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Are the current methods of remediation to reduce nitrate contamination in groundwater in the developing world effective? A systematic review

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9. Appendix

Appendix 1

This table shows only the searches in Web of Science. The searches for scoping and in Google Scholar were too large to be tabulated in this format. 71 results were imported from the full literature search in Web of Science, including 2 from citation chasing. 8 were found in Google Scholar and the remaining 45 were found from the scoping exercise, where results were still used as they fit within the limits.

Table 1: Web of Science search results

Web of Science	Limits	Search terms	Results	Imported into EndNote X2
Topic	2003-2013 English	'nitrate' AND 'groundwater'	5070	
Refined by: 'China' OR 'Tunisia' OR 'Nigeria' OR 'India' OR 'Thailand' OR 'Algeria' OR 'Iran' OR 'Chile' OR 'Turkey' OR 'Ghana' OR 'Philippines' OR 'Brazil' OR 'Bangladesh' OR 'Pakistan' OR 'Mexico' OR 'Argentina'	2003-2013 English	'nitrate' AND 'groundwater'	1002	
Refined by: 'China' OR 'Tunisia' OR 'Nigeria' OR 'India' OR 'Thailand' OR 'Algeria' OR 'Iran' OR 'Chile' OR 'Turkey' OR 'Ghana' OR 'Philippines' OR 'Brazil' OR 'Bangladesh' OR 'Pakistan' OR 'Mexico' OR 'Argentina'	2003-2013 English	'nitrate' AND 'groundwater' 'removal' OR 'reduction'	326	26
Refined by: 'China' OR 'Tunisia' OR 'Nigeria' OR 'India' OR 'Thailand' OR 'Algeria' OR 'Iran' OR 'Chile' OR 'Turkey' OR 'Ghana' OR 'Philippines' OR 'Brazil' OR 'Bangladesh' OR 'Pakistan' OR 'Mexico' OR 'Argentina'	2003-2013 English	'nitrate' AND 'groundwater' AND 'contamination' OR 'pollution'	508	
Refined by: 'China' OR 'Tunisia' OR 'Nigeria' OR 'India' OR 'Thailand' OR 'Algeria' OR 'Iran' OR 'Chile' OR 'Turkey' OR 'Ghana' OR 'Philippines' OR 'Brazil' OR 'Bangladesh' OR 'Pakistan' OR 'Mexico' OR 'Argentina'	2003-2013 English	'nitrate' AND 'groundwater' AND 'contamination' OR 'pollution' AND 'ion exchange' OR 'nanofiltration' OR 'denitrification' OR 'reverse	93	15

		osmosis'		
Refined by: 'China' OR 'Tunisia' OR 'Nigeria' OR 'India' OR 'Thailand' OR 'Algeria' OR 'Iran' OR 'Chile' OR 'Turkey' OR 'Ghana' OR 'Philippines' OR 'Brazil' OR 'Bangladesh' OR 'Pakistan' OR 'Mexico' OR 'Argentina'	2003-2013 English	'nitrate' AND 'groundwater' AND 'contamination' OR 'pollution' AND 'ion exchange' OR 'nanofiltration' OR 'denitrification' OR 'reverse osmosis' AND 'review'	1	
Refined by: 'China' OR 'Tunisia' OR 'Nigeria' OR 'India' OR 'Thailand' OR 'Algeria' OR 'Iran' OR 'Chile' OR 'Turkey' OR 'Ghana' OR 'Philippines' OR 'Brazil' OR 'Bangladesh' OR 'Pakistan' OR 'Mexico' OR 'Argentina'	2003-2013 English	'nitrate' AND 'groundwater' 'removal' OR 'reduction' AND 'ion exchange' OR 'nanofiltration' OR 'denitrification' OR 'reverse osmosis'	95	17
Refined by: 'China' OR 'Tunisia' OR 'Nigeria' OR 'India' OR 'Thailand' OR 'Algeria' OR 'Iran' OR 'Chile' OR 'Turkey' OR 'Ghana' OR 'Philippines' OR 'Brazil' OR 'Bangladesh' OR 'Pakistan' OR 'Mexico' OR 'Argentina'	2003-2013 English	'nitrate' AND 'groundwater' 'removal' OR 'reduction' AND 'review'	6	
Refined by: 'China' OR 'Tunisia' OR 'Nigeria' OR 'India' OR 'Thailand' OR 'Algeria' OR 'Iran' OR 'Chile' OR 'Turkey' OR 'Ghana' OR 'Philippines' OR 'Brazil' OR 'Bangladesh' OR 'Pakistan' OR 'Mexico' OR 'Argentina'	2003-2013 English	'nitrate' AND 'groundwater' AND 'intervention'	1	
Refined by: 'China' OR 'Tunisia' OR 'Nigeria' OR 'India' OR 'Thailand' OR 'Algeria' OR 'Iran' OR 'Chile' OR 'Turkey' OR 'Ghana' OR 'Philippines' OR 'Brazil' OR 'Bangladesh' OR 'Pakistan' OR 'Mexico' OR 'Argentina'	2003-2013 English	'nitrate' AND 'groundwater' AND 'biological dentrifcation'	82	13
Refined by: 'China' OR 'Tunisia' OR 'Nigeria' OR 'India' OR 'Thailand' OR	2003-2013 English	'nitrate' AND 'groundwater' AND 'ion	48	

‘Algeria’ OR ‘Iran’ OR ‘Chile’ OR ‘Turkey’ OR ‘Ghana’ OR ‘Philippines’ OR ‘Brazil’ OR ‘Bangladesh’ OR ‘Pakistan’ OR ‘Mexico’ OR ‘Argentina’		exchange’		
Refined by: ‘China’ OR ‘Tunisia’ OR ‘Nigeria’ OR ‘India’ OR ‘Thailand’ OR ‘Algeria’ OR ‘Iran’ OR ‘Chile’ OR ‘Turkey’ OR ‘Ghana’ OR ‘Philippines’ OR ‘Brazil’ OR ‘Bangladesh’ OR ‘Pakistan’ OR ‘Mexico’ OR ‘Argentina’	2003-2013 English	‘nitrate’ AND ‘groundwater’ AND ‘nanofiltration’	9	
Refined by: ‘China’ OR ‘Tunisia’ OR ‘Nigeria’ OR ‘India’ OR ‘Thailand’ OR ‘Algeria’ OR ‘Iran’ OR ‘Chile’ OR ‘Turkey’ OR ‘Ghana’ OR ‘Philippines’ OR ‘Brazil’ OR ‘Bangladesh’ OR ‘Pakistan’ OR ‘Mexico’ OR ‘Argentina’	2003-2013 English	‘nitrate’ AND ‘groundwater’ AND ‘reverse osmosis’	8	

Appendix 2

This is a full list of the included results. The studies are numbered in the order they were examined to minimise bias. This table was used for reference throughout this review as the key details for each study can be easily seen.

Table 2: Full list of included results

No.	Author and year	Removal process	Location	Groundwater	Amount removed % Remaining concentration (mg/L)	Strength of study
1	Huang *et al.*, 2012	Biological denitrification	Beijing, China	99.89mg/L synthetic	100% (0mg/L)	Strong
2	Mahvi *et al.,* 2011	Nanofiltration	Kerman, Iran	38.1mg/L	62.2% (14.4mg/L)	Strong
3	Aslan and Turkman, 2005	Biological denitrification	Turkey	100mg/L synthetic	91% (9mg/L)	Weak
4	Tong *et al.,* 2013	Biological denitrification	Beijing, China	221.5mg/L synthetic	99.9% (0.22mg/L)	Strong
5	Ayyasamy *et al.,* 2009	Aquatic plants	Tamilnadu, India	110mg/L	68.2% (35mg/L)	Strong
6	Prasad *et al*., 2005	Electro-reduction	Tamilnadu, India	190mg/L	81.1% (36mg/L)	Weak
7	Ayyasamy *et al.,* 2007	Biological denitrifcation	Rajasthan, India	460mg/L	90.2% (50mg/L)	Weak
8	Wan *et al.,* 2009	Biological denitrification	Beijing, China	97.24mg/L	95% (4.86mg/L)	Weak
9	Wang *et al.,* 2009	Biological denitrification	Beijing, China	56.82mg/L	100% (0mg/L)	Strong
10	Qian *et al.,* 2011	Biological denitrification	Anhui, China	269.93mg/L	88.5% (31.12mg/L)	Weak
11	Chen *et al.,* 2003	Catalytic reduction	Hangzhou, China	100mg/L synthetic	89.4% (10.6mg/L)	Weak
12	Liu *et al.,* 2012	Hydrogen reduction	Anhui, China	120mg/L synthetic	73% (32.4mg/L)	Strong
13	Wang and Wang, 2013	Biological denitrification	Beijing, China	221mg/L synthetic	100% (0mg/L)	Strong
14	Hekmatzadeh *et al*., 2012	Ion exchange	Shiraz, Iran	63.3mg/L	95.4% (2.9mg/L)	Strong
15	Rajakumar *et al.,* 2008	Biological denitrification	Tamilnadu, India	100mg/L synthetic	99.4% (0.06mg/L)	Weak
16	Samatya *et al*., 2006	Ion exchange	Manisa, Turkey	195mg/L	96.1% (7.65mg/L)	Weak

17	Wang and Wang, 2012	Biological denitrification	Beijing, China	221mg/L	100% (0mg/L)	Weak
18	Hong *et al.*, 2012	Biological denitrification	Beijing, China	442mg/L synthetic	98.5% (6.63mg/L)	Weak
19	Zhao *et al*., 2011	Biological denitrification	Beijing, China	221mg/L synthetic	97% (7mg/L)	Strong

This is the table showing the information for all of the studies which included reference to the other variables. This table shows which studies examined more than one variable, and which studies examined no other variables.

Table 3: Other variables within studies

	Author and year	Removal process	pH	Flow rate	Temperature	Initial concentration	Time
1	Huang *et al.*, 2012	Biological denitrification			Denitrification rate at 27.5°C was 1.36 times higher than at 15°C		
2	Mahvi *et al.*, 2011	Nanofiltration		Flow rate 0.4mg/L = 75.7% nitrate removal 0.8mg/L = 69.3%			
3	Aslan and Turkman, 2005	Biological denitrification			Almost complete removal of 100mg/L nitrate at 31°C		
4	Tong *et al.,* 2013	Biological denitrification					
5	Ayyasamy *et al.,* 2009	Aquatic plants				This suggests the optimum initial nitrate concentration in the medium was 300mg/L	
6	Prasad *et al.*, 2005	Electro-reduction	Highest efficiency at pH 2 and pH 8				

7	Ayyasamy *et al.,* 2007	Biological denitrifcation					
8	Wan *et al.,* 2009	Biological denitrification					
9	Wang *et al.,* 2009	Biological denitrification	Denitrification effect excellent at neutral and alkalescent pH				
10	Qian *et al.,* 2011	Biological denitrification					
11	Chen *et al.,* 2003	Catalytic reduction				Higher initial concentration linear relationship with higher removal rate	
12	Liu *et al.,* 2012	Hydrogen reduction	Higher nitrate reduction rate obtained at acidic over neutral conditions			Nitrate removal rate promotes with increasing nitrate concentration	Nitrate removal rate increases with increasing raction time
13	Wang and Wang, 2013	Biological denitrification					
14	Hekmatzadeh *et al.*, 2012	Ion exchange		The breakthrough time generally occurred faster with higher flow rates		That initial nitrate concentration has a negligible effect on the total adsorption capacity	
15	Rajakumar *et al.,* 2008	Biological denitrification	The maximum of nitrate was reduced from 100 to 0.61mg/L (99.4%) in pH 7		At 30°C, about 90% of reduction was noticed at 24h and attained 99.4% at 48h		
16	Samatya *et al*., 2006	Ion exchange					
17	Wang and Wang, 2012	Biological denitrification			100% efficiency at 25°C reduced to 40% efficiency at 12°C		Removal efficiency increased gradually with running time
18	Hong *et al.*, 2012	Biological denitrification					
19	Zhao *et al*., 2011	Biological denitrification					

Appendix 4

These tables contain the information for all 24 included studies, including those which were not included for extraction. The first table is blank and shows all the information included for data extraction. Where possible, the information within the tables has been copied exactly out of the studies to minimise the risk of misinterpretation and bias.

Study information	Author and year	Study title	Peer reviewed? Y/N	
Groundwater	Location	Groundwater resource details	Inclusion/exclusion criteria	
			Developing country	
			Groundwater	
			Listed method	
			Outcome	
Nitrate removal	Type of removal method	Description of method	Description of comparator/control	
Methods of analysis of removal	Objectives		Method of data collection and analysis	
Results (Intervention)	Concentration of nitrate in groundwater:			
Study Quality	Outcome	Quality	Overall	

Study information	Author and year	Study title		Peer reviewed? Y/N
	Huang G., Fallowfield H., Guan H. and Liu F. (2012)	Remediation of Nitrate-Nitrogen contaminated Groundwater by a Heterotrophic-Autotrophic Denitrification Approach in an Aerobic Environment		Yes
Groundwater	Location	Groundwater resource details	Inclusion/exclusion criteria	
	Beijing, China	22.6mg/L (NO_3-N) 99.89mg/L NO_3	Developing country	Y
			Groundwater	Synthetic
			Listed method	Y
			Outcome	Y
Nitrate removal	Type of removal method	Description of method	Description of comparator/control	
	Biological Denitrification	Heterotrophic-autotrophic denitrification upflow columns mixed with spongy iron, methanol and mixed bacteria	A comparison was made of denitrification rates near the temperature optimum, 27.5±1.0°C and at ambient groundwater temperature (15.0±1.0°C) in Shenyang, China.	
Methods of analysis of removal	Objectives		Method of data collection and analysis	
	The objectives of this study were to: (1) investigate deoxygenation capacities of the HAD; (2) determine the contributions of AD, HD, and CR to the overall NO_3-N removal in the HAD; (3) evaluate the effects of C to N ratio and water temperature on the performance of the HAD.		Inorganic nitrogen (NO_3-N, NO_2-N, and NH_4-N) was analyzed using a FOSS-Tecator FIAStar 5000 flow injection analyzer	
Results (Intervention)	Concentration of nitrate in groundwater:			
	After 5 days, 100% nitrate removed by heterotrophic-autotrophic denitrification			
Study Quality	Outcome	Quality	Overall	
	Stated	Valid	Strong	

Study information	Author and year	Study title	Peer reviewed? Y/N	
	Mahvi et al., (2011)	Nitrate removal from aqeous solutions by nanofiltration	Yes	
Groundwater	Location	Groundwater resource details	Inclusion/exclusion criteria	
	Kerman province, Iran	38.1 mg/L.	Developing country	Y
			Groundwater	Y
			Listed method	Y
			Outcome	Y
Nitrate removal	Type of removal method	Description of method	Description of comparator/control	
	Nanofiltration	Nanofiltration membrane (polypiperazine amid thin-film composite) with a negative surface charge. Surface : 0.002m^2	The results have been matched with Paugam et al. in France, Santafé-Moros et al. in Spain and also Choi et al. in Korea	
Methods of analysis of removal	Objectives	Method of data collection and analysis		
	The aim of this study was to investigate nitrate removal process from aqueous solutions by NF membranes under different circumstances	To examine the effect of nitrate initial concentration, synthetic sample was prepared with 100, 150, 200, 250 Fig. 1. Schematic of a nanofiltration membrane (1: feed tank, 2: permeate flow, 3: concentrate flow, 4: pump, 5: barometer, 6: NF membrane). and 300 mg NO_3^-/L as KNO3 and the system was run at a flow rate of 0.4 L/min. Standard nitrate solutions were prepared by dissolving the potassium nitrate (KNO_3) with appropriate amounts of distilled water		
Results (Intervention)	Concentration of nitrate in groundwater:			
	38.1mg/L starting. 0.4L/min flow rate = 14.4mg/L (62.2%) 0.8L/min flow rate = 17.1mg/L. (55.1%)			
Study Quality	Outcome	Quality	Overall	
	Stated	Valid	Strong	

Study information	Author and year	Study title	Peer reviewed? Y/N	
	Aslan S. and Turkman A. (2005)	Combined biological removal of nitrate and pesticides using what straw as substrates	Yes	
Groundwater	Location	Groundwater resource details	Inclusion/exclusion criteria	
	Turkey	100mg/L	Developing country	Y
			Groundwater	Synthetic
			Listed method	Y
			Outcome	Y
Nitrate removal	Type of removal method	Description of method	Description of comparator/control	
	Biological denitrification	Wheat straw used as carbon substrate in a biological denitrification reactor	*Not evident*	
Methods of analysis of removal	Objectives		Method of data collection and analysis	
	The main objective of this study was to determine the simultaneous microbial removal of nitrate and endosulfan (+ _ or I + II) ($C_9H_6Cl_6O_3S$), fenitrothion ($C_9H_{12}NO_5PS$) and trifluralin ($C_{13}H_{16}F_3N_3O_4$) in a biodenitrification reactor using wheat straw as carbon source and support particles.		Nitrite-nitrogen was determined using analytical kits (14776) and a photometer Merck SQ 300; and nitrate-nitrogen was measured according to the brucine method	
Results (Intervention)	Concentration of nitrate in groundwater:			
	Started at 100mg/L reduced to 9mg/L 91%			
Study Quality	Outcome	Quality	Overall	
	Stated	Not valid	Weak	

Study information	Author and year	Study title	Peer reviewed? Y/N	
	Tong S., Zhang B., Feng C., Zhao Y., Chen N., Hao C. *et al.* (2013).	Characteristics of heterotrophic/biofilm-electrode autotrophic denitrification for nitrate removal from groundwater	Yes	
Groundwater	Location	Groundwater resource details	Inclusion/exclusion criteria	
	Qinghe, Beijing, China	50mg/L (NO_3-N) 221.5mg/L NO_3	Developing country	Y
			Groundwater	Synthetic
			Listed method	Y
			Outcome	Y
Nitrate removal	Type of removal method	Description of method	Description of comparator/control	
	Biological denitrification	Sludge collected from sewage treatment plant which acclimated for 7 days and water input into an intensified biofilm-electrode reactor	As the comparison, 10 ml deionized water was added into 100 ml of the sterilized growth medium in 250 ml conical flasks (4 replicates). The concentration of NO3 -N in the blank test was 300 ± 3 mg/L.	
Methods of analysis of removal	Objectives		Method of data collection and analysis	
	Not evident		NO_3 -N, NO_2 -N and NO_4-N both in influent and effluent were determined by ultraviolet spectrophotometer (HACH, DR 5000, USA) according to standard methods	
Results (Intervention)	Concentration of nitrate in groundwater:			
	221.5mg/L to 0.22mg/L 99.9% efficiency			
Study Quality	Outcome	Quality	Overall	
	Stated	Not valid	Weak	

Study information	Author and year	Study title	Peer reviewed? Y/N	
	Ayyasamy P.M, Rajakumar S. et al, 2009	Nitrate removal from synthetic medium and groundwater with aquatic macrophytes	Yes	
Groundwater	Location	Groundwater resource details	Inclusion/exclusion criteria	
	Tamil Nadu, India	90-110 mg/L	Developing country	Y
			Groundwater	Y
			Listed method	Y
			Outcome	Y
Nitrate removal	Type of removal method	Description of method	Description of comparator/control	
	Uptake by aquatic plants	Uptake of nitrate by water hyacinth, water lettuce and salvinia	Control experiments were also performed the same nitrate solution concentrations, but without aquatic plants.	
Methods of analysis of removal	Objectives		Method of data collection and analysis	
	The objective of this study was to examine the capability of aquatic macrophytes for the removal of high concentrations of nitrate from groundwater. The efficiency of aquatic plants for the removal of nitrate was investigated using groundwater samples collected from Rajasthan and Tamil Nadu		The nitrate concentration was estimated using the phenol disulphonic acid method.	
Results (Intervention)	Concentration of nitrate in groundwater:			
	Reduction from 110 mg/L to 35 mg/L after 10 days (68.2%)			
Study Quality	Outcome	Quality	Overall	
	Stated	Valid	Strong	

<table>
<tr><td rowspan="2">Study information</td><td>Author and year</td><td>Study title</td><td colspan="2">Peer reviewed? Y/N</td></tr>
<tr><td>Prasad P. K., Nisha Priya M. and Palanivelu K. (2005).</td><td>Nitrate removal from groundwater using electrolytic reduction method</td><td colspan="2">Yes</td></tr>
<tr><td rowspan="5">Groundwater</td><td>Location</td><td>Groundwater resource details</td><td colspan="2">Inclusion/exclusion criteria</td></tr>
<tr><td rowspan="4">Tamilnadu, India</td><td rowspan="4">190 mg/L</td><td>Developing country</td><td>Y</td></tr>
<tr><td>Groundwater</td><td>Y</td></tr>
<tr><td>Listed method</td><td>Y</td></tr>
<tr><td>Outcome</td><td>Y</td></tr>
<tr><td rowspan="2">Nitrate removal</td><td>Type of removal method</td><td>Description of method</td><td colspan="2">Description of comparator/control</td></tr>
<tr><td>Electro-reduction</td><td>A divided electrolytic cell with anode and cathode compartments of 600ml</td><td colspan="2">Not evident</td></tr>
<tr><td rowspan="2">Methods of analysis of removal</td><td colspan="2">Objectives</td><td colspan="2">Method of data collection and analysis</td></tr>
<tr><td colspan="2">To investigate the possibility of using a simple electrolytic method for removal of nitrate in groundwater, to establish optimum operating conditions namely pH, current intensity and reaction time for the reduction of nitrate below the standard limit</td><td colspan="2">The analysis of nitrate was carried out using DIONEX ion chromatograph</td></tr>
<tr><td rowspan="2">Results (Intervention)</td><td colspan="4">Concentration of nitrate in groundwater:</td></tr>
<tr><td colspan="4">190mg/L to 36 mg/L (81.1%)</td></tr>
<tr><td rowspan="2">Study Quality</td><td>Outcome</td><td>Quality</td><td colspan="2">Overall</td></tr>
<tr><td>Stated</td><td>Not valid</td><td colspan="2">Weak</td></tr>
</table>

Study information	Author and year	Study title	Peer reviewed? Y/N	
	Zhang D. Y., Li G. H., Wang Y. and Zhou G.Z. (2006)	Structure and function of slow release organic carbon source in groundwater in-situ denitrification	Yes	
Groundwater	Location	Groundwater resource details	Inclusion/exclusion criteria	
	Beijing	*Not evident*	Developing country	Y
			Groundwater	N
			Listed method	Y
			Outcome	Y
Nitrate removal	Type of removal method	Description of method	Description of comparator/control	
	Denitritification	Slow-release organic carbon dissolves into water to support denitrification as electron donors	*Not evident*	
Methods of analysis of removal	Objectives		Method of data collection and analysis	
	Evaluation of difference slow-release organic carbon sources		Nitrate detected by UV spectrophotometer	
Results (Intervention)	Concentration of nitrate in groundwater:			
	Between 82.1-90.7% effiency			
Study Quality	Outcome	Quality	Overall	
	Stated	Not valid	Very weak	

Study information	Author and year	Study title	Peer reviewed? Y/N	
	Ayyasamy P.M., Shanthi K. Lakshmanaperumalsamy P., Lee S-J., Choi N-C., Kim D-J. (2007).	Two stage removal of Nitrate from Groundwater using Biological and Chemical treatments	Yes	
Groundwater	Location	Groundwater resource details	Inclusion/exclusion criteria	
	Rajasthan, India	460mg/L nitrate	Developing country	Y
			Groundwater	Y
			Listed method	Y
			Outcome	Y
Nitrate removal	Type of removal method	Description of method	Description of comparator/control	
	Biological denitrification	Biological denitrification and chemical coagulation	*Not evident*	
Methods of analysis of removal	Objectives		Method of data collection and analysis	
	Two stage treatment system is attempted using biological and chemical methods for a more efficient removal of nitrate from groundwater		After sand filtration, nitrate concentration was determined	
Results (Intervention)	Concentration of nitrate in groundwater:			
	460mg/L to 50mg/L 90.2%			
Study Quality	Outcome	Quality	Overall	
	Stated	Not valid	Weak	

<table>
<tr><td rowspan="2">Study information</td><td>Author and year</td><td>Study title</td><td colspan="2">Peer reviewed? Y/N</td></tr>
<tr><td>Zhou M., Fu W., Gu H., Lei L. (2007)</td><td>Nitrate removal from groundwater by a novel three-dimensional electrode biofilm reactor</td><td colspan="2">Yes</td></tr>
<tr><td rowspan="5">Groundwater</td><td>Location</td><td>Groundwater resource details</td><td colspan="2">Inclusion/exclusion criteria</td></tr>
<tr><td rowspan="4">China</td><td rowspan="4">Not evident</td><td>Developing country</td><td>Y</td></tr>
<tr><td>Groundwater</td><td>N</td></tr>
<tr><td>Listed method</td><td>Y</td></tr>
<tr><td>Outcome</td><td>Y</td></tr>
<tr><td rowspan="2">Nitrate removal</td><td>Type of removal method</td><td>Description of method</td><td colspan="2">Description of comparator/control</td></tr>
<tr><td>Biological denitrification</td><td>Reservoir of water input to cylindrical reactor containing biofilms</td><td colspan="2">Not evident</td></tr>
<tr><td rowspan="2">Methods of analysis of removal</td><td colspan="2">Objectives</td><td colspan="2">Method of data collection and analysis</td></tr>
<tr><td colspan="2">Not evident</td><td colspan="2">Nitrate concentration determined by IC</td></tr>
<tr><td rowspan="2">Results (Intervention)</td><td colspan="4">Concentration of nitrate in groundwater:</td></tr>
<tr><td colspan="4">60% efficiency</td></tr>
<tr><td rowspan="2">Study Quality</td><td>Outcome</td><td>Quality</td><td colspan="2">Overall</td></tr>
<tr><td>Stated</td><td>Not valid</td><td colspan="2">Very weak</td></tr>
</table>

<table>
<tr><td rowspan="2">Study information</td><td>Author and year</td><td>Study title</td><td colspan="2">Peer reviewed? Y/N</td></tr>
<tr><td>Wan D., Liu H., Qu J. Lei P., Xiao S., Hou Y. (2009)</td><td>Using the combined bioelectrical and sulfur autotrophic denitrification system for groundwater denitrification</td><td colspan="2">Yes</td></tr>
<tr><td rowspan="5">Groundwater</td><td>Location</td><td>Groundwater resource details</td><td colspan="2">Inclusion/exclusion criteria</td></tr>
<tr><td rowspan="4">Fengtai district, Beijing</td><td rowspan="4">97.24mg/L nitrate</td><td>Developing country</td><td>Y</td></tr>
<tr><td>Groundwater</td><td>Y</td></tr>
<tr><td>Listed method</td><td>Y</td></tr>
<tr><td>Outcome</td><td>Y</td></tr>
<tr><td rowspan="2">Nitrate removal</td><td>Type of removal method</td><td>Description of method</td><td colspan="2">Description of comparator/control</td></tr>
<tr><td>Biological dentrification</td><td>Groundwater pumped into sulfur autotrophic denitrification part and bioelectrochemical hydrogen autotrophic denitrification part of reactor</td><td colspan="2">To compare with other heterotrophic biological denitrification systems (including bioelectrochemical reactors, hydrogen dependent reactor and sulfur packed-bed reactor), the main operation parameters for the best removal capacity of each reactor</td></tr>
<tr><td rowspan="2">Methods of analysis of removal</td><td colspan="2">Objectives</td><td colspan="2">Method of data collection and analysis</td></tr>
<tr><td colspan="2">Not evident</td><td colspan="2">The concentrations of NO_3^--N, NO_2^--N, SO^{2-}_4 and $S_2O^{2-}_3$ were determined by ion chromatograph</td></tr>
<tr><td rowspan="2">Results (Intervention)</td><td colspan="4">Concentration of nitrate in groundwater:</td></tr>
<tr><td colspan="4">4.86mg/L 95%</td></tr>
<tr><td rowspan="2">Study Quality</td><td>Outcome</td><td>Quality</td><td colspan="2">Overall</td></tr>
<tr><td>Stated</td><td>Not valid</td><td colspan="2">Weak</td></tr>
</table>

<table>
<tr><td rowspan="2">Study information</td><td>Author and year</td><td>Study title</td><td colspan="2">Peer reviewed? Y/N</td></tr>
<tr><td>Wang Q., Feng C., Zhao Y., Hao C. (2009)</td><td>Denitrification of nitrate contaminated groundwater with fiber-based biofilm reactor</td><td colspan="2">Yes</td></tr>
<tr><td rowspan="5">Groundwater</td><td>Location</td><td>Groundwater resource details</td><td colspan="2">Inclusion/exclusion criteria</td></tr>
<tr><td rowspan="4">Qinghe, Beijing</td><td rowspan="4">56.82mg/L</td><td>Developing country</td><td>Y</td></tr>
<tr><td>Groundwater</td><td>Y</td></tr>
<tr><td>Listed method</td><td>Y</td></tr>
<tr><td>Outcome</td><td>Y</td></tr>
<tr><td rowspan="2">Nitrate removal</td><td>Type of removal method</td><td>Description of method</td><td colspan="2">Description of comparator/control</td></tr>
<tr><td>Biological denitrification</td><td>Anaerobic sludge poured into reactor where bacteria use methanol as terminal electron acceptor.</td><td colspan="2">To allow a comparison with other biological denitrification systems (including single heterotrophic, single autotrophic, bioelectrochemical, three-dimensional, and combined reactors), the main operational parameters at the best removal capacity for each reactor type</td></tr>
<tr><td rowspan="2">Methods of analysis of removal</td><td colspan="2">Objectives</td><td colspan="2">Method of data collection and analysis</td></tr>
<tr><td colspan="2">The aim of the present study is to investigate the performance of the fiber-based biofilm reactor, and to optimize the running parameters of the reactor to treat nitrate contaminated groundwater.</td><td colspan="2">NO_3^-–N, NH_3^-N and NO_2^-–N were determined by ultraviolet spectrophotometer (HACH, DR5000) according to standard methods</td></tr>
<tr><td rowspan="2">Results (Intervention)</td><td colspan="4">Concentration of nitrate in groundwater:</td></tr>
<tr><td colspan="4">56.82mg/L to 0.00mg/L (100%)</td></tr>
<tr><td rowspan="2">Study Quality</td><td>Outcome</td><td>Quality</td><td colspan="2">Overall</td></tr>
<tr><td>Stated</td><td>Valid</td><td colspan="2">Strong</td></tr>
</table>

<table>
<tr><td rowspan="2">Study information</td><td>Author and year</td><td>Study title</td><td colspan="2">Peer reviewed? Y/N</td></tr>
<tr><td>Qian J., Wang Z., Jin S., Yong L., Chen T. and Fallgren P.H. (2011).</td><td>Nitrate removal from groundwater in columns pack with reed and rice stalks</td><td colspan="2">Yes</td></tr>
<tr><td rowspan="5">Groundwater</td><td>Location</td><td>Groundwater resource details</td><td colspan="2">Inclusion/exclusion criteria</td></tr>
<tr><td rowspan="4">Anhui, China</td><td rowspan="4">50mg/L (NO_3-N)
269.93mg/L (NO_3)</td><td>Developing country</td><td>Y</td></tr>
<tr><td>Groundwater</td><td>Y</td></tr>
<tr><td>Listed method</td><td>Y</td></tr>
<tr><td>Outcome</td><td>Y</td></tr>
<tr><td rowspan="2">Nitrate removal</td><td>Type of removal method</td><td>Description of method</td><td colspan="2">Description of comparator/control</td></tr>
<tr><td>Biological denitrification</td><td>Reed and rice stalks as solid substrates</td><td colspan="2">Not evident</td></tr>
<tr><td rowspan="2">Methods of analysis of removal</td><td colspan="2">Objectives</td><td colspan="2">Method of data collection and analysis</td></tr>
<tr><td colspan="2">The objective of this study was to determine if reed and rice stalks in a bioreactor could serve as an effective substrate to sustain and enhance denitrification in groundwater, therefore intercepting the groundwater with high nitrate concentrations that flows into the Chaohu Lake.</td><td colspan="2">Nitrate determination was carried out using the standard ultraviolet (UV) spectrophotometric method</td></tr>
<tr><td rowspan="2">Results (Intervention)</td><td colspan="4">Concentration of nitrate in groundwater:</td></tr>
<tr><td colspan="4">269.93mg/L to 31.12mg/L (88.5%)</td></tr>
<tr><td rowspan="2">Study Quality</td><td>Outcome</td><td>Quality</td><td colspan="2">Overall</td></tr>
<tr><td>Stated</td><td>Not valid</td><td colspan="2">Weak</td></tr>
</table>

Study information	Author and year	Study title	Peer reviewed? Y/N	
	Chen Y-x. , Zhang Y. and Liu H-y. (2003)	Reduction of nitrate from groundwater: powder catalysts and catalytic membrane	Yes	
Groundwater	Location	Groundwater resource details	Inclusion/exclusion criteria	
	Hangzhou, China	100mg/L	Developing country	Y
			Groundwater	Synthetic
			Listed method	Y
			Outcome	Y
Nitrate removal	Type of removal method	Description of method	Description of comparator/control	
	Catalytic reduction	Catalytic nitrate reduction adding Pd and Cu membrane	*Not evident*	
Methods of analysis of removal	Objectives		Method of data collection and analysis	
	The objective of the present work is to show possible ways to improve the catalytic nitrate reduction in activity and selectivity, and decide the optimum reaction conditions.		Samples were periodically taken out from the suspension and analysed after filtered by 0.45μm filter film. Concentrations of NO_3^- and NO_2^- anions in catalytic experiments were analysed with Dionex-120 by ion chromatograph	
Results (Intervention)	Concentration of nitrate in groundwater:			
	100mg/L to 10.6mg/L (89.4%)			
Study Quality	Outcome	Quality	Overall	
	Stated	Not valid	weak	

Study information	Author and year	Study title	Peer reviewed? Y/N	
	Lacasa E., Canizares P. Sáez C., Fernández F. J. and Rodrigo M.A. (2011)	Removal of nitrates from groundwater be electrocoagulation	Yes	
Groundwater	Location	Groundwater resource details	Inclusion/exclusion criteria	
	Spain	25mg/L	Developing country	N
			Groundwater	Synthetic
			Listed method	Y
			Outcome	N
Nitrate removal	Type of removal method	Description of method	Description of comparator/control	
	Coagulation	As to the electrochemical experiments, the coagulant reagent was derived from the dissolution of iron or aluminium electrodes that had been placed in a single compartment electrochemical flow cell	*Not evident*	
Methods of analysis of removal	Objectives		Method of data collection and analysis	
	The goal of this work was to increase the knowledge on the removal of nitrates through electrocoagulation and to go into the mechanisms that this process involves. The performances of the coagulation and electrocoagulation processes were compared to one another in order to identify the highest nitrate removal efficiencies using the lowest necessary coagulant dosages.		Nitrate ions were characterized using ion chromatography	
Results (Intervention)	Concentration of nitrate in groundwater:			
	Not evident			
Study Quality	Outcome	Quality	Overall	
	Not stated	Not valid	Very weak	

Study information	Author and year	Study title	Peer reviewed? Y/N	
	Liu H.B., Chen T.H., Chang D.Y., Chen D., Liu Y., He H.P. *et al*. (2012)	Nitrate reduction over nanoscale zero-valent iron prepared by hydrogen reduction of goethite	Yes	
Groundwater	Location	Groundwater resource details	Inclusion/exclusion criteria	
	Anhui province, China	120mg/L	Developing country	Y
			Groundwater	Synthetic
			Listed method	Y
			Outcome	Y
Nitrate removal	Type of removal method	Description of method	Description of comparator/control	
	Hydrogen reduction	Nanoscale zero-valent iron prepared by hydrogen reduction of natural geothite	In addition to compare with NZVI-N and NZVI-H under different pH for reduction of nitrate, OZVI was bought from Tianjin Jixing with grain size of 0.074 mm or so.	
Methods of analysis of removal	Objectives		Method of data collection and analysis	
	In this paper, the effect of reaction time, nitrate concentration, iron-to-nitrate rate on nitrate removal rate over NZVI-H and NZVI-N was investigated.		NO_3^-: UV (ultraviolet) spectrophotometry	
Results (Intervention)	Concentration of nitrate in groundwater:			
	120mg/L to 32.4mg/L 73%			
Study Quality	Outcome	Quality	Overall	
	Stated	Valid	Strong	

Study information	Author and year	Study title	Peer reviewed? Y/N	
	Sierra-Alvarez R., Beristain-Cardoso R., Margarita S., Gómez J., Razo-Flores E. a d Field J.A. (2007).	Chemolithotrophic denitrification with elemental sulfur for groundwater treatment	Yes	
Groundwater	Location	Groundwater resource details	Inclusion/exclusion criteria	
	Not stated	102mg/L	Developing country	N
			Groundwater	Y
			Listed method	Y
			Outcome	N
Nitrate removal	Type of removal method	Description of method	Description of comparator/control	
	Denitrification	A packed-bed bioreactor supplied with S^0:limestone granules (1:1, v/v) was started up utilizing a chemolithotrophic denitrifying enrichment culture in the form of biofilm granules that was pre-cultivated on thiosulfate.	Controls lacking inoculum were run in parallel to monitor the possible abiotic degradation of the electron donor and electron acceptor.	
Methods of analysis of removal	Objectives		Method of data collection and analysis	
	The purpose of this study is to investigate the kinetics of denitrification linked to elemental sulfur under varying nitrate and elemental sulfur levels, and to demonstrate the feasibility of autotrophic denitrification with elemental sulfur for the removal of nitrate at concentrations comparable to those found in contaminated groundwater.		Nitrate, nitrite, sulfate and thiosulfate were determined by ion chromatography	
Results (Intervention)	Concentration of nitrate in groundwater:			
	‘Near complete’			

Study Quality	Outcome	Quality	Overall
	Not stated	Valid	Very weak

Study information	Author and year	Study title	Peer reviewed? Y/N	
	Wang X. M. and Wang J. L. (2013).	Nitrate removal from groundwater using solid-phase denitrification process without inoculating with external microorganisms	Yes	
Groundwater	Location	Groundwater resource details	Inclusion/exclusion criteria	
	Beijing, China	50mg/L NO_3-N 221mg/L NO_3	Developing country	Y
			Groundwater	Synthetic
			Listed method	Y
			Outcome	Y
Nitrate removal	Type of removal method	Description of method	Description of comparator/control	
	Biological denitrification	Solid carbon source used made from reed and sugar cane. Main component is cellulose	*Compared with 11 other studies using solid carbon sources*	
Methods of analysis of removal	Objectives		Method of data collection and analysis	
	The main objective of this study is to investigate the efficiency of nitrate removal from groundwater using a continuous flow reactor packed with biodegradable snack ware (BSW) without inoculating with external microorganisms.		The filtrate was subjected to analyses of concentrations of NO_3-N, NO_2-N, ammonia and DOC according to standard methods	
Results (Intervention)	Concentration of nitrate in groundwater:			
	100%			
Study Quality	Outcome	Quality	Overall	
	Stated	Valid	Strong	

<table>
<tr><td rowspan="2">Study information</td><td>Author and year</td><td>Study title</td><td colspan="2">Peer reviewed? Y/N</td></tr>
<tr><td>Hekmatzadeh A.A, Karimi-Jashani A., Talebbeydokhti N. and Klove B. (2012).</td><td>Modelling of nitrate removal for ion exchange resin in batch and fixed bed experiments</td><td colspan="2">Yes</td></tr>
<tr><td rowspan="5">Groundwater</td><td>Location</td><td>Groundwater resource details</td><td colspan="2">Inclusion/exclusion criteria</td></tr>
<tr><td rowspan="4">Shiraz, Iran</td><td rowspan="4">63.3mg/L</td><td>Developing country</td><td>Y</td></tr>
<tr><td>Groundwater</td><td>Y</td></tr>
<tr><td>Listed method</td><td>Y</td></tr>
<tr><td>Outcome</td><td>Y</td></tr>
<tr><td rowspan="2">Nitrate removal</td><td>Type of removal method</td><td>Description of method</td><td colspan="2">Description of comparator/control</td></tr>
<tr><td>Ion exchange</td><td>A nitrate selective ion exchange resin named IND NSSR was obtained from Ion Exchange India LTD. This material is a macroporous strongly basic anion resin that is suitable for the removal of nitrate from water.</td><td colspan="2">It is important to note that few comparisons have been done between empirical and theoretical equilibrium models for ion exchange resins. Model parameters were estimated and compared to those obtained in equilibrium experiments.</td></tr>
<tr><td rowspan="2">Methods of analysis of removal</td><td colspan="2">Objectives</td><td colspan="2">Method of data collection and analysis</td></tr>
<tr><td colspan="2">The aim of the present research is to study and model the removal of nitrate from synthetic solutions and groundwater through the use of a selective ion exchange resin called IND NSSR in both batch and fixed bed systems</td><td colspan="2">Nitrate ions were analyzed using a UV spectrophotometer instrument (HACH DR/5000) at a wavelength of 220 nm.</td></tr>
<tr><td rowspan="2">Results (Intervention)</td><td colspan="4">Concentration of nitrate in groundwater:</td></tr>
<tr><td colspan="4">63.3mg/L to 60.4mg/L (95.4%)</td></tr>
<tr><td rowspan="2">Study Quality</td><td>Outcome</td><td>Quality</td><td colspan="2">Overall</td></tr>
<tr><td>Stated</td><td>Valid</td><td colspan="2">Strong</td></tr>
</table>

Study information	Author and year	Study title	Peer reviewed? Y/N	
	Lin Y-F., Jing S-R., Lee D-Y., Chang Y-F. and Shih K-C. (2008)	Nitrate removal from groundwater using constructed wetlands under various hydraulic loading rates	Yes	
Groundwater	Location	Groundwater resource details	Inclusion/exclusion criteria	
	Tainan County, Taiwan	*Not evident*	Developing country	Y
			Groundwater	N
			Listed method	Y
			Outcome	Y
Nitrate removal	Type of removal method	Description of method	Description of comparator/control	
	Biological denitrification	Constructed wetland with anoxic environment for biological denitrification	*Not evident*	
Methods of analysis of removal	Primary/secondary outcomes		Method of data collection and analysis	
	The objectives of the study were to (1) compare the discrepancy in nitrate removal performance between the different types of constructed wetlands operated identically, (2) investigate the effects of HLR and NLR on nitrate removal of the constructed wetlands and (3) determine the best fitting nitrate removal reaction model using internal longitudinal transect data.		Water samples were analysed for NH_4–N, NO_2–N, NO_3–N and PO_4–P contents by an ion chromatograph	
Results (Intervention)	Concentration of nitrate in groundwater:			
	95%			
Study Quality	Outcome	Quality	Overall	
	Stated	Not valid	Very weak	

<table>
<tr><td rowspan="2">Study information</td><td>Author and year</td><td>Study title/aims</td><td colspan="2">Peer reviewed? Y/N</td></tr>
<tr><td>Rajakumar S., Ayyasamy P.M, Shanthi K., Thavamanu P., Velmurugan P. Song Y.C. et al. 2008.</td><td>Nitrate removal efficiency of bacterial consortium (Pseudomonas sp. KW1 and Bacillus sp. YW4) in synthetic nitrate rich water</td><td colspan="2">Yes</td></tr>
<tr><td rowspan="5">Groundwater</td><td>Location</td><td>Groundwater resource details</td><td colspan="2">Inclusion/exclusion criteria</td></tr>
<tr><td rowspan="4">Tamil Nadu, India. Kodaikanal and Yercaud lakes.</td><td rowspan="4">100mg/L</td><td>Developing country</td><td>Y</td></tr>
<tr><td>Groundwater</td><td>Synthetic</td></tr>
<tr><td>Listed method</td><td>Y</td></tr>
<tr><td>Outcome</td><td>Y</td></tr>
<tr><td rowspan="2">Nitrate removal</td><td>Type of removal method</td><td>Description of method</td><td colspan="2">Description of comparator/control</td></tr>
<tr><td>Biological denitrification</td><td>Different carbon substrates such as glucose, starch, cellulose, sucrose and acetic acid</td><td colspan="2">The sterilised synthetic medium without any carbon source was maintained as control to compare the efficiency of carbon source on nitrate removal by bacterial species.</td></tr>
<tr><td rowspan="2">Methods of analysis of removal</td><td colspan="2">Objectives</td><td colspan="2">Method of data collection and analysis</td></tr>
<tr><td colspan="2">The aim of the present paper was to investigate the applicability of the aerobic mixed bacterial cultures (KW1 + YW4) isolated from lake water and sediment for high rate nitrate reduction from synthetic wastewater</td><td colspan="2">Not evident</td></tr>
<tr><td rowspan="2">Results (Intervention)</td><td colspan="4">Concentration of nitrate in groundwater:</td></tr>
<tr><td colspan="4">100mg/L to 0.6mg/L (99.4%)</td></tr>
<tr><td rowspan="2">Study Quality</td><td>Outcome</td><td>Quality</td><td colspan="2">Overall</td></tr>
<tr><td>Stated</td><td>Not valid</td><td colspan="2">Weak</td></tr>
</table>

Study information	Author and year	Study title	Peer reviewed? Y/N	
	Samatya S., Kabay N., Yüksel Ü., Arda M and Yüksel M. (2006).	Removal of nitrate from aqueous solution by nitrate selective ion exchange resins	Yes	
Groundwater	Location	Groundwater resource details	Inclusion/exclusion criteria	
	Manisa, Turkey	195mg/L	Developing country	Y
			Groundwater	Y
			Listed method	Y
			Outcome	Y
Nitrate removal	Type of removal method	Description of method	Description of comparator/control	
	Ion exchange	The aqueous solutions and ground water sample was delivered down-flow to the column at a flow rate of SV (space velocity) of 20 h_1 using a peristaltic pump	*Not evident*	
Methods of analysis of removal	Objectives		Method of data collection and analysis	
	The aim of this work is to present experimental results on the removal of nitrate by nitrate selective ion exchange resin, Purolite A 520E.		The analyses of nitrate, chloride, and sulfate ions we carried using a Shimadzu model ion chromatography equipment (Model LC 10 A*i*).	
Results (Intervention)	Concentration of nitrate in groundwater:			
	195mg/L to 7.65mg/L (96.1%)			
Study Quality	Outcome	Quality	Overall	
	Stated	Not valid	Weak	

Study information	Author and year	Study title	Peer reviewed? Y/N	
	Wang X.M. and Wang J.L. (2012)	Denitrification of nitrate-contaminated groundwater using biodegradable snack ware as carbon source under low-temperature condition	Yes	
Groundwater	Location	Groundwater resource details	Inclusion/exclusion criteria	
	Beijing, China	Obtained from around 50mg/L of NO_3-N in the influent 221mg/L NO_3	Developing country	Y
			Groundwater	Synthetic
			Listed method	Y
			Outcome	Y
Nitrate removal	Type of removal method	Description of method	Description of comparator/control	
	Biological denitrification	The reactor was packed with 60 g of BSW as carbon source and biofilm support.	*Not evident*	

Methods of analysis of removal	Objectives	Method of data collection and analysis
	The main objective of this study was to investigate the denitrification performance of a continuous-flow reactor packed with BSW as carbon source under a low-temperature condition (12°C)	The filtrate was subjected to analyses of concentrations of NO_3-N, NO_2-N, ammonia and DOC according to standard methods
Results (Intervention)	Concentration of nitrate in groundwater:	
	50mg/L to 0mg/L (100%)	

Study Quality	Outcome	Quality	Overall
	Stated	Not valid	Weak

Study information	Author and year	Study title	Peer reviewed? Y/N	
	Hong S., Zhang J. Feng C., Zhang B and Ma P. (2012).	Enhancement of nitrate removal in synthetic groundwater using wheat rice stone	Yes	
Groundwater	Location	Groundwater resource details	Inclusion/exclusion criteria	
	Beijing	100mg/L (NO_3-N) 442mg/L NO_3	Developing country	Y
			Groundwater	Synthetic
			Listed method	Y
			Outcome	Y
Nitrate removal	Type of removal method	Description of method	Description of comparator/control	
	Biological denitrification	Water passed through columns operated under anoxic conditions	*Not evident*	
Methods of analysis of removal	Objectives		Method of data collection and analysis	
	The objective of this laboratory study was to evaluate the enhancement of denitrification using WRS and GAC as biofilm carriers without phosphor and trace elements added under different hydraulic retention times (HRT) and C/N ratios.		The $NO3^-$-N was determined using a UV spectrophotometer (HACH, DR 5000)	
Results (Intervention)	Concentration of nitrate in groundwater:			
	442mg/L to 6.63mg/L (98.5%)			
Study Quality	Outcome	Quality	Overall	
	Stated	Not valid	Weak	

Study information	Author and year	Study title	Peer reviewed? Y/N	
	Zhao Y., Feng C., Wang Q., Yang Y., Zhang Z., and Sigiura N. (2011).	Nitrate removal from groundwater by cooperating heterotrophic with autotrophic denitrification in a biofilm-electrode reactor	Yes	
Groundwater	Location	Groundwater resource details	Inclusion/exclusion criteria	
	Beijing, China	50mg/L (NO_3-N) 221mg/L NO_3	Developing country	Y
			Groundwater	Synthetic
			Listed method	Y
			Outcome	Y
Nitrate removal	Type of removal method	Description of method	Description of comparator/control	
	Biological denitrification	Sewage sludge used for biofilm in reactor	To allow a comparison with other biological denitrification systems (including single heterotrophic, single autotrophic, bioelectrochemical, three-dimensional, and combined reactors), the main operational parameters at the best removal capacity for each reactor type are summarized in Table 1.	
Methods of analysis of removal	Objectives		Method of data collection and analysis	
	The objective of this work was to investigate the effect of HRT, carbon to nitrogen ratios (C/Ns), and electric current (I) on nitrate remediation and to optimize the operating parameters of the reactor for cooperative heterotrophic denitrification and autotrophic denitrification.		NO_3^-–N, NH_3^-N and NO_2^-–N were determined by ultraviolet spectrophotometer	
Results (Intervention)	Concentration of nitrate in groundwater:			
	221mg/L to ~7mg/L (97%)			

Study Quality	Outcome	Quality	Overall
	Stated	Valid	Strong

Appendix 5

This is the protocol, which was written with the aims to outline the process of the systematic review.

Nitrates in Groundwater: Systematic Review Protocol

1. Introduction

This report aims to show what has been achieved so far for this research project and what is yet to be finished. It outlines a protocol for the study and it will also discuss the problems encountered since the start of the project.

1.1. Background and literature review

Nitrates are anions that are highly soluble in water and are found naturally in water courses/bodies. Typically, industrial regions have greater concentrations than rural areas (WHO, 2011). However, many groundwater sources are contaminated with elevated concentrations of nitrate due to leaching and run-off, which has health implications for humans and livestock, and leads to algal blooms in water bodies. Nitrates are found in groundwater largely due to the increased application of inorganic fertilisers to increase crop yields. The other causes of nitrates in groundwater are wastewaters that contain biological waste.

Groundwater is abstracted for human drinking water use but may also be used for irrigation and livestock drinking water. In humans, nitrate poisoning leads to methaemoglobinemia which is more commonly known as blue-baby syndrome (Bhatnagar and Sillanpää, 2011). This occurs when nitrate is reduced to nitrite in the gastrointestinal tract; the nitrite converts Fe^{2+}found in haemoglobin, which usually binds oxygen, to Fe^{3+} which cannot join with oxygen (O'Neill, 1985). Methaemoglobinemia occurs in adults and older children but is especially severe in infants younger than 6 months. This is because of the microbial colonies in the gut of infants favour the pH for nitrate reduction (McDonald and Kay, 1988). In livestock such as cattle, nitrate poisoning is very quick and cattle may die within a day of consuming contaminated water (Bhatnagar and Sillanpää, 2011). Additionally, amino acids in the human digestive tract can react with the nitrite that is formed from nitrate ingestion creating nitrosamines which are carcinogenic (O'Neill, 1985).

There are physical processes to remove nitrate from groundwater, including ion exchange and reverse osmosis and biological processes using microorganisms, known as denitrification (Gómez *et al.*, 2000).

Ion exchange processes use resins to exchange nitrate with either bicarbonate or chloride ions. However, this leads to waste waters containing the nitrate and the exchanged ions (Reddy and Lin, 2000). Consequently, this waste brine needs treating as a result of its corrosive nature (Bhatnagar and Sillanpää, 2011). Ion exchange is preferred by some for the removal of nitrates because of the lower financial cost compared with alternative removal processes (Canter, 1996). Reverse osmosis is another intervention employed to remove nitrates. This process involves increasing the pressure within a reverse osmosis cell and forcing the water contaminated with nitrate through a semi-permeable membrane which is constructed to withstand these high pressures (Canter, 1996).

Biological denitrification turns nitrate into harmless nitrogen gas through stepwise reduction as follows:

$$NO_3^- \rightarrow NO_2^- \rightarrow NO \rightarrow N_2O \rightarrow N_2$$

Liquid carbon substrates are inputted into the contaminated waters for the denitrifying bacteria to use as an energy source with nitrate being the terminal electron acceptor (Soares and Abeliovich, 1998). While organic carbon substances such as methanol and acetate are widely used, cheaper cellulosic materials are also an option (Volokita *et al.*, 1996). Elemental sulphur can also be used as an energy source for biological denitrification because it is not toxic or expensive (Soares, 2002). Using microorganisms to remove nitrate biologically is temperature dependent (Bhatnagar and Sillanpää, 2011). Methanol has been proposed as producing the highest denitrification results but this may still contaminate the water if it is used for drinking water purposes (Shrimali and Singh, 2001).

It is important to investigate nitrate contamination in developing countries because they have an increasing agricultural industry growing cash crops, biofuel feedstock crops as well as food to sustain them. As a result of rapid development, agriculture has grown enormously with consequent increased use of nitrate heavy fertilisers. This increases the risk of run-off and leaching into watercourses. Many of these developing countries also lack the infrastructure for drinkable water so groundwater is often abstracted for drinking. Around one third of the global population use groundwater as their main water supply (UNEP, 2002). Some may even be using private wells which have an increased risk of contamination from agricultural run-off and untreated sewage waste (WHO, 2011). Additionally, reduced access to healthcare makes these populations more vulnerable to the effects of methaemoglobinemia and the presence of pre-existing medical conditions increases the chance of the condition developing (McDonald and Kay, 1988).

2. Objectives of the review

This project is a systematic review of the interventions to remove nitrates from groundwater in developing countries.

Primary question: Are the current interventions to reduce the impact of nitrate contamination in groundwater in the developing world effective?

Secondary question: By which criteria are these interventions considered effective?

The objective of this study is to collect secondary data of relevant studies through searching of databases and the web to determine whether interventions are effective.

3. Methods

Many searches were undertaken to find relevant information; these have revealed an extensive range of diverse information and literature. Additionally, to widen the understanding of the actual techniques used and background knowledge of the subject, material has been read that explains the methods of removing nitrates.

3.1. Scoping

A preliminary scoping exercise was undertaken to establish how much literature is available. In scoping the literature, Web of Science, Primo and Google Scholar were used to search but have concluded that the limited scope of Primo makes it unsuitable for a project of this nature. The search syntaxes were varied to gain more and wider results but this process of varying search terms will be refined for the data collection process.

3.2. Searching and syntax

Many search terms have been used in the scoping exercise. The first search in Web of Science contained “remove nitrate *water China” but this did not raise enough results so the study was broadened to include the developing world, as well as China. Through preliminary scoping it was found that search syntaxes have to be varied in order to produce the most relevant results.

The full search will follow a systematic process to find the best subsets of studies. This process is hierarchical starting with broad search terms that are refined within each search. Using Web of Knowledge and searching topics produces the most results which need to be narrowed.

1. Broad topic search term: ‘nitrate AND (water OR groundwater)’
2. Location: ‘China’
3. Process: ‘removal OR reduction’
4. Further refine: ‘contamination OR removal’
5. Key intervention: ‘ion exchange’
6. Further refine: ‘review’

This search process was carried out as part of the scoping exercise and will be the process followed during the full search. Each step reduces the number if results but increases the relevance of results. Once the keywords are finalised through this process in Web of Knowledge, they will also be searched in Google Scholar and Google for NGOs and government sites.

The searching also included citation chasing within studies. Searches of printed literature were also undertaken in Primo and books.

Project searches will include developing countries and this will be done in Web of Science using the advanced search tools to only include studies from certain countries. What constitutes a developing country has been determined using information from The International Statistics Institute, which groups countries using World Bank information on Gross National Income per capita. From this list, the 18 most common countries from the results of the Web of Science search for “nitrate groundwater”.

Table 1 – Countries included in developing

Algeria	Argentina	Bangladesh	Brazil	Chile	China
Ghana	India	Iran	Malaysia	Mexico	Nigeria
Pakistan	Philippines	Taiwan	Thailand	Tunisia	Turkey

3.3. Limits

Searches will only include studies in English as foreign language studies can lead to translation errors. Only studies dated 1980 onwards will be used. This will allow for comparison against countries that were developing but are now considered developed.

3.4. Search results

The materials found are exported into EndNote X2 to facilitate the searching of titles and abstracts looking for relevant studies. This will be the method for finding the literature to use in the final search, by picking out key words from those saved into EndNote. Also recorded is the search syntax that found this result and the search engine/database used.

3.5. Study inclusion and quality

Studies imported into EndNote will be assessed for keywords in their titles and abstracts. Where these keywords are found, the full study will be examined. Selecting key words is a subjective process and will require a significant number of studies to ensure there is a satisfactory amount.

The studies will be screened for the population, the intervention, comparisons and the outcome (PICO). The populations are those in the developing countries. The intervention is the technology implemented to remove nitrates. The comparisons are the other interventions used and the outcome is if the groundwater concentration of nitrate is lower than the WHO guideline of 50mg/L.

Duplicated studies will be excluded.

4. Problems encountered

Having undertaken the scoping exercise to ensure there was adequate literature about the topic, it was decided to adapt the subject of this study and thus primary question. Therefore, the initial primary question has changed from “Are interventions to reduce the impact of nitrate contamination in groundwater on human health in Northern China effective?” to “Are interventions to reduce the impact of nitrate contamination in groundwater on human health in the developing world effective?”. Whilst there is literature surrounding nitrate contamination of groundwater in Northern China, a region deeply affected by nitrate contamination, there is not enough literature relating to interventions and removal methods.

5. Future work

The structure of the report will be a systematic review and as such will follow this structure:

1. Abstract
2. Introduction
    - 2.1. Aims and objectives (primary and secondary questions)
    - 2.2. Rationale

2.3.Background and literature
3. Methods including protocol
3.1. Search process and syntax
3.2. Quality evaluation
3.3. Data extraction and interpretation
4. Results and presentation of data
5. Discussion
6. Conclusions
6.1. Summary and conclusions drawn
6.2. Further studies and improvements
7. References
8. Appendices

6. References

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