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Exploring Spatial Disparities in Safe Drinking Water Provision in Uttarakhand: A GIS-Based Analysis

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Abstract: Safe and reliable drinking water is a crucial component of public health and sustainable development. It is also explicitly recognized as a key target under the United Nations Sustainable Development Goals (SDG 6: Clean Water and Sanitation). In hilly states like Uttarakhand, geographic and infrastructural challenges often hinder uniform water access, leading to marked spatial disparities between urban and rural areas. This study investigates the availability and accessibility of safe drinking water across Uttarakhand using secondary data from the Census of India (2001 and 2011). The research classifies water sources based on proximity to households (within premises, near premises, and away from premises) and analyzes their distribution using quantitative indices and spatial mapping techniques. A Rural–Urban Difference (RU) index and a composite Drinking Water Source Availability and Accessibility Index (DWSAAI) were computed to assess intra-state disparities. Choropleth maps generated using QGIS version 3.38 highlight variations in access levels across districts, revealing significant progress in lowland and urban regions while many hill districts continue to face accessibility challenges. The findings underscore the importance of context-sensitive interventions, enhanced infrastructure, and climate-resilient water management policies, especially under national schemes like the Jal Jeevan Mission. The study emphasizes the role of GIS in identifying gaps and supporting evidence-based water governance in mountainous regions.

Keywords: Safe Drinking Water, Spatial Disparities, GIS Mapping, Uttarakhand, Hill Region Development.

Introduction

Access to safe drinking water is a fundamental necessity for human well-being, yet disparities persist in many regions, particularly in hilly states like Uttarakhand. Ensuring universal access to safe drinking water remains a significant challenge due to geographical constraints, seasonal variations, and infrastructural limitations. According to the Census of India (2011), only 46.6% of households in India had access to drinking water within their premises, with rural areas facing more difficulties than urban regions. While nationwide efforts like the Jal Jeevan Mission (JJM) aim to improve water accessibility, hilly states such as Uttarakhand face unique challenges related to terrain, water source distribution, and seasonal fluctuations (NITI Aayog, 2020). Recognizing the need for safe and potable tap water supply, the Government of India launched the Jal Jeevan Mission (JJM) in August 2019, in partnership with states, to provide adequate, quality-assured, and long-term drinking water supply to all rural households (Ministry of Jal Shakti, 2023). At the start of JJM, only 16.8% of rural households had access

to tap water connections, but as of December 2023, approximately 71.51% of rural households have been provided with tap water connections (Ministry of Jal Shakti, 2023). Uttarakhand, however, faces specific challenges due to its mountainous topography, which complicates infrastructure development and consistent water supply. The region relies heavily on springs, rivers, and groundwater sources, yet seasonal variations and climate change-induced fluctuations impact their availability (CGWB, 2021). Additionally, the provision of safe drinking water remains a key priority under JJM, particularly in regions affected by chemical contaminants like arsenic and fluoride. The Ministry of Health & Family Welfare (MoH&FW) collaborates with state governments to monitor and mitigate waterborne diseases through the Integrated Disease Surveillance Program (IDSP) (Ministry of Jal Shakti, 2023). Given the incidence of waterborne diseases in many rural areas, the government has issued technical guidelines and awareness programs for the detection, prevention, and management of water contamination-related health issues (MoH&FW, 2023). Singh et al. (2012) highlight that Uttarakhand faces severe water crises, with over 2 million people lacking consistent access to clean water. Both surface and groundwater sources are diminishing, and contamination from human, industrial, and natural activities is worsening the quality of drinking water. They emphasize the need for organizational and technical reforms, particularly in hill regions, to ensure sustainable water management. Chauhan et al. (2020) assess the potability of spring water in a hilly village, finding that while physicochemical parameters were within permissible limits, coliform contamination was widespread. Their health survey showed a strong correlation between water contamination and diseases like dysentery, diarrhea, and typhoid. They recommend systematic water treatment before use. Sharma et al. (2014) discuss bank filtration (BF) technology as a sustainable and cost-effective water pre-treatment method. Their study highlights the effectiveness of BF in improving both water quantity and quality by removing contaminants naturally through aquifer filtration. The research presents BF as a viable solution for the hilly terrains of Uttarakhand but does not assess its large-scale implementation feasibility. Rani (2022) examines regional disparities in safe drinking water availability across India using Census data from 1981 to 2011. Her study reveals significant improvements in access to drinking water, from 38% in 1981 to 85.5% in 2011. However, a notable rural-urban gap persists, and some states continue to struggle with accessibility. Although this study highlights disparities at the national level, it does not provide a focused analysis for Uttarakhand, where the terrain poses unique challenges. Sinha et al. (2022) conduct a spatio-temporal analysis of water quality in Uttarakhand's River sources using multivariate statistical techniques. Their findings indicate worsening water quality over time due to runoff, agricultural activities, and urbanization. They identify six major hydrochemical components linked to health issues, emphasizing the need for continuous monitoring. However, their study does not assess accessibility disparities within the state. Ghosh et al. (2022) explore inequalities in drinking water access among social groups across India. Their district-level spatial analysis shows that Scheduled Caste (SC) and Scheduled Tribe (ST) communities face higher deprivation despite improvements in infrastructure. The study underscores the need for targeted policies to bridge these disparities. However, a district-level assessment specifically for Uttarakhand is lacking. Most studies analyze drinking water issues at a national level, without specifically addressing Uttarakhand's unique geographical and infrastructural challenges. There is a need for a focused study that identifies intra-state variations in drinking water

accessibility across different districts in Uttarakhand. Research has not sufficiently evaluated the effectiveness of water policies and interventions in reducing disparities within Uttarakhand. This study aims to analyze regional disparities in safe drinking water accessibility in Uttarakhand, focusing on rural-urban differentials, the impact of geographic and climatic factors, and the effectiveness of government interventions such as JJM in ensuring safe drinking water access. The findings will contribute to policy recommendations for sustainable water management in hilly regions.

Study Area: Uttarakhand, one of the states within the Indian Himalayan region, lies between latitudes 28.44° N and 31.28° N and longitudes 77.35° E and 81.01° E. (Fig.1) The state was carved out of northern Uttar Pradesh in the year 2000 (Kaur, S. 2023). It is covering a total area of approximately 53,483 square kilometers (Government of Uttarakhand, 2022). It is widely recognized for its rich spiritual and religious heritage, diverse ecological zones, and deep-rooted cultural traditions. Geographically, the state is divided into two main regions—Garhwal in the west and Kumaun in the east. These regions together comprise 13 districts and 95 development blocks. Uttarakhand is characterized by diverse topography, ranging from high snow-capped Himalayan peaks to forested hills and fertile plains. About 86% of the state's area is hilly, and around 65% is covered with forests, making access to essential services like drinking water and sanitation more challenging, particularly in remote and rural areas. (Forest Survey of India, 2021). According to Census 2011, the state has a total population of around 10.1 million, with 70% living in rural areas. Drinking water sources include rivers (e.g., Ganga and Yamuna), springs, lakes, and groundwater, but their availability and quality vary considerably across districts (Singh et al., 2012). Surface water sources are rapidly declining, and groundwater levels are showing a downward trend, particularly in the mid and lower Himalayan regions (Chauhan et al., 2020).

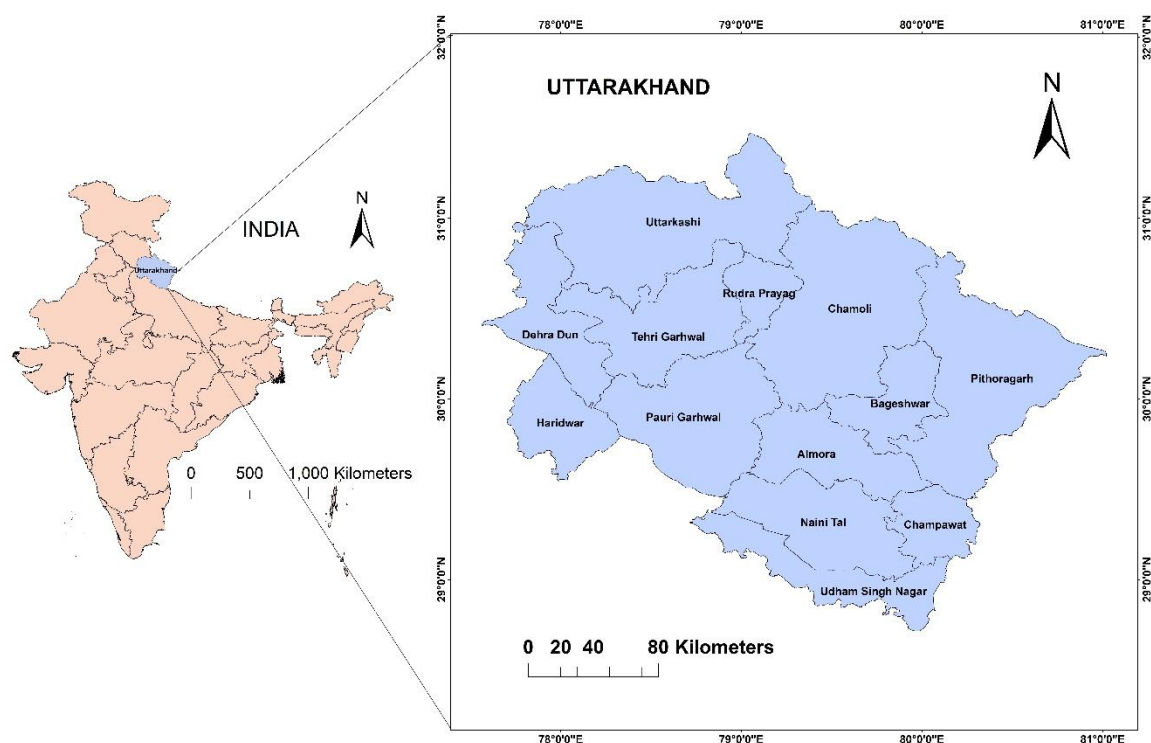


Fig.1 Location map for Uttarakhand state.

Material and Methods

This study primarily relies on secondary data collected from the Census of India 2001 and 2011, which provide detailed information about the source and location of drinking water across urban and rural households. The data include the categorization of drinking water sources as well as their proximity to the household (i.e., within premises-the water source is located on the household's property, near premises- water source located within the radius of 100 m from premises (urban) and 500 m(rural), and away from premises- water source is located outside the radius of 100 m from the urban premises and 500 m from rural premises). In Census 2001, three major sources were categorized under *safe drinking water*: Tap water, Hand pump and Tube well. In Census 2011, the classification was expanded to four safe drinking water sources: Tap water from treated source, Tap water from untreated source, Hand pump and Tube well/borehole.

Table:1 Drinking wate sources have taken by the census of India.

Census year	
2001	2011
Tap Hand pump	Tap water from treated sources Tap water from untreated sources

Tube well	Hand pump
Well	Tube well/ borehole
Spring	covered well
River/canal	uncovered well
Tank/pond/lake	Spring
Other sources	River/canal
	Tank/pond/lake
	Other sources

Safe drinking water sources in bold text.

To examine disparities between rural and urban households, the Rural–Urban Difference (RU) was calculated using the following formula:

RU= Urban Households with Safe Water sources–Rural Households with Safe Water sources

Drinking water source availability and accessibility index(DWSAAI) has been computed for the for the year of 2011. All parameter given in the table 1 have been taken into consideration. Parameters are considered positive except drinking water sources away from the premises. To compare indicators across districts, Min-Max Scaling was applied;

- For positive indicators (which are related to better performance)

$$\text{Scaled Value} = \frac{\text{Max Value} - \text{Min Value}}{\text{Current Value} - \text{Min Value}}$$

- For negative indicators (which are related to low performance)

$$\text{Scaled Value} = \frac{\text{Max Value} - \text{Min Value}}{\text{Max Value} - \text{Current Value}}$$

All scaled values were averaged for each district:

$$\text{DWSAAI} = \frac{\sum(\text{All Scaled Values})}{\text{Total Number of Factors}}$$

Ranking is given to all districts based on DWSAAI. To visualize the spatial disparities in access to drinking water across Uttarakhand, choropleth maps were created using QGIS (v3.38). District-wise layers were digitized, and thematic mapping was performed to show: Access to safe drinking water sources, Distance to water sources (within/away premises), Rural-urban disparities, Performance ranking based on DWSAAI.

Results and Discussion

Availability of Drinking water sources in Uttarakhand

The availability of drinking water sources in Uttarakhand shows notable changes between the 2001 and 2011 Census years, reflecting both progress and persisting disparities across rural and urban regions. Overall, there was a marginal increase in the percentage of households with access to drinking water within premises, rising from 45% in 2001 to 46% in 2011. At the same time, the percentage of households depending on sources near premises decreased from 38% to 32%, while those relying on away premises sources slightly increased from 17% to 20%,

indicating a mixed trend in accessibility. In rural areas, a positive shift was observed in the proportion of households with water sources within premises, increasing from 33% to 40%. However, the share of households collecting water from near premises decreased from 47% to 37%, and those accessing water from away premises rose from 20% to 23%. This suggests that although more rural households gained access to water within their homes, a significant portion still faces challenges in accessing water from distant locations, pointing to uneven improvements in rural water infrastructure. Urban areas, on the other hand, demonstrated consistently better access to drinking water sources. The percentage of urban households with water availability within premises improved from an already high 82% to 85% over the decade. Dependence on sources near premises reduced from 13% to 10%, and households accessing water from away premises remained constant at 5%. These figures indicate strong water provisioning systems in urban Uttarakhand, with the majority of households enjoying convenient access to safe drinking water.(Fig.2)

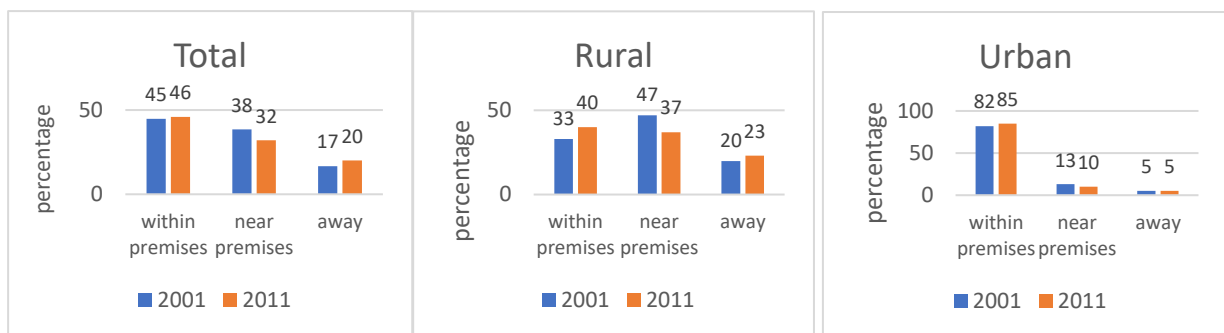


Fig. 2 Availability of drinking water sources in Uttarakhand (%)

Availability of Drinking water sources within the premises

In 2001, large parts of the state, especially in rural and hilly regions such as Pauri Garhwal, Tehri Garhwal, Chamoli, Bageshwar, Champawat, and Pithoragarh, recorded low accessibility — with many districts showing less than 45% of households having water within premises. In contrast, urban districts like Dehradun, Haridwar, and Nainital already had a high percentage of such access, often above 61%, due to better piped water infrastructure and urban governance.

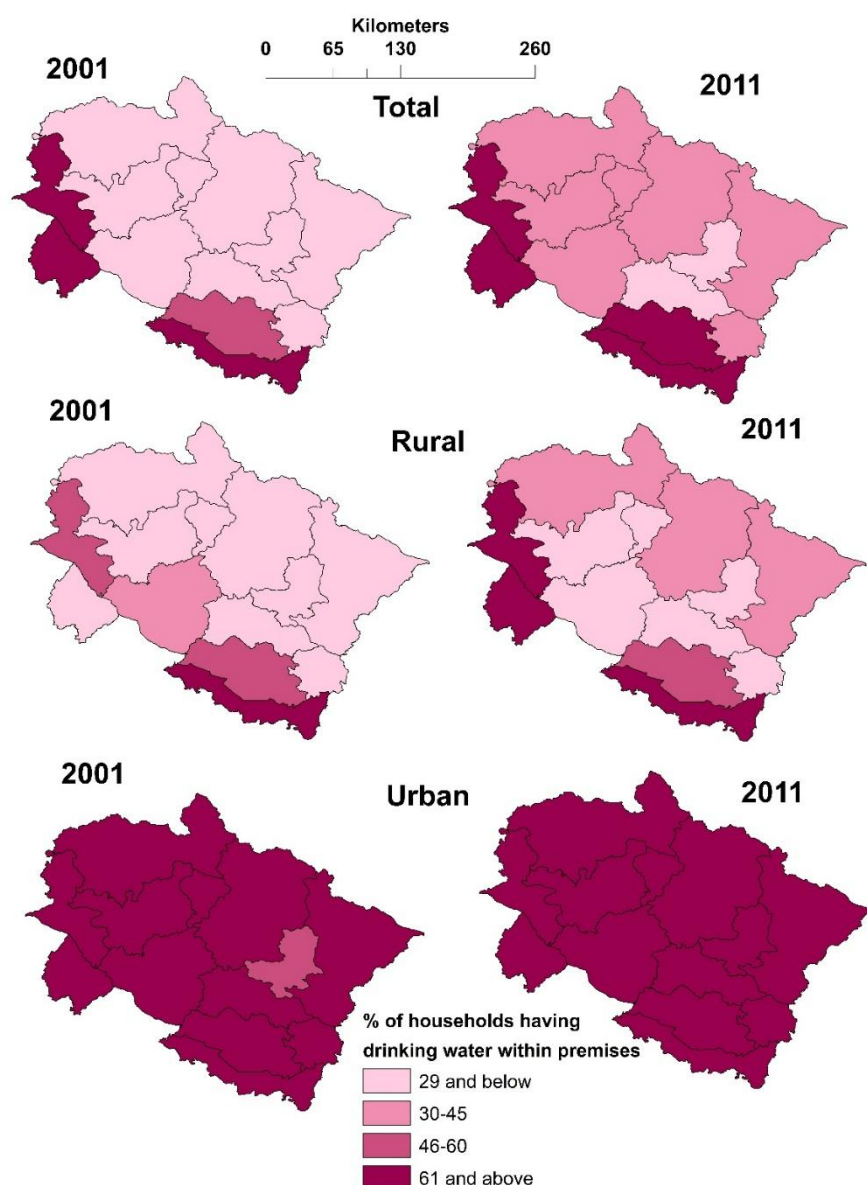


Fig.3 Households Having Drinking water sources within Premises

By 2011, there was a noticeable shift in accessibility. The proportion of households having access to water within premises increased significantly in rural areas, particularly in Udham Singh Nagar, Haridwar, Nainital, and parts of Pauri Garhwal and Almora. For example, Haridwar and Udham Singh Nagar crossed the 61% threshold, reflecting major improvements driven by central and state-sponsored rural drinking water programs such as NRDWP (National Rural Drinking Water Programme). Meanwhile, urban areas like Dehradun and Haldwani in Nainital maintained or improved their already high access levels — often nearing 85–90%.

However, despite the overall improvement, several hill districts such as Chamoli, Uttarkashi, and Pithoragarh still lagged behind in 2011, with many areas in the 30–45% range. This persistence of lower coverage can be attributed to challenges like rugged terrain, sparse population, and difficulty in constructing piped water supply infrastructure in remote areas. Moreover, seasonal water scarcity, dependency on natural springs, and lack of maintenance in hilly regions further impacted household-level accessibility.

Availability of Drinking water sources near the premises

In 2001, a significant number of districts (mainly in the central and eastern regions such as Almora, Bageshwar, Pithoragarh, and Chamoli) had 46% to 60% or even above 61% of households accessing drinking water near their premises. However, by 2011, this percentage decreased in many districts, especially where water became available within premises due to infrastructural development. Areas like Dehradun, Haridwar, and Udham Singh Nagar showed a decline in near-premises access as households gained water access directly within premises instead.

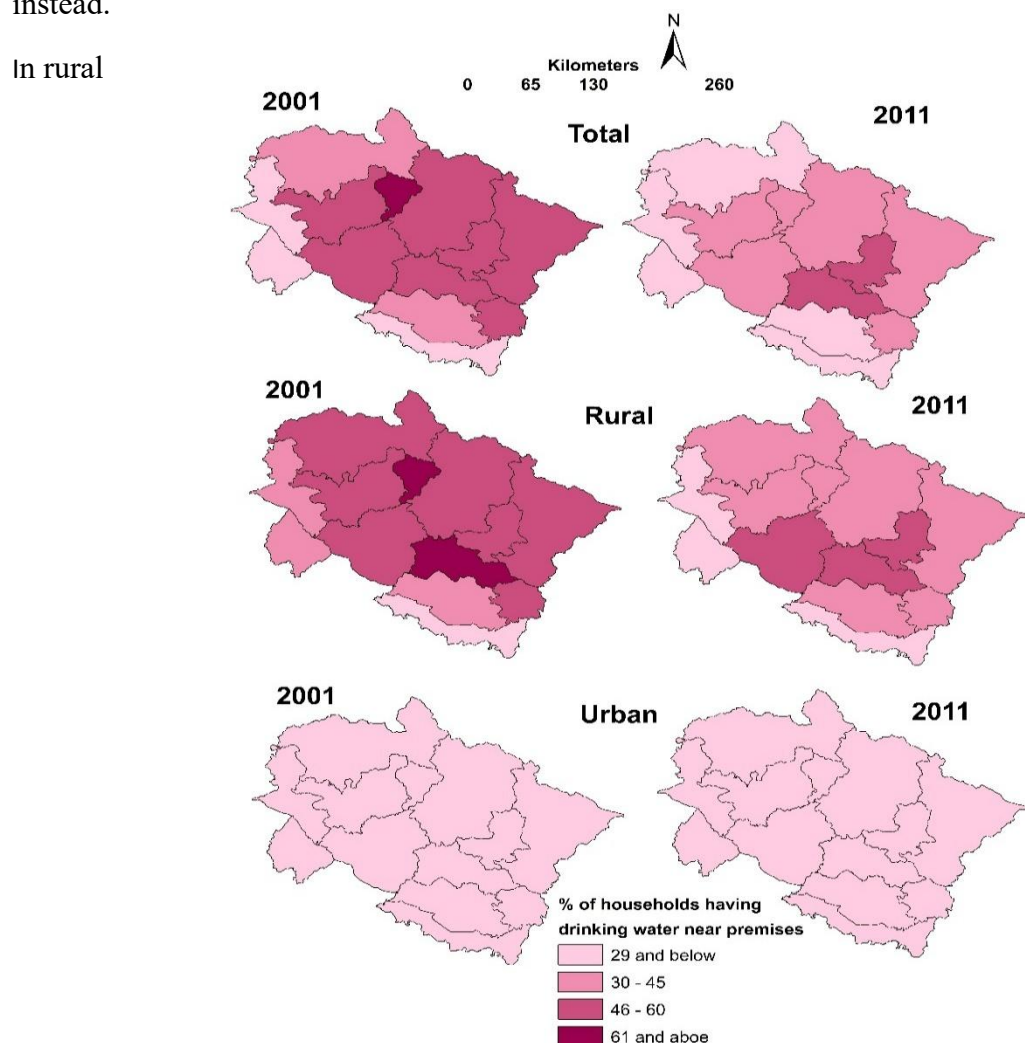


Fig. 4 Households Having Drinking water sources near Premises

Uttarakhand, 2001 shows a high dependency on near-premises water sources, particularly in central districts such as Tehri Garhwal, Pauri Garhwal, Almora, and Pithoragarh, where over 60% of households fetched water from sources close to their homes. In 2011, there's a

noticeable reduction in this category as many households transitioned to within-premises access, especially in southern rural plains like Haridwar and Udham Singh Nagar. However, hill districts still remained moderately dependent on near-premises sources (30–60%).

Urban Uttarakhand in both 2001 and 2011 shows very low dependency on near-premises water sources, with most districts in the 29% and below category. This suggests that urban areas had already shifted towards piped water supply within premises by 2001. Between 2001 and 2011, there's no major increase in near-premises access, reaffirming that urban growth was aligned with improved infrastructure for direct water supply to homes.

Availability of Drinking water sources away premises

In 2001, most districts showed 29% or lower households depending on distant water sources, except Almora, which stood out with 30–45% of households accessing drinking water away from their premises. By 2011, this trend slightly expanded to neighboring districts like Pithoragarh and Chamoli, but most regions continued to show low dependency, indicating improved water accessibility either within or near premises. Rural Uttarakhand had similar patterns in 2001 and 2011. In 2001, Almora district had the highest share of rural households (30–45%) fetching water from distant sources. This condition persisted and slightly worsened by 2011 as more districts in the central hill zone (like parts of Bageshwar and Pauri) entered the 30–45% category. This may be due to geographic challenges in laying infrastructure in mountainous terrain, dependence on seasonal springs, and slow development of piped water systems. Urban regions of Uttarakhand show minimal dependence on away-from-premises water sources in both years. All districts fall in the 29% and below category, suggesting that urban centers had already achieved substantial water supply improvements, with access either within or near the premises.

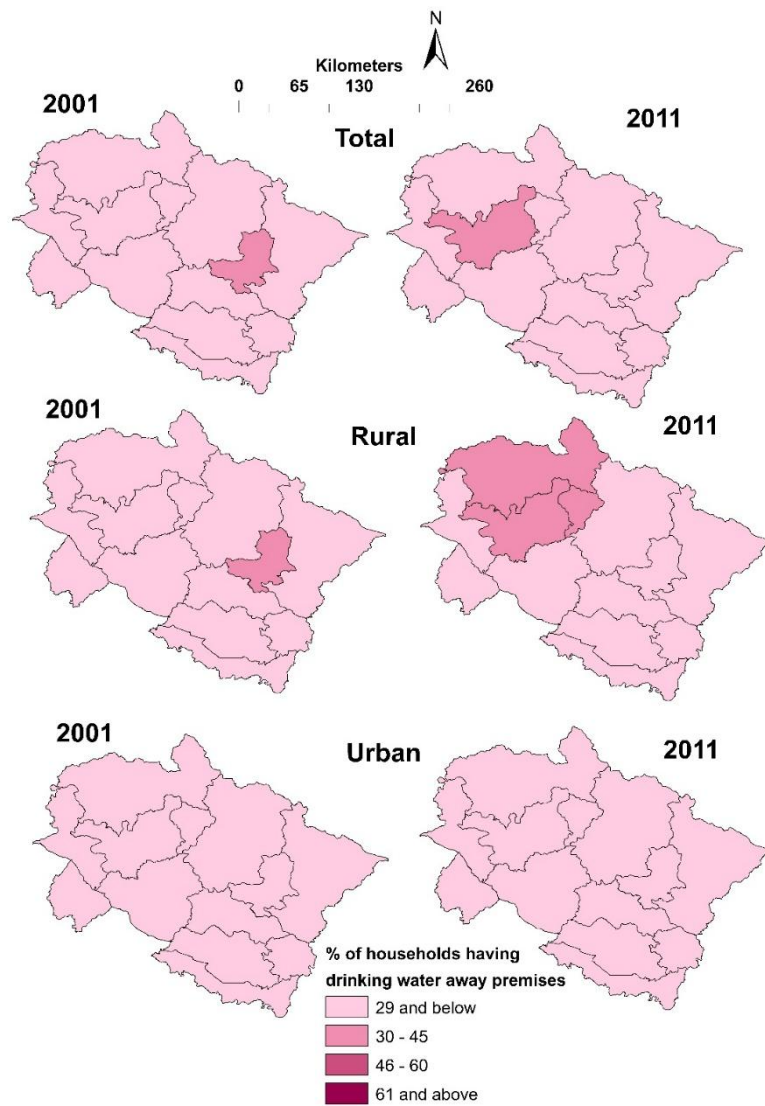


Fig.5 Households Having Drinking water sources away Premises

Access to Rural and Urban households

The Figure 6 shows a significant improvement in the use of safe drinking water in Uttarakhand from 2001 to 2011. In 2001, only about 41% of total households had access, with rural at 40% and urban at 47%. By 2011, access increased sharply—total households reached 89%, rural 88%, and urban 98%. This reflects major progress in water infrastructure, especially in rural areas.

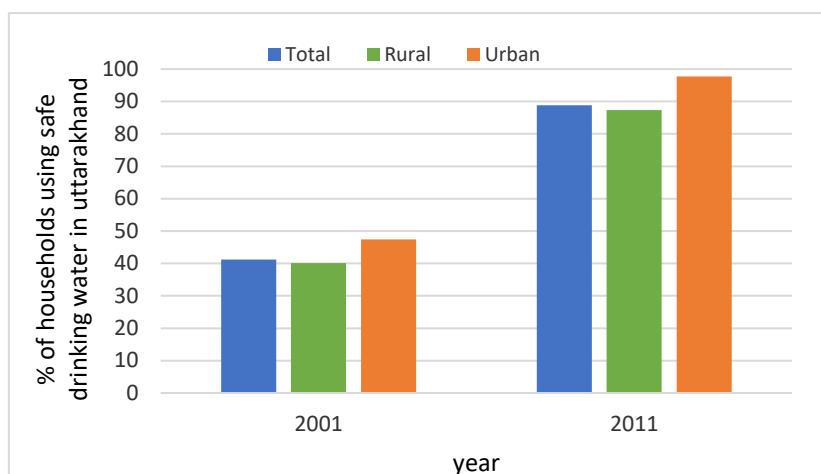


Fig.6 Percentage of households using safe drinking water in uttarakhand.

The series of maps depict the significant improvement in access to safe drinking water sources across Uttarakhand between 2001 and 2011 for total, rural, and urban households. In 2001, a large portion of the state, particularly the central and eastern hilly districts like Almora, Bageshwar, and Champawat, had relatively low coverage of safe drinking water, with only 30–45% of households having access. By 2011, all districts in the state reported above 60% coverage, reflecting a remarkable enhancement in water infrastructure. This improvement is largely attributed to the implementation of national schemes such as Bharat Nirman and the National Rural Drinking Water Programme (NRDWP), which prioritized safe water access in both rural and remote areas.

For rural households, the maps indicate that the central hilly regions, including districts like Chamoli and Pauri Garhwal, had limited access to safe drinking water in 2001. However, by 2011, even these rural districts had improved significantly, with more than 60% of households accessing safe water. This progress was driven by targeted rural development initiatives and improved funding for water supply schemes in difficult hill terrains. In the case of urban areas, most towns and cities such as Dehradun, Haldwani, and Roorkee already had relatively better access to safe water in 2001, with 46–60% coverage. By 2011, urban areas too reached over 60% coverage, thanks to urban infrastructure reforms under programs like the Jawaharlal Nehru National Urban Renewal Mission (JNNURM), which strengthened piped water systems and treatment facilities.

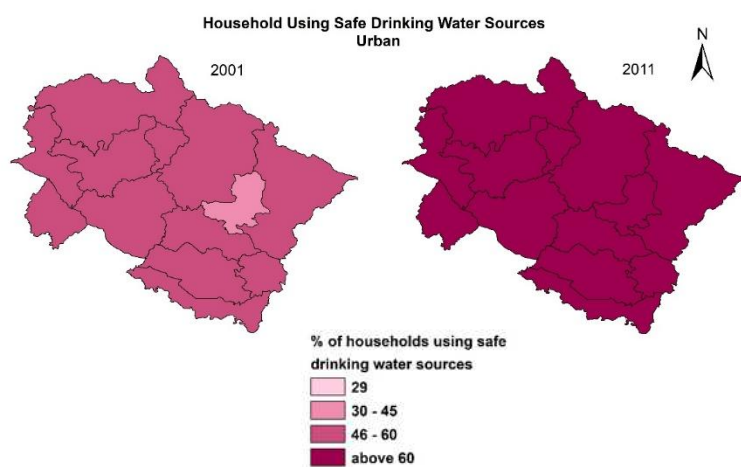
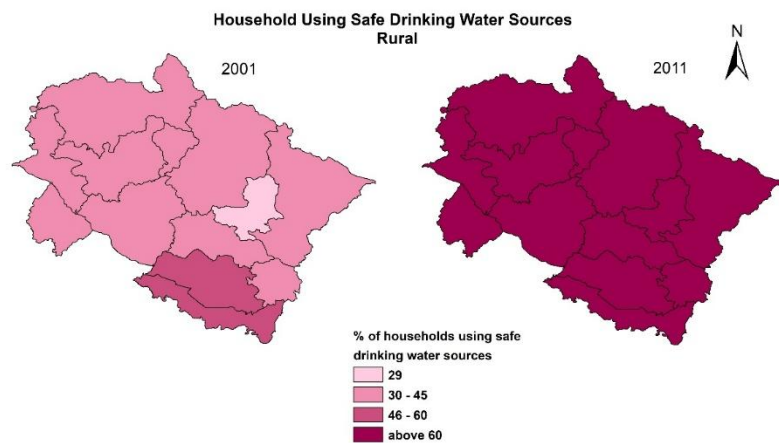
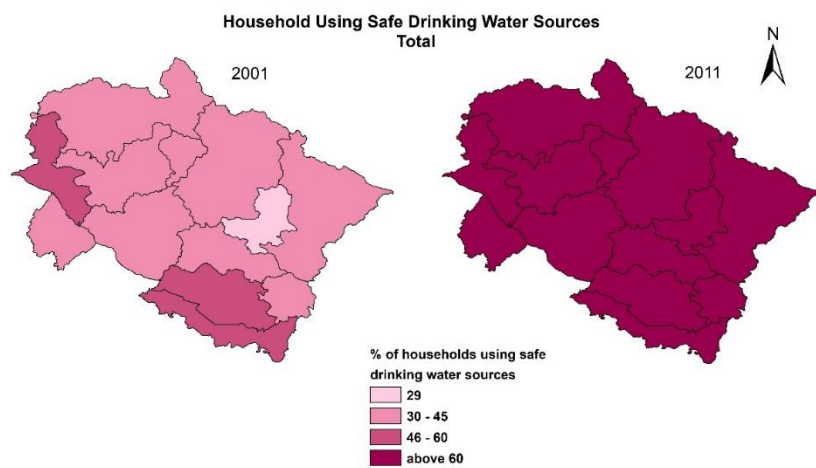


Fig.7 Households using safe drinking water

Rural Urban Difference and DWSAAI

In 2001, the districts of Uttarkashi, Champawat, and Tehri Garhwal exhibited a rural-urban gap in access to safe drinking water ranging between 11% to 20%. However, by 2011, this urban-rural difference had widened and was observed in six districts—Uttarkashi, Champawat, Tehri Garhwal, Almora, Bageshwar, and Pithoragarh. This indicates that although overall access to safe drinking water improved across the state, urban areas in these districts experienced faster progress compared to their rural counterparts, leading to an increased disparity in access.

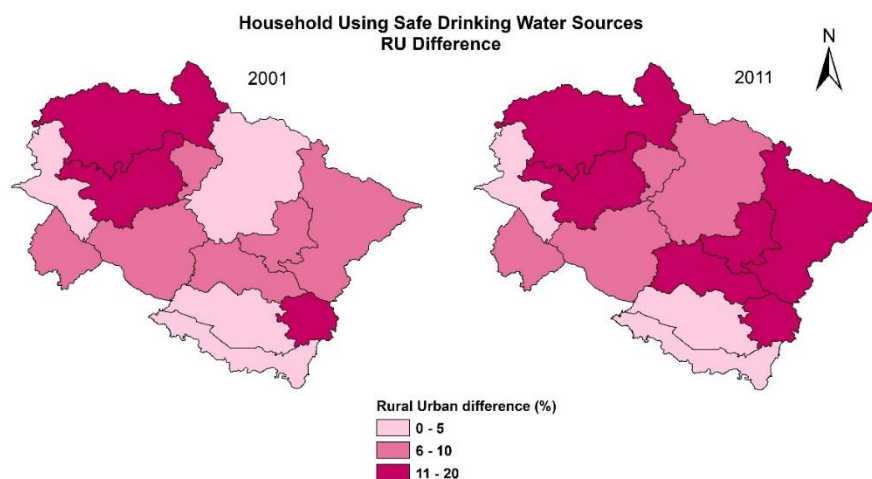


Fig.8 Rural and urban households using safe drinking water

The ranking of Uttarakhand's districts based on the Drinking Water Security Assessment and Awareness Index (DWSAAI) reveals significant spatial disparities in water accessibility, infrastructure, and awareness. Udham Singh Nagar ranks highest (Rank 1), indicating the best performance in terms of drinking water availability, accessibility, and awareness, likely due to its developed plain geography, agricultural base, and better infrastructure. Haridwar (Rank 2) and Dehradun (Rank 3), both urban and institutional centers, also show strong performance due to better municipal services and public awareness initiatives. Nainital (Rank 4) and Pauri Garhwal (Rank 5) perform moderately well, possibly due to tourism-led development and moderate infrastructure support.

In the middle rankings, districts like Pithoragarh (Rank 6), Chamoli (Rank 7), and Almora (Rank 8) show a mix of rural-urban characteristics, with challenges in terrain and coverage leading to moderate performance. Bageshwar (Rank 9) and Champawat (Rank 10) fall in the lower-middle category, indicating issues with infrastructure and consistent water access in hilly regions. At the bottom of the index, Rudraprayag (Rank 11), and Tehri Garhwal along with Uttarkashi (both Rank 12), reflect the most critical conditions. These remote mountainous districts face logistical challenges, limited infrastructure, and low awareness levels, contributing to their poor drinking water security performance. This ranking highlights the

urgent need for targeted interventions in high-altitude and rural regions of the state to bridge the water access and awareness gap.

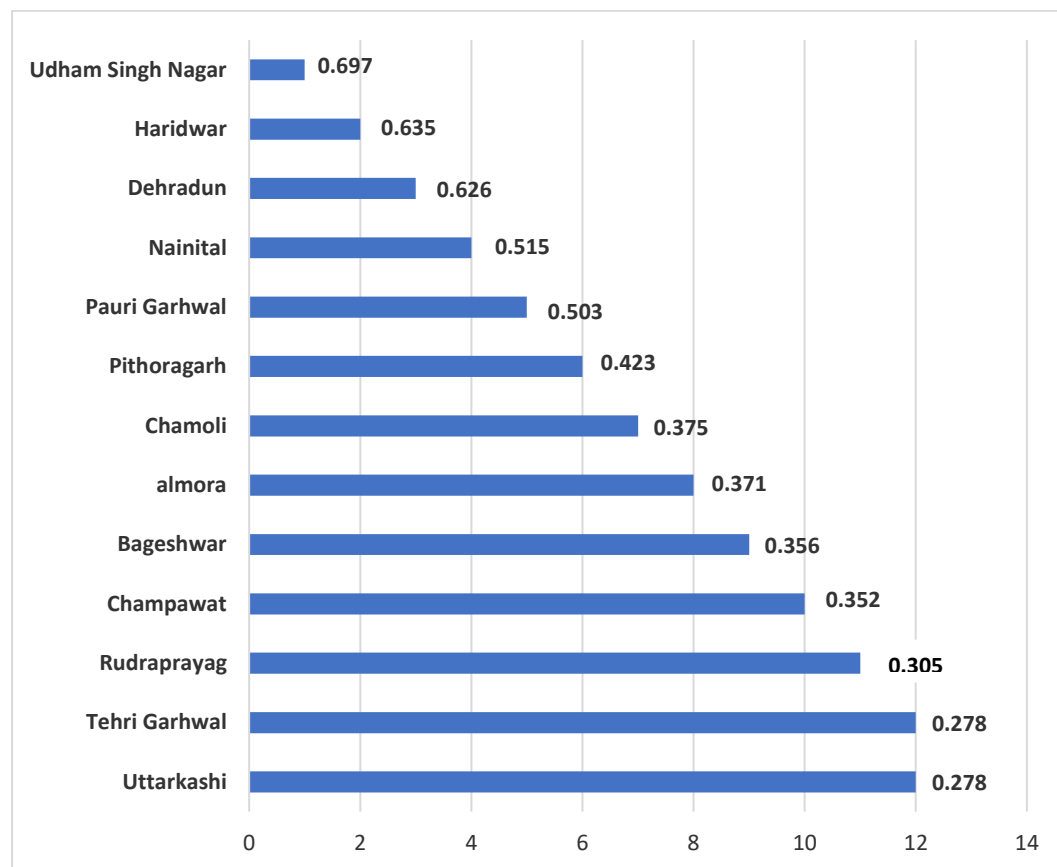


Fig.9 Rank of Districts of Uttarakhand in drinking water sources availability and accessibility index (DWSAAI), 2011 (values on the each bars show the final score of the index)

Conclusion: This study has revealed significant spatial disparities in the provision of safe drinking water across Uttarakhand, emphasizing the divide between urban and rural regions, as well as between lowland and hilly districts. While improvements have been made under national schemes like the Jal Jeevan Mission (Ministry of Jal Shakti, 2023), the data from Census 2001 and 2011 highlight that accessibility remains a major concern, especially in mountainous areas such as Chamoli, Pithoragarh, and Uttarkashi, where geographic and climatic factors complicate infrastructure development. The use of GIS tools allowed for detailed visualization of disparities, making it clear that while urban centers such as Dehradun and Haridwar have high levels of within-premises water access, many rural districts continue to depend on near or away-premises sources, often requiring time-consuming and labor-intensive collection efforts (Kaur, 2022). The calculated Rural–Urban Difference (RU) and the Drinking Water Source Availability and Accessibility Index (DWSAAI) offered quantifiable measures of inequity, reinforcing the need for targeted policy interventions. These disparities are further exacerbated by seasonal variability, declining groundwater levels, and the contamination of existing water sources (CGWB, 2021; Singh et al., 2012). As Singh et al. (2012) note, over 2 million people in Uttarakhand lack consistent access to clean water—a

figure that underscores the urgency of improving water governance and sustainability in fragile ecosystems.

Compounding this issue is the deteriorating quality of river water in the region. As demonstrated by Seth et al. (2014), major rivers in the Kumaun region—Gola, Kosi, Ramganga, Saryu, and Lohawati—have experienced a decline in water quality due to anthropogenic activities, untreated effluent discharge, poor sewerage systems, and geogenic influences. Their findings, based on hydrochemical analysis and water quality indices, reveal that these rivers are unsuitable for drinking, although they remain suitable for irrigation. Springs serve as lifelines for over 60% of the hill population in Uttarakhand, yet thousands have dried up in the last two decades (NIH, 2018). Programs like NITI Aayog's "Spring Rejuvenation for Water Security in Himalayas" and Uttarakhand's State Action Plan on Climate Change (SAPCC, 2014) stress the urgent need for catchment area protection, groundwater recharge, and community-based water governance .

In this context, spring and river restoration emerges as a critical strategy for enhancing both water availability and quality in Uttarakhand. Springs, which are vital drinking water sources for a majority of the hill population, are rapidly drying due to climate change, deforestation, and unplanned development. River restoration—through ecological flow maintenance, catchment area treatment, and pollution control—is equally essential to rejuvenate the state's natural water resources.

To address both access and quality issues, a multi-pronged, policy-backed approach is needed:

- Strengthening infrastructure under the Jal Jeevan Mission, which aims for functional household tap connections (FHTCs) by 2024 (Ministry of Jal Shakti, 2023);
- Restoring and protecting springs and rivers through integrated watershed development (Tambe et al., 2012);
- Incorporating traditional knowledge in water governance at the village level (Joshi & Dai , 2010);
- Using GIS and remote sensing for real-time monitoring and equitable planning (Kumar et al., 2022);
- Promoting community participation, especially of women, in water management initiatives.

Ensuring long-term water security and resilience in Uttarakhand will require the synergistic implementation of science, policy, and local stewardship. As the region faces increasing climatic stress and population growth, restoring the natural hydrological systems of the Himalayan foothills is no longer optional—it is essential.

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