WATER TREATMENT OPTIONS FOR ION AND MINERAL REMOVAL

A tabulated review of different technologies and their application to the removal of solutes from water.

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METHOD	ACR.	APPLICATION	TECHNICAL DESCRIPTION	PROS	CONS	COMMENTS & LINKS
1. FILTRATION						
Aeration and filtration	A+F	Removal of iron, manganese, taste, odour and colour. Simple aeration can be used to remove volatile organic compounds (VOCs).	Introduction of air into a stream of raw water followed by filtration to remove oxidised chemicals. Chlorine, or another oxidising agent, can be used to aid the process. Different filter options can be used for elevated iron levels (green sand). Pre-treatment used if water has a low pH.	Simple to run and can often be constructed from locally available materials, e.g. sand and gravel.	Oxidisation of manganese, especially at neutral pH, requires an agent, e.g. chlorine. Maintenance required as filter will clog. Efficiency and removal rate need to be constantly monitored. High iron levels in raw water and pH can affect performance.	This technique can also remove other chemicals, such as arsenic, which might be bound to metal (hydr)oxides.
Sand (or synthetic media) filtration – slow and rapid	SF	Removal of viruses, bacteria and some larger oxidised chemicals.	Pressure (rapid) or gravity (slow) filtration using natural or synthetic media. Rapid systems often rely on coagulant pre-treatment step. Slow filtration relies to some extent on development of a microbial layer on the media – the 'Schmutzdecke'.	Good treatment option for surface waters and removal of colloidal matter. Slow filters can, if operating optimally, also remove microbial contamination.	Limited applicability for dissolved ion removal without an oxidising step beforehand. Regular maintenance (back-wash or cleaning) of rapid sand filters is required. Schmutzdecke takes time to develop in slow sand filters, requires maintenance and constant flow through.	https://www.mrwa.com/WaterWorksMnl/Chapter%2018%20Filtration.pdf https://sswm.info/sswm-university-course/module-6-disaster-situations-planning-and-preparedness/further-resources-0/slow-sand-filtration https://www.lenntech.com/products/filtration-media/filtration-media.htm

Ultra-filtration	UF	Removal of bacteria, viruses and dissolved organics.	Filter media sized to remove most viruses, bacteria and colloidal matter.	Low pressure pre-treatment option for reverse osmosis (RO). Filter option for most viruses and some dissolved organics.	Limited applicability for dissolved ion removal without oxidising step beforehand.	https://www.lenntech.com/Data-sheets/Dow-Ultrafiltration-Product-Manual-L.pdf
Ceramic filter	CF	Removal of viruses, bacteria and some larger oxidised chemicals.	Factory or local filter material usually made into 'candles' and often in simple gravity set-up. Some options have activated carbon cores for chlorine and dissolved organic removal.	Simple and relatively cheap.	Limited applicability for dissolved ion removal without pre-oxidising step, if this is appropriate for the chemical. Locally made versions can have serious quality issues. Lifespan is limited, some maintenance required, activated carbon option can lead to biofilm clogging.	https://humanitarian.doulton.com/humanitarian-aid/products/
Nano-filtration	NF	Water softening, removal of heavy metals, reduction of salt contents of slightly brackish water and removal of disinfection by-products (DBPs).	Pressure and membrane-based solution. Dissolved salts are rejected in the range of 20-98%. Salts with monovalent anions (e.g. NaCl or CaCl2) have rejections of 20-80%. Salts with divalent anions (e.g. $MgSO_4$) have higher rejections of 90-98%.	Requires lower pressure feed than RO units and hence energy costs are less. Long-life span and relatively simple management. Hardness rejection is high, generally >=90%. Softens water without ion exchange and therefore no increased sodium and TDS level in finished water. Organic molecules with molecular weights greater than 200-400 are rejected.	Some membranes (spiral type) are more sensitive to contaminants than others (tubular/straw type). Water might need to be pre-treated if there is a risk of fouling. Salt rejection can be <80% and raw water quality has large impact on applicability as a solution. Requires scheduled and other maintenance – backwash etc.	https://www.lenntech.com/processes/pesticide/nanofiltration/nanofiltration.htm#ixzz5ZZW6vly3 http://technomaps.veoliawatertechnologies.com/municipalsolutions/en/nanofiltration.htm

2. ADSORPTION						
Activated carbon/charcoal	AC/Char	Removal of disinfection residuals (catalytic reduction), organic contaminants (adsorption), disinfection by-products and some dissolved metals (e.g. lead)	Activated carbon has a large surface area and strong physical adsorption properties. Granular activated carbon (GAC) or powdered activated carbon (PAC) filters, beds or cartridges.	Improves taste and odour of finished water. Good disinfection residual removal prior to RO and sensitive membrane filtration systems. Readily available in cartridges to fit into flow through pressurised systems.	Can become a major source of bacterial and endotoxin contamination. Not an effective filter and will release fines. Need to monitor as depletes over time and lifespan is hard to predict. Monitor FRC to ensure removal, especially if being used as pre-treatment for RO and NF systems. pH of raw water has an impact on performance and sizing.	http://extensionpublications.unl.edu/assets/pdf/g1489.pdf
Activated alumina	AA	Typically used for the removal of arsenic and fluoride.	Ions are adsorbed to surface of AA. Water pH should be less than 8.5. For fluoride, a pH between 5 and 6 is optimum. For arsenic, a pH of 7 is recommended.	Point-of-use and larger scale applications. A good point-of-use option for removal of some contaminants and technology is scalable. Can be regenerated by heating to release water.	The success is pH dependent. Pre- treatment to reduce pH may be necessary for activated alumina to be effective. Media can become bacteriologically contaminated. Backwashing and maintenance required to prevent ‘cementing’ of the media. Continuous flow is optimal.	https://articles.extension.org/pages/31568/drinking-water-treatment-activated-alumina

(Granular) Ferric hydroxide	GFH	Removal of some dissolved ions, often applied to removal of arsenic and fluoride in drinking water.	Granular media in flow through cartridges or pressure vessels.	Relatively cheap solution for the removal of some ubiquitous and problematic chemicals found in groundwater.	Performance is strongly pH dependent as with most adsorption technologies and can require pre-treatment to adjust pH. Other constituents can interfere with performance. Will not lower overall TDS significantly.	http://archive.unu.edu/env/Arsenic/Pal.pdf http://www.evoqua.com/en/brands/IPS/Pages/GFH-Media.aspx

3. CHEMICAL METHODS						
Coagulation, flocculation and sedimentation	CFS	Removal of suspended matter (and some chemicals) from raw water, often, but not exclusively, in surface water treatment processes.	Dosing of raw water with appropriate chemical – often aluminium sulphate or ferric chloride - causing coagulation of suspended matter then flocculation and sedimentation and/or filtration through media.	Cheap and scalable solution for improving water quality. Can remove or reduce levels of some dissolved constituents, e.g. iron, if they oxidise/precipitate or adsorb during flocculation.	Causes change in pH with some chemical additives. Introduces residual chemicals into finished water. Waste sludge from process needs to be treated and disposed of properly.	https://www.mrwa.com/WaterWorksMnl/Chapter%2012%20Coagulation.pdf http://www.veoliawatertechnologies.co.za/water-technologies/flocculation-sedimentation-water-treatment/
Nalgonda Technique	NT	Fluoride removal technique developed in India	Addition of aluminium sulphate and lime to raw water causes flocculation and precipitation to which fluoride ion is bound. Has been described as a household level technique and at a larger scale using a post-dosing filtration step.	Relatively cheap solution which can be implemented at the household level with the proper training (the ‘two-bucket method’).	Benefits (removal rates) need to be quantified and monitored. Household level programmes require people understand benefits and are willing to make time and money investments.	https://wedc-knowledge.lboro.ac.uk/resources/conference/22/Dahi.pdf

Lime softening	LS	Removal of hardness (Ca + Mg) in water by addition of lime - $Ca(OH)_2$ – or soda ash (sodium carbonate) - Na_2CO_3	Dosing of raw water with lime to achieve saturation with respect to carbonate species and their precipitation out of solution. Removes calcium and, to a lesser extent, magnesium from water.	Reduces overall TDS if lime used, although not significantly. Does not rely on exchange using a sodium-based product, which results in higher levels of sodium in finished waters. Levels of some other dissolved ions (iron, manganese, arsenic and lead) and organic matter might be reduced as they are bound to the precipitate.	Can increase TDS with some chemicals, e.g. sodium based. Elevates the pH of water and this usually needs to be adjusted by addition of CO_2 into finished water. Not particularly efficient means of removal. Poor economies of scale in small scale applications.	https://www.mrwa.com/WaterWorksMnl/Chapter%2016%20Lime%20Softening.pdf

4. Ion-exchange Methods						
(Water) Softeners	WS	Removal of Ca + Mg hardness in water. Fe and Mn may also be removed.	Resin beads fixed with sodium exchange with calcium and magnesium in feed water.	Relatively simple and easily available technology. One option as pre-treatment of hard water in RO systems unless anti-scaling agent used as an alternative.	Replaces Ca and Mg with Na, so increase in sodium level in finished water. Does not reduce overall TDS. Requires monitoring and maintenance to ensure effectiveness. Backwashing and regeneration of exchanger required on regular basis.	
Deioniser (DI)	DI	Removal of both cationic and anionic dissolved ions.	Cationic and anionic exchange media used in mixed or dual bed systems. Cationic Exchange Resin exchanges dissolved cations (Na, Ca etc.) with H^+. Anionic exchange resin exchanges dissolved anions (Cl, SO_4 etc) With OH^-. Resins are regenerated by using HCl and NaOH or bleach.	Suitable for waters with relatively low TDS.	Ineffective at removing organic contaminants. May become a site for bacterial growth. Resins require regeneration with chemical solutions. Not suitable for waters with high TDS - rapid wasting of resins in this application.	Product water has high resistivity (> 1MOhm/cm); monitoring of resistivity alerts if resin beds are exhausted. https://puretecwater.com/downloads/basics-of-ion-exchange.pdf

Ion selective exchange	ISEx	Removal of a broad range of dissolved ions and chemicals.	The order of anion resin affinity is: $SO_4^{2-} > NO_3^- > Cl^- > HCO_3^- > OH^- > F^-$ Thus, to remove nitrate and sulphate a chloride (Cl) based resin can be used. The order of cation resin affinity is: $Pb^{2+} > Ca^{2+} > Mg^{2+} > Na^+ > H^+$ Dependent on application there are four principle types of resin; strong base anion, weak base anion, strong acid cation, weak acid cation.	Incredibly useful technology if there is a need to remove individual or related constituents of water. Many resins are available, see links to right. Good option for nitrate removal – standard technology for this application.	Regeneration produces wastewater with high TDS. Does not reduce overall TDS significantly. Possible poor removal of some trace elements. Produces toxic waste product that requires safe disposal.	https://www.lenntech.com/Data-sheets/Ion-Exchange-for-Dummies-RH.pdf https://www.samcotech.com/difference-cation-anion-exchange-resins/ https://www.lenntech.com/Data-sheets/Ion-Exchange-Resin-Comparison-Chart-B.pdf
Hybrid ion-exchange	HIEx	Removal of a broad range of dissolved ions and chemicals.	Uses ion selective properties of resins combined with adsorption.	Proponents claim that this is a good pre-treatment method prior to finishing with RO units as removes hardness and silicates.	Requires regeneration. Unclear what products are available as this is an emerging technology. Produces toxic waste product that requires safe disposal.	http://drinkwellsystems.com/hix/ https://www.tandfonline.com/doi/pdf/10.1080/07366299.2012.735510?needAccess=true http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.867.4123&rep=rep1&type=pdf

5. ELECTROSTATIC/CHARGE-BASED TECHNOLOGIES						
Electrodialysis, and Electrodialysis Reversal	ED & EDR	Lowering/removal of TDS.	Applied voltage (DC) and ion selective membranes remove dissolved ions from water. The process is usually arranged in progressive stages, called stacks. EDR is like ED but it also uses periodic reversal of polarity to effectively reduce membrane scaling and fouling.	Effective at TDS of between 100 and 3000ppm. Chemical free operation possible under certain conditions. Reportedly long membrane life span.	Pre-treatment of water often required. Particles that do not carry an electrical charge are not removed and some substances can neutralize the membrane, such as large organic anions, colloids, iron oxides and manganese oxide Reject stream can be high. Scale inhibitor and acid may be required for process control to prevent scaling. Periodic chemical cleaning is typically conducted using acid, caustic, EDTA, disinfectant, or other anti-scaling chemicals.	https://www.suezwatertechnologies.com/products/electrodialysis-reversal-water-treatment https://www.lenntech.com/electrodialysis.htm#ixzz5PVNpDrYo https://www.saltworkstech.com/technology/flex-edr-advanced-electrodialysis-reversal-system/
Electro-deionization (EDI)	EDI	Lowering/removal of TDS.	Combines semi-impermeable membrane technology with ion-exchange media. Often a polishing treatment used after RO when high water purity is required.	Produces extremely low TDS as a finishing treatment system. No concentrated waste and low energy requirement.	EDI cannot be used for water having hardness higher than 1. Conductivity of feed water must be very low (<40uS/cm).	https://www.lenntech.com/library/edi/edi.htm#ixzz5PVJtu0Cz https://www.lenntech.com/edi_plants.htm
Continuous electric deionizer (CEDI)	CEDI	Lowering/removal of TDS.	Ion exchange membrane, mixed	Produces very low TDS, ultrapure waters.	Requires pre-treatment using RO, intended for finishing of low TDS waters for high-end	http://www.ierjournal.org/pupload/mitpgcon/MC1-07.pdf

			bed resin (MB-12) and positive and negative electrode to remove impurities from feed water.		laboratory and industrial applications.	
(Membrane) capacitive deionisation	(m)CDI	Lowering/removal of TDS.	Similar use of anode and cathodes (electrodes) as per ED and EDR. The membrane serves to prevent exchange of ions between electrodes. Regeneration of electrodes achieved by reversal or turning off current supply and flushing.	Based on inexpensive materials. Produces low waste volumes with good recovery rates. Reportedly good energy efficiencies.	Most effective at relatively low TDS waters (<3,500ppm). Not widely available on the market as an emerging technology but shows promise.	http://voltea.com/wp-content/uploads/2016/03/402D002_Rev01_Tech-Bulletin_Technology-Comparison-1.pdf https://www.wur.nl/upload_mm/0/c/e/3d7104b9-7caf-4025-a4eb-8a76b9214724_Poster%202014%20Jouke.pdf

6. MEMBRANE/OSMOSIS METHODS						
Reverse Osmosis	RO	Lowering/removal of TDS.	Filtration process of water across a very tight membrane with ionic rejection of 90% to 99%.	Cost-effective as widely available in pre-fabricated units. Removal of most ions and contaminants. Widely available.	Chlorine, chloramines, the pH of water, disinfectants, and bacteria all potentially destroy the membrane. High energy requirement. Maintenance issues. Pre-treatment needs to be tailored to raw water quality. Operation and maintenance schedules critical to efficiency and longevity of units. Long term consumption of demineralised water is not considered healthy.	https://www.lenntech.com/products/LennRO/index.html
Forward Osmosis	FO	Lowering/(partial) removal of TDS.	Induces movement of water into an osmotic agent (mixture of NH_3-CO_2). Subsequent decomposition of osmotic agent leaves water behind. Technology behind emergency rehydration bags.	Lower energy demand than RO (although some dispute this) and thinner membranes can be used. Lower pressures required, reducing risk of membrane fouling.	Very slow and requires chemicals which render water unpotable. Requires more R&D to achieve potable water output.	https://www.designboom.com/design/hti-osmosis-filtration-pouches-for-emergency-refief/

7. DISTILLATION						
Distillation	Dis	Removal of TDS.	Water is heated to produce ion free vapour which is then condensed.	Able to treat waters with very high TDS.	Simple technology. High energy demands. Can lead to concentration of pesticides and herbicides if boiling point >100deg.C. Very large energy requirements. Fouling of heating elements from mineral precipitation common.	Many simple units available.
Multi-stage flash distillation	MSF	Lowering/removal of TDS.	Utilises multiple stages with progressively lower pressure chambers.	Able to treat waters with very high TDS, e.g. sea water. Economical on a large scale.	Energy intensive, commercially viable only at large scale outputs. Very concentrated brine as waste.	Produces around 60% of the desalinated sea water globally.
Multiple-effect distillation	MED	Lowering/removal of TDS.	Saline feed water is heated to produce water vapour that is then used in the next stage to vaporise more feed water prior to condensing.	Current MED plants typically operate at lower temperatures than MSF. Consequently, chemical scaling, i.e., precipitation of sparingly soluble salts is less of an issue. Can receive waters with extremely high TDS, e.g. sea water.	Energy intensive, commercially viable only at large scale outputs. Very concentrated brine as waste. First stage temperature must be limited to prevent mineral deposition (<70^{o}C) and final stage temperature needs to be	https://www.youtube.com/watch?v=9Qa0MM7hK3s

				Economical on a large scale.	at least ambient temperature to induce condensing.	
Vapour compression distillation	VCD	Lowering/removal of TDS.	Water vapour under pressure is used, in part, to heat incoming raw water in a cylinder before condensing and being collected for use.	Produces low TDS water. Well established technology.	Issues of maintenance and scaling. Requires energy for compression.	Commonly used on ships and submarines in the past, see; https://www.youtube.com/watch?v=iC3QeCvdxxw https://vapor-compression-distiller.com/vapor-compression-distiller-process
Membrane Distillation	MD	Lowering/removal of TDS.	Micro-porous hydrophobic membrane separates two aqueous solutions at different temperatures, this temperature gradient on the membrane results in a vapour pressure difference, the membrane only allows water vapour to pass through.	Suitable for small scale applications and can use latent heat from industrial applications. Can be fitted to a genset (?)	Considered to be in the early stages of development and output capacity might be an issue.	Project launched by a Dutch consortium. Trials carried out on units that deliver 0.5-1m^3/hr. See here; http://www.earto.eu/fileadmin/content/10_Hidden_Pages/Case_Studies_2011/TNO-Memstill_Asian_Water_pub.pdf

						http://www.hellebrekerstechnieken.com/memstill
Humidification Dehumidification Desalination	HDH	Lowering/removal of TDS.	Like all thermal desalination techniques – based on vapour condensation to remove TDS.	Developments required to improve overall cost for reasonable output.	Ability to utilize low grade and renewable energies as heat source to drive the system.	http://web.mit.edu/lienhard/www/IDA_Perth_Presentation_2011.pdf
Solar (still) distillation	S(s)D	Lowering/removal of TDS.	Utilizes the natural process of evaporation to capture purified water. A simple passive SSD system produces 2–5L/m^2/day and a modified system optimized for maximal output around 30L/m^2/day.	Sustainable and appropriate for small scale application – household. Low energy requirements. Likely to work best in arid environments where high TDS water might be an issue.	Some consider it impractical as a primary drinking water source. Slow to yield quantity. Capital cost can be quite high for larger plants.	Some small-scale products available; http://desolenator.com/ Their community model claims 10m^3/day.

8. ADSORPTION DESALINATION (ADS)						
Adsorption Desalination	ADS	Removal of TDS.	Used in conjunction with other distillation technologies to overcome issues of ambient temperature in final condensation stages. Employs an adsorbent–adsorbate silica gel which switches from hydrophobic and hydrophilic depending on temperature.	Improves recovery with existing systems. Natural/renewable energy sources can be used to release water from the silica-gel.	An emerging technology and one that could lead to lower energy demand in smaller scale applications if latent heat is used in the process.	https://www.youtube.com/watch?v=9Qa0MM7hK3s
Note: Technologies are of interest for further investigation.						