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Sanitation Coverage and Groundwater Dependence in an Open Defecation Free Indian City: Evidence from Varanasi

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Abstract

Urban sanitation programmes in India are typically assessed through indicators of infrastructure provision and toilet usage, while their interaction with groundwater dependence and household water practices receives relatively limited attention. This study examines the relationship between sanitation coverage, groundwater reliance, and household perception of groundwater quality in Varanasi city, an Open Defecation Free urban area under the Swachh Bharat Mission. The analysis is based on primary data from a household survey of 420 households across twelve water supply sub-zones, focusing on sanitation access, drinking water sources, perceived groundwater quality, and water treatment behaviour.

The results indicate near-universal sanitation access, with 99.3% of households reporting regular toilet use and negligible open defecation. However, dependence on groundwater remains high, as 63.1% of households rely on private groundwater sources for drinking water. Household perception of groundwater quality is largely favourable, with around 80% of respondents reporting overall satisfaction. At the same time, physical quality concerns particularly seasonal sand intrusion were reported by nearly one-quarter of households. Despite these issues, more than half of the households consume groundwater without any form of treatment, reflecting a reliance on perception rather than precautionary water safety practices.

Although this study does not involve laboratory-based groundwater quality testing, existing hydrogeological research has documented nitrate and bacteriological contamination in shallow aquifers of Varanasi, indicating recognised subsurface vulnerability. The findings point to a perception–risk gap in groundwater-dependent ODF cities, where sanitation achievements and improved surface cleanliness may reinforce confidence in groundwater quality despite documented contamination risks. The study highlights the need to integrate sanitation interventions with groundwater monitoring and urban water safety planning to support sustainable public health outcomes.

Keyword: Urban groundwater; sanitation coverage; drinking water sources; water quality perception; on-site sanitation; groundwater vulnerability; Varanasi

1. Introduction

Groundwater remains a critical source of drinking water in Indian cities, particularly where municipal water supply is intermittent, unevenly distributed, or inadequate to meet growing urban demand. Rapid urbanisation, high population density, and infrastructural constraints have led many households to rely increasingly on private groundwater sources such as borewells, handpumps, and submersible pumps. While groundwater offers reliability and convenience, it is also vulnerable to contamination from urban activities, especially sanitation-related wastewater disposal in cities dominated by on-site sanitation systems.

Urban sanitation has long been recognised as a key determinant of groundwater quality in India. Practices such as open defecation, unlined pits, and poorly managed septic systems have contributed to microbial and physical contamination of shallow aquifers, particularly in densely built environments. In response to these challenges, the Government of India launched the Swachh Bharat Mission (SBM) in 2014 with the objective of eliminating open defecation and improving sanitation access through large-scale toilet construction and sustained behaviour change initiatives. Under Swachh Bharat Mission–Urban, cities were encouraged to achieve Open Defecation Free (ODF) status, signalling near-universal toilet usage.

By the late 2010s, a large number of Indian cities, including Varanasi, were declared ODF. This marked an important milestone in urban sanitation, reflecting substantial improvements in toilet access, usage, and surface-level environmental cleanliness. However, sanitation outcomes under SBM have largely been evaluated through indicators such as toilet coverage, reduction in open defecation, and visible improvements in urban hygiene. Much less attention has been paid to how sanitation improvements interact with groundwater use and household water behaviour in cities where groundwater continues to be the primary drinking water source.

Sanitation success does not necessarily translate into reduced groundwater dependence or improved groundwater safety. In many ODF cities, households continue to rely heavily on private groundwater sources due to limitations in piped water supply. At the same time, the transition from open defecation to toilet-based sanitation often increases the volume of wastewater entering the subsurface through septic tanks and soak pits. In hydrogeologically vulnerable urban settings, this shift represents a reconfiguration rather than an elimination of contamination pathways, moving risks from surface exposure to subsurface interaction with aquifers.

Household perception represents another important yet underexplored dimension of sanitation outcomes. In the absence of routine water quality testing, households commonly assess groundwater quality using sensory indicators such as colour, taste, smell, and the presence of physical impurities. Improved sanitation and cleaner surroundings may enhance confidence in groundwater quality, even where subsurface risks persist. Such perception-driven confidence can influence water consumption, storage, and treatment behaviour, with significant implications for public health and groundwater sustainability.

Varanasi provides a particularly relevant context for examining these interactions. As one of India's oldest and most densely populated cities, it exhibits a complex urban fabric characterised by mixed land use, high groundwater dependence, and varied sanitation infrastructure. Despite achieving ODF status under SBM, the city continues to rely substantially on private groundwater sources for drinking water. Seasonal issues such as sand intrusion and turbidity are locally reported, while systematic household-level groundwater quality monitoring remains limited.

Existing studies on urban sanitation in India have primarily focused on infrastructure provision and behavioural outcomes, while groundwater research has tended to emphasise hydrogeological or chemical assessments without integrating sanitation-related behavioural dimensions. Consequently, there is limited household-level empirical evidence linking sanitation coverage, groundwater dependence, and perception-based water quality assessment in ODF urban settings. While hydrochemical studies provide essential information on contamination, they offer limited insight into how households perceive risk and decide whether to treat their drinking water. This behavioural gap is critical for understanding the implications of sanitation-led urban transformation.

Although this study does not involve laboratory-based groundwater quality testing, concerns regarding subsurface vulnerability in Varanasi are well supported by existing hydrogeological evidence. Previous studies have reported nitrate enrichment and bacteriological contamination in shallow aquifers of Varanasi and the surrounding Middle Ganga Plain, largely attributed to on-site sanitation, urban wastewater infiltration, and high population density (CGWB, 2018; Saha et al., 2019). These findings confirm that groundwater quality risks in the city are documented and real.

Against this backdrop, the present study examines the sanitation–groundwater interface in Varanasi using primary household survey data. By combining indicators of sanitation access, drinking water sources, perceived groundwater quality, and water treatment behaviour, the analysis moves beyond infrastructure coverage to identify patterns of groundwater dependence and perception in a post-ODF urban context.

Objectives of the Study

The specific objectives of the study are to:

1. Assess household sanitation access and toilet usage in Varanasi city following its declaration as an Open Defecation Free city under Swachh Bharat Mission.
2. Examine household dependence on groundwater for drinking water across different water supply sub-zones of the city.
3. Analyse household perception of groundwater quality and associated water treatment behaviour in an ODF urban context.

2. Study Area

The study was conducted in Varanasi, an urban centre located in eastern Uttar Pradesh along the left bank of the River Ganga. The city is characterised by high population density, mixed land use, and substantial reliance on groundwater for domestic water supply due to intermittent and uneven municipal water provision. Varanasi lies within the middle Ganga alluvial plain, where shallow aquifers composed of sand, silt, and clay are widely accessed through borewells, handpumps, and submersible pumps and are vulnerable to contamination from urban activities.

Under the Swachh Bharat Mission–Urban, Varanasi has been declared Open Defecation Free, with near-universal toilet access and minimal open defecation. At the same time, on-site sanitation systems dominate wastewater disposal, and household dependence on groundwater remains high. This combination of improved sanitation coverage and persistent groundwater reliance makes the city a suitable case for examining sanitation–groundwater interactions in an urban context. The location of the study area and the water supply sub-zones used for household sampling are shown in Figure 1.

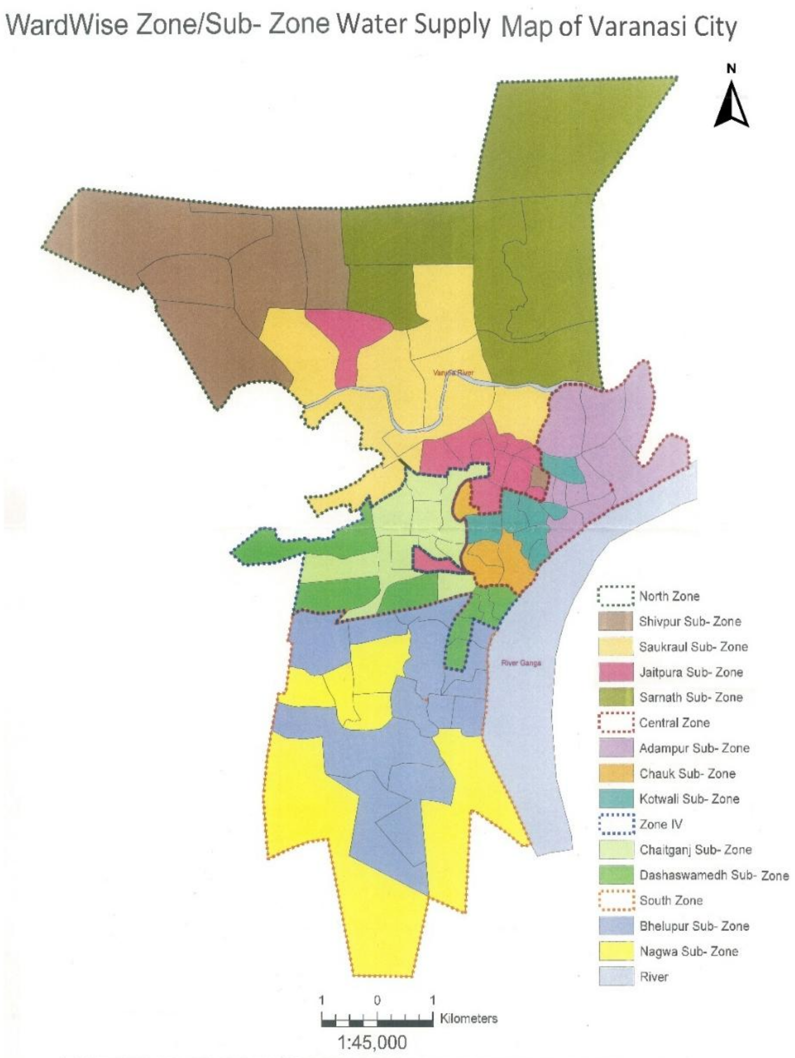

Figure 1. Location of Varanasi city and water supply sub-zones

3. Data and Methodology

3.1 Research Design

The study adopts a cross-sectional, household-level survey design to examine sanitation access, groundwater dependence for drinking water, and household perception of groundwater quality in an Open Defecation Free (ODF) urban context. The approach is descriptive analytical and is based on primary data collected through a structured questionnaire. The methodology is designed to generate quantitative evidence linking sanitation coverage with groundwater use and water-related behaviour at the household scale, rather than establishing causal relationships.

This design is appropriate for urban water and sanitation studies where household perception, access, and behaviour play a critical role and where systematic water quality monitoring data are often unavailable at the city scale.

3.2 Study Area and Sampling Framework

The study was conducted in Varanasi city, Uttar Pradesh, which has been declared ODF under the Swachh Bharat Mission–Urban. Given the spatial heterogeneity in water supply infrastructure and groundwater reliance across the city, water supply sub-zones were used as the primary sampling units rather than administrative wards. This ensured representation of areas with varying levels of municipal water access and groundwater dependence.

Varanasi city comprises 12 water supply sub-zones, each characterised by distinct infrastructural and socio-spatial conditions. A purposive sampling approach was adopted to select households from each sub-zone, ensuring coverage of core city areas, riverfront zones, planned neighbourhoods, and peripheral settlements.

3.3 Sample Size Determination

Sample size was calculated using Taro Yamane's formula, commonly applied in socio-environmental research for finite populations:

$$n = \frac{N}{1 + N(e)^2}$$

where
n = required sample size,
N = total population,
e = acceptable margin of error.

Using a 5% margin of error, the calculated sample size was approximately 400 households. To ensure uniform spatial representation and account for non-response, the final sample size was fixed at 420 households, with 35 households surveyed from each water supply sub-zone.

3.4 Data Collection

Primary data were collected during 2024–2025 through a structured household questionnaire survey. Respondents were selected from adult household members responsible for water collection or water-related decision-making. Participation was voluntary, and respondents were informed about the purpose of the study.

The questionnaire was designed to directly address the three objectives of the study and included both objective and perception-based questions. To reduce ambiguity, questions were kept simple and were administered in the local language where required.

3.5 Variables and Indicators

The analysis is based on a set of variables designed to capture household sanitation access, dependence on groundwater for drinking water, and perception-driven water use behaviour in an Open Defecation Free urban context. Sanitation-related variables include the availability of toilet facilities at the household level, the type of toilet used (private, shared, or public), and the occurrence of open defecation practices. These indicators were used to assess the extent of sanitation coverage and usage following the city's ODF declaration under Swachh Bharat Mission.

Groundwater dependence was assessed through variables related to the primary source of drinking water, distinguishing between public and private sources, and by identifying the specific type of groundwater source used, such as borewells, handpumps, or submersible pumps. Additional indicators captured the physical accessibility of drinking water by recording the location of the water source relative to the household premises, including whether the source was located within the premises, outside the premises, or at a distance from the household. These variables together provide insight into the degree of reliance on groundwater and the convenience associated with its use.

Perceived groundwater quality and associated behaviour were evaluated using perception-based indicators commonly applied in household water studies. Respondents were asked to report their assessment of groundwater colour, taste, and smell, as well as the occurrence of sand or other physical impurities, including seasonal variations where applicable. An overall assessment of groundwater quality was also recorded. In addition, information on household water treatment behaviour was collected, including the use of filtration devices, cloth filtration, boiling, or the absence of any treatment. These variables were used to examine how sanitation coverage and environmental conditions influence household confidence in groundwater quality and decisions related to water treatment.

Table 1. Variables and Indicators Used in the Study

Domain	Variable	Indicator / Measurement
Socio-economic	Age	Age group of respondent
	Sex	Male / Female
	Education	Level of education attained
	Occupation	Type of employment
Sanitation	Toilet access	Availability of toilet (Yes/No)
	Type of toilet	Private / Shared / Public
	Open defecation	Practice of open defecation
Water source	Drinking water source	Public / Private
	Groundwater use	Borewell / Handpump / Submersible
Accessibility	Location of water source	Within premises / Outside / Distance
	Colour	Satisfactory / Unsatisfactory

Water quality (perceived)	Smell	Present / Absent
	Taste	Satisfactory / Occasional issue
	Sand content	Present / Seasonal
Behaviour	Water storage	Bucket / Filter / Earthen pot
	Water treatment	None / Filter / Cloth / Boiling

3.6 Data Processing and Analysis

Survey responses were coded and digitised for analysis. Descriptive statistics, including frequencies and percentages, were used to summarise sanitation access, drinking water sources, groundwater dependence, and perception of groundwater quality. Zone-wise comparison was carried out to highlight intra-urban variation.

Results are presented using tables for numerical values and figures for visual comparison, ensuring clarity and avoiding redundancy. The analysis focuses on identifying patterns between sanitation coverage, groundwater reliance, and household behaviour in an ODF urban context.

Given the perception-based nature of the data, the study does not attempt to quantify chemical or microbiological groundwater contamination. Instead, it emphasises how sanitation outcomes and environmental conditions shape household confidence in groundwater and influence water treatment behaviour.

3.7 Ethical Considerations and Limitations

No personally identifiable information was collected. The study acknowledges limitations related to reliance on self-reported perception rather than laboratory-tested water quality data and the cross-sectional nature of the survey. It is important to note that while the broader research project included hydro-chemical analysis of groundwater samples, this specific study focuses exclusively on the socio-behavioral dimensions of water use. The objective here is not to validate the water quality itself, but to understand the 'Perception-Risk Gap' how users perceive safety versus how they act, regardless of the actual chemical status.

4. Results and Discussion

4.1 Sanitation Status in an Open Defecation Free City

The household survey reveals near-universal sanitation coverage in Varanasi city. As presented in Table 2 and Figure 2, 99.3% of surveyed households reported access to and regular use of toilet facilities, while open defecation was reported by only 0.71% of respondents. Private toilets were used by 58.81% of households, whereas 35.24% depended on shared facilities and 5.24% relied on public toilets. The extremely low incidence of open defecation reflects the substantial improvement in sanitation access and usage following the city's declaration as Open Defecation Free under the Swachh Bharat Mission.

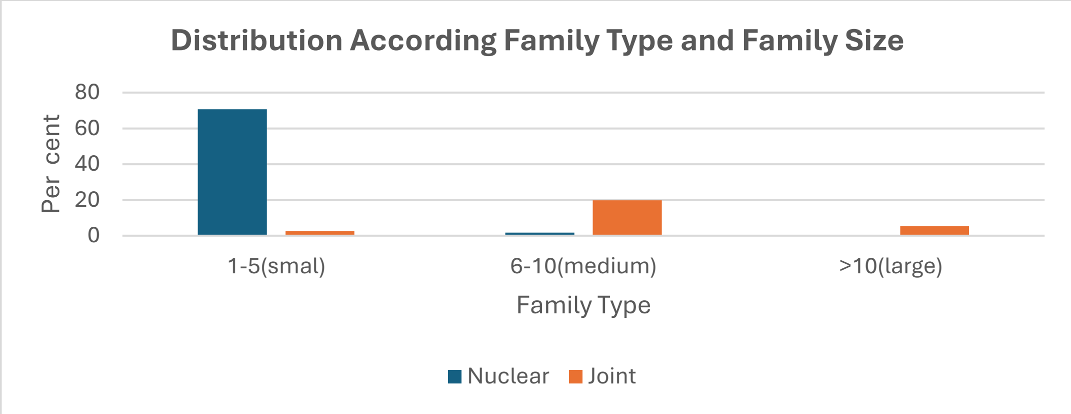

Figure 2. Distribution of toilet facilities among households

The relatively high reliance on shared sanitation facilities reflects space constraints and the dense built form of older parts of the city. At the same time, the findings indicate that lack of sanitation access is no longer a primary constraint for urban households, creating an appropriate context for examining post-ODF interactions between sanitation outcomes and groundwater use.

Table 2. Distribution of Households by Sanitation Facility

Sanitation Facility	Number of Households	Percentage (%)
Private toilet	247	58.81
Shared toilet	148	35.24
Public toilet	22	5.24
Open defecation	3	0.71
Total	420	100

4.2 Household Dependence on Groundwater for Drinking Water

Despite high sanitation coverage, household dependence on groundwater for drinking water remains substantial. As shown in Table 3 and Figure 3, 63.1% of households rely on private groundwater sources, whereas only 36.9% depend on public water supply systems such as municipal connections and government-installed handpumps or tubewells. Within the category of private sources, borewells and submersible pumps predominate, together accounting for 42.14% of household drinking water supply.

Table 3. Sources of Drinking Water among Surveyed Households

Source of Drinking Water	Number of Households	Percentage (%)
Public sources		

Municipal water connection	89	21.19
Government handpump	56	13.33
Government tubewell	10	2.38
Total public sources	155	36.9
Private sources		
Own handpump	72	17.14
Well	16	3.81
Borewell / Submersible	177	42.14
Total private sources	265	63.1
Grand total	420	100

This continued reliance on groundwater points to a decoupling between sanitation improvements and transitions in drinking water sources. Even in an ODF city, groundwater continues to serve as the most reliable and convenient source of drinking water for a majority of households, largely because municipal water supply remains intermittent or unevenly distributed. As a result, the responsibility for ensuring water quality and safety is effectively transferred to individual households, increasing the importance of perception-based assessment and related water use behaviour.

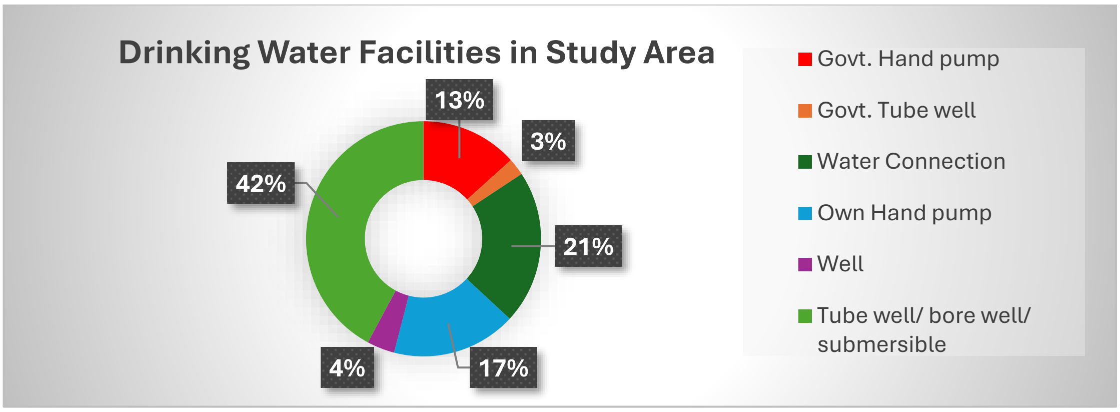

Figure 3. Sources of drinking water used by households

Spatial variation further reinforces this pattern. As shown in Figure 4, dependence on groundwater is highest in older and densely populated zones such as Chowk, Kotwali, and Jaitpura, whereas relatively lower reliance is observed in areas with more consistent municipal water supply. These spatial contrasts emphasise the need to account for intra-urban heterogeneity when interpreting sanitation outcomes and drinking water dependence within the city.

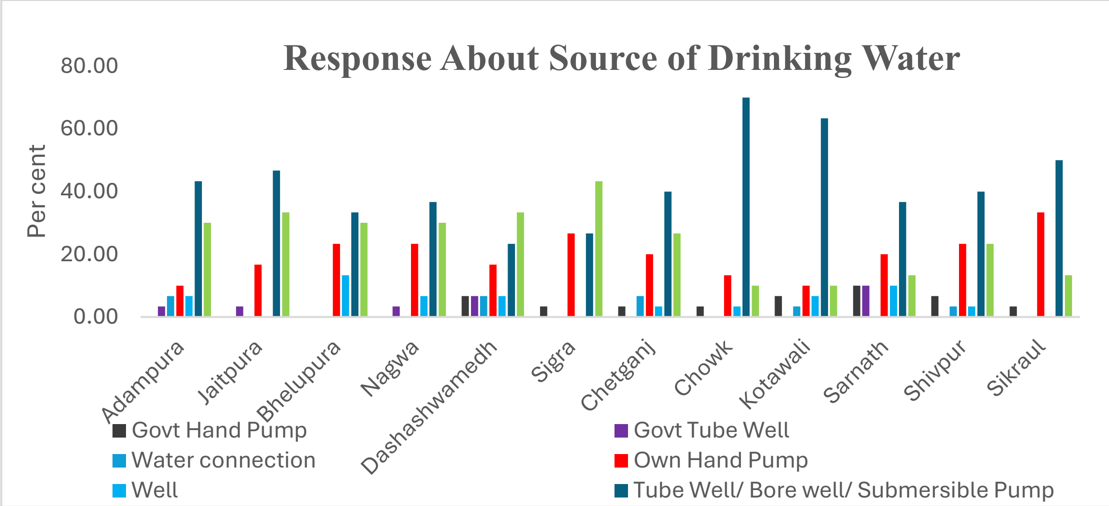

Figure 4. Zone-wise dependence on groundwater for drinking water

4.3 Accessibility of Drinking Water Sources

Physical accessibility of drinking water sources further helps explain household reliance on groundwater. As shown in Figure 5, 62% of households reported having their drinking water source within their premises, while 22% accessed water from outside the premises and 16% obtained water from a more distant location. This high level of within-premises access is largely associated with private groundwater sources, which offer convenience and greater control over water availability. The proximity of groundwater sources reinforces habitual dependence and reduces incentives for households to shift towards public water supply systems or adopt precautionary water treatment practices. In sanitation-improved urban environments, such convenience-driven reliance on groundwater may therefore persist even in the presence of underlying subsurface contamination risks.

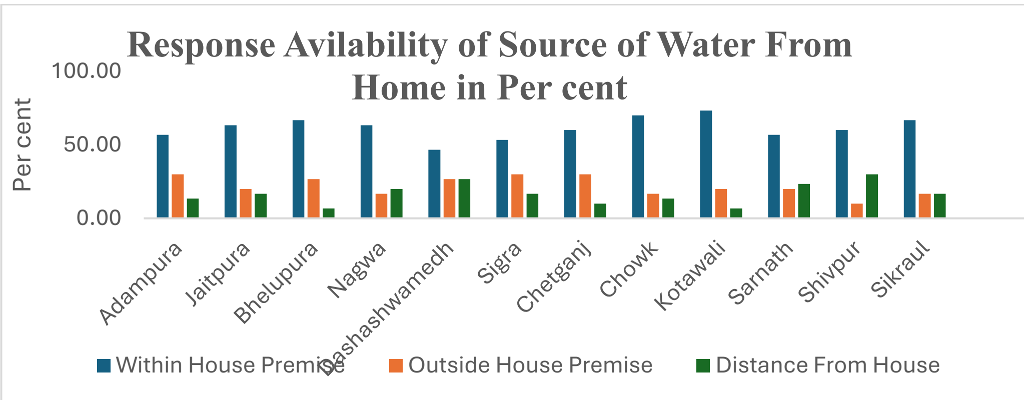

Figure 5. Location of drinking water source relative to household premises

4.4 Perceived Groundwater Quality

Household perception of groundwater quality is generally favourable, as indicated in Table 4 and Figure 6. Around 80% of respondents rated overall groundwater quality as satisfactory. Assessment of individual quality attributes also reflects a high level of confidence, with 67% of households expressing satisfaction with groundwater colour, 93% reporting the absence of any noticeable smell, and 70% indicating satisfaction with taste.

Table 4. Household Perception of Groundwater Quality

Quality Parameter	Satisfied (%)	Occasional Issue (%)	Unsatisfied (%)
Colour	67	24	9
Smell	93	–	7
Taste	70	24	6
Sand content	76	–	24
Overall groundwater quality	80	–	20

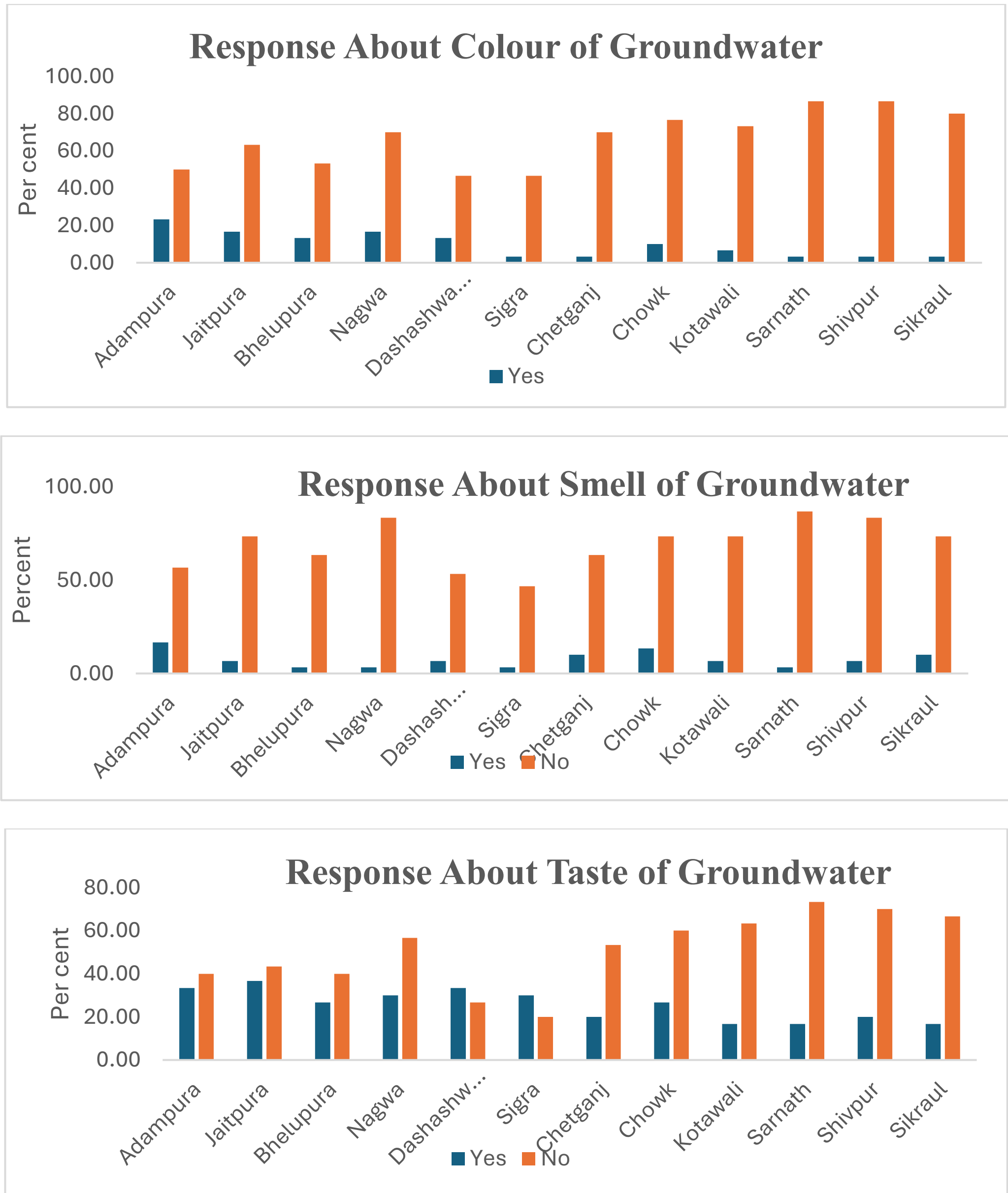

Figure 6. Household perception of groundwater quality indicators

However, physical impurities particularly sand emerge as the most frequently reported concern. As shown in Figure 7, 24% of households reported the presence of sand in groundwater, commonly described as a seasonal issue during the monsoon and post-monsoon periods. Although sand intrusion does not necessarily imply chemical or microbiological contamination, it has a noticeable influence on user experience and shapes household perception of water quality.

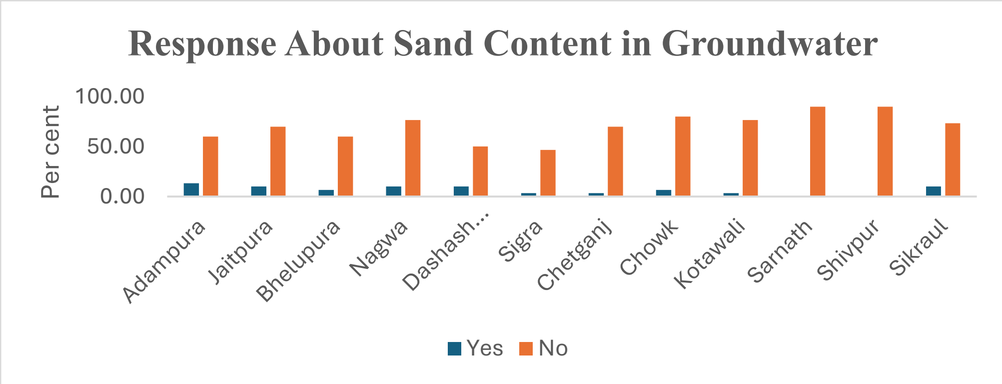

Figure 7. Occurrence of sand in groundwater

The coexistence of high overall satisfaction alongside localised and seasonal quality issues suggests that households may have normalised certain groundwater-related problems. Improvements in sanitation and visible environmental cleanliness can reduce surface cues of contamination, thereby reinforcing confidence in groundwater quality even when subsurface vulnerabilities persist.

4.5 Water Treatment Behaviour and Perception–Risk Gap

Water treatment behaviour closely mirrors household perception of groundwater quality. As shown in Table 5 and Figure 8, 55% of households consume groundwater without any form of treatment. Only 15% reported using filtration devices, while 6% relied on cloth filtration, mainly to remove sand. Boiling of drinking water was reported by only around 1% of households and was generally practiced on an occasional rather than routine basis.

Table 5. Water Purification Practices Adopted by Households

Water Treatment Practice	Number of Households	Percentage (%)
No treatment	231	55
Water filter / purifier	63	15
Cloth filtration	25	6
Boiling (occasional)	4	1
Other methods	97	23
Total	420	100

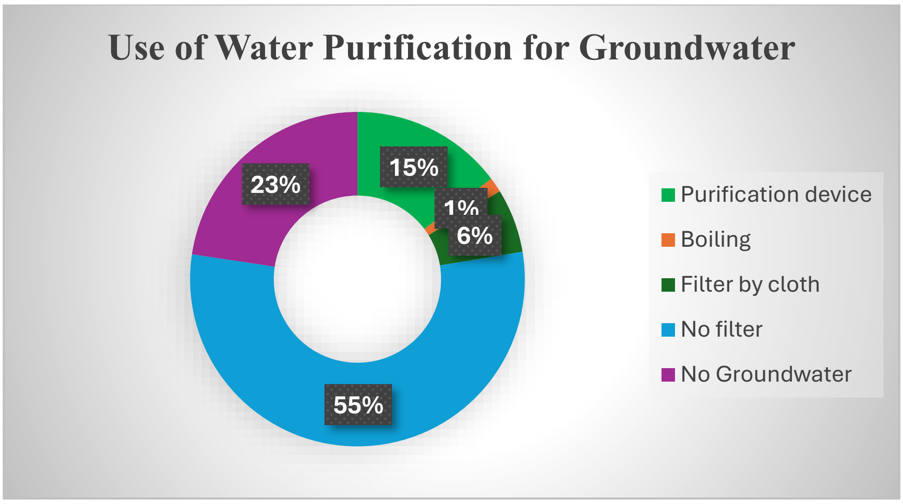

Figure 8. Water purification practices adopted by households

The limited adoption of water purification measures points to a perception–risk gap, in which improved sanitation and visible environmental cleanliness contribute to a high level of confidence in groundwater quality. Even households that experience seasonal sand intrusion tend to rely on temporary, low-cost coping strategies rather than sustained water treatment practices. This pattern suggests that sanitation-led improvements may, in the absence of systematic water quality monitoring or effective risk communication, indirectly reinforce continued reliance on untreated groundwater.

4.6 Sanitation Outcomes and Groundwater Implications

Taken together, the results indicate that sanitation success in Varanasi has not been accompanied by a reduction in groundwater dependence or a corresponding increase in water treatment behaviour. Instead, near-universal sanitation coverage coexists with continued reliance on groundwater and a high level of confidence in its quality. While the transition from open defecation to toilet-based sanitation has clearly improved surface hygiene, it may also have altered wastewater pathways, increasing subsurface interaction in areas dominated by on-site sanitation systems.

These findings suggest that ODF status, although a major public health achievement, should not be interpreted as a guarantee of groundwater safety in cities where groundwater remains the primary drinking water source. In the absence of integration between sanitation programmes, groundwater quality monitoring, and household-level risk awareness, sanitation gains may obscure persistent subsurface vulnerabilities.

Conclusion

This study examined sanitation coverage, groundwater dependence, and household perception of groundwater quality in Varanasi city following its declaration as Open Defecation Free under the Swachh Bharat Mission. The findings confirm near-universal access to sanitation and regular toilet use, underscoring the effectiveness of recent urban sanitation interventions. At the same time, high sanitation coverage has not translated into reduced dependence on groundwater, which continues to serve as the primary drinking water source for a majority of households.

Household assessment of groundwater quality is generally favourable, with limited concern expressed regarding sensory attributes such as colour, taste, and smell. Nonetheless, seasonal physical issues most notably sand intrusion were reported by a substantial proportion of respondents, while water treatment practices remain limited. More than half of the households consume groundwater without treatment, pointing to a perception–risk gap that appears to be reinforced by improved sanitation and visible environmental cleanliness.

The findings suggest that Open Defecation Free status should not be viewed as a proxy for groundwater safety in cities that remain dependent on on-site sanitation and private groundwater extraction. While sanitation improvements have clearly enhanced surface hygiene, subsurface vulnerabilities may persist or even intensify. Integrating sanitation programmes with groundwater monitoring, wastewater and faecal sludge management, and household-level risk awareness is therefore critical to ensure that sanitation gains are not accompanied by unrecognised groundwater quality risks in groundwater-dependent urban settings.

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References

1. Ahamad, A., Madhav, S., Singh, P., Pandey, J., & Khan, A. H. (2018). Assessment of groundwater quality with special emphasis on nitrate contamination in parts of Varanasi City, Uttar Pradesh, India. Applied Water Science, 8, 115. https://doi.org/10.1007/s13201-018-0759-x
2. Mohan, K., Srivastava, A., & Rai, P. K. (2011). Groundwater in the city of Varanasi, India: Present status and prospects. Quaestiones Geographicae, 30(3), 47–60.
3. Raju, N. J., Ram, P., & Gossel, W. (2009). Groundwater quality in the lower Varuna River basin, Varanasi district, Uttar Pradesh, India: Nitrate and other contaminant distribution. Journal of Geological Society of India, 73(2), 178–187.
4. Prajapati, R., Singh, A. K., & Tripathi, J. K. (2018). Water quality index assessment of drinking water in Varanasi District. Journal of Scientific Research, 62, 13–20.
5. Guptaa, D. (2019). An assessment of groundwater quality of Varanasi District. EWJST, 14(02), 019014.
6. Ali, S. (2024). Groundwater quality assessment and suitability for drinking and agriculture in India. PMCID Articles.
7. Central Ground Water Board (CGWB). (2018). Groundwater Yearbook: Uttar Pradesh (2017–18). Ministry of Jal Shakti, Government of India.
8. Singh, S., Raju, N. J., Gossel, W., & Wycisk, P. (2016). Hydrochemical assessment of pollution potential of leachate from municipal waste disposal and its impact on groundwater quality in Varanasi environs. Arabian Journal of Geosciences, 9(2), 1–13.

9. Raju, N. J., Shukla, U. K., & Ram, P. (2011). Hydrochemistry for the assessment of groundwater quality in Varanasi: A fast-urbanizing center in Uttar Pradesh, India. Environmental Monitoring and Assessment, 173, 279–300.
10. Motohashi, K. (2025). Negative externalities on water quality and health in India.