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Reverse Osmosis is not a Viable Option for Water Purification in Water Stressed Regions of India.

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Abstract: *Pollution of water bodies is on the rise all over the world. In India, water pollution and lack of available safe water is particularly devastating for the health, social and economic situation of the local populations. Today, approximately seventy percent of India's surface water bodies are unfit for human consumption[1] and over the past decades, people have turned to ground water as their primary source of water for everyday needs. However, increased urbanization and population growth is resulting in over-exploitation of India's ground water sources. In 1947, at the time of independence, India's water availability per person was over 5,000 cubic meters per person per year. Fifty years later, the actual usable quantity has fallen to an estimated 1,122 cubic meters per person per year[2]. Over-extraction of ground water is causing the ingress of salinity and other pollutants in coastal and inland areas. The decreased water availability compounded with increased pollution has sparked a search for technologies to produce clean water from polluted sources. Many consumers as well as community organizations (governmental and non-governmental) have turned to Reverse Osmosis (RO) for elimination of contaminants. However, the drawback is that RO generates concentrated effluent that must be properly managed in order to avoid environmental contamination of ground water in the long term. The deterioration in water quality is leading to a rapid adoption of more and more RO installations. This article illustrates that utilizing Reverse Osmosis as sole means of drinking water purification will only worsen the situation in the long term.*

I. Introduction: India's Current Water Situation

Water contamination can be broadly categorized into three classes: chemical, biological and physical.

1. Chemical contamination includes naturally occurring pollutants such as fluoride, arsenic and iron as well as man-made pollutants from untreated industrial waste and from agro-chemicals etc. Salinity is typically an indicator used to describe all dissolved chemical contamination. Salinity is not just 'common salt' as we know it - sodium chloride - but can also be dissolved calcium, magnesium, sulfate, bicarbonate, boron, and other ions. It is assessed in terms of 'total dissolved solids' (TDS) and measured in part per million or mg/liter. The health hazards of chemical contamination and salinity are described in Figure 1.
2. Biological contamination comes from untreated waste, open composting, open defecation, etc.
3. Physical contamination typically refers to abnormal pH, excess sediment or turbidity or any other physical feature that renders the water undrinkable.

Sources of Ground Water Contamination

In several states of India, water sources have higher than permissible levels of hazardous materials as described in Figure 1.

Figure 1: Commonly Occurring Water Contaminants

Contaminant	Source	Health Consequences	Occurrence/Population affected in India
Arsenic	Geogenic (Underground Rock and Alluvial Formations)	Nausea and vomiting, decrease in red and white blood cells, abnormal heart rhythm, damage to blood vessels, darkening of the skin and the appearance of small "corns" or "warts" on the palms, soles, and torso[8]. High levels of arsenic can result in death.	Excess level of > 0.05 mg/L affects nearly 16 million people in five states[2].
Fluoride	Geogenic (Underground Rock and Alluvial Formations)	Denser bones in adults, but bones may be more fragile and brittle if exposure is excessive. Dental fluorosis[8].	Excess levels > 1.5 mg/L fluoride is found in 199 districts of 19 states[4]. Over 66 million people are at risk for fluorosis[2].
Heavy Metals	Untreated Industrial Waste	Cadmium: kidney damage[8]. Lead: severe brain and kidney damage[8]. Mercury: permanent damage to brain and kidneys[8]. Manganese: changes in nervous system and behavior, effects include slow and clumsy movements[8].	Untreated (industrial and domestic) waste is contaminating water sources with heavy metals such as mercury, lead, nickel, chromium and manganese in various parts of the country[2].

Contaminant	Source	Health Consequences	Occurrence/Population affected in India
Iron	Geogenic (Underground Rock and Alluvial Formations)	Not considered harmful to the human body but Iron rich water is not considered desirable and can add biological contamination to the water.	Iron is found in 23 states and territories in India[4].
Nitrate	fertilizers, septic systems and manure	In animals, Nitrate alters thyroid function, amyloidosis of the liver, kidney, spleen, and adrenal glands, and affects lung and liver[8].	All of India's fourteen major river systems are heavily polluted[1]. Nitrate is the most common contaminant. High levels of nitrate are found in all water sources where there is heavy usage of fertilizer and pesticides[1].
DDT (Dichlorodiphenyltric-hloroethane), HCH (Hexachlorocyclohex-ane)	Pesticides and Insectides	DDT affects the nervous system. 6-10 mg/kg leads to headache, nausea, vomiting, confusion, and tremors. The International Agency for Research on Cancer (IARC) has determined that DDT is possibly carcinogenic to humans. The IARC has also classified HCH (all isomers) as possibly carcinogenic to humans[8].	Pesticides and heavy metals detected in drinking and ground water in different parts of India. (Bouwer H, 1989; Dikshit TSS et al, 1990; Jani JP et al, 1991; Kumar S, 1995; Bansal OP et al, 2000; Ray PK, 1992). HCH and DDT were detected in different sources of water – wells, hand pumps and ponds in Bhopal[9].
Salinity	Over drafting of ground water aquifers, saline soil, seawater intrusion, etc.	Saline water cannot be used for drinking, bathing or cooking as it is not drinkable and causes skin lesions if used for bathing.	Affecting 13 out of 28 states[5]. In some areas of Rajasthan and Gujarat, salinity is so extreme that well water is used directly for salt manufacturing by solar evaporation[4].

Human Contamination Sources

Man-made contamination is mainly caused by socio-cultural factors (open defecation, open composting, etc.), untreated sewage from large-scale urbanization & industrialization as well as agricultural practices. India's improving standard of living among its fast growing urban population is contributing to large amounts of solid and liquid waste. Sewage from cities has increased from an estimated 5 Billion Liters/day in 1947 to 30 Billion Liters/day as of 1997. Of this, only 10 percent is treated[3].

Physical Contamination Sources

Physical water contamination can fall into any of the following categories: Turbidity, Color, Taste, Odor and pH.

1. Turbidity is the cloudy appearance in water, usually caused by suspended organic and inorganic material. High turbidity water does not have any adverse health consequences on its own but it can interfere with disinfection methods and provide nutrients for bacteria and viruses to proliferate.
2. Color is caused by presence of organic material and/or metal(s). Color and turbidity are often related. Lower turbidity water tends to have less color. As with turbidity, there is no direct health consequence. However, presence of color is indicative of undesirable material(s) in the water. For example, brown water is typically caused by rust indicating presence of iron; green water indicative of algae, etc.
3. Taste: Bad taste in water can be attributed to high level of contaminants such as a sulfurous smell due to excessive bacteria, metallic taste from presence of Iron and/or copper or excessive salty taste from high salinity.
4. Odor: We can detect odor down to ppb (parts per billion). Presence of odor is associated with presence of contaminant(s) as discussed above in the color and taste sections.
5. pH: Water in the pH range of 6.5 to 8.5 is considered suitable for human consumption. High (alkaline) or low (acidic) pH is typically caused by natural sources in ground water.

Reverse Osmosis – The Purification of Unclean Water

Many residential, office, rural and urban communities in India have turned to Reverse Osmosis technology as a means to purify the water. RO is heavily marketed as a household product in urban sectors while community level RO Systems are being installed in rural areas by various NGOs (Non Governmental Organizations) through state sponsored programs.

What is Reverse Osmosis: RO is the opposite of the natural process of osmosis. During osmosis, pure water will flow through a semi-permeable membrane from the dilute side to the concentrated side until both sides have reached the same level of concentration. In Reverse Osmosis, the natural process of osmosis is reversed: by using high pressure, pure water is forced to flow through the membrane from the concentrated side to the more dilute side. Figure 2 depicts this process.

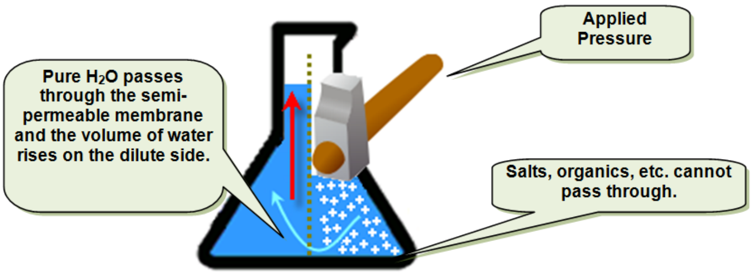

Figure 2. Reverse Osmosis Process

A RO system has a very selective semi-permeable membrane which typically rejects 99% of the impurities from source water resulting in very pure water on the other side of the membrane. The rest of the water which has all the impurities is sent down the drain as reject. A typical RO operates at a recovery rate of 15% to 60%. The recovery rate is defined as:

Percent Recovery = Permeate (Purified Water) Flow rate x 100%/ Feed water flow rate [11].

For example, if 100L (Liters) of contaminated feed water is fed into a RO system operating at 60% recovery rate, that system will provide 60 Liters of purified water. This means for a RO system that has 60% recovery rate, for every 100 Liters of feed water, 40 Liters of water is discarded as waste to achieve 60 Liters of purified water.

II. Reverse Osmosis – The Limitations

The principle limitations of RO technology are its environmental impact: the power requirement of running the high pressure pump, disposing of highly concentrated waste water and capital plus disposal cost associated with membranes and filters.

In comparison to conventional distillation water purification technologies such as ME (Multi Effect) or MSF (Multi Stage Flash), a RO system consumes 48% more energy[10] (RO Requires= 7.6 K-Wh/m^3 per kg purified water, ME/MSF utilizes 3.6 K-Wh/m^3 per kg of purified water). However, the power issue can be mitigated using renewable energies such as Solar or Wind Power. Furthermore, most RO membranes have pre-filters which need to be replaced on regular intervals. The used pre-filters have to be thrown away after single use which adds to the environmental cost associated with solid waste generation.

However, the biggest challenge to operating a RO system in water stressed regions is dealing with the amount and pollution level of the reject waste water which can be substantial depending on the recovery rate of the RO system. Figure 3 shows differences in reject waste water generation to produce 75 Liters of purified water at various recovery rates.

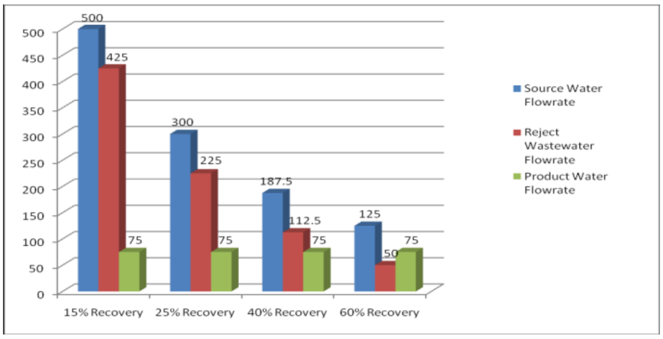

Figure 3. Wastewater Generation for Various Recovery Rates

As seen in Figure 3, in a higher recovery RO system, less water is rejected. However, the concentration of pollutants increases with increasing the recovery rate. Figure 5 illustrates the adverse effect of high TDS and high volume of reject water at various recovery rate scenarios. Concentration of the reject waste water TDS was calculated using the following formula[12]:

$$C_c = C_f *[1-(Y*(1-(C_f-C_p/C_f)))/(1-Y)]$$

C_c = Reject Waste water TDS (ppm)

C_f = Source Water TDS (ppm)

C_p = Product Water TDS (ppm)
Y = Recovery Rate expressed in fraction

	15% Recovery	25% Recovery	40% Recovery	60% Recovery
Source Water Flow (Liters Per Minute)	**500**	**300**	**187.5**	**125**
Reject Flow (Liters Per Minute)	**425**	**225**	**112.5**	**50**
Product Water Flow (Liters Per Minute)	**75**	**75**	**75**	**75**
Source Water TDS (ppm)	**3000**	**3000**	**3000**	**3000**
Product Water TDS (ppm)	**500**	**500**	**500**	**500**
Reject Wastewater TDS (ppm)	**3029**	**3500**	**4500**	**7000**

Figure 5. Effect of RO System on Reject Water Quantity and Quality

As shown in Figure 5, at lower recoveries, more waste water is generated which is either the same pollution level as source water or starts to increase in pollution concentration as recovery is increased. Thus, at higher recoveries (> 60%) the effluent pollution concentrations have more than doubled. At present, India has no regulatory policy for the safe disposal of concentrated rejected water; it is common to discharge the rejected water back into the environment. Long term discharge of untreated rejected water into the environment will render the soil and ground water contamination to irreparable levels. The situation may come that it will not be possible to purify the water even via RO. Increasing salinity in the soil and water will also negatively affect the agricultural productivity levels.

III. Reverse Osmosis Installations – Current Trend

Despite the intrinsic shortcomings of RO, many domestic and government supported installations are put precisely in regions which have severe problems of water quality and availability. In Punjab where ~95% (112 out of 118 blocks[5]) of the ground water aquifers are over their recharge limit (extraction is greater than recharge) and ground water salinity is affecting 35% of the state (6 out of 17 districts[5]), the Punjab State Government is pursuing community run RO systems to meet rural water needs. With the collaboration of NGOs, the Punjab government has installed 120 water service centers, a combination of RO and UV units, that service 600 villages[7]. More service centers are in the pipeline.

Similarly, in the state of Haryana, where 66% (71 out of 108 blocks[5]) of the ground water aquifers are over their recharge limit and ground water salinity is affecting 55% of the state (11 out of 20 districts[5]); the Haryana government has installed over 63 RO based systems [7]. The state of Gujarat suffers from over 80%[5] saline water sources and the adoption rate of RO technology is very prevalent due to the need for good quality drinking water. Hundreds of RO plants ranging from 5-10 Liters per hour to 5000 Liters per hour[6] have sprung up all over the state to meet the demand. In Gujarat alone, this is leading to ~ 0.5 Million Liters Per Day of high TDS (TDS>1000 mg/L) reject water into the ground and surface water sources of a state already struggling with issues of water salinity and availability.[5] The Water and Sanitation Management Organization (WASMO) of Gujarat is embarking on a rural water treatment programs throughout the state. It is planning to install RO plants in villages through a variety of management options[6].

IV. Conclusion

India needs aggressive water conservation techniques and alternative water purification technologies to cope with the demand for good quality water for its growing population and their increasing needs. The lack of regulatory policy for ground water mining as well as the availability of government subsidized electricity provides individuals and communities with inexpensive ground water. With rejected water doubling in concentration and being discharged (untreated) back into the environment will lead to a rise in the overall TDS of the ground water and soil salinity over the course of time. Long term effect may include decline in agricultural productivity and hindering of manufacturing capabilities due to lack of fresh water. This paper is calling for a longer and more extensive study to be conducted to examine long term effects of discharging RO reject water and its safe disposal in water stressed regions of India. Further research should also be carried out to develop eco-friendly technology alternatives to RO filtration.

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Lalit Mohan Sharma is Director, Adaptive technologies at SM Sehgal Foundation. He is a graduate civil engineer and holds a Masters of Technology (Management & Systems) from Indian Institute of Technology, Delhi. Under his leadership IRRAD's water management program has been recognized widely. The organization has won UNESCO-Water Digest 'Best Water NGO' award for 'Revival of Rural Water Resources' in 2009 and 2010 and 'Best Water NGO' for 'Rain Water Harvesting' 2008 and Ministry of Water Resources, Government of India 'Ground Water Augmentation Award-2010'. Ground Water Augmentation Award by Government of India in 2011, FICCI Water Award 2013: first prize under NGO category for excellence in water management and conservation, The Institution of Engineers (India) 'Water Conservation Award-2013'. He has presented several papers on issues related to integrated and sustainable development of water resources and sanitation.