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ORIGINAL ARTICLE

Low cost bench scale community level water treatment system and adsorption method for removal of nitrate from groundwater

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Abstract

Nitrate contamination has gain significant research interest, since presence of nitrate in large quantity in drinking water, often causes health disorders. In present day situation, nitrate removal is important aspects of water treatment process. Prevailing process, conditional influence and various approaches play important role in nitrate remediation. Various physical and chemical methods are available to remove the nitrate from groundwater; these are effective in removal but expensive in operation. To overcome these limitations, low cost bench scale water system with suitable adsorption method is adopted. In the present study, a treatment system was developed for community level comprising of anoxic batch reactor; filtration unit and a chlorination unit. Adsorption method is extremely useful in nitrate removal for different dosages such as: 5 g/L, 7.5 g/L, 10 g/L, since it retains nitrogen within the root zone. From the experiment, it is found that, low cost bench scale treatment method was effective in nitrate removal as material used were cost effective and locally available. Adsorbent method such as fly ash shows prominent result compared to other adsorbent such as activated carbon for an optimized condition of 7.5 g/L. Hence it can be recommended compared to other methods.

Keywords Adsorption · Groundwater · Nitrate · Water treatment · Bench scale · Low cost

Introduction

Ground water is one of the main sources for drinking in many rural communities, as well in some large cities. Most of the surface resources are exposed to contamination; ground water has received the attention, since common belief that ground water is clean and fresh. Due to anthropogenic activities, urbanization and agricultural farming has made the environment pollution as growing concern. Ground water contamination with respect to nitrate is observed in many places. A fertilizers application in larger quantity with over irrigation leads to pollution of groundwater. Nitrate is one of the inorganic pollutants caused due to industrial, animal and human waste through the activity of microbes. Nitrates in both surface and subsurface sources will be the most important aspects for pollution. Nitrates having driving force with soil, since both soil and nitrates are negative charged ions. Entry of nitrates in water environment is due to application of nitrate fertilizers, which are soluble in water. Due to excessive water, soil result in leaching, carry nitrate fertilizers along with water. Portion of nitrate fertilizer absorbed by water and remaining portion enters to ground water through infiltration and causes the ground water pollution. In ground water, nitrogen occurs in the form of nitrates and does not have any bonding with soil during leaching condition. Presence of large quantity of nitrates in ground water has adverse effect on human and animal's health. Hence, from ground water nitrates has to be removed.

Most of the studies addressed the methods for removal of nitrates in ground water and few are discussed. Schipper and Vojvodic-vukovic (2000) used denitrification method for observed amount of removal of nitrate. Mohseni-Bandpi et al. (2013) review the process for the removal of nitrate from water, which includes both heterotrophic and autotrophic. Archna and Sobti (2012) analyzed nitrate removal process for both ground water as well as industrial water using denitrifying methods. Della et al. (2007) explained

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latest development of nitrate removal, most proper process by means of economical and technical in particular, Mediterranean countries. Choi et al. (2009) adopted hybrid technology of bioremediation and electro kinetics to remove nitrate in the soil. Hell et al. (1998) assessed the desalination efficiency in view of nitrate removal. Song et al. (2012) synthesized an anion exchange resin in binary co-existence system for selective nitrate removal. Van der Hoek and Klapwijk (1987) explained a new technique for nitrate removal from the source of ground water. (Yang et al. (2013) explained method to photo catalytically reduce nitrate in IX brine. Zhang and Angelidaki (2013) developed denitrification cell (SMDDC) to in situ nitrate removal from groundwater. Barbosa et al (2013) here finding was related to pH reduction and buffering properties. Luo et al. (2008) here, feasibility of removal of nitrate groundwater, containing dissolved oxygen was investigated. Yadla et al. (2012) analysed fly ash absorption performance for lead removal. Murali Naik and Aruna (2019) explained batch adsorption of zinc from waste water using neem powder and saw dust as adsorbent. Haider et al. (2014) variety of adsorbents, discusses mechanisms, modification methods, application were examined. Mohan and Singh (2002) found that adsorption occurs at low and high concentration. Kargi and Cikla (2006) used powdered waste sludge from aqueous solution. Kumar and Bandyopadhyay (2006) Cd(II) by rice husk, was investigated. Apiratikul and Pavasant (2008) biosorption by a dried green was investigated. Sciban et al. (2006) found sawdust and hardwood have good adsorption capacities. Daifullah et al. (2003) used two types of adsorbents made from rice husk. Bayat (2002) two different fly ashes were compared. Afsin-Elbistan and Seyitomer analyzed ability of remove nickel copper and zinc. Conca and Wright (2006) induced metal stabilization process. Ncube and Su (2012) volatile organic compounds removal from silica gel under dynamic conditions was theoretically investigated. Banerjee et al. (2003) adsorption of toxic metal ions on fly ask for different parameter was compared on untreated fly ash. Viraraghavan and Rao (1991) used fly ash adsorption methods in chemical removal process. Yadava et al. (2008) here empirical model were tested. Dahab (1991) here nitrate treatment processes progress was reviewed. Gayle et al. (1989) explained biological denitrification of water.

Many physical chemical and Biological methods are available in removal of nitrates. In general physical and chemical methods are widely used, such as: reverse osmosis, electro dialysis, ion-exchange and zero-valent metals. These methods are not feasible due to its operation expense and close monitoring. To overcome these problems: low cost bench scale community level water systems were adopted with suitable adsorbent methods. This method is less expensive due to use of locally available material and effective in removal of nitrate compared to other adsorbent such as activated carbon. In the present study, a treatment system was developed for community level comprising of anoxic batch reactor; filtration unit and a chlorination unit. Ground water sample was collected located at Mysugar industrial area, of Mandya district from bore well sources. The fly ash used in experiment was collected from Raichur thermal power plant, Karnataka. It belongs to ASTM classification "C" and collected from open dry dumps. These are very economical and feasible compared to other methods.

Operational strategy

Whole experiment was done in five phases and explained below.

Phase 1: Includes nitrate removal feasibility from synthetic water was studied.

Phase 2 and Phase 3: Includes optimization of carbon source.

Phase 4: Includes the evaluation of nitrate removal under various nitrate loading.

Phase 5: Includes evaluation of a treatment system.

Table 1 shows details of the experiments done during the study period.

Low cost bench scale treatment system

In the present study, a treatment system was developed for community level comprising of anoxic batch reactor; filtration unit and a chlorination unit. Here sample was collected from mysugar industrial area of Mandya district. Table 2 represents the details of the laboratory scale treatment system. Figure 1 show the water treatment system setup.

Table 1 Details of experiments done during the study period

Study/phase	Carbon source	Feed	Nitrate nitrogen concentration in feed	Days of operation	Parameters analysed/monitored
Community-based treatment system					
Fifth	0.05 g/2 L	Ground water	70 mg/L	2–3 weeks	COD, nitrate, nitrite, ammonia, pH, chlorides, fluorides, alkalinity, hardness, phosphates, sulphates, TS, TDS

Table 2 Details of the community level water treatment system

Anoxic reactor	
Diameter, cm	22
Height, cm	20
Volume, L	5
Filtration unit	
Length, cm	20
Height, cm	20
Width, cm	18
Disinfection unit	
Diameter, cm	10
Height, cm	15

After water from the denitrifying unit containing suspended solids and micro-organisms and the same was treated in a sand filtration unit which will improve the quality of effluent water. Finally water from the filtration unit is subjected to the disinfection process. Chlorine was added as disinfectant to remove the micro-organisms.

Fly ash

The colour of fly ash used in the study is grey and its nature is refractory. The fly ash used in the experiment was collected from open dry dumps of Raichur thermal power plant, Karnataka state and it is shown in Fig. 2. Chemical and physical properties of fly ash were presented in Tables 3 and 4.

Details of adsorption studies

Adsorption method is extremely important since it retain nitrogen within the root zone for a certain time period. Organic matter and clay concentration determines the cation exchange capacity of soil. Cation exchange process help to

Fig. 1 Setup of bench scale water treatment system

Fig. 2 Adsorbent used in the study

Table 3 Chemical properties of Adsorbent

Chemical configuration	Percentage (%)
Silica (%)	55–65
Alumina range (%)	22–25
Calcium (%)	5–6
Magnesium range (%)	1
Titanium range (%)	Traceable
Manganese range (%)	1
Phosphorous range (%)	1
Sulphate (%)	0.1
Iron oxide (%)	–
Sodium oxide (%)	–
Unburnt carbon (%)	1–5
Potassium value (%)	0.9

Table 4 Physical properties of adsorbent

Physical configuration	Values
Colour	Light grey
Value of specific gravity	2.07
Grain size distribution	
Sand fraction (%)	54.00
Silt and clay fraction (%)	46.00
Unconfined compressive strength at MDD (kPa)	51.40

absorb the nitrate ions through clay (negatively charged) and organic collides.

Preparation of adsorbent

From open dry places, fly ash was collected. After completion of dry process, it is sieved into different fractions. To complete this process, sieve shaker machine were used. Obtained fraction was preserved and used as adsorbent.

Experimentation

Various experiments done during adsorption are shown in the Table 5.

- In a 250 mL conical flask, 50 mL aqueous solution and 10 g of adsorbent was added having the size of 52 µm.
- For about 1 h, sample is shaken at room temperature.
- Remaining samples were prepared by adding 10 g of adsorbent
- Exposed to varying agitation times say 5 min, 10 min, 20 min, and 30 min.
- Using Whatman filter papers, samples were filtered and it was analysed in Spectrophotometer to obtain final concentrations of nitrate.
- Using other adsorbent sizes, experimental procedure was repeated say: 72 µm, and 100 µm. Also adsorbent dosages say: 5.0 g/L and 7.5 g/L were adopted.

Results and discussion

Bench scale treatment system

Treated water from anoxic batch reactor contained some amounts of solids and micro-organisms a bench scale water treatment system was developed consisting of anoxic reactor, filtration unit and disinfection unit were collected including raw water was collected and analysed for all water quality parameter. During this study, groundwater was used as feed and since it contain less amount of nitrate nitrogen it was amended with 50 mg/L of KNO_3, so concentration of nitrate nitrogen in the feed was around 70 mg/L. Result of this study is represented in Table 6. From table, it is found that the nitrate is nearly completely removed (83%) while the permissible limit for drinking quality standards (CPHEEO) is 45 mg/L. Very low amount of nitrite and ammonia nitrogen was observed in the different units. pH was varied from 7.5 to 7.9. Initially COD was 384 mg/L and at the end of denitrification, it was 16 mg/L and in the final treated water, it was 8 mg/L. There was no considerable variation in total alkalinity while total hardness reduced from 1360 to 880 mg/L; similarly calcium hardness reduction was observed. There was considerable amount of sulphate reduction was observed in the anoxic reactor and in the treated water, it was below detection time. The total solid reduction was observed in the

Table 5 Details of experiments done during adsorption

Study/phase	Adsorbent dosage (fly ash) (g/L)	Feed	Nitrate nitrogen concentration (mg/L)	Adsorbent size (µm)	Parameter analysed
Optimizing conditions for nitrate nitrogen removal					
First	5.0	Synthetic water	30	52	Nitrate nitrogen
	7.50		40	72	
	10.0		50	100	

Table 6 Performance of different units

Parameters in mg/L	Raw water	Start of reaction	Denitrified water	Filtered water	Disinfected water	CPHEEO standards	
						Permissible	excessive
Nitrate	18.9	65.2	10.5	8.4	7.78	45	–
Nitrite	0.19	0.16	0.28	0.04	0.04	–	–
Ammonia	0	3.2	6.6	3.1	1.9	–	–
pH	7.52	7.89	7.9	7.82	7.8	7.0–8.5	6.5–8.5
COD	64	384	16	8	8	–	–
Chlorides	210	134	114.8	38.2	38.2	200	600
Total alkalinity	536	478	328	324	316	–	–
Total hardness	1240	1360	1160	880	880	300	600
Calcium hardness	720	800	480	360	360	75	200
Sulphate	208	124	88.7	0	0	200	400
Fluoride	0.6	0.6	0.4	0.4	0.4	0.5	1.0–1.5
Iron	0.069	0.0069	0	0	0	0.3	1.0
Phosphate	1.3	6.1	3.5	3.5	3.9	–	–
Turbidity (NTU)	25	30	20	9.8	8	10	25
TDS	934	910	886	868	868	–	–
TS	952	914	892	420	400	500	1500
Calcium	288	320	192	144	144	75	200
Magnesium	126.88	136.64	165.92	126.88	126.88	50	150
MPN (per 100 mL)	11		17	3	0	0	0

filtration unit and in the final treated water, it was 400 mg/L which is well below the drinking quality standard value of 500 mg/L. In the raw water sample, 11 per 100 mL MPN was observed after denitrification it increased to 17 per 100 mL, probably from the seed sludge some amount of MPN might have been added. Whereas after filtration MPN was reduced to 3 per 100 mL while after disinfection it was 0.

Feasibility of nitrate removal from synthetic water trial studies with addition of low cost carbon source in anoxic batch reactor was conducted. From the studies conducted with different dosage of carbon source (ragi straw), it was observed that 0.05 g of ragi straw powder/2 L of raw water is optimal dosage for complete nitrate removal wherein 100% nitrate removal is observed in 3 days. From the economic point of view, ragi straw is considered as the efficient carbon source, on which fewer or no investment have to be made. By performing batch reactor cycles, i.e., decanting the treated water was replaced with fresh water continuously for three cycles, nitrate removal was observed to take place in a day and no seeding is required for each cycle. From the study, it is found that the seed added (cow dung) was effective in enriching denitrifying organisms under anoxic conditions. The powdered ragi straw added acted as carbon source during denitrification. In the previous studies, several researchers have used methanol, ethanol and acetate as carbon source for denitrification which is economically not viable. The treatment system developed is suitable for rural water supply schemes wherein groundwater is used. The treated water characteristics which were found to be potable with various parameters were well below the drinking water quality standards.

Adsorption

Nitrate nitrogen removal by adsorption experiments

Synthetic water was prepared by dissolving 48.93 mg, 65.25 mg, and 81.56 mg of potassium nitrate in 1000 mL tap water so as to obtain three concentrations such as: 30 mg/L, 40 mg/L and 50 mg/L of nitrate nitrogen, respectively. 30 mg/L, 40 mg/L and 50 mg/L initial concentration nitrate nitrogen in synthetic water samples were tried to study the variation of removal with different initial loading conditions.

Optimizing the conditions for nitrate nitrogen removal

30 mg/L, 40 mg/L and 50 mg/L initial concentration of nitrate nitrogen in synthetic water samples were tried to study the variation of removal with different loading conditions. For the optimization of adsorbent dosage, fly ash of 10 g, 7.5 g and 5 g were added to 1000 mL of synthetic water samples. For the optimization of adsorbent size, 52 µm, 72 µm and 100 µm were used in this study. The optimization of adsorption time, samples were taken at 5 min, 10 min,

20 min and 30 min and analysed for nitrate nitrogen after filtering. The removal efficiency was very quick and more than 80% efficiency was obtained after 5 min at low particle size for all dosages tried. At 20th and 30th min, the removal efficiencies were almost same and no much increase was found in the removal due to the exhaustion of the adsorbent. The values obtained after the experiments are listed in tables below.

For 10 mg/L of adsorbent dosage, the removal efficiency was 100% after 30 min for 52 µm and 72 µm adsorbent size for all the three initial nitrate nitrogen concentrations. Even though the adsorbent size was high, the removal efficiency low. The result obtained from 10 g/L adsorbent dosage is presented in Table 7.

The removal efficiencies for the initial concentration of 30 mg/L NO_3^-, after 30 min, for the adsorbent dosage of 7.5 g/L of sample, at particle size 52 µm, 72 µm and 100 µm were 100%, 100%, and 86.23%, respectively. Similarly for 40 mg/L NO_3^- initial concentration of particle size 52 µm, 72 µm and 100 µm the removal efficiencies were 100%, 100% and 85.07%, respectively. And for 50 mg/L of NO_3^- of particle size 52 µm, 72 µm and 100 µm were 100%, 100% and 82.96%. The result obtained from 10 g/L adsorbent dosage is presented in Table 8.

The removal efficiencies for the concentration of 30 mg/L of nitrate after 30 min, for the adsorbent dosage of 5.0 g/L of sample of particle size 52 µm, 72 µm and 100 µm were 86.86%, 86.56% and 76.53%, respectively. Similarly for 40 mg/L nitrate initial concentration after 30 min, for the adsorbent dosage of 5.0 g/L of sample, of particle size 52 µm, 72 µm and 100 µm were 86.66%, 85.56% and 74.23% respectively. And for initial concentration of 50 mg/L of NO_3^-, after 30 min the efficiencies of nitrate removal at particle size 52 µm, 72 µm and 100 µm were 83.78%, 83.65% and 72.5%, respectively. The result obtained from 10 g/L adsorbent dosage is presented in the Table 9.

Increase in nitrate nitrogen concentration in the samples, results in slight increase in the removal efficiency, due to higher adsorbate results in decrease of overall % removal. The removal efficiencies were almost equal at particle size 52 µm, 72 µm. but 100 µm size the removal efficiency was less. An average there was 95% removal for the dosages of 10 g and 7.5 g of fly ash/L of sample. For 5.0 g/L the average removal efficiency was around 75%. Hence 7.5 g of adsorbent/L of sample at particle size 72 µm was used for the next experiments with actual groundwater samples.

Conclusion

This study was done to know the feasibility of removing nitrate from ground water under anoxic condition. The results from bench scale community level water treatment system showed that it is very much efficient in the removal of nitrates, total coli form and as well as hardness. All the material used in the system was local, cheap and readily available. After the treatment, it is found that all the parameters were according to the standards of drinking water quality. From the studies on adsorption, fly ash which is solid waste material can be effectively used as an adsorbent for the

Table 7 Results of nitrate nitrogen removal using 10 g fly ash as adsorbent/L of sample

Adsorbent size and % of removal	Time, min				
	0	5	10	20	30
Nitrate nitrogen in mg/L (52 µm adsorbent size)	30	2.53	0.03	BDL	BDL
% removal	–	91.50	99.80	100	100
Nitrate nitrogen in mg/L (72 µm adsorbent size)	30	2.81	0.038	BDL	BDL
% removal	–	90.61	99.80	100	100
Nitrate nitrogen in mg/L (100 µm adsorbent size)	30	5.23	4.10	3.99	3.78
% removal	–	82.54	86.32	86.66	87.38
Nitrate nitrogen in mg/L (52 µm adsorbent size)	40	3.51	0.04	BDL	BDL
% removal	–	91.20	99.87	100	100
Nitrate nitrogen in mg/L (72 µm adsorbent size)	40	7.57	6.12	5.93	5.82
% removal	–	90.20	99.87	100	100
Nitrate nitrogen in mg/L (100 µm adsorbent size)	40	7.57	6.12	5.93	5.82
% removal	–	81.06	84.70	85.15	85.43
Nitrate nitrogen in mg/L (52 µm adsorbent size)	50	10.51	9.15	8.52	8.43
% removal	–	90.51	99.87	100	100
Nitrate nitrogen in mg/L (72 µm adsorbent size)	50	4.92	0.066	BDL	BDL
% removal	–	90.15	99.86	100	100
Nitrate nitrogen in mg/L (100 µm adsorbent size)	50	78.97	81.69	82.96	83.15
% removal	–	78.97	81.67	82.96	83.15

Table 8 Results of nitrate nitrogen removal using 7.5 g fly ash as adsorbent/L of sample

Adsorbent size and % of removal	Time, min				
	0	5	10	20	30
Nitrate nitrogen in mg/L (52 µm adsorbent size)	30	2.85	0.74	BDL	BDL
% removal	–	90.47	97.80	100	100
Nitrate nitrogen in mg/L (72 µm adsorbent size)	30	3.47	0.39	BDL	BDL
% removal	–	88.41	98.67	100	100
Nitrate nitrogen in mg/L (100 µm adsorbent size)	30	5.50	4.64	4.20	4.13
% removal	–	81.67	84.51	85.51	86.23
Nitrate nitrogen in mg/L (52 µm adsorbent size)	40	3.90	1.18	BDL	BDL
% removal	–	90.20	97.87	100	100
Nitrate nitrogen in mg/L (72 µm adsorbent size)	40	4.66	1.26	BDL	BDL
% removal	–	90.20	99.87	100	100
Nitrate nitrogen in mg/L (100 µm adsorbent size)	40	7.57	6.12	6.93	5.82
% removal	–	80.06	83.70	84.15	85.43
Nitrate nitrogen in mg/L (52 µm adsorbent size)	50	5.01	1.75	BDL	BDL
% removal	–	90.51	99.87	100	100
Nitrate nitrogen in mg/L (72 µm adsorbent size)	50	6.12	1.85	BDL	BDL
% removal	–	87.15	96.86	100	100
Nitrate nitrogen in mg/L (100 µm adsorbent size)	50	9.89	8.86	8.86	8.52
% removal	–	80.23	82.28	82.74	82.96

Table 9 Results of nitrate nitrogen removal using 5 g fly ash as adsorbent/L of sample

Adsorbent size and % of removal	Time, min				
	0	5	10	20	30
Nitrate nitrogen in mg/L (52 µm adsorbent size)	30	5.24	4.12	3.99	3.94
% removal	–	82.50	86.25	86.70	86.86
Nitrate nitrogen in mg/L (72 µm adsorbent size)	30	5.31	4.65	4.18	4.03
% removal	–	82.27	84.49	86.06	86.56
Nitrate nitrogen in mg/L (100 µm adsorbent size)	30	8.32	7.25	7.16	7.04
% removal	–	72.25	75.83	76.12	76.53
Nitrate nitrogen in mg/L (52 µm adsorbent size)	40	6.37	5.96	5.54	5.35
% removal	–	84.06	85.05	86.32	86.66
Nitrate nitrogen in mg/L (72 µm adsorbent size)	40	6.99	6.12	5.84	5.77
% removal	–	90.20	99.87	85.27	85.57
Nitrate nitrogen in mg/L (100 µm adsorbent size)	40	14.74	8.93	10.33	10.31
% removal	–	71.07	73.22	74.16	74.22
Nitrate nitrogen in mg/L (52 µm adsorbent size)	50	10.51	8.49	8.99	8.10
% removal	–	79.04	83	83.75	83.78
Nitrate nitrogen in mg/L (72 µm adsorbent size)	50	10.93	8.81	8.24	8.27
% removal	–	78.12	82.86	83.5	83.65
Nitrate nitrogen in mg/L (100 µm adsorbent size)	50	15.51	14.37	13.98	13.74
% removal	–	68.98	71.24	72.03	72.50

treatment of groundwater. When compared to other adsorbents like activated carbon. It is found that, fly ash is very effective in the removal of nitrates from groundwater. The optimized conditions were 7.5 g fly ash/L dosage; 72 µm particle size the nitrate removal efficiency was very high. Also 15 min of contact time nitrogen removal efficiency was 100%.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Informed consent For this type of study, formal consent is not required.

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