes to purify water, but they are either chemical dependent like Chlorination, or capital intensive or laborious like boiling and may requires further treatment inputs. For example, Chlorination though capable of reducing the risk of diarrheal disease by 44–84 percent, (Luby *et al*., 2004) but has relatively low protection against some viruses and parasites, lower effectiveness in water contaminated with organic and certain inorganic compounds, Potential objections to taste and odour and concerns about the potential long-term carcinogenic effects of chlorination by-products. Similarly, the disadvantage of boiling water is that it has expensive operating costs and is unsustainable especially in rural poor communities. The consumption of wood coupled with deforestation degrades the natural environment, (Peter-Varbanets *et al.,* 2009). Boiling is time consuming and is not recommended when a quick and

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reliable water supply is required. Boiling at the household scale will cause indoor air pollution, resulting in smoke inhalation and possibly respiratory disease, (Schmidt and Cairncross, 2009). Improving the effectiveness of stoves would reduce the amount of smoke produced but the cost of cooking fuel is another problem. Boiling will not remove solids or visible particulate matter and thus, needs to be combined with a filtration system for maximum purification. Solar disinfection of water mostly referred to as SODIS is a purification procedure to make water potable by using solar energy to remove biological contaminants such as bacteria, viruses, protozoa and worms from contaminated water. However, the process cannot remove non-biological contaminants like toxic chemicals, heavy metals and the likes, (Wikipedia, 2022). The solar water disinfection mainly adopts some mix of electricity generated by photovoltaics panels (solar PV), heat (solar thermal) and solar ultraviolet (uv) light collection. The solar PV deliver electrolytic process which disinfect the water by generating oxidative free radicals which kill pathogen by damaging their chemical structures. On the other hand, stored solar electricity from a battery operated at low light level or at night to power ultra violet lamp to do the secondary disinfection. The heat (solar thermal) disinfection uses heat from the sun to heat the water at about 70°C to temperature < 100 °C for a short period of time this water is referred to as pasteurized water. The ultraviolet SODIS means involves using sunlight to kill pathogens in water by a combined action of UV light and increased temperature from sunlight only to water enclosed in repurposed PET plastic bottles, (Wikipedia, 2022), this is the most common form of SODIS, plate 1.

Plate 1: SODIS – Exposing water to sunlight in PET plastic Bottles
Source: Kamal, (2018). https://www.rural21.com

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Investigating into, and implementing simple small-scale household treatments that can be operated and maintained by local communities, will allow developing countries to improve their standard of living. Lantagne *et al*., (2009) reported the input of International Network to Promote Household Water Treatment and Safe Storage Organization's success that significantly reduce waterborne diseases through the application and promotion of household scale water treatment systems to countries facing extreme conditions following the Southern Asian tsunami disaster. This study thus employed Physical and non-chemical dependent approach using biosand filter in accordance with center for affordable water and sanitation Technology (CAWST, 2009) specifications due to its simplicity, affordability and ability to be constructed and used in individual's home. This household water treatment with Biosand Filter involves the following stages, (CAWST, 2009).

Source - Sedimentation - Filtration - Disinfection - Safe Storage

- Sedimentation remove larger particles and often > 50% of pathogens
- Filtration to remove smaller particles and often > 90% of pathogens
- Disinfection to remove, deactivate or kill any remaining pathogens

The household water treatment process majorly involves removing pathogens which is the prominent water quality concern from drinking Water. It also improves the microbiological quality and may be accompanied with solar disinfection (SODIS), (CAWST, 2009). The biosand filter has five distinct zones: 1) inlet reservoir zone, 2) standing water zone, 3) biological zone, 4) non-biological zone, and 5) gravel zone. In the overall, the biosand filter removes bacteria, protozoa, helminth, viruses as well as physical parameters such as turbidity, iron, and so on, (CAWST, 2009).

OBJECTIVES OF THE STUDY

The objectives of the study were to;

i. Determine the status of surface water and level of contamination
ii. Construct and load Biosand filter using local materials

iii. Evaluate the performance of the Biosand filter by running surface water of known level of contaminant over it.

Materials and Methods

Study Area

The study was be conducted in the water resources laboratory of The Oke-Ogun Polytechnic Saki. Saki presently had one local government and two local council development areas. It is situated in Oyo north senatorial district located on latitude 8° 40' 3.43"N and on longitude 3° 24' 38.15"E on global map and has an annual rainfall of about 900-1000 mm on wet days, 72.7% relative humidity and temperature range of 21.8 to 31.2 °C (OYSADEP Annual Report, 2015). The vegetation within the study area is a typical Guinea Savannah with favorable rainfall. The area had distinct wet and dry seasonal periods lasting between April to October and November to March, respectively. The peak of precipitation is traditionally between August and September. Due to the nature of the topography, Saki Township is well drained by the major tributaries of River Orogun, Ofiki and Oyan which flow southwards into the Atlantic ocean. Other major rivers available are; foofo, oge etc. Saki Township is connected with public water system mainly through oge dam but is currently serving less than 10% of the inhabitants nearer the location only and at epileptic scale.

Materials

The following materials were used for the study for field and laboratory works and the materials for construction of the biosand filter.

Apparatus Needed for Water Sampling

The apparatus needed comprises of polyethylene bottle, plastic water sampling bottles, volumetric measuring cylinders, funnel, Erlenmeyer flasks, stop watch, thermometer, pH meter, Nitrite gloves, Nose mask, towel, Beaker, Measuring Tape, Filter paper, and Foil paper.

Equipment Needed for Water Samples Tests

COSLAB Water treatment kits (Four types, each to measure; Physical parameters such as colour, Turbidity, odour etc; chemical parameters such as pH, Lead, Iron, Arsenic, Ammonia, Total dissolve solid, dissolve oxygen etc.; Nutrient parameters such as Nitrate, Nitrite, sulphate, phosphate etc.; Pathogenic parameters such as E. Coli (Escherichia coli) etc.

REAGENTS

Nitric Acid (HNO_3) for disinfection, and Distilled water

Plate 2: Some of the various experimental apparatus

Materials for the Construction of Biosand Filter

CAWST, (2009) specification was adopted in constructing a plastic biosand filter of cubic cross-section 0.3m by 0.3m breadth and 0.9m high using local materials for construction as well as local sand/ aggregates filtration media.

Construction Material

Materials used to construct the biosand filter includes; Clear polyethylene plastic sheet (5mm thickness), Light Stainless angle, Plastic gum, PVC pipe of 12mm (½ inch) in diameter, 12mm elbow, 12mm diameter faucet.

Biosand Filter Bed Material

The bed materials were sourced locally within the living environments and includes; Drainage gravel 12mm (½”), Separating gravel 6mm (¼”), concrete sand 1mm (0.04”), filtration sand 0.7mm (0.03”).

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Methodology

Determination of the status of surface water and level of contamination

Samples of water were collected at river Foofo at around the midstream (where people collect water most) and 25m downstream and labeled S1, S2 respectively and analyzed for; Physical parameters - colour, Turbidity, odour; chemical parameters - pH, Lead, Iron, Arsenic, Ammonia, Total dissolve solid (TDS), dissolve oxygen (DO); Nutrient parameters - Nitrate, Nitrite, sulphate, phosphate, and Pathogenic parameter tested was E. Coli (Escherichia coli).

Construction and Operation of the Biosand Filter

The biosand filter with square cross-section 0.3m and overall height was 0.9m was adopted. The four sides each 0.3m x 0.9m and the top and bottom each 0.3m x 0.3m were cut from the plastic sheet. The plastic frame corners was supported with light angle bar after being joined together with plastic gum. The top plate is a removable cover with two opposite edge projections that serve as stopper. A central hole was made at center of the cover and then secure with white rubber net. The PVC pipe connects one elbow facing up at the side of the filter at 20 mm distance from the base and run around the body of filter to a height of 0.7m, then another elbow was used to branch off the pipe to deliver the treated water via a faucet used to end the pipe line plate 2.

Collection, Washing and loading of the Filter Bed Material

Drainage gravel and separating gravel of suitable sizes were handpicked from heap of building gravels and sand collected from heap of building's fine aggregates and sieved to separate them into various size range required for the study. The filter bed material were separately washed as much as possible in a container till the washing water becomes clean as the original. They were then sun dried for 6 hours. The filter bed were loaded according to their sizes. The biggest drainage gravel were first loaded and evenly spread in the filter to a depth of 50mm from bottom, followed by separating gravel layer 50mm, filtration sand layer 500mm and top sand silts which is smallest occupied 50mm depth plate 3.

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Plate 3 view showing the structure of the constructed Biosand Filter

Evaluating the performance of the Biosand filter by running surface water of known level of contamination over it.

The loaded filter was gradually supplied with the collected raw water samples from the same source, spot and period through the top cover netted hole until the sand arrangement becomes fully saturated. The water supplied to the filter continues until a depth of water of about 200mm above the sand level was attained and left for about 5 minutes for it to equalize, so that a shallow layer of water sits atop the sand. The faucet was then opened after 5mins (CAWST 2009), the treated water coming out of the faucet were collected in a graduated container and the time taken to fill the container was noted with respect to the initial depth of water above the sand level in the filter. The process was continued until the optimum flow rate of the filter was achieved at 0.4 litre/minute equation 1 (CAWST 2009). The water collected at this stage was analyzed for the above stated parameters.

Results and Discussions

Results of the physical, chemical, nutrient and pathogenic parameters which are of health concerns for the raw water samples collected at stations S1 and S2 are shown in Table 1. The last column shows the world health organization's (WHO, 2022) allowable values of these parameters. The result indicates that the water at both stations S1 and S2 were heavily polluted as the observed values of colour, turbidity and odour to a great extent exceeds the allowable values stipulated by WHO except pH which falls within the acceptable range. Total dissolved solids (TDS), Dissolve oxygen (DO), nitrate (NO_3^-), Nitrite (NO_2^-) and Arsenic all had lower concentrations than the maximum allowable values. TDS is considered good for consumption in water but only becomes unpalatable at concentrations greater than 1000mg/l. Large amount of DO in water is an indication of freshness of the water but depletion of DO encourage the microbial reduction of NO_3^- to NO_2^- and sulfate (SO_4^{2-}) to sulfide while too huge amount of DO exacerbate corrosion of metal pipes, increase ferrous iron in solution with discoloration of the water, (WHO, 2022). The lower amount of DO in the raw samples indicates that the water is not fresh enough for drinking. The resulting higher amount of nitrites due to low DO in the sample are toxic to human and animals especially infants. It harm the body by disrupting the oxygen delivering ability of hemoglobin in the blood stream, (H_20 Distributor, 2022). Also, the resulting sulfide in the form of hydrogen sulfide is of aesthetic concern that results in disagreeable taste and odor to the water, (Pennstate Extension, 2022). Drinking water with high level of sulfate results in diarrhea and dehydration which is more

Table 1: Physical, chemical, nutrient and pathogenic properties of raw water samples.

S/N	Parameter	Unit	Recorded (S1)	Values (S2)		WHO, 2022 Values
1.	Colour	TCU	80	155		Not exceeding 15
2.	Turbidity	NTU	95	80		0.2
3.	Odour		Foul	Foul		Unobjectionable
4.	pH	Mg/l	6.71	6.49		6.5 – 8.5
5.	Lead	Mg/l	0.011	0.194		0.01
6.	Iron	Mg/l	1.41	15.642		NHG/<0.3**
7.	Arsenic	Mg/l	0.00	0.006		0.01
8.	Ammonia	Mg/l	4.32	166.12		NHG/0.5***
9.	TDS	Mg/l	578.50	227.56		600
10.	Dissolve oxygen	Mg/l	2.00	3.00		NHG/5-9.1*

11.	Nitrate (NO_3^-)	Mg/l	1.76 3.21		50
12.	Nitrite (NO_2^-)	Mg/l	0.222 0.754		3
13.	Sulphate (SO_4^{2-})	Mg/l	9.00 122.00		250 – 1000
14.	Phosphate (PO_4^3)	Mg/l	2.5 18.7		1.0
15.	Escherichia (E coli	Mg/l	4.00 3 x 10^3		Absent

NLS – No health-based guideline value has been proposed for the parameters by WHO, (2022).
*Omid, (2021) value: ** EHFS, (2010): *** (ODHS, 2000).
Source: Authors' field survey

severe in infants but less than 500mg/l is okay for infants while adult and old children may not be affected by that level, (MDH, 2019a). Long term exposure of Arsenic in drinking water and food results in cancer and skin lesions, cardiovascular diseases and diabetes. Fetal and early childhood exposure impart negatively on the cognitive development and increased death in young adults, (WHO, 2018). Arsenic pose no health challenges due to lower level in the samples. Lead (Pb) had higher values in both samples and thus pose health risk as it is capable of affecting human across all ages but more severe on children, infants and fetuses even at very small concentration. Pb is a toxic metal that is persistent in the environment and accumulate in the body overtime and for this reason, EPA set maximum contaminant level to be zero, (CDC, 2022). Pb attacks the brain and central nervous system and may result in coma, convulsion or death. Children who survives severe Pb poisoning may be left with intellectual disability, behavioral disorder or reduced intelligence, (WHO, 2021). Iron had very high values compared to the allowable, though it does not invoke any health risk as the body needs iron to transport oxygen in blood, it only pose some problem if harmful bacteria have entered the water as some harmful organisms need iron to grow and the iron hinders the removal of harmful bacteria, (MDH, 2019b). As little as 0.3mg/l iron can cause water to turn reddish brown in colour, (EHFS, 2010). Ammonia in samples are far higher than the stipulated value.

Ammonia in water is immediately non-toxic to human and higher animals but long term ingestion of water containing more than 1mg/l may damage internal organs system and at concentration below 1mg/l, ammonia is directly toxic to aquatic life. It is irritant when in air and causes burning of the eyes, nose, throat and lung at level > 100mg/l, (ODHS, 2000). Phosphate recommended level is 1.0mg/l the obtained value in the raw water samples are higher. Too much phosphate results in increased growth of algae and large aquatic plants which can result in decreased level of DO and subsequent euthrophication. Algae boom produces algae toxins which can harm both human and animal health, (EPA, 2021). Escherichia coli (E coli) is an indicator of fecal contamination which must be zero in drinking water, (WHO, 2022). This pathogenic strain is present in large amount in the normal intestine of human and animals but poses no harm there. It present a health risk when in other parts of the body where it can result to serious disease like urinary tract infections, bacteraemita and meningitis. There are many enteropathogenic E-coli based on their poisonousness and venomousness and some causes acute diarrhea while majority have tendency to develop into more fatal disease with children under 5 years of age at most risk of developing haemolytic uraemic syndrome, (WHO, 2022). The huge amount present in the raw water samples ie. 4.00mg/l and 3x103mg/l indicates that the water is fecal contaminated to large extent. In the overall, the water is heavily polluted and therefore not suitable for human consumption. The need to bring the water to suitable consumption level brings about the construction of biosand filter for treating the water collected at the same source, point and time.

Biosand Filtration

Flow rate determination

With water level at 100mm above sand level, The filtration took 10 minutes to fill 5litres

Flow Rate = $\frac{discharge}{Time\ Taken} = \frac{5L}{10min}\ 0.40\ litre/min$ (1)

Performance evaluation of the Biosand Filter

Water obtained at the optimum flow rate was thereafter analyzed to determine the efficacy of the biosand filter. Table 2 shows the results of the biosand filter treated water and the last column of the table gives the WHO, 2022 values to compare and contrast. The biosand filter is able to eliminate all the harmful substances in the raw water samples in both stations S1 and S2

Table 2. Physical, chemical, nutrients and pathogenic parameters of biosand filtered water

S/N	Parameter	Unit	Recorded Values (S1)	(S2)	WHO, 2022 values
1.	Colour	TCU	5.00	5.00	Not exceeding 15
2.	Turbidity	NTU	1.10	1.0	0.2
3.	Odour		non	non	Unobjectionable
4.	pH	Mg/l	6.72	6.90	6.5-8.5
5.	Lead	Mg/l	0.01	0.011	0.01
6.	Iron	Mg/l	0.011	0.09	NHG/<0.3**
7.	Arsenic	Mg/l	0.000	0.01	0.01
8.	Ammonia	Mg/l	1.20	2.14	NHG/0.5***
9.	TDS	Mg/l	149.57	155.00	600
10.	DO	Mg/l	11.20	12.00	NHG//5-9.1*
11.	Nitrate (NO_3^-)	Mg/l	0.01	0.11	50
12.	Nitrite (NO_2^-)	Mg/l	0.001	0.002	3
13.	Sulphate (SO_4^{2-})	Mg/l	1	3.20	250- 1000
14.	Phosphate (PO_4^{3-})	Mg/l	0.98	1.01	1.0
15.	Escherichi (E coli)	Mg/l	0.001	4.00	Absent

NLS – No health-based guideline value has been proposed for the parameters by WHO, (2022).

*Omid, (2021) value** EHFS, (2010): *** (ODHS, 2000)

Source: Authors' field survey

respectively except ammonia whose reduction was still slightly above the stipulated limit though 76.8 % and 98.7% removal was achieved. Consuming ammonia in water does not pose any serious health challenges except when the consumption becomes prolonged at higher quantity. The sources of ammonia could be traced and prevented from entering the water body. The biosand filter raises the DO level from 2.00 to 11.20 and from 3.00 to 12.00 at S1 and S2 respectively which is an indication of improved freshness and quality on the water. The E-coli was 100% removed in S1 but in S2, it was reduced from too enormous value of $3x10^3$mg/l to a paltry 4.00mg/l which was approximately 99.90% removal.

Conclusion and Recommendation

Local communities with abundant surface waters are not aware of the health impacts of consuming contaminated water derived from these surface waters. Those that are aware do not have the required experience to treat the water or they think good quality water can only be achieved through government treatment plants only. Wherever these plants are available, it is usually grossly inadequate to cater for the teeming population. In addition, the use of chemical based treatment of water for drinking scared a lot of people because of some believe that these chemicals may later be injurious or have a long term health effects. This is further compounded with the lack of fund to get the required chemical to treat the water. Other methods of treating water such as boiling could also be capital intensive as the means of heating – electricity, stove, gas and so on may not be affordable day in day out.

Water samples from Foofo river was found to be heavily polluted, biosand filter constructed and used to treat the water shows that it is effective in removing the contaminants and in the overall brings the water to acceptable state. Thus the biosand filter is effective in treating surface water and required only limited cost of construction and free of occasional maintenance. The biosand filter should be andled with care as well as the treatment process to avoid secondary contamination. Time to time analysis of the water should be done to ascertain the level of contamination at different period, as any surface water is open to contamination from various sources both point and non-point sources.

Biosand filter should be adopted as an inhome, non-chemical based water treatment method. Government, non-governmental organization (NGO) as well as meaning citizens should sensitive people around to be cautious of dumping refuse either directly or indirectly on the water. Health effects of inhabitants around the river that consumed the water should be investigated.

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