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Monsoon Rainfall and Household Drinking-Water Quality in India: A Review of TDS, pH and Turbidity in Tap, RO-Treated and Packaged Water

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Abstract

Each time the monsoon rains arrive, the Indian urban water utility faces the same issue – the storm deposits organic material and silt in their reservoirs and the people notice that the water coming from the tap is not clear. Households adapt by increasing their use of reverse osmosis (RO) purifiers and packaged drinking water and, but rarely, have studied these three water sources together in the context of the rains. This review compiles published evidence of the effect of monsoon rainfall on commonly measured parameters of drinking water quality – total dissolved solids (TDS), pH, and turbidity – for three types of drinking water, municipal tap water, household RO-treated water and packaged drinking water. A narrative review of peer-reviewed field studies, Indian Standards IS 10500:2012 and IS 14543:2016, World Health Organization (WHO) Guidelines, National Green Tribunal order and the municipal advisories were undertaken. Most of the literature suggests that both surface-fed supplies and intermittent piped supplies provide a second avenue for mineral deterioration due to rain, which causes dilution of dissolved minerals, and to distribution failures, which introduce high levels of turbidity. The RO treatment process provides a good protection on the changes in TDS and turbidity to the consumer, but produces low mineral, mildly acidic effluents, whose quality can depend on proper maintenance of the membranes. Packaged water seems to be the most consistent of the three, due to a regulated source and because it is required to be certified;

however, not all packaged water is certified. The review determines that the source most likely to show measurable moonsoon change is tap water, the primary gap is the lack of paired, same-locality comparisons, and offers a protocol that will help address this gap.

Keywords: total dissolved solids; pH; turbidity; monsoon; drinking water quality; reverse osmosis; packaged drinking water

1. Introduction

Safe drinking water is the foundation for nearly all other public-health improvements, including child growth and the control of enteric disease. In India the issue is not if water comes to a house but how it comes to a house when it is consumed. Urban families frequently rely on multiple sources simultaneously: water from their municipal water supply, water from the municipal water system that has been filtered using a domestic RO system, and sealed packaged water in bottles or 20 litre containers. These sources have different pathways to the consumer, and each of these paths is sensitive to different weather.

It is during the south-west monsoon that differences are most significant. Soil, leaf litter, and urban runoff are washed into lakes and rivers by the heavy rain, altering the chemistry of source water in days and causing treatment plants that were built for dry season conditions to become stressed. When pipes are not in use during a part of the day in many Indian cities, as is common, contaminated groundwater and surface water can also enter the system through pipe leaks during periods of reduced pressure (Kumpel & Nelson, 2013). The monsoon is also a natural hotspot for any study of household water since epidemiological studies in other areas have correlated extreme rainfall with waterborne disease outbreaks (Curriero et al., 2001; Cann et al., 2013).

Three parameters are especially convenient to monitor such change since they are inexpensive to measure and have been subject to national standards and are responsive to precipitation. Mineral and salt content of water (TDS) affects taste. pH affects pipe/fitting corrosion and the effectiveness of chlorine disinfection. Cloudiness of water due to suspended particles is known as turbidity and is not only an aesthetic problem but is also a recognised indicator that the water may be contaminated with microorganisms which are shielded from disinfection by the suspended particles (WHO, 2017). None of these three is a direct indicator of the ability of the

water source to be rendered microbiologically safe, but they provide an early and practical indication of the behavior of the water source.

A vast amount of Indian literature documents the seasonal variation in both groundwater and surface water resources; comparatively, a lesser volume of these documents helps to trace water to the household tap; and a still smaller volume of these documents compares the water from the tap, RO, and packaged water from the same locality during a period of rain. The aims of this review are therefore to summarise the reported impacts of monsoon rainfall on TDS, pH and turbidity in each of the three sources, (b) compare these results with Indian and WHO benchmarks, (c) explain how these results are reported and (d) identify gaps and suggest a field protocol for a comparative study on a locality basis. The working hypothesis that is followed in the review is that out of the three sources the municipal tap water will change the most between pre-monsoon and post-heavy-rain conditions.

2. Scope and Method of the Review

This is a narrative review and not a systematic review or meta-analysis. The sources were identified using the keywords, pre-monsoon, post-monsoon, seasonal variation, turbidity, total dissolved solids, reverse osmosis, packaged drinking water, bottled water and intermittent water supply from the databases, such as Google Scholar, Directory of Open Access Journals, publishers' websites and web portals of the government of India. Peer-reviewed studies conducted in India and/or in similar monsoon climates, primary standards documents and official orders and advisories were considered as priorities. The studies were included provided that they provided at least one of the three parameters in a seasonal or rainfall context or compared the RO treated or packaged water against Indian standards. The findings of the included studies are compared qualitatively, owing to the differences in design, sampling and instruments.

3. The Three Parameters and Their Benchmarks

3.1 Total dissolved solids

TDS consists of a mixture of inorganic salts (mainly calcium, magnesium, sodium, potassium, bicarbonate, chloride, and sulphate) and a minor organic component. However, the WHO has no health based guideline for TDS, rather it's related to palatability where water below

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approximately 600 mg/L is considered good and above approximately 1,000 mg/L water is increasingly unpalatable (WHO, 2003, 2022). The field TDS meters are not actual mass measurement devices for the dissolved solids. They determine the electrical conductivity and convert it with a fixed ratio, and their results are estimates that vary in accuracy based on the composition of ions in the sample (APHA, 2017). Very low TDS is another point of concern as the demineralised water is low in calcium and magnesium which could lead to more aggressive attack on plumbing (Kozisek, 2005).

3.2 pH

There is no health based guideline value for pH in drinking water with the concentrations that are usually found in drinking water, but it is one of the most important operational parameters (WHO, 2022). Acidic water can cause pipes to rust, and can also cause the mobilization of metals like lead and copper, while alkaline water can decrease the effectiveness of chlorine disinfection and may scale pipes. Rainwater is slightly acidic naturally due to the absorption of carbon dioxide from the atmosphere and the surface sources can contain organic acids which can change the pH of the water following heavy rain.

3.3 Turbidity

Turbidity of water is measured optically, which is the light-scattering ability of suspended clay, silt, organic matter and microorganisms, and is reported in nephelometric turbidity units (NTU). Water kept without chlorination should have a turbidity level of less than 1 NTU, ideally 0.2 NTU, as this is below what consumers can detect (WHO, 2017). Other studies conducted in the U.S. and other countries have linked short-term spikes in treated-water turbidity to gastrointestinal illness, but this evidence is not consistent (Schwartz et al., 1997; Mann et al., 2007).

3.4 Applicable standards

This review has consolidated the limits for piped and other general drinking water in Table 1, and for packaged drinking water in Table 2 (IS 10500:2012, 2016; IS 14543:2012, 2016).

Table 1. Limits for TDS, pH and turbidity under Indian and WHO benchmarks

Parameter	IS 10500:2012 (acceptable / permissible)	IS 14543 (packaged water, max)	WHO Guidelines
TDS (mg/L)	500 / 2,000	500	No health-based value; taste deteriorates above about 600–1,000
pH	6.5–8.5 / no relaxation	6.5–8.5 (see footnote 3)	No health-based value; operational range commonly 6.5–8.0
Turbidity (NTU)	1 / 5	2	Below 1, ideally about 0.2, for effective disinfection

Sources: BIS (2012, 2016); WHO (2003, 2017, 2022). Values compiled by the author.

4. Monsoon Effects on Municipal Tap Water

4.1 Changes at the source

Most of the Indian seasonal studies are performed on raw sources instead of taps, however, they represent the direction of change which a treatment plant receives. Two effects recur. The first is dilution - the conductivity and TDS of the lakes and rivers will be reduced by the large volumes of low mineral content rain water. The lower electrical conductivity of drinking-water sources in Thatta district, Pakistan, was observed during the post monsoon period, which was explained by high flows, while the slight increase in pH was correlated with the same dilution (Mahmood et al., 2014). The second effect was an increase in turbidity, as before rainfall turbidity was approximately 5.1–5.5 NTU, while after the rains it was 6.9–8.7 NTU, as recorded in this study and attributed to bank erosion and higher flow.

Groundwater can act in other ways. For aquifers, where rain recharges salts are released from the soil, TDS can increase, not decrease, following the rains. Bairwa et al. (2024) studied groundwater quality of Tonk district, Rajasthan and observed that some samples had TDS concentration above permissible limits for both pre- and post-monsoon, and that the maximum TDS concentration was higher during the post-monsoon period. It is important to note the difference in it for the design of any tap water study, whether TDS decreases or increases at the tap, will be dependent on the source from which the local water is drawn whether it is surface reservoirs or bore wells.

4.2 Changes within the distribution network

Even well treated water can have a negative impact during its journey to the household. Mains charging is intermittent, i.e. mains are charged during limited periods of the day, which is common in Indian cities (Kumpel & Nelson, 2016). Contaminated water can leak into the pipe through a joint that is leaking, and transient pressure waves can pull contaminated water in through a joint even in a nominally pressurized system (LeChevallier et al., 2003). Kumpel and Nelson (2013) observed that indicator bacteria were more frequently and at higher levels detected in the tap water from intermittent supply compared to continuous supply in the town of Hubli-Dharwad. They also observed that the quality of the source water decreased marginally during the rainy season but the intermittently supplied water taps had considerably higher concentration of indicator bacteria in the rainy season compared to the dry season. When water was again supplied to the pipes, the follow-up study found a rise in turbidity and bacterial counts in the water initially flushed from pipes, which is plausible because of saturated soil and higher groundwater tables around buried pipes during monsoon conditions (Kumpel & Nelson, 2014).

4.3 An urban illustration: Mumbai

Mumbai exemplifies the same. The city is dependent on seven lakes for supply among which Bhatsa reservoir is the main lake in this city. In October 2024, the Brihanmumbai Municipal Corporation blamed a spate of complaints of smoky water on three to four days of continuous rain over the Bhatsa catchment and requested residents to purify and boil water prior to consumption (Lokmat Times, 2024). There are no measured values reported on this episode, it was only mentioned in the press, however it does indicate that rainfall-induced turbidity can flow through a large conventional treatment system to levels that can be discerned at the tap. It also provides an explanation as to why many homes in such cities would cleanse their homes once again during the monsoon season.

5. RO-Treated Water

Reverse osmosis pushes water across a semi-permeable membrane which will not allow most dissolved ions to pass, and essentially none of the suspended particles (Greenlee et al., 2009). Theoretically, this means that the quality of the RO product is not contingent on how well the feed water quality is at the tap when it is raining: if the TDS and turbidity is bad at the tap

during the rains, the product should also be bad. Typical domestic units for sale in India include a sediment filter, a carbon filter, an RO membrane and sometimes an ultraviolet filter and a mineral or TDS cartridge.

There are three features of RO behaviour relevant to a monsoon comparison. First of all, the effectiveness of the membrane produces low mineral content water. Gani et al. (2023) found that the output water from a household RO unit contained 40 to 50% less dietary minerals (including fluoride and magnesium) in the tap water in Srinagar and the cost of water from a household RO was three to four times that of tap water. Secondly, RO water has a slightly acidic pH because the water used for RO is slightly acidic by nature. DCO diffuses through the membrane and the bicarbonate, which buffers the water, is largely rejected, resulting in the product water typically having a lower pH than the feed water, and the pH is often less than 6.5 unless the unit remineralises its output (Greenlee et al., 2009).

Third, RO performance is dependent upon maintenance. The monsoon season brings high turbidity feed water that will cause sediment pre-filters to become loaded rapidly and increase the potential for membrane fouling, resulting in decreased rejections and an increase in the permeate TDS (Greenlee et al., 2009). It is therefore important to note that a household unit that is served on a fixed calendar might be different during the rains compared to the dry season. Therefore, with every RO sample, the age of the filters should be recorded as well as the date of the last filter service. A related requirement is that if domestic RO is used (where it is not required) then it consumes electricity and causes a substantial loss of feed water—this is referred to as a life-cycle study (Garfí et al., 2016; Gani et al., 2023).

6. Packaged Drinking Water

In India, packaged drinking water is prepared from ground or surface water by the process of treatment, generally involving filtration, RO and disinfection, at licensed plants and sold with the BIS certification mark (BIS, 2016). Packaged water should not exhibit marked seasonal variation at the point of sale as the water is controlled and the product is sealed prior to the arrival of monsoons to the consumer. The risks which may be relevant are, however, in the individual treatment plants, in the storage, and in the large informal market for jar water which may not be certified.

There is an inconsistent picture in published Indian studies. Bhardwaj and Sharma (2021) conducted a study on 24 PET bottles of six brands purchased from Noida to check the physico-chemical parameters against the standard IS 14543 and observed that the physico-chemical parameters were found to be within standard (pH 6.72-6.97) and turbidity was below 1 NTU. In Delhi, Singla et al. (2014) tested packaged water sold throughout the city and found that some samples contained excessive levels of chemicals and bacteria, and recommended that the quality of such water should be better controlled and licensed. The results indicate that brand or supply chain is more important than season for packaged water, and the comparative study should include same brands, and if possible, same batches, across the season. There is a smaller controllable variable: before testing the bottles were kept in the heat or in direct sunlight, which adds an unnecessary source of variation; therefore, the samples should be stored in the same manner.

7. Comparative Synthesis

When these strands are combined, one can make a senseful prediction of the relative strength of the three sources during a monsoon event. Table 2 outlines the likely trend of change. These expectations are not experimental results, but hypotheses to be tested and they are suggestions based on the literature reviewed above and the mechanisms described in the literature.

Table 2. Expected direction of change after heavy monsoon rain, by water type

type	TDS	pH Water	Turbidity
Municipal tap (surface-fed)	Likely decrease through dilution	Small shift; direction depends on source and treatment	Likely increase; largest expected change
Municipal tap (groundwater-fed)	May increase where recharge mobilises salts	Small shift	May increase, especially under intermittent supply
Household RO	Low and largely stable; may rise if membrane is fouled	Slightly acidic and stable	Low; stable if pre-filters are maintained
Packaged (certified)	Stable within brand	Stable within brand	Low and stable

Source: Author's synthesis of Mahmood et al. (2014), Kumpel and Nelson (2013, 2014), Greenlee et al. (2009), Bhardwaj and Sharma (2021), Bairwa et al. (2024) and Gani et al. (2023).

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The result of the synthesis is in support of the working hypothesis. Only one of the three water sources is subjected to both source-level and distribution-level effects of rain, namely tap water and turbidity is the parameter most likely to capture both the source-level and distribution-level effects of rain. RO and packaged water should differ from tap water less in the change that occurs due to rain, and more in the base water properties, with RO water being low in minerals and slightly acidic, and packaged water being standard, subject to brand compliance.

8. Research Gap and a Proposed Locality-Based Protocol

This is a specific gap highlighted in this review. Seasonal studies are frequently conducted, but typically sample raw sources in wide pre- and post-monsoon periods several months apart, and do not involve RO and packaged water. Very few (if any) report all three household sources in the same area, before and immediately after a specified heavy-rain event, using the same instruments all the time. The following protocol is suggested for doing that.

Study area and sites. Choose 5-10 sampling points in one municipal ward and indicate if they receive continuous and/or intermittent water supply from surface or underground water. Take tap water samples at each place, RO permeate from the house hold unit (with the details of the make, age and last servicing) and sample of packed water of same two brands purchased at one outlet, if available one batch.

Sampling schedule. Pre-monsoon round shall be taken in the second half of May and post-rain round shall be taken within 24-48 hours of the nearest IMD station with heavy rainfall of at least 64.5 mm.1 and the rainfall observation shall be reported based on the published IMD records. If the same time of day is chosen for sampling in both rounds, and the initial sample is collected from the tap water, and the subsequent sample is collected after a short flush, then the first flush effect can be distinguished from the steady state quality.

Measurement. Use a pH meter calibrated daily with buffers at pH 4, 7 and 10; a conductivity meter calibrated against a standard conductivity solution; and a nephelometric turbidimeter that is calibrated with formazin or stabilised standards (APHA, 2017). Collect at least 3 replicate readings for each sample; use the same containers throughout the study and the same meters

and analyse samples immediately or store cool and dark in containers with a record of holding time.

Analysis. Report each parameter as Mean ± Standard Deviation for each water type and period, and compare the results with Table 1. If the Shapiro-Wilk test shows that the water type is not normally distributed, use a Wilcoxon signed-rank test to compare pre- and post-rain differences within each water type; otherwise, use a paired t-test. Use two way repeated measures ANOVA (water type x period) and Tukey post hoc tests to compare water types. The results can be displayed by bar charts and box plots. If the study doesn't already include total coliform and E. coli testing, it would be greatly enhanced by including these tests since during monsoon, the microbial safety becomes very important.

9. Public Health Relevance

The take-home points from the literature were that during the rains, the choice of drinking-water source is what is most important, and that each source has its own risk. Turbid tap water is not just an aesthetic problem in the monsoon season, but is a warning to boil or properly filter water, since turbidity can provide a cover for pathogens to resist the action of the residual chlorine (WHO, 2017). The primary benefits of the RO units are their ability to filter turbidity and dissolved contaminants, but this protection is only effective if the pre-filters and membranes are kept clean and the water is used routinely without any minerals.The advantage of the RO units is that they remove turbidity and dissolved contaminants, but only if the pre-filters and membranes are cleaned and they are used repeatedly with no minerals present in the water, which can result in financial and environmental costs. Purchasing water with a certification mark provides confidence that the water is generally reliable, but when samples have been found not to comply, the certification mark is the best indicator of quality, not the price. The results indicate that pipe pressure during the monsoon might be as effective as increased treatment at the plant (Kumpel & Nelson, 2013, 2016) for utilities.

10. Limitations of this Review

There are a number of weaknesses in this review. It is narrative and not systematic, and the choice of studies will be based on judgement, and may not be comprehensive. Most of the seasonal studies located focused on raw water sources or surface water, and not on household

taps, so results from these studies are extrapolated to some degree to the tap water case. The studies also utilize different instruments and sampling periods and the definition for monsoon season precludes quantitative pooling. Lastly, the three parameters discussed are indicators and do not inform about microbial contamination, heavy metals or emerging contaminants, which are also subject to change when it rains.

11. Conclusion and Recommendations

There is clear evidence of a pattern. There are two pathways through which monsoon rainfall impacts municipal tap water: 1) at the source and 2) in the distribution system, and turbidity is the parameter most likely to see the impact of monsoon rainfall, although TDS might decrease in surface-fed systems and increase in some groundwater-fed systems. The consumer is relatively protected from these fluctuations when they are using their household RO treatment system, but gets slightly acidic, low-mineral water and requires periodic maintenance. The most reliable sources are certified packaged water, which is regulated more by the quality of the brand than by time of year. Tap water is thus the water source that is most likely to exhibit a measurable change after heavy rain (hypothesis stated at the beginning of this review).

There are a number of practical suggestions provided below. Households should boil or filter tap water if it is turbid during the rainy season, or if they are advised to do so by the municipality at that time. Before considering RO treatment, RO users should check the TDS level of their water supply, and service pre-filters more frequently in the monsoon season. Packaged water should be purchased only from those products that have the BIS certification mark and should be kept away from heat and the sun. Paired, locality-based research should be conducted and extended to microbial and heavy-metal parameters for more than one monsoon season as proposed in Section 8.

Declarations

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