Poll Res. 39 (4) : 1180-1187 (2020)

ISSN 0257–8050

TREATMENT OF POTABLE WATER SAMPLES USING ECO-FRIENDLY *PHYLLANTHUS EMBLICA* – A SOLUTION FOR WATER POLLUTION

THAMARAI SELVI C.[1], RAVICHANDRAN S.[2], BOSELIN PRABHU S.R.[3], PRASHANTH G.K.[4], KRISHNAIAH G.M[4]. AND SATHYANANDA H.M.[4]

[1]*Department of Biotechnology, Mother Teresa Women's University, Kodaikanal 62 4101, India*
[2] *Chemistry, Lovely Professional University, Phagwara 144 411, Punjab, India*
[3] *ECE, Surya Engineering College, Mettukadai 638 107, India*
[4]*Department of Chemistry, Sir M. Visvesvaraya Institute of Technology, Bengaluru 562 157, Affiliated to Visvesvaraya Technological University, Belagavi 590 018, India*

(Received 29 March, 2020; Accepted 20 May, 2020)

ABSTRACT

The problems of water pollution in the rich and the poor nations are different in various aspects. In this paper, the potable water samples were collected in and around typical distillery industry from Puliyamarathadi, Sangaramoorthy Patti, Muthalakam Patti, Varatharajan Puram, Kullapuram, Cement Road, Villapuram, Pottal Patti, Karisal Kulam, and Palrangapuram in Madurai district. The present study is mainly aimed to remove the TDS, water hardness and chloride from potable water using natural coagulants. The main objective of this research work is to collect and analyze the physico-chemical characteristics of the potable water samples, to assess the microbial population present in the samples, to remove the impurities from contaminated water samples using natural coagulants such as *Strychnos potatorum* L seeds and *Phyllanthus emblica* wood, to find the phyto-compounds present in the coagulants using GC-MS technique, to assess the antimicrobial activity of natural coagulants, and to identify the coagulant protein present in the plant material.

KEY WORDS : Drinking water, Water Pollution, Natural coagulants, Microbial population, Water samples

INTRODUCTION

In this study, plant based materials such as *Phyllanthus emblica* wood, and *Strychnos potatorum* L seed powder were used to remove the impurities from the water samples. It was observed that the treatment with the wood pieces of *Phyllanthus emblica* showed the higher reduction of impurities from the water than nirmali seeds and the optimum dosage was found to be 1g. The potable water samples were treated with different dosages of *Strychnos potatorum* seed powder. Among the dosages, higher reduction of impurities was observed in 0.4 g of seed powder. The active bio-compounds present in the plant materials were extracted with aqueous, methanol, chloroform and petroleum ether and qualitatively analyzed. The plant materials showed the presence of carbohydrate, saponin, tannin, alcohols, alkaloids, acids, esters, long chain hydrocarbons, steroids, amino acid and nitro compounds.

The GC-MS characterization of both the plant material showed the presence of bio active compounds have different important biological activities such as pharmacological, antibacterial, antifungal, antilisterial, antihypertensive, anti-inflammatory, urokinase, reductase activity on the nature of elemental composition. The potable water contaminated with pathogenic microorganisms and it was confirmed by the presence of microbes includes *Escherichia coli, Pseudomonas, Staphylococcus* and *Bacillus species*. Antimicrobial activity of the

plant materials was analyzed and it was confirmed the reduction of microbial load after the treatment. The rest of the paper has been summarized as follows. Section 2 elaborates the necessary materials and methods. The detailed results and discussions were summarized in Section 3. Finally, Section 4 concludes the paper.

MATERIALS AND METHODS

Water Sample Collection

The potable/drinking water samples were collected from the different water stations around distillery industry from Puliyamarathadi, Sangaramoorthy Patti, Muthalakam Patti, Varatharajan Puram, Kullapuram, Cement Road, palrangapuram, Pottal Patti, Karisal Kulam, and villaouram in Madurai district. Analytical grade chemicals were used throughout the entire study. All the water samples were collected in pre-cleaned polyethylene bottles and transported safely to the laboratory. The pH and temperature of the samples were recorded on spot during the sample collection. All the collected samples were stored under 4 °C and used for further water quality analysis (Gorde and Jadhav, 2013; Kowsalya *et al.,* 2010; Agarwal and Singh, 2017). The sampling sites, sample code, sampling source and total population of that area are given under Table 1.

Choosing *Strychnos potatorum* L seeds (Nirmali seeds) and *Phyllanthus emblica* (Amla) wood

Coagulation is the most effective and economical means to remove impurities (Arun *et al.,* 2013). Coagulant dose is another, very important factor for coagulation efficiency. It is considered that coagulation activity is highly depend on optimum relationship between coagulant dose and bivalent cations present in water. *Strychnos potatorum* L. is a common natural coagulant, used in many parts of Tamil Nadu, India for the treatment of drinking water and it is commonly known as Nirmali (Fig. 1).

This plant belongs to Loganiaceae family and it is commonly called as 'Tetankottai' in Tamil, 'Kataka' in Kannada and 'clearing nut tree' in English. That was the first reported as plant based coagulant used for water and wastewater treatment. The seeds extracts of the plant is anionic polyelectrolyte and form coagulation by inter-particle bridging.

Phyllanthus emblica Linn (*Emblica officinalis,* Amla, Indian Gooseberry) belongs to the Phyllanthceae family is widely used for medicinal purposes for over 2,000 years (Figure 2). Tree is normally reaching about 18 meters (60 feet) and rarely up to 30 meters (100 feet) in height. The plant is indigenous to a large area ranging from Nepal, Southern India and Sri Lanka, throughout South-East Asia to Southern China. All parts of this plant are used medicinally with a vast range of applications including antioxidant, antibacterial, antidiabetic, hypolipidemic, antiulcerogenic, hepatoprotective, gastroprotective, and chemopreventive properties. It is useful in the treatment of haemorrhages, diarrhoea, dysentery, anaemia, jaundice, diabetes, fever, bronchitis and cough (Ashok Kumar et al., 2008).

Preparation of Plant Extract

The *Strychnos potatorum* plant seed and *Phyllanthus emblica* wood powder (Jenifer *et al.,* 2016) were collected and dried at room temperature for 2 - 3 days and further dried at 60° C. The dried seed were extracted with aqueous and methanol extract used soxhlet apparatus. The extracts were filtered with the Whattman filter paper and then dried by using rotary evaporator. The filtrate was stored in screw cap bottle at -20° C for further use.

Table 1. Detail of Sampling sites, samples and total population

Sl. No.	Sampling sites/ water stations	Sample code	Sampling source	Total population of sampling sites
1	Puliyamarathadi	S1	Bore water	2000
2	Sangaramoorthy patti	S2	Bore water	3500
3	Muthalakam Patti	S3	Dam water	3500
4	Varatharajan Puram	S4	Bore water	1000
5	Kullapuram	S5	Bore water	1500
6	Cement Road	S6	Bore water	10000
7	Palrangapuram	S7	Bore water	11200
8	Pottal Patti	S8	Bore water	1000
9	Karisal Kulam	S9	Bore water	1000
10	Villapuram	S10	Bore water	16500

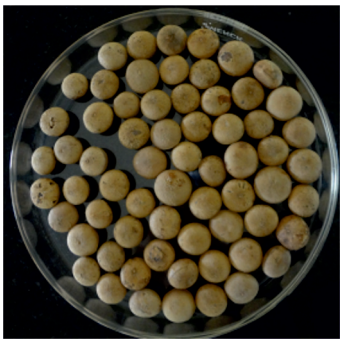


Fig. 1. *Strychnos potatorum* L. Seeds

Enumeration of microbes by spread plate techniques[SPC (Standard Plate count)]

Collection and isolation of microbes

The water samples were serially diluted under aseptic condition and the inoculums were placed on nutrient agar medium. Spread plate method was followed to have clear growth of microbial colonies. The inoculated plates were incubated at suitable temperature for 24 hours.

Dilution of the sample

To about 99 mL of the sterile distilled water, 1ml of the sample was added aseptically and mixed thoroughly. From this, 1 mL was transferred aseptically to 9 mL of sterile distilled water to obtain 10^{-3} to 10^{-7} dilutions. Then 1 mL from each dilution was transferred aseptically into sterile petriplates. Nutrient agar medium was used to estimate the total heterotrophic bacterial colonies grown.

Antibacterial activity analysis by Disc Diffusion Method

Disc diffusion method was carried out for antibacterial susceptibility testing. The standard method was used to assess the presence of antibacterial activities of the plant extract. Mueller Hinton agar (MHA) plates were prepared. Overnight nutrient broth culture of test organisms were seeded over the MHA plates using sterile cotton swab so as to make lawn culture. The discs which had been impregnated with aqueous and methanol extracts of disc were placed on the MHA with the control disc and subjected to antibacterial screening. The plates were then incubated at 37 °C for 18-24 hours depending on the species of bacteria used in this test. After the incubation, the plates were examined for inhibition zone.

Fig. 2. *Phyllanthus emblica* wood powder

RESULTS AND DISCUSSION

Fresh water is a finite resource, essential for agriculture, industry and for human existence. Without adequate quantity and quality of fresh water, sustainable development will not be possible. Certain physical, chemical and microbiological standards are required to ensure the palatability of water and safety for drinking before it can be used as potable.

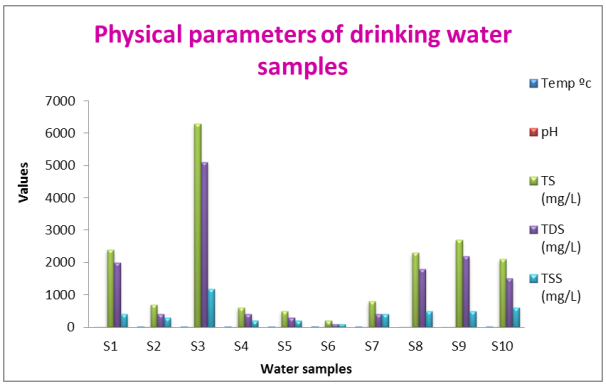
Physico-chemical characterization of drinking water samples

The collected drinking water samples were analyzed for various physical and chemical water quality parameters and the results are depicted in Table 2, 3 and Graph 1, 2.

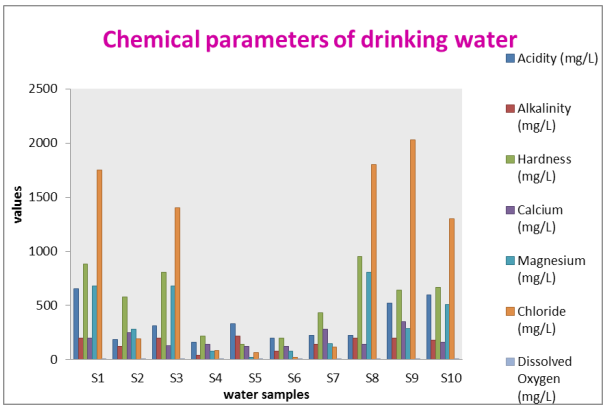
The color and odor of all the ten samples under present study were colorless and odorless. Color in water samples may be caused by the presence of minerals such as iron and manganese. It may also be caused by the substances of vegetable origin such as algae and weeds. Pure water is colorless. Generally water acquires color due to foreign substances such as organic matter of soil, vegetation, minerals and aquatic organisms. Most of the trade wastes discharged into water system have stated colors due to organic dyes and inorganic complexes. Water becomes intensely colored due to interaction between naturally occurring components and the trade effluents which make it unsuitable for various purposes. Colored water is aesthetically not acceptable for potability and all our samples were colorless.

The pH of all the drinking water samples collected was found to within the standard value (near neutral to alkaline) 7.5 – 9.5, but varied for each sample. pH is precisely the hydrogen ion

activity. The desirable pH range of drinking water given by BIS is 6.5 – 8.5. The pH of the samples tested fluctuated within the accepted level except for few samples with alkaline nature. Water having pH below 6.5 cause corrosion of metal pipes, resulting in the release of toxic metals such as zinc, lead, cadmium, copper etc. Generally, pH of water is influenced by geology of catchments area and buffering capacity of water. It was observed that sample S1 (Puliyamarathadi), sample S3 (Muthalakam Patti), sample S8 (Pottal Patti), sample S9 (Karisal Kulam), and sample S10 (Villa Puram) have higher amount of TDS and it was beyond the BIS limit. Lower concentration of TDS was observed in samples 2, sample 4, sample 5 and sample 7 within the permissible limit. Among all the samples, S6 has very less amount of TDS. High TDS in ground water maybe due to ground water pollution that came from both residential and sugar industry discharge.



Graph 1. Physical parameters of drinking water samples



Graph 2. Chemical parameters of drinking water

The acidity of the analyzed samples was ranges from 160 mg/L- 655 mg/L. The results of the samples were found to be 655 mg/L for S1, 185 mg/L for S2, 815 mg/L for S3, 160 mg/L for S4, 330 mg/L for S5, 200 mg/L for S6, 225 mg/L for S7, 225 mg/L for S8, 525 mg/L for S9 and 600 mg/L for S10. Acidic pH of water may be due to the dissolved carbon dioxide and organic acids such as fulvic and humic acids which are derived from decay and subsequent leaching of plant materials. During dry seasons, there may be death and decay of plants due to lack of sufficient water which increases the organic acid content of waterin turn causing acidity. Further reduction in water volume in the wells and also decreases the pH during dry season.

The alkalinity of all the samples was in the range of 40 mg/L – 200 mg/L. Among all the samples, S4 and S6 have very low concentration of alkalinity that is 40 mg/L and 80 mg/L. Rest of the samples such as S1, S2, S3, S5, S7, S8, S9 and S10 contain higher alkalinity and the values are 200 mg/L, 120 mg/L, 200 mg/L, 220 mg/L, 140 mg/L, 200 mg/L, 200 mg/L, 80 mg/L respectively. The higher alkalinity might have been caused by the ground water contamination due to the effluents from sugar industry in those areas. The alkalinity content in water provides an idea of natural salts present in water. This may lead to increase in alkalinity of

Table 2. Physical parameters of drinking water samples

Sl. No.	Sample	Color	Odor	Temp	pH	TS (mg/L)	TDS (mg/L)	TSS (mg/L)
1.	S1	Colorless	Odorless	22 ºC	7.2	2400	2000	400
2.	S2	Colorless	Odorless	24 ºC	6.5	700	400	300
3.	S3	Colorless	Odorless	26 ºC	6.3	6290	5100	1190
4.	S4	Colorless	Odorless	24 ºC	6.2	600	400	200
5.	S5	Colorless	odorless	25 ºC	6.7	500	300	200
6.	S6	Colorless	odorless	27 ºC	7.5	200	100	100
7.	S7	Colorless	Odorless	23 ºC	6.6	800	400	400
8.	S8	Colorless	odorless	22 ºC	8.5	2300	1800	500
9.	S9	Colorless	odorless	21 ºC	9.5	2700	2200	500
10.	S10	Colorless	odorless	26 ºC	8.9	2100	1500	600

ground water. The potential of water to neutralize a strong acid is called alkalinity; hence alkalinity of water is due to existence of bicarbonates, carbonate and hydroxide compounds of calcium, sodium and potassium (Patil and Patil, 2009). It is composed primarily of carbonate (CO_3^{2-}) and bicarbonate (HCO_3^-). Alkalinity acts as a stabilizer for pH. Excessively high causticity levels can result in a type of caustic attack of the boiler called "Caustic embrittlement". Higher values of pH hasten scale formation in water heating apparatus and decrease germicidal potential of chlorine.

The amount of hardness were with the range of 140 mg/L – 950 mg/L, calcium ranges from 120 mg/L – 350 mg/L and magnesium in 20 mg/L – 810 mg/L. The values of hardness for the water samples were higher than the standard permissible limit in samples S1, S3, S8, S9 and S10 than the rest of the water samples. Highest amount of calcium was found in S9. Samples S4 and S5 contain lower concentration of magnesium. The chloride is a chemical parameter found in the range of 20 mg/L – 2028 mg/L. the permissible limit of chloride content in drinking water according to BIS is 200 mg/L – 1000 mg/L to the maximum. Here, all the samples possessed different concentrations of chloride content. The sample S6 has the least amount of chloride about 20 mg/L. Among these samples S1, S3, S8, S9 and S10 samples have higher chloride and exceeded the permissible limit. The presence of chloride in water slightly higher amounts may be due to natural processes such as the passage of water through natural salt formations in the earth or it may be an indication of pollution from industrial waste contamination (Yin, 2010; Agarwal *et al.,* 2019).

The physico-chemical parameter values were obtained for drinking water samples are given in Table 2 and 3 and Graph 1 and 2. From the results, it was found that the quality of the water varied considerably from one location to another. The obtained values were compared with BIS (Bureau of Indian Standard) standard. All the parameters of the samples were found within the standard permissible limit except few parameters such as TDS, hardness and chloride in sample S1 (Puliyamarathadi), sample S3 (Muthalakam Patti), sample S8 (Pottal patti), sample S9(Karisal kulam), and sample S10 (Villa puram). Hence, those samples only subjected to treatment with natural plant materials- ***Phyllanthus emblica* wood** (7 years old only) and ***Strychnos potatorum* L** seeds and the treatment time was up to 2hrs.

Removal of impurities from contaminated water samples by using natural coagulants

Water samples with higher concentration of TDS, hardness and calcium were treated with naturally available organic materials. The drinking water samples S1, S3, S8, S9 and S10 have higher pollutants including TDS, Hardness and Chloride than the permissible limits when compared with other samples. Hence, the natural plant materials were used for the treatment. The impurities reduction percentage is presented in Tables 4 and 5 and graphically represented in Graph 3 and 4.

Treatment of drinking water samples by using Phyllanthus emblica wood

In order to avoid tannin content from *Phyllanthus emblica* wood, only 7 years old wood was used for treatment. It was observed that the concentration of contaminants reduced gradually after treatment with the wood pieces of *Phyllanthus emblica,* after 2

Table 3. Chemical parameters of drinking water

Sl. No.	Sample	Acidity (mg/L)	Alkalinity (mg/L)	Hardness (mg/L)	Calcium (mg/L)	Magnesium (mg/L)	Chloride (mg/L)	Dissolved Oxygen (mg/L)
1	S1	655	200	880	200	680	1750	4
2	S2	185	120	580	250	280	190	6
3	S3	315	200	810	130	680	1400	5
4	S4	160	40	220	140	80	85	8
5	S5	330	220	140	120	20	65	7
6	S6	200	80	200	120	80	20	7
7	S7	225	140	430	280	150	115	7
8	S8	225	200	950	140	810	1800	4
9	S9	525	200	640	350	290	2028	3
10	S10	600	180	670	160	510	1300	5

hr of time duration. Finally, overall reduction of TDS, Hardness and Chloride in terms of percentage for sample S1 was 50%, 60% and 82 %, for S3 the reduction was 72%, 75% and 84 %, in S8 the removal was 66%, 57 % and 77%, in S9 the reduction was 45%, 60 % and 82% and in S10 the reduction was 46%, 55% and 84% respectively. Among the chemical impurities higher amount of chloride has removed by the wood. Tables 4 and Graph 3.

Removal of hardness and chloride were increased when increase the dosage of Amla wood up to 1 g. After that no considerable reduction of hardness was noticed. It suggests that 1 g of plant material is an optimum dosage. After the treatment white precipitate of salt has seen in the vessel during filtration. It showed the ability of Amla would precipitate the hardness causing chemical species thereby the Ca, Mg and hardness has been reduced followed by TDS also. Chelating process followed by precipitation process of Amla might have reduced the hardness from drinking water.

Higher total hardness could be due to discharge of effluents and untreated waste from polluting industries to nearby surface water sources. The higher value of total hardness observed could be due to the low water level and high rate of evaporation during summer. Bureau of Indian Standards desirable limit for total hardness in drinking water is 300 mg/L. Hardness prevents lather formation with soap and increases the boiling point of water. Normally, water hardness does not cause any direct health problems, but may cause economic problems.

Hardness below 300 mg/L is considered potable but beyond this limit produces gastrointestinal irritation& other health issues. Extremely hard water may lead to increased incidences of urolithiasis. Chloride is one of the major inorganic constituents in water. The salty taste produced by chloride concentration in potable water is variable and depends on the chemical composition of water. The reason could be the contamination of the water by sewage, infiltration, dissolution of chloride from soil and leaching of solid waste during rainfall. Hence, it must be uttered the water treatment.

Table 4. Effect of *Phyllanthus emblica* wood on reduction of TDS, hardness and chloride from drinking water

Sl. No.	Sample	% of reduction		
		TDS	Hardness	Chloride
1.	S1	50	60	82
2.	S3	72	75	84
3.	S8	66	57	77
4.	S9	45	60	82
5.	S10	46	55	84

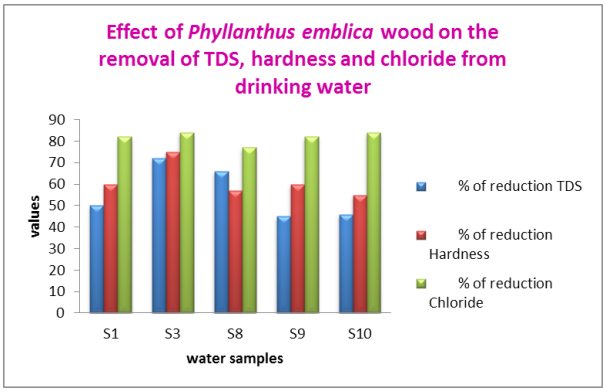
Treatment of drinking water samples using *Strychnos potatorum* L seeds

Addition of *Strychnos potatorum* L seed powder reduced the concentration of contaminants gradually with an increase in dose from 0.5 mg/L to 1.5 g/L after 2 hour of treatment. Tables 5 and Graph 4

Finally, the overall percentage reduction of TDS, hardness and chloride were found to be for the S1 was 35 %, 54 % and 74 %, S3 was 80 %, 62 % and 82 %, S8 was found to be 55 %, 42 % and 75 %, S9 was 36 %, 53 % and 75 % and S10 33 %, 51 % and 76 % respectively. In the list of natural coagulants the Seeds of *Strychnos potatorum* (*S. potatorum*) and *Moringa oleifera* (*M. oleifera*) have shown promising results even in turbid water. Direct filtration with *S. potatorum* seeds as coagulant appeared effective in clarifying turbid water. This property is attributed due to the presence of polyelectrolyte, proteins, lipids, carbohydrates and alkaloids containing the –COOH and free –OH surface groups in the seed.

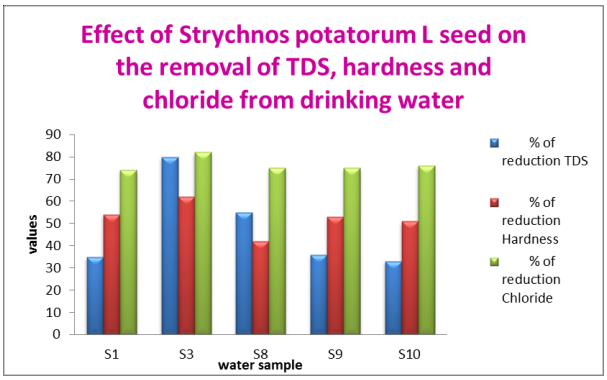
The removal mechanism of natural coagulant was mediated by adsorption, charge neutralization and polymeric bridging effect. Frequently used plant based coagulants include Nirmali seeds (*Strychnos potatorum), Moringa oleifera, Tannin and Cactus*. Use of these coagulants shows important progresses in sustainable environmental technology as they are renewable resources and their application is directly related to the improvement of quality of life.

The antioxidant property of nirmali seed is



Graph 3. Effect of *Phyllanthus emblica* wood on reduction of TDS, hardness and chloride from drinking water

responsible for the reduction of nitrate, TDS and COD from waste water. The presence of Galactan and galactomannan polysaccharide of nirmali seed is producing floc formation followed by coagulation process. Thereby the hardness, TDS and chloride chemical species were removed by the nirmali seeds.



Graph 4. Effect of *Strychnos potatorum* L seed on reduction of TDS, hardness and chloride from drinking water

Table 5. Effect of *Strychnos potatorum L* seed on reduction of TDS, hardness and chloride from drinking water

Sl. No.	Sample	% of reduction		
		TDS	Hardness	Chloride
1.	S1	35	54	74
2.	S3	80	62	82
3.	S8	55	42	75
4.	S9	36	53	75
5.	S10	33	51	76

Also the coagulating property of nirmali seeds must be due to the presence of coagulating protein such as 4,5-diamino-2-hydroxypyrimidine, 4-amino-2,6-dihydroxy-5-nitrosopyrimidine and 1 hexyl-1-2-nitrocyclohexane.

CONCLUSION

Water pollution is any physical or chemical change in water that can adversely affect organisms as well as water quality. It is a global problem, affecting both the industrialized and the developing nations. The water pollution problems in the rich and the poor nations, however, are quite different in many aspects. In this paper, the potable water samples were collected in and around typical distillery industries from Puliyamarathadi, Sangaramoorthy Patti, Muthalakam Patti, Varatharajan Puram, Kullapuram, Cement Road, Villapuram, Pottal Patti, Karisal Kulam, and Palrangapuram in Madurai district. The present investigation concludes that the collected potable water samples were contaminated with pollutants from the nearby industries. The treatment of potable water is much important before supplying to the public. The treatment with *Phyllanthus emblica* wood and *Strychnos potatorum L seeds*, can be used for the treatment of drinking water effectively. After the treatment, the drinking water should be boiled before going to be consumption. The plant based materials used for the treatment of water, follow eco-friendly techniques and it is an alternative for chemical coagulant treatments.

REFFERENCES

Agarwal, M. and Singh, M. 2017. A Characteristics and adsorption capacities of Biosorbents for Cr(VI) removal from aqueous solution: A Review, *International Journal of Current Research.* 9(5) : 51087-51093.

Agarwal, M., Singh, M. and Hussain, J. 2019. Assessment of groundwater quality with special emphasis on nitrate contamination in parts of Gautam Budh Nagar district, Uttar Pradesh, India Acta Geochim https://doi.org/10.1007/s11631-018-00311-z

Ancy Jenifer, A., Sowmiya Rajalakshmi, B. and Thamarai Selvi, C. 2016. *Phyllanthus emblica* wood an effective bio- resource for potable water softening. *International Journal of Current Research.* 8(07) : 34676-34682.

Arun, K., Vuppaladadiyam, Sowmya, V. and Pallavi Dasgupta, 2013. Comparative Study on Coagulation Process for Vellore Municipal Drinking Water Using Various Coagulants Universal Journal of Environmental Research and Technology, www.environmentaljournal.org Volume 3, Issue 1: 119-126.

Ashokkumar, D., Mazumder, U.K., Gupta, M., Senthilkumar, G.P. and Selvan, V.T. 2008. Evaluation of Antioxidant and Free Radical Scavenging Activities of *Oxystelma esculentum* in various *in vitro* Models**.** *J Comp Integ Med.* 5 (1) : 1-6.

Gorde, S.P. and Jadhav, M.V. 2013. Assessment of Water Quality Parameters: A Review. *Journal of Engineering Research and Applications*. 3 (6): 2029-2035.

Kannan, D. and Mani, N. 2014. Removal of Hardness (Ca2+, Mg2+) and Alkalinity from Ground Water by Low Cost Adsorbent using Phyllanthus emblica Wood. *International Journal of Chemical and Pharmaceutical Analysis.* 1(4): 208212

Kowsalya., Uma, A., Meena, S., Saravanabava, K., Karrunakaran, C.M. and Raman, M.D. 2010.

Assessment of water quality and pollution of Porur Double Lake (Erettaieri), Chennai, *Jr.of Ind. Pol. Control.* 26 (1) : 61-69.

Meena, A.K., Chitra Rajagopal., Parveen Bansal. and Nagar, P.N. 2009. Analysis of water quality characteristics in Selected area of pali District in Rajasthan. *Indian Journal of Environmental Protection.* 29 (11) : 1011-1012.

Packialakshmi, N., Suganya1, C. and Guru, V. 2013. Studies on stychnos potatorum seed and screeing the water quality assessment of drinking water. *International Journal of Research in Pharmaceutical and Nano Sciences.* 3(5): 380-396.

Thamaraiselvi Chandran 2020. Cost Effective and Natural Plant Based Coagulant for Removal of Chloride from Potable Water. *Asian Journal of Chemistry*. 32 (4) : 871-875. https://doi.org/10.14233/ajchem.2020.22478

Yin, C.Y. 2010. Emerging usage of plant-based coagulants for water and wastewater treatment. *Process Biochem.* 45 : 1437-1444. doi:10.1016/j.procbio.2010.05.030