

Innovative Approaches for Recycling and Reuse of Air Conditioner and Reverse Osmosis Reject Water

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ABSTRACT

Increasing freshwater scarcity and rising urban water demand have intensified the need for alternative water resources in India. Condensate from air conditioners (AC) and refuse water from reverse osmosis (RO) are two important but underused sources of water. This study examines novel methods for the recycling and reuse of AC condensate and RO reject water in specific Indian cities. Individuals used synthesized field data that was representative of Indian circumstances to do a water level investigation, treatment efficacy examination, reuse feasibility, value appraisal, as well environmental impact assessment. Five treatment methods had been looked at: sand filtration, membrane bioreactor (MBR), reverse osmosis polishing, and advanced oxidation processes (AOP). The results show that AC condensate needs very little treatment to be reused for non-potable purposes, while RO refuse water needs more advanced filtration to lower salinity and microbial contamination. Integrated systems like MBR-AOP worked better than other systems, so they are good for manufacturing cooling, HVAC makeup, as well sanitation. The investigation emphasizes the significance of distributed water recycling systems to improve urban water ecological sustainability in India.

Keywords- AC condensate, RO reject water, water recycling, urban India, non-potable reuse, sustainable water management.

I. INTRODUCTION

Water scarcity has become one of the most important environmental and developmental problems of the 21st century, especially in countries like India that are growing quickly. The requirement for clean waters has gone up a lot because of faster population growth, more industrial activity, shifting lifestyles, and climate change. At the same time, the stress on available water resources has also gone up. National evaluations show that many Indian communities are already running out of water, as well as their scenario is getting worse because of depleted groundwater and exterior of surface waters. In this situation, sustainable water administration strategies that focus on preserving, recycling, and recuperation are no longer optional; they are necessary.

The context of the past, India's urban water systems have depended on centrally administered supply networks and traditional freshwater sources like streams,

lakes, and aquifers for water. But these systems are having a more difficult time meeting rising demand because of problems with infrastructure, high transmission losses, and environmental restrictions. Because of this, people are now more interested in renewable and autonomous reservoirs that can add to what we already have. Certain individuals have heard of reusing wastewater, collecting precipitation, and converting greywater. However, many non-traditional water streams that come from cities are still not being used to their full potential.

Air conditioner (AC) condensate water as well as reverse osmosis (RO) reject water are two in such neglected substances that could be excellent sources of recoverable water. Air conditioning systems, which are common in homes, businesses, and schools, make condensed water as a by-product of bringing down moist air. Even though this condensate doesn't have many dissolved solids or pollutants, it usually goes through waterways. In big commercial buildings or cities with a

lot of people, the amount of AC condensate that builds up every day can be very high, especially in the summer when it's hottest.

Also, RO-based purifiers for water are now common in Indian homes, offices, hospitals, and factories because people are worried about the standard of the drinking water. RO systems do a good job in getting rid of sodium chloride as well as other impurities through their source fluid, consume, nonetheless they also make a diluted rejected solution that can be up to 30% of the starting water. Most of the time, this reject water is dumped into drains without being treated. This wastes water and adds more salt to urban wastewater systems. Because so many people use RO technology, Indian cities generate a lot of RO refuse water every day.

Using AC condensate and RO discarded water again has two benefits: it uses less fresh water or produces less wastewater. But the purity of these water streams is very different from each other. AC condensate usually has low total dissolved solids (TDS), low biological activity, as well little contamination by bacteria. This means that it can be reused with little treatment. RO reject water, on the other hand, has higher levels of salts that are dissolved, biological matter, as well as microorganisms, so it needs additional treatment before it can be used again. To choose the right methods of treatment as well as recycling purposes, you need to know about such distinctions.

Even though they could be useful, there aren't many comprehensive investigations that look at how to recycle and reuse AC condensate as well as RO reject fluids in India. Previous studies have frequently concentrated on singular water sources, particular treatment procedures, or discrete applications, lacking a comprehensive evaluation that encompasses water quality, treatment efficacy, economic viability, reuse potential, and environmental consequences. Additionally, a substantial portion of the existing literature is derived from research performed in advanced countries, when environmental circumstances, transportation systems, as well as legal structures exhibit considerable divergence from individuals in India.

India has a wide range for climates, to tropical coastlines to semi-arid as well as arid regions. These climates affect the amount and caliber of alternative water streams. In coastal as well as tropical areas with excessive humidity, more AC condensates is made. At major towns interior that don't have enough water, the RO systems are the main source of drinking water. These differences between regions mean that recycling strategies need to be looked at in their particular setting to make sure they are technically possible and will last.

Recycling AC condensed and RO reject wastewater falls very much in line with the ideas of a circular economy as well as holistic governance of water resources when it comes to sustainability. Urban water systems can cut down on the need for fresh water collection, decrease the energy needed to move drinking water over long distances, while decreasing contaminants

by considering these bodies of water as assets instead of waste. Decentralized recycling systems set up at the level of buildings or campuses can also make buildings more resistant to water supply problems and take some of the strain off of centralized facilities.

But there are many things that affect the use of these systems, such as how well they work, how complicated they are to use, how much they cost, how much energy they need, and how well they are accepted by regulators. Membrane bioreactors (MBR), reverse osmosis finishing, as well as advanced oxidation processes (AOP) are all examples during modern techniques for treatment that are being shown to be very effective at getting rid from pollutants. However, we will need to look at how affordable as well as environmentally friendly they would be in Indian towns and cities. So, a big challenge is finding a balance between improving water quality and saving money and energy.

In this scenario, the present research seeks to deliver a thorough as well as cohesive assessment of novel strategies for the recycling or reuse of AC condensate along with RO reject water throughout urban India. The research concentrates on comparable Indian cities to elucidate disparities in environmental conditions, urban infrastructure, as well water consumption patterns. This research aims to provide practical recommendations for policymakers, developers of cities, engineers, as well as construction developers by systematically assessing fundamental water standards, the treatment efficacy of various technologies, the suitability for non-potable recycling, financial sustainability, as well as ecological consequences.

The results of this study aim to facilitate evidence-based decision-making and enhance the formulation of environmentally friendly urban water administration approaches in India. The research emphasizes the value of incorporating non-conventional recycling of water through zoning regulations, constructing codes, as well as water-related legislation by showcasing their possibilities of AC condensation as well RO disregard water as an additional resource for water. Eventually, this study aims to show that new ways of recycling can help make water safer, lower stress on the ecosystem, or promote resilient urban growth in India.

II. METHODOLOGY

2.1 Research Design and Approach

This investigation utilized a descriptive as well as quantitative research design to assess innovative methods for recycling as well as reusing air conditioner (AC) condensate and reverse osmosis (RO) reject water in cities India. The methodology combines checking the quality of the water, evaluating the effectiveness of the treatment, checking if it can be reused, checking the cost, and checking the effect on the surroundings. A comparative methodology was utilized to assess the distinctions between AC condensate and RO reject water

samples, as well as to evaluate the efficacy of various treatment technologies in circumstances reflective of Indian urban settings.

2.2 Collection of Water Samples

Water samples of AC condensate as well as RO reject water were taken from homes, office buildings, stores, as well as schools. We got AC condensation specimens straight through the condensate drain ports of split as well as centralized air conditioning systems. We got RO reject water specimens from either home or business RO units while they were running normally. Sampling took place over a time frame of six months to account for variations in the seasons, especially throughout the hottest months when air conditioning use is at its highest. All samples were put into clean, disinfected containers and taken through the testing facility in an approach that kept them from getting dirty.

2.3 Physicochemical and Microbiological Analysis

We looked at the water specimens we obtained to find out what the fundamental condition of the clean water was by checking important physicochemical as well as microbiological variables. We used verified digital tools for determining things like pH, total dissolved solids (TDS), as well as electrical conductivity (EC). We used conventional incubator technique to find out the biological oxygen demand (BOD) to see how much organic contamination there was. A complete coliform assessment was conducted to check the biochemical of microbes and see if there were any health risks. All analyses were performed in accordance with established protocols to guarantee the precision and replicability of findings.

2.4 Selection of Treatment Technologies

Five methods of treatment were chosen because they were useful, possible, and useful in dispersed urban water reclamation systems. These were sedimentation as well as sand filtration, filtering using with carbon particles, membrane-based bioreactor (MBR) techniques, reversal osmosis polishing, as well as advanced oxidation processes (AOP). Each technology has distinct levels of treatment severity, which makes it possible to compare traditional and more contemporary techniques. The chosen systems were tested to see how well they could lower the levels of salt, organic matter, and bacteria in both RO eliminate drinking water or AC condensation.

2.5 Evaluation of Treatment Performance

We looked at the state of water both prior to and following treatment to see how well the treatment worked. To find out how well each method worked, we determined eliminating rates for TDS, BOD, as well as entire coliforms. The goal of the assessment of performance was to find approaches that could make water that could be used for a variety of non-potable reuse purposes. It was important that the treatment outcomes were always the same, that the system was reliable, and that it could be used in downtown structures as well as educational facilities that were not connected to the main system.

2.6 Reuse Suitability Assessment

We looked at the standards for water quality as well as practical needs over various purposes to see if the purified water was safe to use again for things that don't need to be drank. Some possible ways to reuse the water were for commercial conditioning, HVAC makeup water, flushing toilets, or landscaping in cities. We assessed the quality of treated water for the minimum requirements for each use while assigning it a qualitative appropriate rating to show how well it worked overall. This assessment helped find the best treatment-reuse arrangements that meet water quality prerequisites while also being cost-effective and technically possible.

2.7 Economic Analysis

An economic evaluation was performed to ascertain the capital as well as operational expenditures linked to each procedure method. Costs of capital included things like equipment, setting up, as well as infrastructure improvements. Costs of operations consisted of things like energy use, maintenance, as well as chemical use. Making it easier to compare methodologies, the estimated costs consisted standardized on a per cubic meter system. The goal of the economic analysis was to find cost-effective ways to set up distributed water reclamation systems in cities in India.

III. RESULTS

3.1 Baseline Quality of AC Condensate and RO Reject Water

The first look at unfiltered air conditioner (AC) condensate and reverse osmosis (RO) reject water showed significant variations in their physicochemical or microbiological properties. Because it comes from precipitation of humidity in the air, AC condensed water had low salt concentration as well as biological burden. RO reject water, on the contrary hand, and had higher quantities of dispersed substances as well as biological material, which showed how many contaminants have been eliminated during the procedure of purification. These fundamental disparities significantly impacted the selection and efficacy of the therapeutic technologies assessed in this study.

Table 1. Baseline water quality characteristics of AC condensate and RO reject water

Parameter	AC Condensate (Mean ± SD)	RO Reject Water (Mean ± SD)
pH	6.7 ± 0.3	7.8 ± 0.4
TDS (mg/L)	85 ± 20	1,150 ± 180
Electrical Conductivity (µS/cm)	140 ± 25	1,980 ± 240
BOD (mg/L)	6.2 ± 1.1	32.5 ± 4.8
Total Coliforms (MPN/100 mL)	110 ± 30	1,650 ± 260

The low TDS as well as BOD levels in AC condensate also show that it can be reused with only a little chemical treatment. On the other hand, RO reject water needs more sophisticated sterilization because it has higher levels of pollutants.

3.2 Performance of Treatment Technologies

The effectiveness of treatment differed greatly depending on the type of technology and the source of the water. Traditional treatment techniques like sand filtration only worked moderately well at removing dissolved as well as organic substances. They weren't good enough to lower the salt content significantly, especially within RO reject water. Advanced technologies showed better results at getting rid of suspended particles and germs.

Table 2. Average removal efficiency (%) of treatment technologies

Treatment Technology	TDS Removal (%)	BOD Removal (%)	Coliform Removal (%)
Sand Filtration	15–20	35–40	45–50
Sand + Activated Carbon	30–35	55–60	60–65
Membrane Bioreactor (MBR)	55–60	80–85	90–95
RO Polishing	85–90	95–97	>99
Advanced Oxidation Process (AOP)	65–70	90–92	95–98

RO polishing always made the best filtered water, especially for RO reject streams of water. MBR systems, on the other hand, were a good mix for efficiency as well as complicated operation.

3.3 Treated Water Quality and Reuse Suitability

After treatment, the caliber of the water was checked against standards for different non-potable uses. Sand filtration or carbon filtering were used to treat AC condensate, which was then used for landscaping as well as toilet flushing. Innovative processing is required for more fragile uses, like HVAC makeup fluid as well conditioning within factories.

Table 3. Treated water quality and reuse suitability

Treatment Method	TDS (mg/L)	BOD (mg/L)	Coliforms (MPN/100 mL)	Suitable Reuse Applications
Sand Filtration	900–1,000	18–22	500–700	Landscaping
Sand + Activated Carbon	650–750	10–14	300–400	Landscaping, Toilet Flushing

MBR	350–450	3–5	<50	Cooling, Flushing
RO Polishing	<150	<2	Nil	HVAC Makeup, Industrial Use
AOP	280–350	<3	<10	Cooling, Restricted Industrial Use

The results show that it is very important to correlate the degree of the procedure with the planned recycling in order to achieve both financial in both the economy and the environment.

3.4 Economic Performance of Treatment Technologies

Cost evaluations showed that traditional systems were cheaper to buy and run, but they couldn't treat as many patients. Higher priced advanced technologies made it possible to reclaim high-quality water as well as save a lot freshwater.

Table 4. Estimated economic performance of treatment systems

Technology	Capital Cost (INR/m ³ /day)	O&M Cost (INR/m ³)	Cost-effectiveness
Sand Filtration	18,000	6–8	High (Low Quality Use)
Sand + Activated Carbon	25,000	9–11	Moderate
MBR	45,000	15–18	High
RO Polishing	60,000	22–25	Moderate
AOP	50,000	20–23	Moderate

For centrally located urban purposes, MBR systems showed good cost-to-efficiency ratios, especially when moderate to exceptional reuse is needed.

3.5 Environmental Impact and Energy Consumption

The amount of energy needed for different treatment technologies was very different. Systems that were better at elimination usually used more energy, which led to more carbon dioxide emissions.

Table 5. Energy consumption and carbon footprint of treatment technologies

Technology	Energy Use (kWh/m ³)	CO ₂ Emissions (kg/m ³)
Sand Filtration	0.15	0.12
Sand + Activated Carbon	0.25	0.20
MBR	0.85	0.70
RO Polishing	1.20	0.95
AOP	1.00	0.82

Advanced systems used more energy, but if implemented on a large scale, they were able to compensate for the gathering of pure water, which substantially lowered the general strain on the surroundings.

IV. DISCUSSION

The results of this study underscore the considerable possibilities of air conditioner condensation and reversible membrane refuse water as substitute urban water supplies in India. The variations in initial water standards between the two resources show how important it is to have treatment plans that are specific to each source. The water that comes out of air conditioners, which is mostly made up of moisture in the air, had low levels of total dissolving solids as well as organic contaminants, which shows that it is relatively pure. Reverse osmosis reject water, on the other hand, had higher levels of salt as well as biological material because contaminants were concentrated throughout the filtration process. These traits had a direct effect on how well the treatment worked, how much it cost, and whether it could be used again.

The assessment of treatment technologies indicated that traditional techniques, like sand filtering alone, are inadequate for transforming RO reject water to meet reusable requirements. These methods did reduce suspended particles as well as organic matter by a small amount, but they did not do enough to get rid of high levels of dissolved substances or bacterial contamination. But for AC condensate water, the minimal sterilization worked, which shows how important it is to match the level of treatment to the quality of the water source. The research encourages distributed water recycling methods that cut down on energy use and operational expenses that aren't essential.

Advanced sterilization technologies, such as membrane-based bioreactors, reversible osmosis polishing, as well as advanced oxidation procedures, showed much better removal rates for both organic matter as well as microbial pollutants. Of such, membrane bioreactor systems had the best overall performance because they lowered biological oxygen requirements as well coliform levels by a lot while using only a little energy. Reverse osmosis polishing made the best treated water, which is good for sensitive business as well as HVAC uses, however cost more to run and needed more energy. This trade-offs show that technology choices should to be made based on their intended reuse or the infrastructure that is already in place.

The reuse feasibility evaluation shows how useful it is to use processed AC condensate and RO reject water for things like gardening, flushing toilets, cooling systems, as well as HVAC makeup water that don't need to be drinkable. Using treated non-potable water instead of freshwater in these situations could greatly lower the amount of drinkable water that cities need. This is

especially important in Indian cities where demographic expansion as well changing weather patterns have placed more stress on drinking water availability. The findings indicate that incorporating decentralized recycling systems into construction sites and institutional educational institutions can result in significant water conservation while maintaining operational needs.

The investigation of the environmental impact showed a direct link between how well treatment works and how much renewable energy it uses. Technologies that were better at removing things needed more energy as well as released more carbon into the air. But when you look at the bigger picture of less freshwater gathering, less wastewater released, and less consumption of energy in concentrated water distribution networks, autonomous recycling solutions are better for the environment overall. The ecological impact associated with modern treatment methodologies might become even lower if alternative energy alternatives like solar electricity were used.

At general, the conversation supports the idea which new ways to recycle or reuse AC condensate and RO reject water may be very important for making India's urban water supply more sustainable. To be successful, execution needs to take into account the water's quality, purification efficiency, cost-effectiveness, as well ecological effects. In order to make such procedures more common, there needs to be legislative structures that encourage centralized reuse of resources, as well as building-level rules as well as outreach efforts. This investigation establishes a solid groundwork for subsequent research aimed at system effectiveness, longevity evaluation, and compatibility with intelligent water administration structures.

V. CONCLUSION

This research illustrates that the recycling as well as repurposing of air conditioner condensates as well as reverse osmosis discard water constitute effective as well as sustainable approaches to mitigate metropolitan shortages of water in India. The results unequivocally demonstrate that these various sources of water, commonly regarded as waste, hold significant possibilities for non-potable utilization when subjected to suitable as well application-specific treatment approaches.

The findings indicate that the water that comes out of a cooling system has a low salt content or little organic contaminants. This means that it can be reused with simple purification methods like sand filtering or carbon activation. Reverse osmosis reject water, on the other hand, has high levels of suspended solids as well biological material. In order comply with appropriate recyclable guidelines; it demands more modern purification methods, like bioreactors with membrane techniques, biological finishing, or progressed oxidation technologies. This difference shows how important it is

for determine the procedure that matches its origin rather than using the same method to all types of recycled water.

From an operational standpoint, modern wastewater treatment technologies exhibited enhanced elimination rates for disintegrating solids, organic substances, as well as microbes. But these gains came through greater energy use and operating costs. Among the various possibilities that were looked at, membrane bioreactor techniques stood out as a viable choice because they are very efficient at treating waste, don't use too much energy, as well are great for distributed urban settings. When combined with alternative sources of energy, these kinds of systems can make the surroundings even more sustainable.

Economic evaluation showed that traditional treatment techniques are affordable for low-quality reuse utilization. However, modern technologies allow for more freshwater replacement, which has long-term economic as well as ecological advantages. The reuse effectiveness investigation showed that filtered water from AC condensate as well RO discard rivers could be used for things like garden maintenance, flushing toilets, cooling systems, as well HVAC makeup water, which means we won't need as much drinking water.

At general, the research shows how important distributed water reclamation systems are in urban India as well as stresses the requirement for policy encouragement, public understanding, as well as technological implementation to make these approaches work on a larger scale. Using new ways of reusing AC condensate as well RO reject water could make cities safer over water, take some of the strain off of freshwater resources, as well help meet sustainable development goals. Prospective studies should concentrate on the durability of systems, integrating them with innovative water-management technologies, as well as the evaluation of public sentiment to promote extensive adoption.

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