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**Technical and Economical Assessment of
Ion exchange and Reverse Osmosis for
Removal of Ammonium from
Groundwater of Kathmandu, Nepal**

네팔 카트만두 지하수에서 암모늄 제거를 위한 이온 교환 및
역삼 투의 기술 및 경제 평가

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Abstract

Technical and Economical Assessment of Ion exchange and Reverse Osmosis for Removal of Ammonium from Groundwater of Kathmandu Nepal

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Groundwater plays a major role in fulfilling the daily water demand of Kathmandu however, presence of ammonia in very high concentration; 0-120 mg/L makes it unsuitable for drinking as it exceeds the 1.5 mg/L ammonium drinking water standard provided by WHO and Nepal drinking water quality standard (NDWQS). The concentration of ammonia varies throughout the groundwater but mostly high concentrations were recorded in the deep groundwater sources (max 120 mg/L) rather than shallow ground water (max 15 mg/L) (Chapagain et al., 2010). The reason behind the dramatically high concentration in deep ground water was studied to be influenced by the deposits of fluvial lacustrine sediments in a reducing environment. Presence of high concentration of ammonia in drinking water causes aesthetic problem and it also limits the use of chlorination as a water treatment method, so its removal is necessary. However very limited studies have been carried out to address this widely discussed issue, hence in our study we have tried to solve this problem by evaluating two of the most plausible

household ammonium removal technology; Ion exchange (IE) and Reverse Osmosis (RO). The study evaluated their performance based on the technical and the economical perspective with the synthetically prepared groundwater composition of Kathmandu in varying ammonium concentration (50mg/L and 15 mg/L). As a result, it was found that IE was comparatively a better ammonium removal technology with 100% ammonia removal even after regeneration than compared to RO whose removal was limited only up to 90%. Furthermore, on cost analysis our study suggests IE to be the most suitable ammonium removal technology for places with lower water consumption (< 50 L/day) like households whereas, RO seemed to be cost effective technology for places with higher water consumption like restaurants, Schools and Communities whose daily water demand exceeds more than >50L/day. Lastly it was also observed that installing a suitable household treatment system can save a lot of money than purchasing commercial water for the longer run.

Keywords: groundwater of Kathmandu, ammonia removal, adsorption.

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Chapter 1. Introduction

1.1 Research Background

The increasing population, modern lifestyle, urbanization, increased economy has amplified the demand of water within the Kathmandu Valley. However, the degrading condition of surface water within the valley and inadequate water supply from the Kathmandu Upatyaka Khanepani Limited (KUKL) has resulted in great dependency towards groundwater. Due to increasing demand of groundwater its water quality has always drawn a large attention among users, governments and researchers. Similarly, several studies have been carried highlighting the issues in groundwater's quality. Researchers have emphasized high level of ammonia ($\text{NH}_4\text{-N}$), iron (Fe), lead (Pb), arsenic (As), cadmium (Cd), E. coli, turbidity and organic matter in shallow and deep groundwater of Kathmandu crossing the drinking water standards by World Health Organization (WHO, 2011) and Nepal drinking water quality standards (NDWQS) (Khatiwada et al., 2002; JICA/ENPHO, 2005; Warner et al., 2008; Chapagain et al., 2010, Shrestha S. et al., 2012).

However, this study focuses only on removal of ammonium ion technology because it was noticed that despite its frequent occurrence and dramatically high concentration; (0-120 mg/L) (Chapagain et al., 2010) in groundwater only handful of studies had been carried out to cater this problem. Even though ammonia in water is not directly harmful for human body, concentration as high as that in drinking water is not recommended as by World Health Organization (WHO, 2011) and Nepal drinking water quality standards (NDWQS) as the permitted concentration of ammonia in drinking water is limited up to 1.5 mg/L.

On the other hand, high concentration of ammonia in drinking water causes esthetical problems, decreases chlorine disinfection efficiency, acts as a secondary source of methemoglobinemia (called as blue baby syndrome) for infants as a nitrite ion under its oxidative conditions and it is also susceptible to stomach cancer for adults (Khanitchaidecha et.al., 2012). Hence removal of ammonia is necessary in order to comply with the drinking water quality standards and avoid the formation of nitrates and nitrites as these forms can be a threat to human health.

Several ammonium removal technologies have been studied and tested over the past decades. Among all of them biological treatment, break point chlorination and air stripping are the most common methods for ammonia removal from water or waste water. (Bernet et al.,2000; Gupta et al., 2015, Guštin, S., & Marinšek-Logar, R. (2011); Xue et al., 2017; Huang et al., 2018). These methods are commonly applied for large scale like in water filtration plants, waste water systems, resource recovery and so on as it demands big infrastructure, skilled labor and technician and spacious place for operation. However, in our study these ammonium removal technologies were not considered as our study mainly focuses on household treatment options and they do not fit in the category. Hence, for the household two of the most plausible technologies were Ion exchange and Reverse Osmosis because of their small configuration, commercial availability and promising salt removal capacities . Hence these two technologies were evaluated in terms of ammonium removal and cost in our study.

Moreover, this study does not utilize a real ground water from a specific location in Kathmandu but instead operates with synthesized water similar to the composition of groundwater in Kathmandu. Due to varying ammonium concentration within the depth, two type of synthetic water were prepared representing the shallow and deep groundwater

conditions of ammonia i.e. 15mg/L and 50mg/L. Furthermore, some preliminary optimization experiments were carried out using batch configuration for Ion exchange and semi-batch for RO test in order to select the best operating conditions for the experiments. Long-term tests were carried out for IE and RO with varying synthetic solutions to observe their performance on ammonium removal. Then, cost was calculated based on the experimental results for both the technologies.

1.2 Objective

The main objective of this study was to evaluate the technical and economic aspects of using Ion exchange (IE) and Reverse Osmosis (RO) as two of the most plausible ammonium treatment methods for household configuration. The study as a whole aimed to provide a handful guide to all the users who are pondering around on choosing between proper household technologies for solving the ammonium problem in their drinking water.

Chapter 2: Literature Review

2.1 Background of the study area:

This study focuses on Kathmandu, the capital city of Nepal. It is located at 27.7172° N latitude and 85.3240° E Longitude of the geographical coordinates. The bowl-shaped valley consists of hills and flat lands at an elevation of 1,300-1,400 m with surrounding hills more than 2000m. The warm and temperate climate with annual precipitation of 1755mm during (June- September) provides the flora and fauna a favorable condition to flourish. Captivating climatic condition, ecstatic natural beauty, plentiful of water resources, cultivable land along with the suitable location for business within and cross country has allured many people in the past and present to reside within the valley. This has rapidly increased the urban population from mid-90's and resulted in unmanaged and haphazard settlement. The population swiftly elevated from 1.5 million in 2001, 2.42 million in 2011, 3.55 million in 2019 and is expected to cross 4 million by 2021(Udmale, Ishidaira et al. 2016). The accelerating population, urbanization and modernization has hence increased the water demand within the valley abruptly. Previously, the water demand was estimated to be between 80 to 100 Liter per capita day (LPCD) for the residents of Kathmandu but now it is estimated as 135 LPCD as per the statement of government of Nepal's capital investment and asset management program of 2010. Due to this reason the water stress in the valley is greatly felt and as a result dependency of groundwater has increased drastically as the surface water within the valley are not fit for secondary or primary usage.

2.2 Groundwater status in Kathmandu:

With the estimated 3.5 million population at the present day (4.94% annual population growth) (Udmale, Ishidaira et al. 2016), Kathmandu is facing one of its biggest challenges in supplying sufficient and potable drinking water to the residents. Estimating 135 Liter per capita day (LPCD) of water demand decided by the government of Nepal's capital investment and asset management program on 2010, the daily water demand crosses over 470 MLD (Million liters per day) for the Kathmandu Valley alone. The capital faces a major water deficit of 60-70 % when Kathmandu Upatyaka Khanepani Limited (KUKL) the only responsible governmental organization fails to fulfil the water demand facilitating only 150 MLD out of total water demand even at its maximum capacity. This has hence increased the groundwater dependency among residents of Kathmandu mainly from the mid 1970's. It was seen that large quantities of groundwater were being pumped by both private individuals and municipal authorities (Dixit et al., 2005). It was also noted that almost 50% of the municipal water needs are being fulfilled by the groundwater (Khatiwada et al., 2002). With this data it can be observed that groundwater plays a major role in fulfilling the daily water demand of residents in Kathmandu where it is not only used secondary purposes but also being deployed for primary purpose i.e. drinking and cooking.

Since, groundwater has been a major player in fulfilling the water demand of the residents of Kathmandu from a long period of time now, ground water quality has become a major concern among users, water practitioners, corporate houses, schools, hospitals, industries policy makers and researchers. Several studies have been carried out discussing about the groundwater quality and most of them have emphasized the poor condition of

groundwater due to high microbial content, turbidity, ammonia and iron (Jha et al., 1996; Khatiwada et al., 2002; Warner et al., 2008; Shrestha S. et al., 2012). These studies highlighted that the groundwater in Kathmandu Nepal is not suitable for drinking without an appropriate treatment. Moreover, the dramatically high concentration of ammonia varying from (0-120 mg/L) (Chapagain et al., 2010) in shallow and deep groundwater within the valley has been widely discussed in all of the previous groundwater quality papers. However, after quite a handful amount of literature review it was found that not many studies were done to cater this problem. Hence this study was carried out to address the geographically unique problem of high ammonium concentration in groundwater.

2.3 Sources of ammonia in groundwater of Kathmandu

High concentration of ammonia in groundwater of Kathmandu, Nepal has been addressed as one of the problematic issues in quality of water as it has been frequently reported in many previous studies (Jha et al., 1996; Khatiwada et al., 2002; Warner et al., 2008; Shrestha S. et al., 2012). More importantly the most cited groundwater quality paper by Chapagain et al., 2010 has reported the concentration of ammonia to be dramatically high in both shallow and deep groundwater samples. In that study concentration of ammonia varied from 0-16 mg/L in shallow groundwater (<85m depth) and 0-120 mg/L in deep groundwater (>85m depth) of Kathmandu. The sources of ammonia in shallow groundwater is possibly due to the anthropogenic causes brought by the contamination of leachate mixing of landfills, animal farming, improper waste disposal and so on. However, the concentration of ammonia in deep groundwater is seen much higher than that in the shallow groundwater even though the contamination is likely to happen that deep. Hence

on research it was found that the reason for surprisingly high concentration of ammonia in deep groundwater was to do with the natural hydrogeochemical environment; groundwater mineralization, decomposition of organic matter, and reduction of groundwater environment (Thanju, J. P, 2012).

2.4 Importance of ammonia removal from water

Despite the fact that ammonia is naturally found in environment as a part of the nitrogen cycle via bacterial processes in soil or from decomposition of organic matter, presence of ammonia in high concentration above 1.5 mg/L estimated by WHO and NDWQS is not permitted. WHO, 2003 claims the presence of ammonia in water indicates the possible bacterial, sewage and animal feces contamination. Similar, ammonia in water also cause a great esthetic problem in water as the threshold odor concentration of ammonia at alkaline pH is approximately 1.5 mg/L, while the taste threshold is 35 mg/L. According to the US EPA health risk assessment model, human health risk caused by ammonia content in drinking water is very low (Qin et al., 2011). However, in case of groundwater in Kathmandu ammonium concentration are as high as up to 80 times the concentration permitted by WHO or NDWQS standards. These high concentration limits the use of chlorine as a disinfection because for every mg of ammonia it requires 10-15 mg of chlorine to react and reaction of ammonia is faster than the rate chlorine kills bacteria hence decreasing the for disinfection by the formation of chloramines (Pressley et al.,1972)

Moreover, ammonia changes in to nitrite ions under oxidative conditions and nitrite is a toxic component as it disables the enzyme lactase in the blood cells, causing hydrogen-

peroxide release. This as a result, oxidizes the divalent iron in hemoglobin in to trivalent iron. Iron (III) containing hemoglobin connects to oxygen with stable ionic bond, which makes oxygen transport impossible, and therefore cause hypoxia or blue baby syndrome. Due to the harmful effect of nitrite, the maximum allowable concentration is 1.5 mg/L.

2.5 Ammonium removal methods

As described in the above paragraphs, ammonia is a commonly found compound in natural environment hence presence of some amount of ammonia in any kind of raw water sources are inevitable. However, high concentration of ammonia in water causes adverse effects on quality of water sources via eutrophication or algal bloom. It is also known toxic to fish, is esthetically unpleasant for drinking and also its oxidative states vary with respect to environment forming nitrates and nitrites which are more prone for adverse health effects to human. This is why, ammonium treatment methods have been widely explored for the past few decades. Some of the prevalent physical, chemical and biological treatment processes include break-point chlorination, chemical precipitation, ion exchange, adsorption , reverse osmosis, air/steam stripping, supercritical water oxidation, electrochemical method and biofiltration treatment, (Bermejo et al., 2008; Bernet et al., 2000; Bodalo et al., 2005; Booker et al., 1996; Guštin and Marinšek-Logar, 2011; Huang et al., 2015a; Lin et al., 2009; Siegrist, 1996; Turan, 2016). All of these above-mentioned treatments have advantages and disadvantages over ammonia removal however a technology is chosen according to user's need and circumstances. And since this study focuses only on household treatment options, some of the limitation of using technologies like break point chlorination, chemical precipitation, air stripping, microwave radiation, super critical oxidation, electrochemical method and biological

treatments include production of disinfectant byproducts, large chlorine consumption, demand of skilled labors, pH dependent, introduction to new pollutants, demand of large infrastructures and space, time consuming process, temperature dependent, some are still in Research and development phase and some are not commercially available (Huang et al.,2018).

On the other hand, out of all these technologies Ion exchange(IE) and Reverse Osmosis(RO) turns out to be the two of the most plausible option for a household configuration as they occupy less space, are relatively small in size, has faster removal rates, simplicity of application and operation, does not demand high skilled labor for operation , are commercially and readily available everywhere, easy to install and can be operated by anyone with little or no knowledge and lastly have promising salt removal capacities. Hence, in this study we have utilized IE and RO as the treatment methods for addressing the ammonium problem in groundwater of Kathmandu.

2.6 Principle of Ion exchange system

Like absorption and adsorption, ion exchange is also a part of sorption process. Ion-exchange process for water treatment is one of the conventionally used purification process with the flexibility to be used as Point of use (POU), Point of entry (POE) or even in municipal scale configuration. It works by adsorbing and exchanging the ions of interest for example; $\text{NH}_4^+\text{-N}$ from the aqueous solution exchanged with the corresponding mobile co-ion (Na^+) which is attached with the fixed chain of counter ion (SO_3^- present in the solid material of the ion exchanger. Although the term ion exchange usually refers to applications of synthetic (man-made) resins, it can be either be natural

or synthetic. There are basically two types of ion exchange; Cation exchange and anion exchange. Both of these ion exchangers work in the same principle however, both of them are utilized in different ways such as cation exchangers are used for elimination or purification of cations like Ca_2^+ , Mg_2^+ or $\text{NH}_4^+\text{-N}$ from the aqueous solution whereas anion exchangers are used for the purification process of anionic groups like fluoride, arsenic or even organic matter. The difference between cation and anion exchangers are the functional groups attached to their polymeric chain or structural framework. Moreover, these two types of ion exchangers are further categorized into four sub categories. For cation exchangers the two sub categories are; strongly acidic (e.g., sulfonate $-\text{SO}_3^-$) and weakly acidic (e.g., carboxylate $-\text{CO}_3^-$) cationic exchangers whereas the sub categories for anion exchangers are also strongly basic (e.g., quaternary amine, $-\text{N}^+(\text{CH}_3)_3$); and weakly basic ($-\text{N}^+(\text{CH}_3)_2$) anionic exchangers.

In our study we utilize few of natural and polymeric cation exchange resin in order to eliminate ammonium ion from the target water. Few examples of natural cation exchangers include soil, varieties of zeolite and clinoptilolite and that for polymeric cation exchange resins include Dowex HCR S/S, Dowex 50w-x8, Purolite MN500, Amberjet 1200 and KU-2-8 (Huang et al., 2017). These natural ion exchangers are usually derived from minerals and possess a three-dimensional (3D) tetrahedral structure of aluminum (AlO_4) and silica (SiO_4) which is connected by the shared oxygen atoms and water molecules. Whereas, for the synthetic ion exchange resins it consists of a crosslinked polymer matrix to which charged functional groups are attached by covalent bonding. A schematic representation of the working principle of resin matrix, crosslinking and functionality is shown in Fig 1. Likewise, a representative equation on ammonium uptake mechanism by strong acid cation as a function of sodium ion is listed in Equation 1. Here

NH₄⁺-N ions are exchanged with Na⁺ ions where R denotes the resin matrix.



In practical use ion exchange resins are used in a packed bed column where water source is continuously passed through the bed in a downward or upward flow. Specific contact time is allowed for the water to retain inside the column maintaining the empty bed contact time (EBCT) usually from 1.5 to 7.5 min. The column is then designed according to the desired flowrate by choosing a specific EBCT and maintaining bed depth around 80 cm. Water is passed through the column until the resin becomes fully exhausted or achieves its breakthrough point. And in order to know the breakthrough point a preliminary column test is performed in the laboratory and a breakthrough curve is designed. The breakthrough curve is usually calculated in bed volumes (BV) and is useful for periodic regeneration and cost calculation. As most of the ion exchange resins are reversible, regeneration is performed in order to reuse the resin. Regeneration is usually performed with the high concentration of presaturant ion; Na⁺ (10-12% NaCl) in case of strong cation exchange resin. Ideally no permanent damage of structure takes place while regeneration however swelling and shrinking of resin is common. Typically, strong acidic cation exchange resin used these days has the ability to process up to 2,700,000 BV of water before it needs replacement (Raymond D. Letterman (1999)).

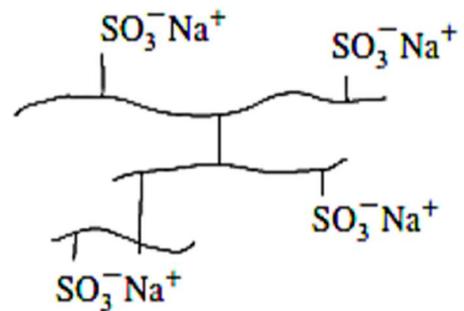
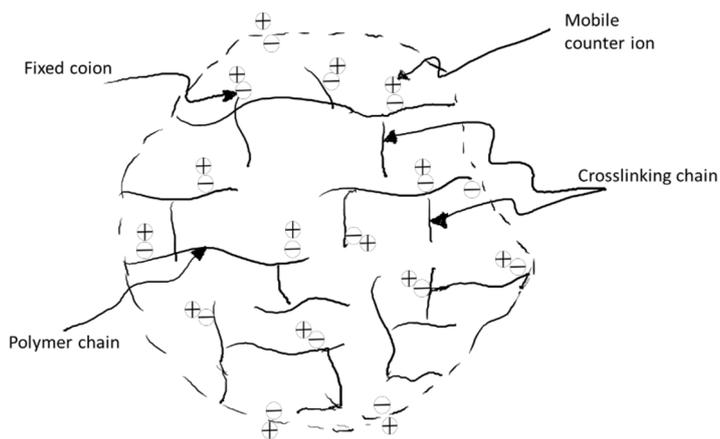
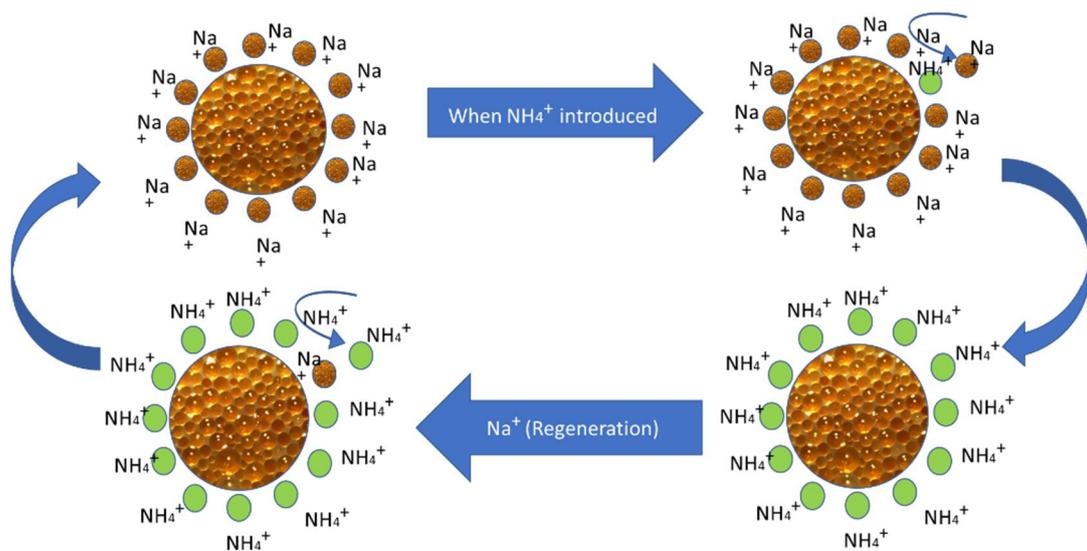


Figure 1 : Schematic on working principle of resin matrix, crosslinking and functionality

2.6 Principle of Reverse Osmosis technology

Unlike ion exchange process, reverse osmosis (RO) technology does not function through adsorption or ion exchange mechanism rather, it operates by forcing a highly concentrated solvent (low water potential) through a partially permeable membrane to a region of low-solute concentration (high water potential) by applying an external pressure higher than the osmotic pressure. RO technology varies with other membrane technologies (microfiltration, ultrafiltration & nanofiltration) with respect to pore size, ion separation mechanism and product of water treated. RO membrane is mostly nonporous or have pores of 0.0001 micrometers in size hence it is capable to remove all the particles above that which includes Bacteria, viruses, larger colloidal particles, precipitates and coagulates, divalent ions and even monovalent ions to some extent. Moreover, the process by which the ions are separated in RO is based on solution diffusion mechanism which is brought by compression and solute concentration difference (Curcio et al., 2009; Crittenden et al., 2005). Since RO membrane utilizes pressure for water purification through a semipermeable membrane it has two effluent; permeate and retentate/concentrate. Permeate are the clean water passed through the membrane with minimal salt concentration and retentate/concentrate are the waste water bypassed through the membrane which is usually higher in salt concentration than the feed solution. This tells us that RO technology has only limited water recovery meaning not all the incoming feed water will necessarily be turned into purified water. The pressure for RO operation ranges from 10 -100 bar but for fresh water use the pressure is usually 2- 17 bar (Lachish U, 2010). Even though RO technologies are widely used for sea water and brackish water desalination in large water plants they are also widely used for drinking water treatment

and are available commercially for small scale, household and potable water filtration configuration.

There are basically two type of RO membrane available; Cellulose Triacetate (CTA) and Thin Film Composite (TFC or TFM) membrane. CTA membrane were developed in early 1960's (historically, the first one to be successfully tested) which is still dominant in the market due to its low cost and higher chlorine tolerant however is prone to biofouling and rejects only 93% of the contaminant. Likewise, TFC was developed in late 1960's as another milestone in membrane technology with much more improved performance than CA in terms of increased membrane fluxes and rejections, flexible pH operation, chemical and thermal stability and less susceptible to organic fouling however, the disadvantage of TFC is that it is chlorine intolerant and can only treat chlorine free water (Hanra et al., 1996).

However, in this study we have utilized a spiral wound configured Thin Film Composite membrane (TFC) for the study. The, schematics on the spiral wound TFC is described in Fig 2 and the structure of TFC is described in Fig 3 where TFC membrane consists mainly of three layers; an ultra-thin dense layer (usually compose of aromatic polyamide) , an asymmetric porous support usually polysulphone and a support layer of a non-woven fabric usually polyester.

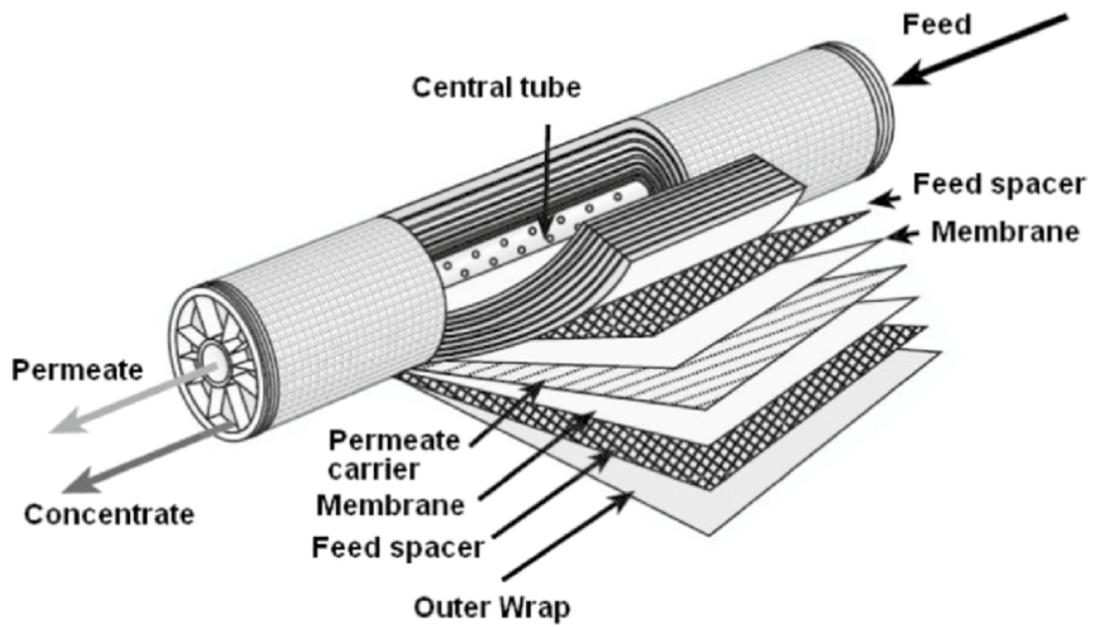


Figure 2 : Schematics of spiral wound RO membrane system (source: Hasani et al., 2019)

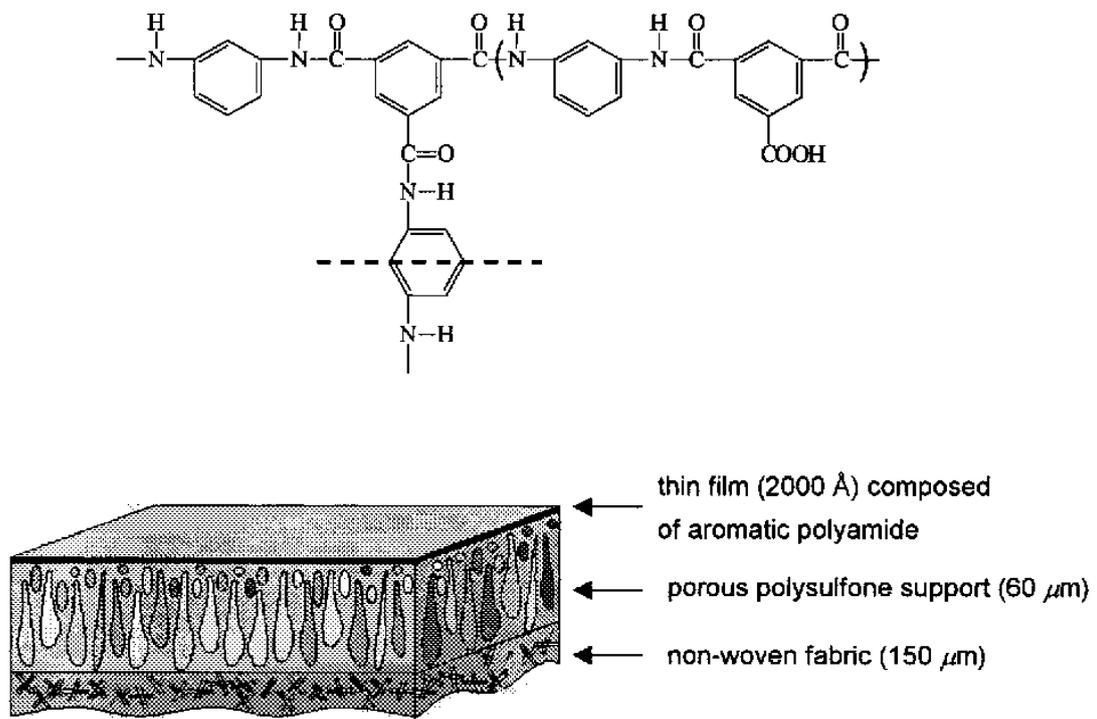


Figure 3: Schematic of the thin-film-composite (TFC) reverse osmosis (RO) membrane and the chemical structure of the aromatic polyamide thin-film layer (Source: Kwak et al., 2001)

Chapter 3. Materials and Method

3.1 Material Synthesis

3.1.1 Preparation of synthetic water

In this study 3 types of solutions were synthesized; Solution 1 contained only one salt of NH_4Cl (190 mg/L) with the $\text{NH}_4\text{-N}$ concentration as 50 mg/L, Solution 2 was prepared as a synthetic groundwater containing eight salts; NH_4CO_3 (282 mg/L), NaHCO_3 (132 mg/L), MgSO_4 (1.50 mg/L), MgCl_2 (31.7 mg/L), KH_2PO_4 (3.58 mg/L), CaCl_2 (93.5 mg/L), KCl (2.75 mg/L) and KHCO_3 (0.07 mg/L) with the $\text{NH}_4\text{-N}$ concentration as 50 mg/L. Similarly, the amount of salts used for solution 3 were; NH_4CO_3 84.7 mg/L, NaHCO_3 (342.4mg/L), MgSO_4 (1.50 mg/L), MgCl_2 (31.7 mg/L), KH_2PO_4 (3.58 mg/L), CaCl_2 (93.5 mg/L), KCl (2.75 mg/L) and KHCO_3 (0.07 mg/L) with the $\text{NH}_4\text{-N}$ concentration as 15 mg/L. It should be noticed that as solution 3 was composed of the similar salts as solution 2 but here only $\text{NH}_4\text{-N}$ and Na^+ concentrations were varied in order to maintain the same ionic strength. The reason behind using similar synthetic water in varying ammonium concentration was to engrave the varying ammonium concentration situation found in groundwater of Kathmandu as it mainly varies according to depth. Therefore, solution 2 with ammonium concentration 50 mg/L was used as a representative condition of deep groundwater and solution 3 with ammonium concentration 15 mg/L was used as the representative ammonium concentration for shallow groundwater of Kathmandu, Nepal. Table 1 summarizes the concentration of ions used in all of the three solutions alongside the deep groundwater quality reference from Chapagain et al., 2010. For solution 2 and 3, they mainly contained salts of calcium and carbonate ions which if mixed together would rapidly precipitate and hence to prevent on spot

precipitation of Solution 2 and 3, they were prepared separately in two different containers for each. First container contained only carbonate and sulfate salts; NH_4CO_3 , NaHCO_3 , MgSO_4 , KHCO_3 while the second container was composed of rest of the four salts including MgCl_2 , KH_2PO_4 , CaCl_2 , KCL . The pH of solution 2 and 3 initially measured to be around 8.3 ± 0.3 . Due to high concentration of carbonate salts, it was later adjusted to pH 7.3 which is the average neutral pH for groundwater of Kathmandu by adding 0.05 M HCL drop wise in the solution. This addition of dropwise 0.05M HCL may have possibly increased the concentration of Cl^- ion in the final solutions increasing the overall ionic strength as well.

Table 1: Solution composition in this study with average values of deep ground water in Kathmandu (Chapagain et al., 2010)

Parameters	Solution 1 (mg/L)	Solution 2 (mg/L)	Solution 3 (mg/L)	Published average value (mg/L)
$\text{NH}_4^+\text{-N}$	50	50	15	23.3
Na^+	-	36.2	93.7	36.2
K^+	-	2.5	2.5	2.5
Mg^{2+}	-	8.4	8.4	8.4
Ca^{2+}	-	33.7	33.7	33.7
Cl^-	127	84.61	84.61	2.3
PO_4^-	-	2.5	2.5	2.5
SO_4^-	-	1.2	1.2	1.2
HCO_3^-	-	314	314	314
pH	5.3	8.3	8.3	6.6-7.3

3.1.2 Analytical methods

All cations including ammonium ion were measured using ion chromatography (IC) (DX-120, Thermo Fisher Scientific Inc, USA). The flowrate was set to 1ml/min, injection volume was 125 μL and the running time was 10 min for each sample. The standard was

recalibrated each time the analysis was carried out. 1ml of sample was taken for every experimental analysis and stored in 1.5ml plastic microtubes. 0.05 M HCL and 0.1 M NaOH was utilized for controlling the pH of the solution as needed. A pH meter (Lab 860, SI Analytics GmbH) was used for pH measurement whereas TDS pen probe (Xiaomi, China) was used for measuring total dissolved solid.

3.2 Experimental Setup

3.2.1 Preliminary test (IE & RO)

Preliminary experiments for both IE and RO were conducted before proceeding with the actual long-term ammonium removal experiment. For the preliminary test in ion exchange, three different materials were utilized and they include granular zeolite(G-Ze), powdered zeolite (P-Ze) and strong acid cation exchange resin (Dowex HCR-S/S) (D-CER). The idea was to select the best material among three different ion exchangers and use it for further experiments. Table 2 shows the specification of the materials used. This preliminary test was carried out in a batch setup. For the batch test a 250 mL glass beaker filled with 200 mL of solution was used in a magnetic stirrer along with 3cm long magnetic bar for uniform mixing. Solution 1 (50 mg/L of only ammonium salt) with varying dose of 0.5, 5,15,25 and 40 g/L were utilized for measuring ammonium adsorption capacity. Samples were collected after 4h of uniform mixing in 250 rpm. Furthermore, kinetics test was also carried out in a batch set up. Here every other operational parameter was kept constant except the dose of ion exchangers used was only 15 g/L and sampling time was in every 30,60,120,180 and 240 mins. Samples were finally stored in a 1.5ml microtubes after filtering it with syringe filter of 45µm pore size.

Similarly, for RO the preliminary test comprised of choosing the best operating pressure. As we know that RO's performance is pressure depended, choosing an appropriate operating pressure for further experiment in order to observe the changes in RO's performance; ammonium removal and water recovery which is brought by the change in operating pressure. Hence, three operating pressure were chosen for this preliminary test and it includes operating pressure of 3 bar, 5 bar and 7 bar. Experiment was carried out with solution 1 (50 mg/L of only ammonium salt) for 4 hours in a semi batch configuration. The membrane used for RO was a polyamide thin film composite membrane of ULP3012-500 (ultra low-pressure membrane with the capacity of 500 Gallon per day (GPD) i.e. 0.08 m³/h) from Toray Co., Japan. The membrane was in a spiral wound configuration.

Table 2: List of adsorbent materials used for adsorption

Adsorbents	Place of Purchase	Physical Properties
Dowex HCR-S/S Cation Exchange Resin (CER)	Lenntech Dow chemical Company, USA	Particle Size – 0.3 -1.2 mm Cation Exchange Capacity –1.9 eq/L Type – Strong acid cation Functional Group – Sulfonic acid Shipping weight – 800 g/L
Granular Zeolite (G-Ze)	Hanchang Industries Co., Ltd, South Korea	Particle Size – 0.15 mm Type – X type Zeolite Si/Al ratio –2.428 (Na ₂) _{3.5} [Al ₇ Si ₁₇ O ₄₈].32(H ₂ O)
Powdered Zeolite (P-Ze)	Hanchang Industries Co., Ltd, South Korea	Particle Size – 0.15 mm Type – X type Zeolite Si/Al ratio –2.428 (Na ₂) _{3.5} [Al ₇ Si ₁₇ O ₄₈].32(H ₂ O)

3.2.2 Long term ammonium removal test (IE & RO)

A long-term ammonium removal test was carried soon after the results obtained from the preliminary test. The test was carried out for 24 hours straight without a pause and the experiment was repeated three times for reliability. For this experiment, column test was

performed for IE and a semi batch setup was done for RO. The column test was carried to mimic the real-world scenario of using IE and to draw the breakthrough curve which will be later used for calculating the cost of IE process.

For IE this test was carried out with a glass column of inner diameter 1cm and height 10 cm. The best selected ion exchanger was utilized as adsorbate and solution 2 (50 mg/L of ammonium salt in synthetic water) was used as adsorbent for this test. Further on for the column test a peristaltic pump from Gilson, France (Miniplus 3 peristaltic, 35-watt, 220 V) with the flowrate of 0.9 ± 0.4 ml/min was used to pump adsorbate into the adsorbent. The bed height was set to 6 cm and rest of the space was covered by glass wool to prevent adsorbent loss in the column. Empty bed contact time (EBCT) and the volume of the column was calculated as 5 min and 4.7 mL respectively using Eq. 2. The amount of adsorbent used for this test was 3.7 ± 0.2 gm. The adsorbent dose was calculated using Eq. 3. Breakthrough point was calculated in bed volumes. Fraction autosampler was used to collect samples every 10 min and samples were analyzed.

ed for every 1 hour of water filtered.

$$NH_4-N \text{ removal } (\%) = (C_o - C_i) / C_o \times 100 \dots\dots\dots (1)$$

$$Q = V / EBCT \dots\dots\dots (2)$$

$$d = m / v \dots\dots\dots (3)$$

where C_i is the initial NH_4-N concentration in mg/L before entering the adsorbent and C_o is the outlet NH_4-N concentration in mg/L after the filtration for Eq. 1. Q is the influent flowrate (m^3/s), V is the volume of the column (m^3) and Empty bed contact time (EBCT) is the total amount of time (min) spent by an adsorbate inside the column at the time of filtration for Eq. 2. Similarly, for Eq. 3, d (g/L) is the shipping weight density of adsorbent, m (g) is the mass of adsorbent utilized in column and v (L) is the volume of the column.

Similarly, for the long-term ammonium removal experiment of RO Solution 2 in a 5L container was used in a semi batch setup. The solution was continuously stirred during the operation for proper mixing and a pressure gauge was installed before the RO to check the pressure. Best operating pressure from the preliminary test was used for this experiment. The experiment was carried out for 24 hours where the sampling was done in the interval of every 1 hour. An external DC fan was connected over the 100-watt booster pump (max pressure 11 bar) for proper heat dissemination to prevent the breakage of pump from 24 hours of continuous operation. The membrane was cleaned with chemicals and DI after completion of every experiment. The procedure of cleaning included acidic and alkaline washing with 0.1% NaOH for 30 mins (Semi batch setup) followed by DI water rinsing for 30 mins (Continuous flow) and again cleaning with 2% citric acid (Semi batch setup) for 30 mins and rinsing with DI for another 30 mins in a continuous flow in a low pressure of 3 bar. Further ammonium ion concentration, water recovery and pH were measured each time a sample was collected. Equation 4 was used for calculating the water recovery of RO. And finally, the experiment was repeated 3 times for reliability.

$$\text{Water recovery (\%)} = (P/F) \times 100 \dots\dots\dots (4)$$

where P is the permeate flowrate measured in L/min and F is the feed flowrate also measured in L/min.

3.2.3 Regeneration test for IE

After the completion of long-term ammonium removal test for IE, regeneration experiment was followed to check the regeneration capacity of that particular ion

exchange material. This experiment was conducted in order to observe the pattern of ammonium removal in that particular ion exchanger when reused after each regeneration. In simple words regeneration experiment was carried out to check whether or not the ion exchange material maintains the similar performance after its frequent regeneration with highly concentrated presaturant ion; Na^+ . For this test, 11% NaCl was utilized as a regenerant and the experiment was performed in an exhausted adsorbate column bed. The process of regeneration started with slow regeneration in counter current mode with EBCT 5 mins and flowrate 0.3 mL/min followed by slow rinse (0.3 mL/min) and fast rinse (0.9 mL/min) in same countercurrent mode for 30 mins each. The amount of adsorbate and nature of adsorbent used was same with previous column experiment.

3.2.4 In varying ammonium concentration (IE & RO)

As the $\text{NH}_4\text{-N}$ concentration varies from (0-120 mg/L) across the depth and location of Kathmandu according to Chapagain et al., 2010. An experiment was carried out to see the ammonium removal behavior of both the technologies when initial concentration is varied. This test was conducted in similar manner with that of previously described long-term ammonia removal test which means 24-hour continuous operation was done in column setup for IE and semi batch setup for RO. However, the solutions used for this experiment was solution 3 i.e. 15 mg/L of $\text{NH}_4\text{-N}$ in a synthetic water. The result obtained from this was later used for proposing different cases for technical and economic considerations.

3.2.5 In presence of organic matter (IE & RO)

Another similar experiment was carried out to observe the ammonium removal behavior in two of the proposed technologies i.e. IE and RO in presence and absence of organic

matter. In order to do so, 5 mg of humic acid from Sigma Aldrich was added to 1 liter of solution 2. Solution containing humic acid was properly mixed for 30 mins and filtered using Whatman filter paper of 45 μ m before the experiment. The color of the solution was yellowish even after the prefiltration. After the preparation of two types of solutions; 1) Solution 2 with humic acid and 2) Solution 2 without humic acid a 2-hour kinetics test was conducted for both IE and RO. This time the test was conducted in batch setup for IE with 200 mL of adsorbent in 250 mL beaker with 15 g/L of adsorbate dose rotated in a mixing speed of 250 rpm. While for RO a semi batch setup with 5L solution in 7 bar operating pressure was carried out. Samples were taken in every 10 mins for 2 hours for both IE and RO.

3.3 Cost calculations

3.3.1 Capital cost (IE & RO)

The capital cost for installment of IE and RO technologies was calculated based on average product pricing from several e-marketing sites like Alibaba, India Mart and Nepal Chemical keeping in mind the market pricing of Kathmandu, Nepal. Likewise, in this study household treatment technology was considered and hence the flowrate was estimated to be 100 GPD i.e. 0.26 L/min for the both RO and IE. Hence in this study with the flowrate of 0.26 l/min a column of 1.3 L is designed using formula presented in equation 2 by keeping the EBCT constant as in the experiment. Similarly, for RO the flowrate estimation lets you choose a favorable membrane as the price of membrane vary according to size and capacity. Moreover, in this calculation the cost of prefilters are not included. However, in actual practice prefilters are recommended for both the technologies and an overview of the cost of prefilter is provided in later section.

Furthermore, the overall cost in this study was divided in to two cases based on ammonium concentration. The main reason to divide it in two cases based on 15mg/L shall be discussed in the results section. Hence the two cases are as follows;

- Case 1: For $\text{NH}_4\text{-N} \leq 15\text{mg/L}$
- Case 2: For $\text{NH}_4\text{-N} \geq 15\text{mg/L}$ and ≤ 50

Based on these cases, four different technical considerations are proposed which shall also be discussed later in the results and discussion section but for now Table 3,4,5 and 6 provides the estimated capital cost of those configurations. Lastly, it should be noted that the capital cost presented in this study is just a close estimation and not the exact value of these technologies as these costs are subjected to change according to availability, market, brand and users need.

Table 3: Estimated capital cost for 1 stage RO system

Capital cost for 1 stage RO system					
Capital Cost	Quality	Quantity	Price per unit	unit	Total
Casing		1	5	\$	5
Membrane	100 GPD	1.0	30	\$	30
Pipe+ fitting +flow restrictors		0	15	\$	15
Pump		1	25	\$	25
Total Capital Cost \$				\$	75

Table 4: Estimated capital cost for 2 column IE system

Capital cost for 2 Column IE system					

Capital Cost	Quality	Quantity	Price per unit	Unit	Total
Casing		2	5	\$	10
Resin	1.31	2.0	2	\$	5.2
Pipe+ fitting +valves			15	\$	15
water meter		1	8	\$	8
Pump		1	15	\$	15
Total Capital Cost \$				\$	53

Table 5:Estimated capital cost for 2 stage RO system

Capital cost for 2 stage RO system					
Capital Cost	Quality	Quantity	Price per unit	unit	Total
Casing		2	5	\$	10
Membrane	100 GPD	2.0	30	\$	60
Pipe+ fitting +flow restrictors		0	15	\$	15
Pump		1	25	\$	25
Total Capital Cost \$				\$	110

Table 6: Estimated capital cost for RO+IE system

Capital cost for RO+ IE					
Capital Cost	Quality	Quantity	Price per unit	Unit	Total
Casing		3	5	\$	15
Membrane	100 GPD	1	30	\$	30
Pipes and knots		0	15	\$	15

Pump (RO+CER)	1	25	\$	40
Resin	1.31	2	\$	5.24
water meter	1	8	\$	8
Total Capital Cost \$			\$	113.24

3.3.2 Operational cost (IE & RO)

The current study investigates the operational cost for using IE and RO treatment technology in $\$/m^3$. The operational cost presented in this study is calculated by utilizing some book values, product's database, few hypothesis and some data from the experimental results for example: breakeven bed volumes from the column test. overall system. Moreover, like the capital cost, operational costs are also divided in to two cases which as mentioned is categorized according to varying NH_4-N concentration in the feed solution. However, in this section, we only provide the way of calculating the operational cost for both IE and RO and the actual cost shall be discussed later in results and discussion section. For calculating the total operational cost one can refer to Eq. 5 where the operational cost includes the cost of replacement, cost of electricity, cost of regeneration for IE and cost of cleaning for RO.

Operational Cost ($\$/m^3$)

$$= (\text{Replacement} + \text{Electricity} + \text{Regeneration (IE)/Cleaning (RO)}) \$/m^3 \dots\dots\dots (5)$$

These costs can be further calculated based on Eq. 6,7,8 and 9.

Replacement cost ($\$/m^3$)

$$= (\text{Capital cost of material} / \text{Total volume of water filtered before its replacement}) (\$/m^3) \dots\dots\dots (6)$$

Electricity cost (\$/m³)

= *pump power(kW) × operating time (h/m³) × electricity cost (\$/kWh) (7)*

Regeneration cost for Ion exchange (\$/m³)

= *Cost of 11% NaCl required per every regeneration (\$/m³) + Cost of electricity for 2 hours cleaning (8)*

Cleaning cost for RO membrane (\$/m³)

= *Cost of 0.1% NaOH and 2% citric acid \$/m³ + 2h of electricity cost \$ / m³ (9)*

Chapter 4: Results and Discussion

4.1 Technical Considerations

4.1.1 Preliminary test (IE & RO)

As described above in the method section, preliminary tests were conducted for IE and RO to select the best operating conditions before proceeding with the experiments. For IE, the preliminary test included selection of best ion exchanger. Three ion exchangers; G-Ze, P-Ze and D-CER were compared according to their ammonium removal capacities and their rate of reaction in a batch test. Shown in Figure 4 (a & b) are the preliminary test result for IE. It can be seen in Fig 4a that the ammonium uptake capacity; Q_e (mg/g) for Dowex HCR S/S (22.2 mg/g) was highest compared to P-Ze (18 mg/g) and G-Ze (13 mg/g) making D-CER most favorable choice for selection in terms of ammonium uptake capacity, similarly the kinetics test from Fig 4 b also showed the results in favor of D-CER with fastest rate of reaction for attaining equilibrium compared to P-Ze and G-Ze. Hence with higher ammonium uptake capacity and fastest rate of reaction, D-CER was chosen as the best ion exchanger among P-Ze and G-Ze. And further experiments for IE were all carried out with D-CER.

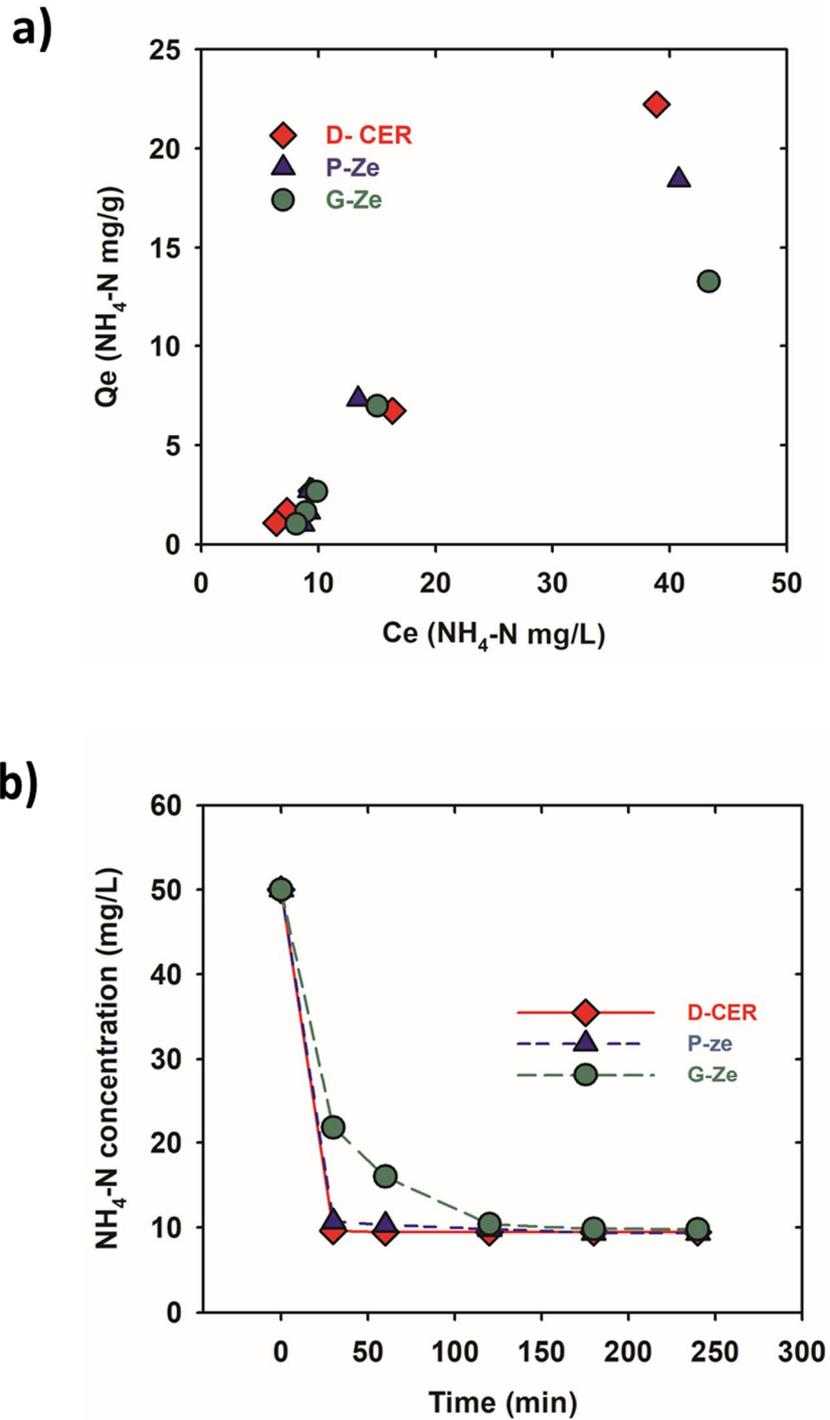


Figure 4(a& b): Preliminary batch test results for selection of best ion exchanger in 50mg/L of NH₄-N concentration a) Ammonium uptake capacities b) Kinetic test operated for 4h

Likewise, the preliminary test for RO includes selection of best operating condition in terms of ammonium removal and water recovery. Shown in Fig 5 is the ammonium removal and water recovery for RO in varying operating pressure of 3, 5 and 7 bar. In the right-hand side is the ammonium removal and in the left is water recovery plotted both in % against varying operating pressure. Referring to the right-hand side of the graph, it can be seen that all the three operating pressure had similar ammonium removal that is 96 %, 95% and 94.7% for 3, 5 and 7 bar respectively for a solution containing only 50 mg/L of ammonium. This result showed that ammonium removal is less vulnerable to change in pressure when it comes to removal of ammonium ions. However, this was not the case for water recovery in varying operating pressure. It was observed that with the increase in operating pressure there is an uplift of water recovery. Highest water recovered was seen for 7 bar with 70% recovery whereas the water recovery for 3 and 5 bar was limited up to 58 and 60 % only. Hence with highest percentage of water recovery and very similar ammonium removal efficiency, 7 bar was chosen as the best operating pressure and was used as the operating pressure for rest of the RO experiments in this study.

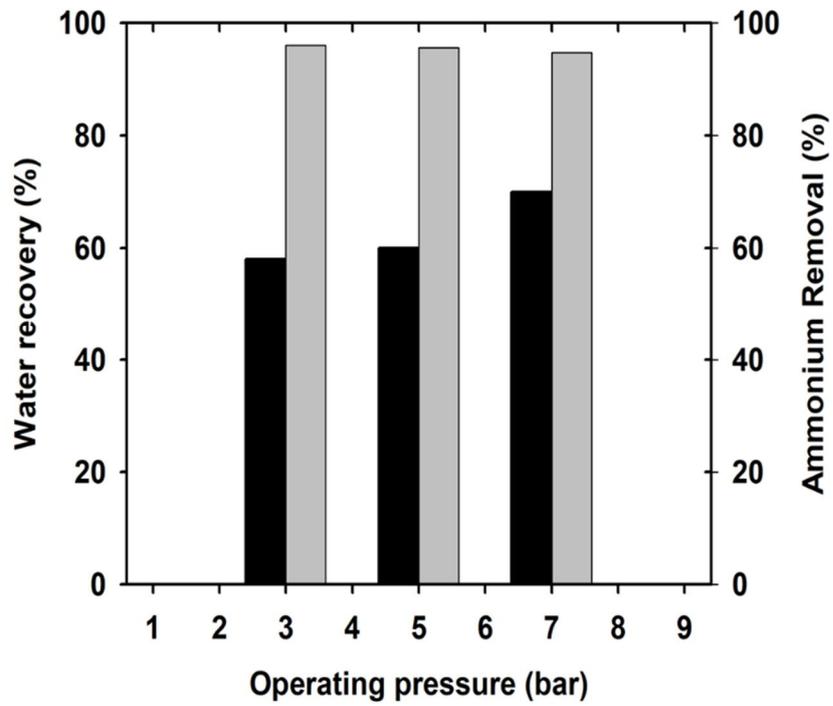


Figure 5: Preliminary test for RO for selection of best operating pressure among 3,5 and 7 bar

4.1.2 Long term ammonium removal test (IE & RO)

This test was carried out to evaluate the ammonium removal performance in IE and RO and for this, solution 2 with ammonium concentration 50 mg/L was utilized in column test for IE and semi batch test for RO was setup for this experiment. Shown in Fig 6 is the test result for 24 hours of long experiment for IE and RO. From the graph we can observe that IE achieved 100% ammonium removal maintaining it for up to 5 hours (BV= 63) and then gradually decreasing with the increase in time or volume of water filtered. Whereas, for RO it was observed that initially it had ammonium removal of 93% but over the increasing time ammonium removal was maintained as 90%. This result shows that even though RO has comparatively low ammonium removal efficiency, it has stable ammonium removal performance but in case of IE it was not the case. We observed that despite having 100% removal efficiency, its removal rate decreases over time demanding regeneration after certain breakeven point for the next use. Therefore, further experiment was carried out for regeneration of IE to check its actual capacity of ammonium removal.

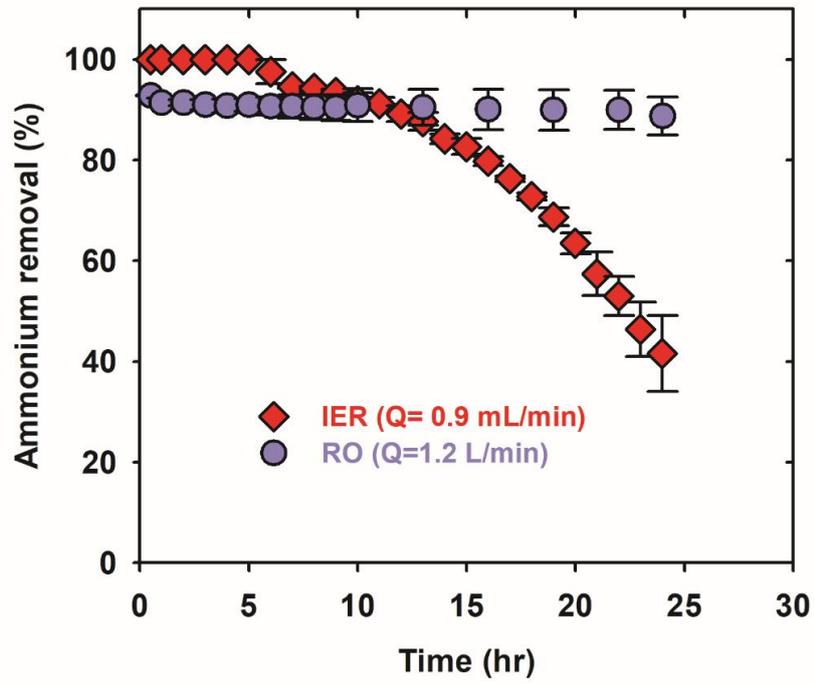


Figure 6: Evaluation of ammonium removal rate in IE and RO with synthetic water composition in $\text{NH}_4\text{-N}$ concentration of 50mg/L

4.1.3 IE regeneration test

After the test results obtained from Fig 6, it was seen that the removal rate of IE decreased over time however one of the advantages of ion exchange resins over other adsorbent materials is its ability to be regenerated time and over. As from the book of Raymond D. Letterman (1999) it was mentioned that the strong cation exchange resin holds the capacity to be regenerated as high as 2.7 million bed volume before its replacement however the regeneration efficiency was unknown. Hence in our study, regeneration experiment was carried with 11% NaCl solution in counter current flow for 5 BV with EBCT 15 mins in order to see if IE maintains 100% removal after regeneration or not. And from Fig 7 it was clearly seen that this particular ion exchange resin had 100% regeneration capacity proving it to be useful and sustainable for use in any situation. Hence, we can say that the regeneration ability of D-CER was 100% and the resin will have the same performance even after periodic regeneration which leaves us with better result for ammonium removal via IE than RO.

Furthermore, this crucial experiment leaves us with the conclusion that for ammonium concentration as high as 50 mg/L single RO technology cannot fulfil the drinking water standard proposed by NDWQS and WHO i.e. 1.5 mg/L with 90% removal but IE with 100% removal can. Hence, this led us to carry the further experiments with Solution 3 in ammonium concentration 15mg/L to observe if RO has the same removal rate even in less concentration and that only one stage RO is suitable for meeting the drinking water standard of 1.5mg/L based on 90% removal or not.

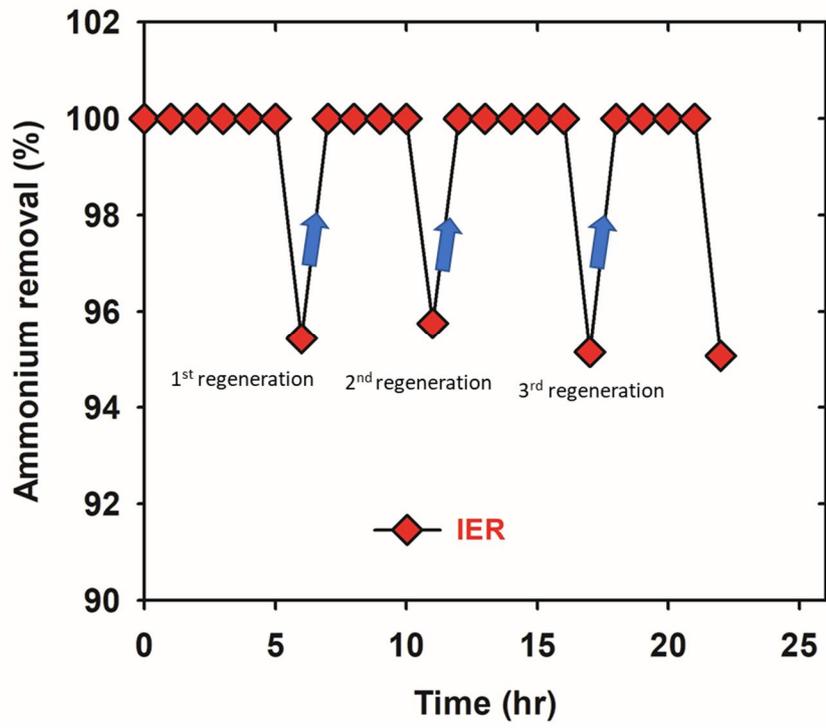


Figure 7: IE regeneration test with 11% NaCl as a regenerant in a counter current mode for 5BV with EBCT as 15 mins

4.1.4 In varying ammonium concentration (IE & RO)

After the regeneration experiment two cases were divided in terms of varying ammonium concentration with the baseline being 15 mg/L of $\text{NH}_4\text{-N}$. As described above the reason for proposing these two cases with the base line concentration specifically as 15mg/L was due to the results obtained from Fig 6 which showed RO to have only 90% removal efficiency. With this result a one stage RO could only be used for treating the water containing ammonium concentration less than 15 mg/L as concentration above would not meet the ammonium drinking water standard of 1.5 mg/L. And in order to have a fair share of cost calculation between IE and RO technology it was important that both the technology meet the ammonium removal standard. Therefore, an additional experiment was carried out with synthetic water of $\text{NH}_4\text{-N}$ concentration 15mg/L (Solution 3) for both RO and IE to observe if the above proposed cases based on 15 mg/L remains valid or not. Mainly a long-term test similar to previous experiment was carried out to check whether or not RO and IE maintain the similar removal and moreover for IE to get the breakeven point for 90% removal whose value would later be used for cost calculation. Shown in Fig 8(a and b) are the long-term experiment graphs for IE and RO. From Fig 8 two important things were observed 1) Lower concentration of $\text{NH}_4\text{-N}$ i.e. 15 mg/L in could maintain 100% removal for longer period of time than that compared to 50 mg/L of $\text{NH}_4\text{-N}$ in same environment (ionic strength), 2) The breakeven point for 15 mg/L was 90% to meet the standard and hence the BV for that was 126 (later used for cost calculation). Similarly, from Fig 8b we could see that RO maintained very similar trend despite the change in concentration giving us the idea that its removal is unaffected by change in concentration of ammonium ion in similar environment. Hence the proposed case based on 15mg/L of $\text{NH}_4\text{-N}$ as a base line holds accountable for both RO and IE.

As a result, two cases were proposed based on the results obtained from Fig 8(a & b) for the appropriate use of IE and RO technologies in different scenarios. These cases were proposed to give a general overview on types of technical consideration one should make while choosing between technologies based on the varying ammonium concentrations and the cases are as follow:

- Case 1: For $\text{NH}_4\text{-N} \leq 15 \text{ mg/L}$

Technical configurations → 1 stage RO and 2 column IE (1 operational and another standby column)

- Case 2: For $\text{NH}_4\text{-N} \geq 15 \text{ mg/L}$ and $\leq 50 \text{ mg/L}$

Technical configurations → 2 stage RO, 2 column IE (1 operational and another standby column) and RO+ IE combined

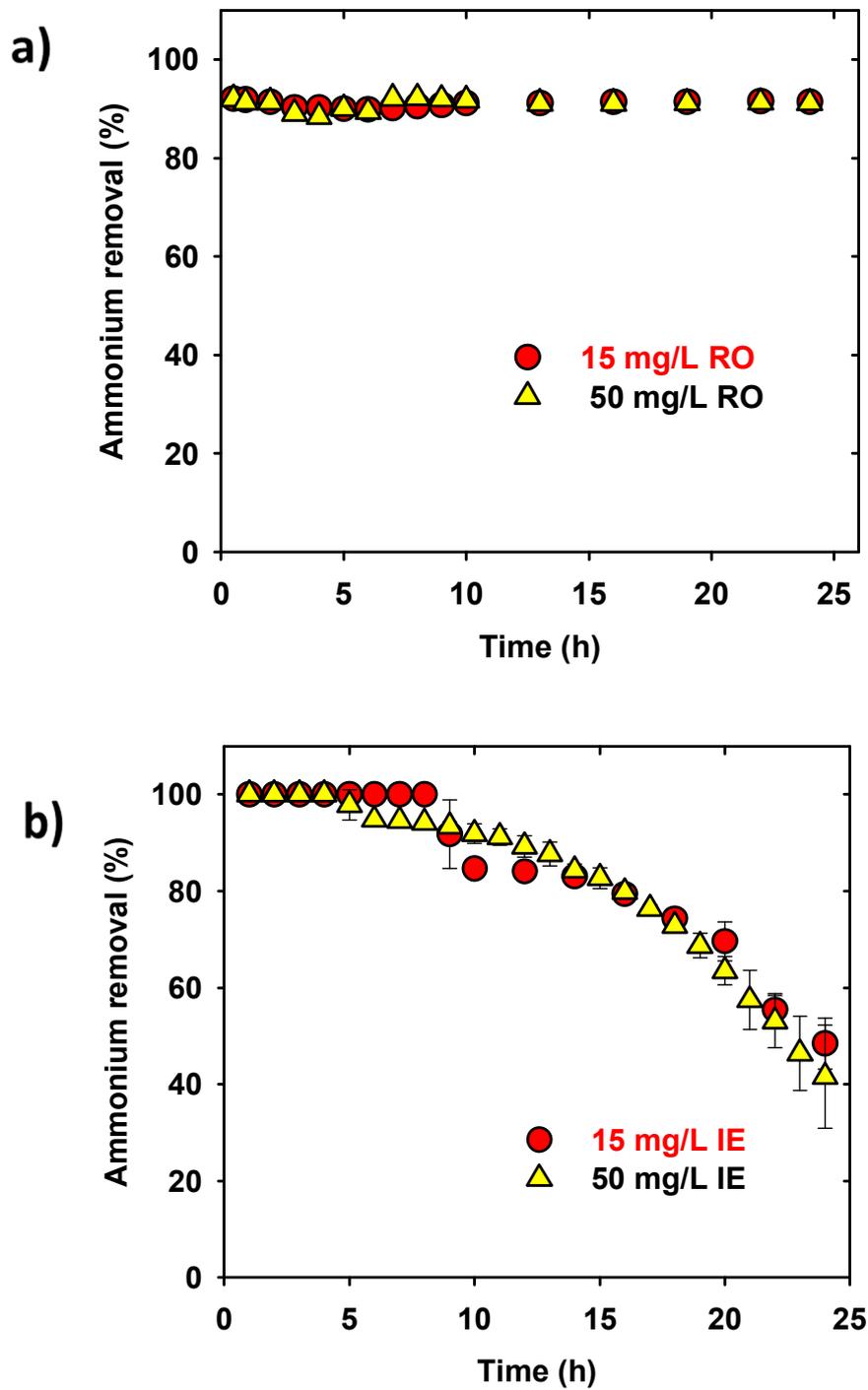
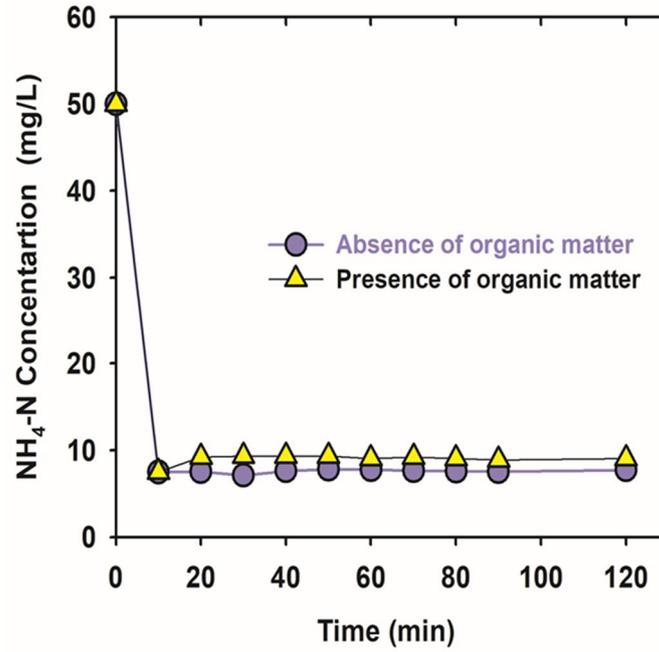


Figure 8 (a & b): Evaluation of ammonium removal rate in varying ammonium concentration (15 and 50 mg/L of $\text{NH}_4\text{-N}$), a) with IE, b) with RO in and RO

4.1.5 In presence of organic matter (IE & RO)

Lastly an experiment was conducted to check the effect of organic matter in these two technologies as high level of DOC up to 5.5 mg/L was mentioned in the same referred water quality document from Chapagain et al., 2010. As described above the main reason of high DOC content in the deep ground water could possibly be from the decomposition of organic matter underneath just like $\text{NH}_4\text{-N}$. Hence a 2-hour kinetic experiment was conducted for both IE and RO in order to monitor the change in ammonium removal against time in the presence and absence of organic matter. Shown in Fig 9 (a & b) is the kinetics graphs for IE and RO with two solutions plotted against ammonium removal vs time in mins. From Fig 9a we can see that presence of organic matter in terms of humic acid has a very subtle increase of $\text{NH}_4\text{-N}$ concentration than that compared to one in the absence of organic matter. Hence, we can say that presence of organic matter just slightly affects the performance of cation exchange resins at the time of ammonia removal. Since organic matter or colloid particles are generally negatively charged it will essentially not take part in competing for the exchange sites the positively charged $\text{NH}_4\text{-N}$ concentration. Moreover, from Fig 9b we can observe no change in ammonium concentration in the presence of organic matter compared to the ammonium concentration in absence of organic matter.

a)



b)

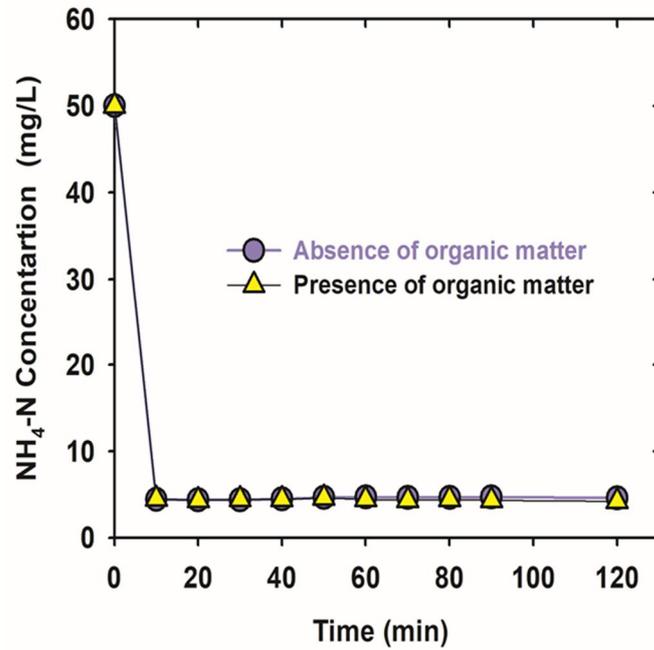


Figure 9(a & b) :2h kinetic test of IE and RO for ammonium removal in presence and absence of organic matter, a) Batch test for IE b) Semi batch test for RO

4.2 Economic Considerations

As the study deals with both the technical and the economical aspect of using IE and RO technologies, hypothetical economic analysis was carried out for this study. Hence, for the cost calculations we have tried to provide a general economical overview on the use of two technologies based on the situations brought by results discussed above in Fig 6,7 and 8, which means the cost is divided in two parts i.e. Case 1 and Case 2 and the overall cost is calculated for 5 technical configurations based on those cases. Moreover, it should be brought in to attention that the cost of prefilters, labor charge, cost of shipping or installation were not considered for the calculation in both the cases.

4.2.1 Case 1: For $\text{NH}_4\text{-N} \leq 15$ ppm

Shown in the Table 5 is the estimated cost calculation for case 1: $\text{NH}_4\text{-N} \leq 15$ ppm which is further divided in to two parts based on technicalities:

⇒ 2 column IE system

⇒ 1 stage RO system

From Table 5 we can see that the capital cost for 2 column IE (\$53; refer to Table 3) system is comparatively cheaper than the capital cost for 1 stage RO (\$75; refer to Table 4) system however, when it comes to operational cost 1-stage RO is twice as cheaper (0.39\$) than the 2 column IE system (0.89). It should be noted that for IE most of its expense comes from regeneration of exhausted resin bed where the cost for replacement and electricity is nearly negligible because we assumed that the resin can be regenerated 2.7 million times and no extra pump is required for IE system as the pressure generated from the tap is good enough for the system to operate. However, the electricity cost is

added at the time of regeneration. Similarly, in Figure 10 (a & b) the schematics for case 1 is depicted. Likewise, shown in Fig 11 (a, b & c) are the graphical illustration of the cost, where 11a shows the capital cost, 11b represents the operational cost and 11c displays the total (capital + operational combined) cost for the technological configurations in case 1. In Fig 11c it was seen that cost of filtering 15mg/L of ammonium concentrated water though RO becomes cheaper than IE after treating 45m³ volume of water.

Table 7 : Cost analysis for Case 1: NH₄-N ≤ 15 ppm

<i>Operational Cost for NH₄-N ≤ 15mg/L</i>						
Method	Capital	Replacement	Electricity	Regeneration/	Total	
	Cost (\$)	cost (\$/m ³)	cost (\$/m ³)	Cleaning cost (\$/m ³)	operational	Cost
						(\$/m ³)
2 column IE system	53	0.0007	0	0.89	0.89	
1 stage RO system	75	0.07	0.29	0.0345	0.39	

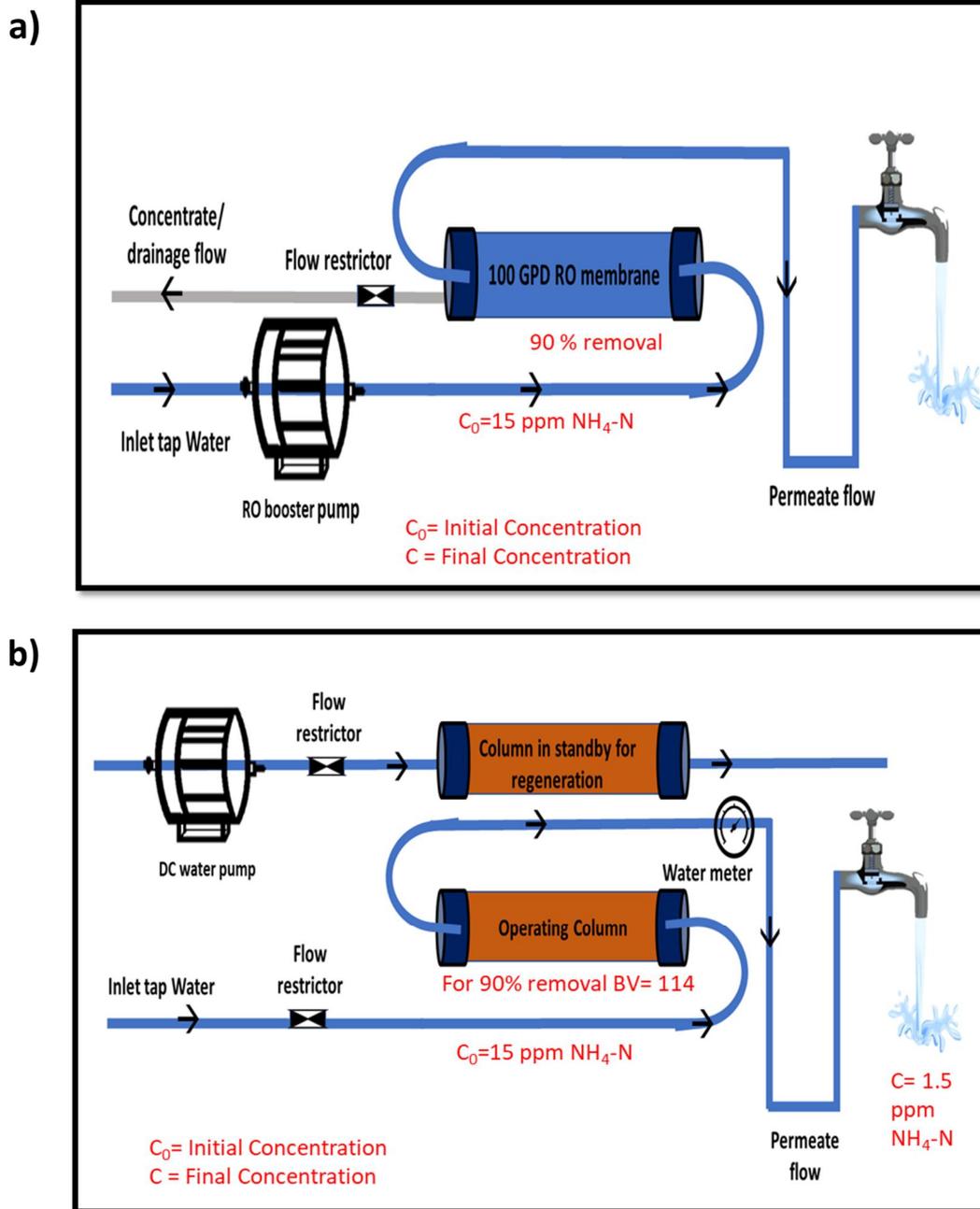


Figure 10 (a & b): Schematic diagram of proposed technical configurations for Case 1: $\text{NH}_4\text{-N} < 15 \text{ mg/L}$, a) 2 column IE system, b) 1 stage RO system for

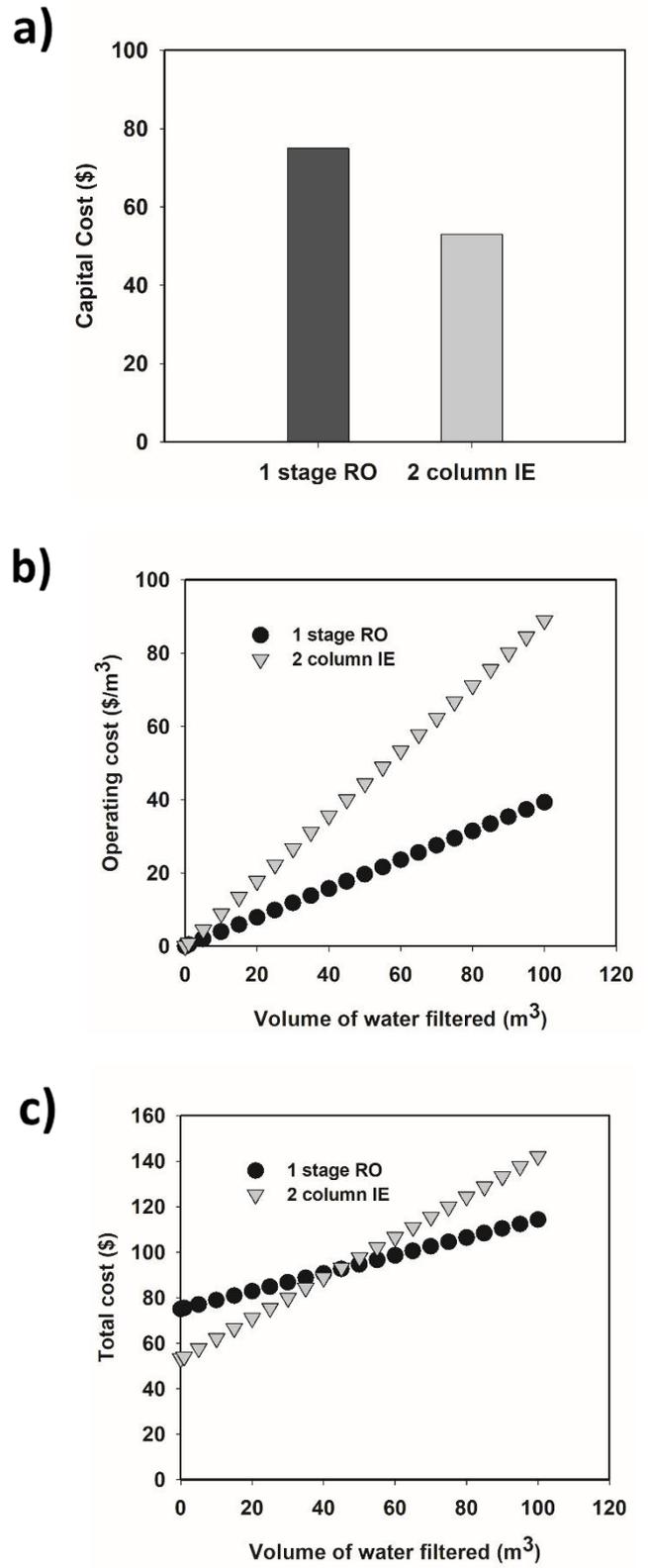


Figure 11(a, b & c): Graphical representation of cost estimation for Case 1: $\text{NH}_4\text{-N} < 15 \text{ mg/L}$ a) Capital cost, b) Operational cost, c) Total cost for 2 proposed technical configurations

4.2.2 Case 2: For $\text{NH}_4\text{-N} \geq 15 \text{ ppm}$ and $\leq 50 \text{ ppm}$

Shown in the Table 6 is the estimated cost calculation for case 2: $\text{NH}_4\text{-N} \geq 15 \text{ ppm}$ and $\leq 50 \text{ ppm}$ which is further divided in to thee parts based on its technicalities:

- ⇒ 2 column IE system
- ⇒ 2 stage RO system
- ⇒ RO+IE combined system

From Table 6 we can see that even though both the cases use same technical configuration for IE technology; 2 column IE (1 stage filtration), their operational cost vary. And the reason behind the surplus of operational cost for same system in case 2 compared to case 1 is due to the selection of breakeven point at different ammonium removal rate for different $\text{NH}_4\text{-N}$ concentration. For example; the breakeven point for case 1 was considered to be 90% for treating 15 mg/L $\text{NH}_4\text{-N}$ which accounted to the BV of 114 but in time of case 2, the breakeven point was considered to be 97% for 50 mg/L $\text{NH}_4\text{-N}$ which decreased the BV by 63 in order to meet the drinking water standard of 1.5 mg/L. So due to change in BV the cost of same technology differed. However, the operational cost for using 2 stage RO increased from 0.39 $\$/\text{m}^3$ to 0.62 $\$/\text{m}^3$. Similarly, the operational cost calculated for the combined technology was based on the operational cost of 1 stage RO and 2 column IE for 50 mg/L with 70% as a breakeven point (BV= 230) totaling to 0.83 $\$/\text{m}^3$.

Similarly, shown in Figure 12 (a, b & c) are the schematics for technical configurations in case 2 and Fig 13 (a, b & c) illustrates the graphical representation for capital cost, operational cost and total (capital + operational combined) cost respectively for thee technological configurations proposed in case 2. From Fig 13a it was observed that the in case of capital cost, cost of RO+CER > 2 stage RO > 2 column IE where as in 13 b we

noticed that the operational cost was highest for 2 column IE followed by RO+ CER and 2 stage RO. Nevertheless, in Fig 13c we observed that despite the high operational cost, 2 column IE system is more suitable option for filtering water up to 60m³ but after that point 2 stage RO becomes the cheapest option for ammonium removal.

Table 8: Cost analysis for Case 2: NH₄-N ≥ 15 ppm and ≤ 50 ppm

Method	Operational Cost for NH ₄ -N ≥ 15 ppm and ≤ 50 ppm					Total operational Cost (\$/m ³)
	Capital Cost (\$)	Replacement cost (\$/m ³)	Electricity cost (\$/m ³)	Regeneration/ Cleaning cost (\$/m ³)		
2 column IE system	53	0.0007	0	1.59		0.89
2 stage RO system	110	0.14	0.41	0.069		0.62
RO+IE combined system	113.24	-	-	-		0.83

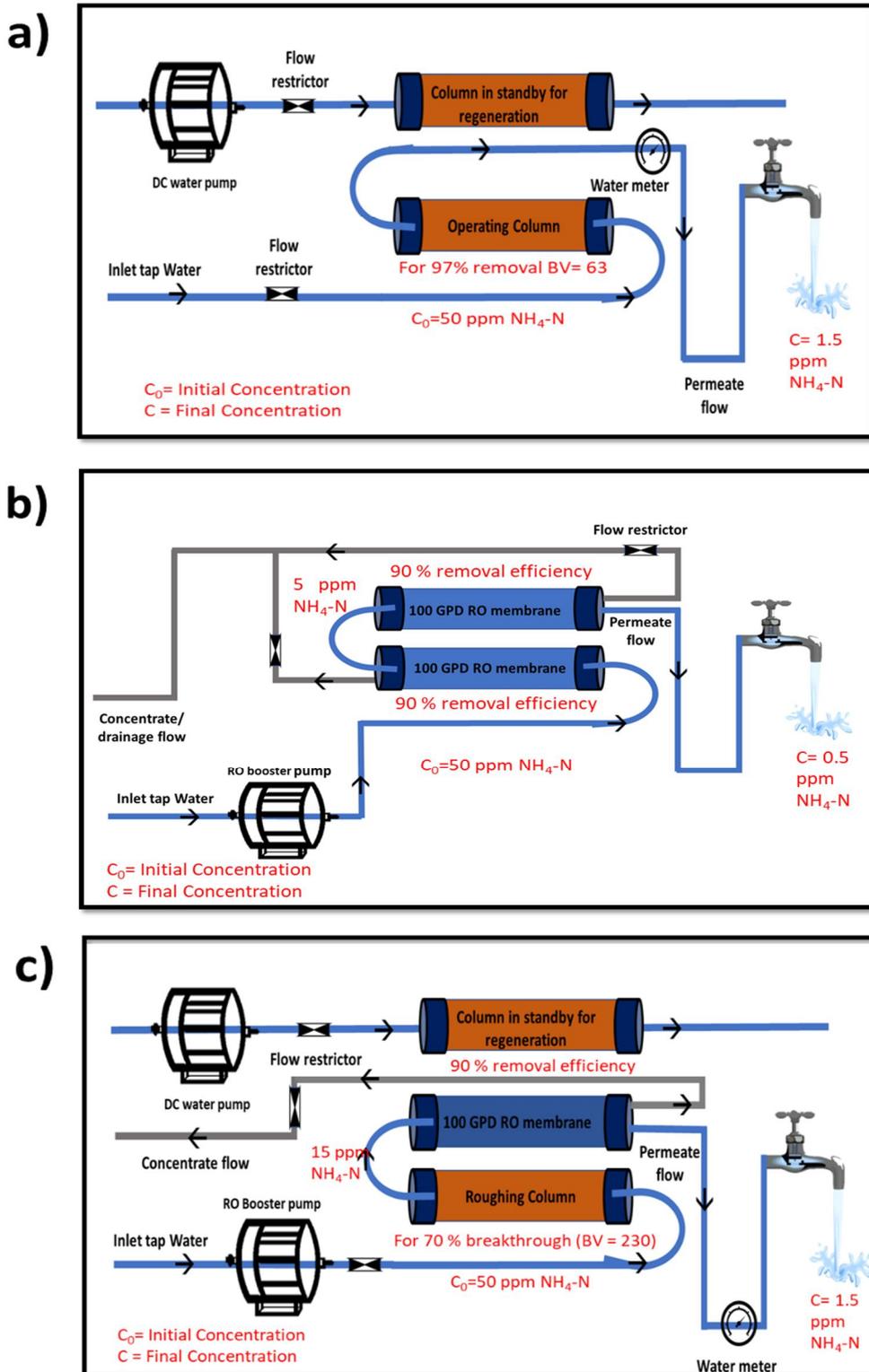


Figure 12 (a, b & c): Schematic diagram of proposed technical configurations for Case 2: $\text{NH}_4\text{-N} \geq 15$ ppm and ≤ 50 ppm, a) 2 column IE system, b) 2 stage RO system & c) RO+IE combined system

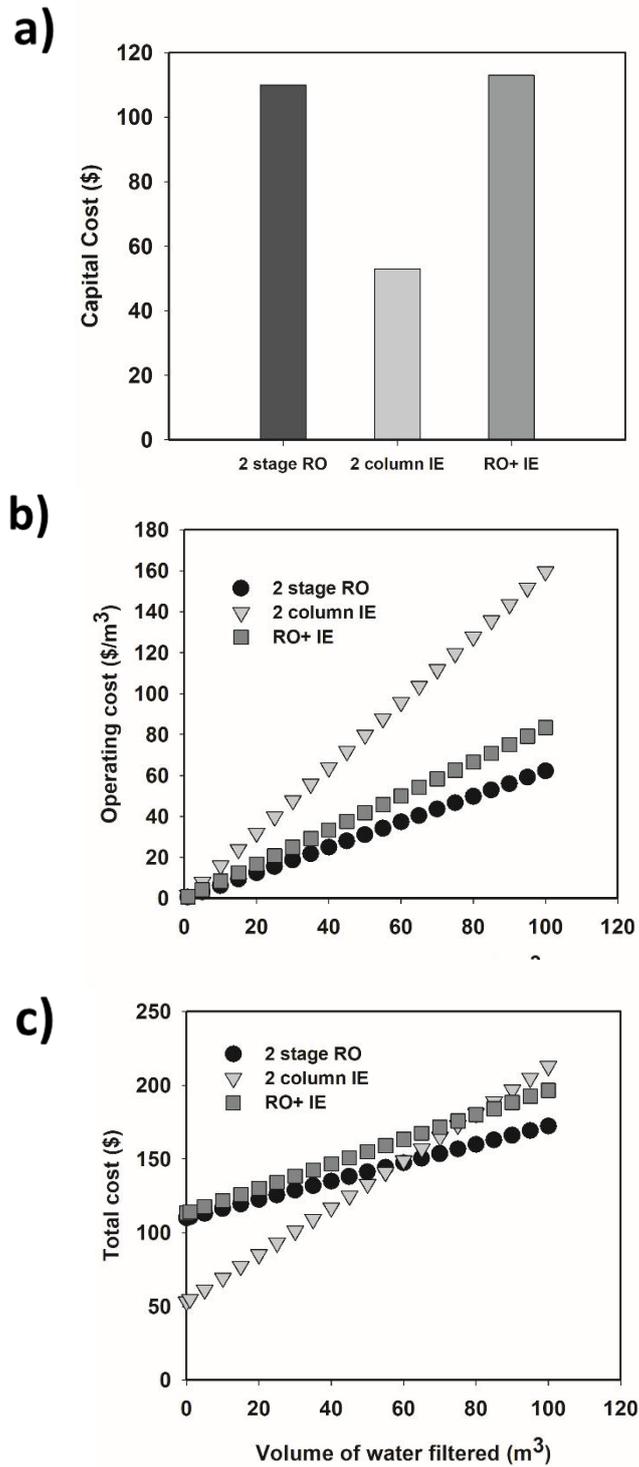


Figure 13(a, b & c): Graphical representation of cost estimation for Case 2: $\text{NH}_4\text{-N} \geq 15$ ppm and ≤ 50 ppm, a) Capital cost, b) Operational cost, c) Total cost for 3 technical configurations

4.2.3 Comparison with commercial bottled water

As the water quality sources started to degrade, a drastic shift towards purchasing packaged, bottled, Jar and Tanker water was seen by people in Kathmandu due to their concerns over quality of drinking water (Warburton 1993). With the most common household treatment options being boiling and ceramic filtrations the increasing source water pollution was not able to meet the drinking water quality standards in terms of biological and physiochemical aspect hence Jar waters were seen widely in use for past few decades now, but a recent study by Maharjan et al., 2018 declared that even the quality of purchased drinking water was unsuitable for drinking as most of the samples for drinking water coming from Jar, bottled or tankers were found contaminated with coliform, ammonia and iron in high content. But even though with questionable quality of commercial drinking water, the demand of Jar waters in Kathmandu Nepal is still increasing as many people believe that the household treatment options including membrane filtrations are costly than purchasing Jar water. Hence our study tries to understand if purchasing questionable quality of jar water is better in terms of economical aspect or is it comparatively cost effective to install a latest household water treatment filter? So, in order to do this, we have tried to include the cost of prefilters in the above listed technical configuration and cost compare all of those above-mentioned technical configurations with the cost of Jar water. It should be noted that this section is truly based on hypothetical estimation and does not include any water quality testing. Hence the sole purpose of this section is to understand the economical aspect of household treatment options and commercially available Jar water. Therefore, the capital cost for prefilters is estimated to be around 20 \$ which includes one sediment filter usually 5micron microfilter or a hollowfiber ultra filter membrane and another is the activated carbon filter

with 5\$ each and rest of the 10\$ as their housing cost. The operational cost is calculated based on assumption that the replacement time for sediment filter is 3 months and that for activated carbon is 1 year. Hence assuming replacement after filtering 1m³ of water for microfilter and 3.6 m³ of water for activated carbon the total operational cost for prefilters alone accounts for 6.88\$/m³. Finally, this cost is included in the total cost of above-mentioned technologies and compared with the Jar water cost. Where the Capital cost for Jar water is assumed to be 5\$ and the operational cost per m³ of filtration to be 20\$ as each 20L Jar water costs around 0.4\$. Fig 14 shows the graphical representation for estimated total cost of filtering certain volume of water with different means of treatments and water options and as seen all the proposed technical configurations be it 1 stage RO or 2 stage RO or IE Column technology or combination of both the technologies with the included cost of prefilters, Jar water still seems expensive for longer run as all the household treatment options becomes cheaper than Jar water after filtering 10m³ of water.

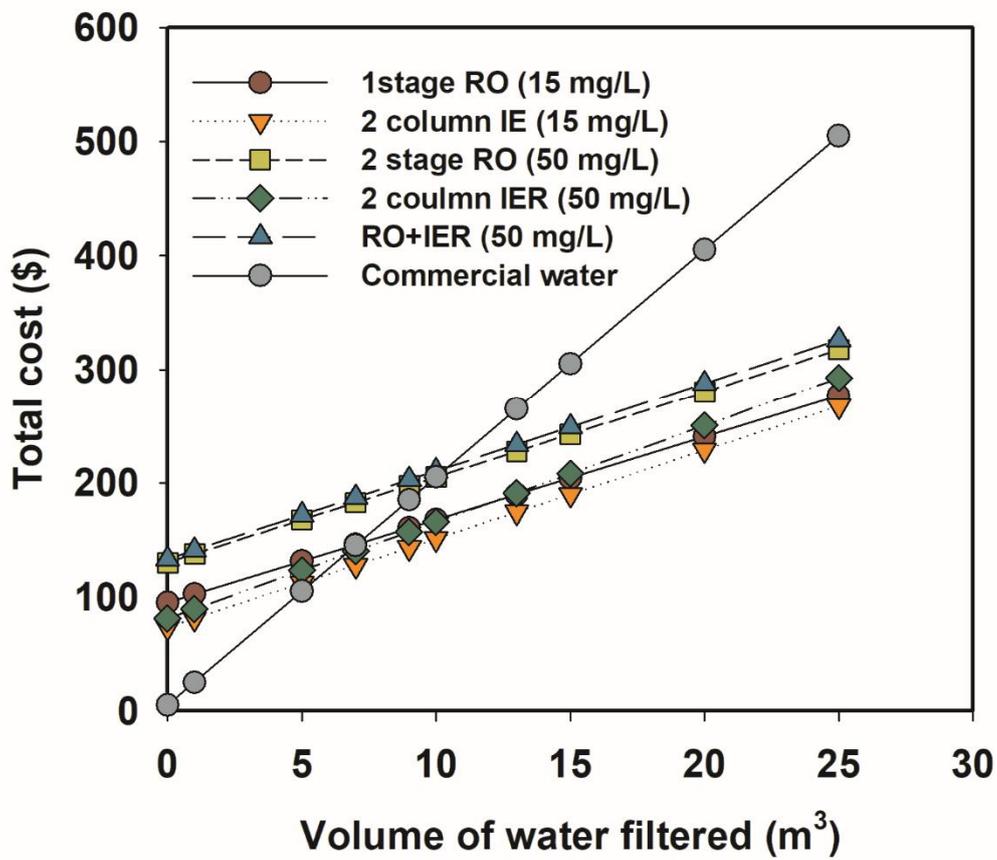


Figure 14 : Cost comparison of all the technological configurations including cost of prefilters with the cost of commercial Jar water

Chapter 5: Conclusion

In this study we evaluated two of the most plausible ammonium removal household methods; IE and RO from the technical and economical point of view. On evaluation it was observed that Ion exchange technology had higher ammonium removal rate than RO even after regeneration (100% and 90%) respectively. Due to this result it was concluded that for places with ammonium concentration less than or equal to 15mg/L both the technologies are perfectly suitable to meet the ammonium drinking water standard of 1.5mg/L but in case of higher ammonium concentration some technical upgrade was felt necessary in case of RO system to meet the standard. Similarly, in case of cost analysis it was noticed that IE systems were more suitable treatment technology for household configuration with daily water demand of 10-15 L/day than RO in both the cases of varying ammonium concentration as IE was found to be a cheaper option for treating 45-60 m³ volume of water. On the other hand, RO was found to be more suitable technology for the places where demand of drinking water is higher than 50L/day treating more than 60m³ within 3 years of operation for example schools, hospitals, restaurants and public places. Furthermore, it was discussed that installing any above proposed household treatment methods for drinking can cost you cheaper after filtering 7-10m³ of water than purchasing a commercially available Jar water. As a whole this study provides a handful guide to users by giving them a brief picture on the functionality, use and consideration of Ion exchange and RO system. However, the study lacks to include other dominant contaminants found in groundwater like microbial contaminant and physical contaminant like iron which probably might affect the technicalities and cost of the treatment system and hence is recommended for further studies.

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