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Research article

Disparities in access to water, sanitation, and hygiene (WASH) services and the status of SDG-6 implementation across districts and states in India

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ABSTRACT

Introduction: Access to affordable and improved Water, Sanitation, and Hygiene (WASH) facilities is essential for people's daily lives, and it is the primary goal of Sustainable Development Goal 6 (SDG-6). However, achieving this goal is a significant challenge for many countries, including India. The aim of this study is to assess the progress made towards achieving SDG-6 targets in Indian districts, states, and Union Territories (UTs) and to identify clusters by measuring spatial inequality of WASH coverage in India.
Aim and objective: The primary objective of this study is to measure the progress made towards achieving the SDG-6 targets for WASH facilities in Indian districts, states, and UTs. To fulfill this objective, the study used the household data of the National Family Health Survey-5 (NFHS-5) conducted from 2019 to 21.
Data and methods: The study used the household data of NFHS-5, which is a nationally representative survey that provides information on household and individual-level characteristics related to health and nutrition. The study identified the variables associated with WASH and created a composite index to measure WASH coverage separately and combined. The study used Gini coefficient to show WASH inequality, and Moran's statistics were used to show spatial dependency.
Result: The study found that the inequality of improved water coverage sources in Indian districts was high. Western and northeastern districts need to catch up in terms of achieving the SDG-6 targets. The value of the Gini coefficient (0.29) indicates that inequality in sanitation coverage is also high. All states have reached close to SDG-6 achievement in hygiene indicators. Goa, Sikkim, Andaman & Nicobar Islands, and Lakshadweep are close to the overall WASH coverage achievements of SDG-6. However, Jharkhand, Orissa, Tripura, Assam, and Rajasthan are behind in meeting the goal of SDG-6.
Conclusion: The study suggests that more government initiatives and investments are needed to increase the availability, accessibility, and affordability of WASH facilities to improve WASH

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conditions in western and northeastern Indian districts. The localization or bottom-up approach by giving responsibility to rural and urban local bodies can also help enforce the achievement of SDG-6. The findings of this study can be used to guide policymakers in developing targeted interventions to improve WASH conditions and reduce inequality in India.

Abbreviations

SDGs:	Sustainable Development Goals
MDGs:	Millennium Development Goals
WASH:	Water, sanitation, and hygiene
WHO:	World Health Organization
UNICEF:	United Nations International Children's Emergency Fund
JMP:	Joint Monitoring Program
SBA:	Swachh Bharat Abhiyan
NRDWP:	National Rural Drinking Water Program
JJM:	Jal Jeevan Mission

1. Introduction

1.1. Background

Access to clean water, sanitation, and hygiene services is recognized as a fundamental human right essential for preserving human health and environmental sustainability [1]. The WASH framework encompasses three pivotal components: clean drinking water (WA), proper sanitation (S), and hygiene practices (H). These components collectively serve as the linchpin for preventing the proliferation of debilitating diseases such as diarrhoea, cholera, dysentery, hepatitis A, and typhoid, fostering communities' resilience [2]. The Millennium Development Goal (MDG) era officially ended in 2015, with the target of halving the proportion of people without sustainable access to clean drinking water and basic sanitation [3]. The SDGs were established in 2015, setting a more ambitious objective of universal access to WASH services by 2030, mandating the progressive reduction of disparities and covering hygiene in addition to water and sanitation [4,5]. Goal 6 of the SDGs shows a major increase in ambition for serving the unreachable, reflecting the recognition of the importance of WASH for a healthy and dignified life and the ratification of the human right to water and sanitation in 2010. Building sanitation, hygiene, and drinking water infrastructure in households promotes social dignity and contributes to social sustainability [6]. Despite recognizing the critical importance of WASH, a significant proportion of the global population continues to grapple with inadequate access to these fundamental services. The international community, acknowledging the significance of WASH, has underscored its commitment by establishing Sustainable Development Goals (SDG 6.1 and 6.2), which aim to eradicate open defecation and ensure the provision of safe and affordable WASH facilities to the global population [1]. The SDG framework, and in particular, SDG 6, marks a substantial evolution beyond the MDGs, with a resolute focus on universal coverage and the specific needs of marginalized populations, including women and girls [7]. Notably, the benefits of WASH extend beyond the boundaries of these objectives, encompassing various facets of human well-being and development, including climate change mitigation, gender equality, urban services, nutrition, health, and education [8]. The Joint Monitoring Program (JMP) by the World Health Organization (WHO) and the United Nations International Children's Emergency Fund (UNICEF) has been established to closely monitor progress toward SDG 6 and assess the global WASH situation [9].

1.2. World scenario of WASH practices

1.2.1. World

According to the WHO Report 2021, between 2016 and 2020, there was progress towards achieving universal access to basic WASH services, with an increase in the global population having safely managed drinking water at home from 70 % to 74 %, safely managed sanitation services from 47 % to 54 %, and handwashing facilities with soap and water from 67 % to 71 %; however, only 81 % of the world's population have access to safe drinking water at home, leaving 1.6 billion without access, only 67 % have safe sanitation services, leaving 2.8 billion without access and only 78 % of the world's population have access to basic handwashing facilities, leaving 1.9 billion people without access [10]. This indicates a significant gap in achieving SDG-6, which aims to ensure access to clean water and sanitation for all by 2030. Furthermore, the report estimates that approximately 297,000 children under five years of age die annually due to diarrhoeal diseases linked to poor sanitation, inadequate hygiene practices, and unsafe drinking water [11].

1.2.2. Latin America

In Latin America and the Caribbean, access to improved water sources increased from 81 % in 1990 to 93 % in 2015 [12]. However, only 66 % of the population in the region had access to safely managed sanitation services in 2017 [13]. Brazil, Argentina, and Paraguay officially report that they are close to meeting SDG 6 targets [14]. However, several countries in Latin America still need to work on achieving SDG 6 targets. Only about 30 % of the population in Haiti has access to basic sanitation services [15]. Similarly, in rural areas of Bolivia, Guatemala, Nicaragua, and Honduras, where most people belong to indigenous communities, 47 %, 58 %, 61 %, and 79 % respectively, have access to basic sanitation services [16].

1.2.3. Africa

In sub-Saharan Africa, rural areas often lack access to basic services, with 62 % of the population lacking access to basic sanitation services in 2015, according to a report by the African Development Bank. The same report estimated that 25 % of the population in the region lacked access to safe drinking water [17]. The WASH situation in Africa is a major concern, with approximately 63 % of the population lacking access to basic sanitation services and 24 % practising open defecation [18]. Additionally, 29 % of the population in sub-Saharan Africa lacks access to safe drinking water sources. These issues have resulted in significant health challenges, with over 300,000 children under five years of age dying each year due to diarrheal diseases associated with poor WASH services [19].

1.2.4. Asia

An estimated 1.2 billion people in Asia lack access to basic sanitation services, and 456 million people still practice open defecation. In terms of drinking water, 535 million people in Asia lack access to safe drinking water sources [20]. The disparities in access to WASH services are particularly pronounced in rural areas, where infrastructure and services are often inadequate or non-existent. In addition, natural disasters such as floods, droughts, and earthquakes can disrupt water and sanitation systems, exacerbating existing vulnerabilities. The situation in Asia is further complicated by rapid population growth, urbanization, and industrialization, which put increasing pressure on already limited water resources and sanitation systems [21,22]. In response to these challenges, various initiatives and programs have been launched in different countries across the region to improve access to WASH services, including the SDGs and the WASH in Schools program [23,24,24–26]. Despite these efforts, significant challenges remain in achieving universal access to safe and sustainable WASH services in Asia. These challenges include inadequate infrastructure, limited resources, and weak governance and management systems.

1.3. WASH situation in India

India, being one of the most populous countries in the world, faces several challenges in achieving SDG 6, particularly at the district level. Despite several initiatives and programs launched by the Government of India, significant disparities still persist in access to safe water and adequate sanitation, particularly in rural areas and marginalized communities [27]. While India has made progress in improving access to safe drinking water and sanitation facilities in recent years, there is still a significant population that lacks access to these basic services [6,28].

According to the JMP for Water Supply, Sanitation, and Hygiene, in 2019, 71 % of the population in India had access to basic sanitation facilities, while only 54 % had access to safely managed sanitation. In terms of access to clean drinking water, 87 % of the population had access to basic services, but only 44 % had access to safely managed drinking water [29]. In addition to inadequate access to water and sanitation services, poor hygiene practices also contribute to the spread of waterborne diseases in India. For example, handwashing with soap is not widely practiced, and open defecation remains a significant problem in some parts of the country [30]. India and other emerging and poor nations must achieve SDG-6. If the goal is accomplished, it will hasten the improvement in general health and aid in reducing regional disparities. Developed nations must assist developing and underdeveloped nations [6].

Several initiatives have been launched by the Indian government to address these challenges, including the SBA (Clean India Mission) launched in 2014, which aims to achieve universal sanitation coverage and make India open-defecation free by 2022. However, the COVID-19 pandemic has also highlighted the urgent need for improved WASH infrastructure and behavior change initiatives in India.

1.4. Relevance of the study and objective

WASH practices are crucial for public health, particularly in densely populated areas with limited access to safe water and sanitation facilities. Several global studies have aimed to develop a collective agenda for WASH research, examining evidence resources, delivery methods, and barriers to decision-making, research, or program activities [31–35]. Rahaman et al. (2021) have assessed the status of drinking water and sanitation services in underprivileged areas, focusing on achieving SDG 6 targets [36]. Quispe-Coica and Pérez-Foguet (2022) presented a methodology to scale SDG 6.1–2 to the sub-national level, highlighting challenges and possibilities [33], while Marchesi et al. (2023) filled gaps in monitoring SDG indicators related to water and sanitation in Brazilian island territories [37]. In India, studies such as Ghosh et al. (2022) have focused on outlining district-level spatial heterogeneity using census 2011 data on the accessibility and availability of drinking water, sanitation, and hygiene. This study aimed to construct district-level WASH poverty indices, considering geographical inequality [38]. Similarly, Biswas et al. (2022) assessed the status of SDG targets 6.1, 6.2, and 6.4 at both national and state levels [6]. Another study by Ghosh et al. (2023) focused on mapping the spatial pattern of district-wise coverage of Improved Drinking Water Source facilities and the magnitude of inequality between social groups, particularly between Scheduled Castes/Scheduled Tribes (SC/ST) and non-SC/ST groups [27]. Previous studies have primarily examined WASH poverty, SDG target status, and inequality at the national or state level, with limited focus on district-level analysis.

Additionally, while some studies have utilized Census data from 2011, no recent census survey has been conducted in India, leaving a gap in up-to-date information on the WASH situation. Thus, there is a critical need for more in-depth district-level analysis utilizing recent data sources, such as the NFHS, to understand the challenges and progress toward SDG-6 at the grassroots level. Therefore, our study aimed to fill this gap by providing a comprehensive district-level analysis of WASH practices in India, focusing on the progress toward achieving SDG-6. We utilized secondary data collected through the NFHS-5 (2019–21) by the Ministry of Health and Family Welfare (MoHFW) and this study does not include a time evolution. Our study provided an in-depth analysis of the challenges faced and progress made in improving WASH practices at the district level. Additionally, our study provided valuable recommendations for policymakers, development practitioners, and other stakeholders to improve access to safe water and adequate sanitation for all in India.

2. Literature review

Access to safe WASH services is essential for public health and overall well-being. Several global studies have examined the disparities in access to WASH services and the status of SDG 6 implementation across different regions. Giné Garriga and Pérez Foguet (2013) emphasized the need for policy instruments supporting decision-making, planning, targeting, and prioritization in WASH services. They introduced the WASH Poverty Index (WASH PI), a multidimensional, thematic indicator designed to identify priority areas for improved service delivery [39]. Garriga et al. (2015) proposed a monitoring framework to compile, analyze, interpret, and disseminate WASH information, particularly at the local level in East and Southern African countries [40]. Roche et al. (2017) highlighted significant challenges in achieving universal WASH access, especially in rural areas of Sub-Saharan Africa [41]. Emenike et al. (2017) assessed water access in Nigeria and found that it is mostly limited to private sources [42]. Ezbakhe and Perez-Foguet (2018) discussed the importance of incorporating data uncertainty into Multi-Criteria Decision Analysis (MCDA) models for effective priority-setting and policy-making in WASH planning [43]. Wang et al. (2019) assessed geographic inequalities in access to improved water and sanitation facilities among Nepalese households, revealing progress at the national level but uneven coverage across developmental and ecological zones [44]. Ohwo (2019) highlighted existing inequalities in WASH services between urban and rural areas in Sub-Saharan Africa [45]. Setty et al. (2020) conducted a systematic study to determine global research priorities and learning needs for achieving Goal 6, revealing limited confidence in managing untreated wastewater and fecal sludge, which are crucial for achieving universal access to WASH services [32]. Zerbo et al. (2021) focused on Sub-Saharan Africa, where WASH coverage remains low, particularly in rural areas, and inadequate access to WASH services contributes significantly to mortality due to diarrheal diseases [46]. Mattos et al. (2021) highlighted the persistent disparities in WASH services in high-income countries, especially among historically marginalized, rural, informal, and Indigenous communities [31]. Rahaman et al. (2021) assessed the WASH situation in urban slums in Bangladesh, revealing low levels of access to safely managed drinking water and sanitation services, indicating substantial challenges in achieving SDG 6 [36]. Abrams et al. (2021) explored WASH access challenges in rural areas and small towns in South Africa, identifying climate change, socioeconomic factors, and historical inequalities as key barriers [47]. Quispe-Coica and Pérez-Foguet (2022) addressed the need for disaggregated data and subnational-level monitoring of WASH services, providing a methodology to assess WASH ladders at the subnational level [33]. Wada et al. (2022) examined WASH disparities among public and private schools in Nigeria, highlighting significant inequalities in WASH knowledge and access between different school types [48]. Shehu and Nazim (2022) discussed the challenges in achieving SDG 6 in Nigeria, emphasizing the need for improved policies and interventions to address water insecurity and hygiene-related issues [34]. Calderón-Villarreal et al. (2022) focused on WASH access among refugee populations, revealing large inequalities across different refugee sites and countries [49]. Marchesi et al. (2023) assessed WASH inequalities among Brazilian maritime island inhabitants, highlighting substantial challenges in accessing drinking water supply and sanitation [37]. Dickin and Gabrielsson (2023) reviewed the measurement and monitoring of WASH inequalities, emphasizing the need for improved approaches to accelerate progress towards universal WASH coverage [50].

In recent years, several studies have focused on assessing the availability, accessibility, and inequality in WASH services across different regions of India. Chaudhuri and Roy (2017) investigated rural-urban inequalities in WASH infrastructural facilities across India, focusing on latrine facilities, treated tap water, improved water sources, and at-home water sources. Using district-level data from the 2011 Census of India, they applied various metrics, including the Bray-Curtis Dissimilarity Index (BCDI), Gini coefficient, Moran's I, and LISA, to characterize spatial patterns. They found that rural-urban inequality in access to treated tap water was the most spatially variable WaSH parameter across the nation. The study revealed that most "improved" water sources in rural India were groundwater-based (hand pump/tube well) and heavily contaminated by pollutants such as fluoride, arsenic, nitrate, and salinity, questioning water safety from these sources. Approximately 54 % of rural households relied on groundwater compared to less than 20 % of urban households. Moreover, about 67 % of rural households still practised open defecation, compared to about 12 % of urban households, indicating the need for stringent management actions and awareness campaigns. Rural-urban inequality in WASH facilities was most pronounced in central Indian states such as Chattisgarh, Bihar, Jharkhand, Odisha, Madhya Pradesh, and Rajasthan [51]. Saroj et al. (2020) conducted a study across six major cities in India (Mumbai, Delhi, Chennai, Bangalore, Kolkata, and Hyderabad) using data from the India Human Development Survey conducted during 2004-05 and 2011–12. Their findings revealed that while there was an improvement in accessibility and overall WASH performance during 2011-12 compared to 2004–05, the change was not significant across cities in terms of WASH availability. Mumbai exhibited better accessibility, whereas Chennai reported a reverse trend with better availability but poor accessibility. The study highlighted the significant intra-city inequality in WASH services, attributable to various factors such as housing conditions, economic status, education level, socio-religious affiliation, and occupational status [52]. Ghosh et al. (2022) focused on assessing WASH poverty among Indian districts to achieve the UN SDG 6 by 2030. They constructed district-level WASH poverty indices and identified clusters of districts with higher levels of WASH poverty, particularly in central and eastern Indian states [38]. Biswas et al. (2022) conducted a national and state-wise analysis of India's progress towards SDG 6 from 2012 to 2020. The study identified States and UTs with 100 % achievement, including Chandigarh, Dadra & Nagar Haveli, Ladakh, Lakshadweep, Sikkim, and Goa. Those in the 66–99 % range, termed as the "Front Runner Stage," include Mizoram, Andaman & Nicobar Islands, Jharkhand, Odisha, Kerala, Gujarat, Chhattisgarh, Jammu & Kashmir, Meghalaya, Arunachal Pradesh, Maharashtra, Uttarakhand, Assam, West Bengal, Nagaland, Tripura, Bihar, Andhra Pradesh, Madhya Pradesh, Uttar Pradesh, Daman and Diu, Puducherry, Telangana, Karnataka, Manipur, Tamil Nadu, Himachal Pradesh, Haryana, Rajasthan, and Punjab. Delhi is the only Union Territory in the "Aspirant Stage" [6]. Ghosh et al. (2023) explored the wide inequality in accessing improved drinking water and sanitation (IDWS) facilities among different geographical spaces and social groups in India. They classified Indian districts based on geographical inequality and inequality between Scheduled Caste/Scheduled Tribe (SC/ST) and other groups. The study revealed that a significant percentage of districts characterized by lower coverage of IDWS facilities also showed more deprivation among SC/ST communities [27]. Roy (2023) analyzed the spatial distribution of limited access to drinking water and sanitation facilities in India using NFHS-5 data. The study revealed regional heterogeneity in WASH services, with certain central and western Indian states facing higher prevalence rates of limited access [53]. These studies collectively underscore the importance of addressing disparities in access to WASH services across different regions of India to achieve the UN Sustainable Development Goal 6 and ensure equitable access to safe drinking water, sanitation, and hygiene for all. However, these studies have certain limitations, including reliance on potentially outdated or limited data and a focus on specific regions or cities, limiting the generalizability of findings. Future research should focus on assessing the effectiveness of policy interventions, tracking progress longitudinally, and developing innovative solutions to address emerging challenges in WASH service provision, such as climate change and urbanization. Table 1 presents findings from global and Indian studies on WASH **[Table 1 pasted].**

3. Methodology

3.1. Database

The study was based on NFHS-5 (2019–21) household data. The NFHS-5 is a nationally representative cross-sectional household survey that interviewed 636,699 households. It was a two-stage stratified sampling where the primary sampling units were selected using probability proportional to size (PPS) sampling. The International Institute for Population Sciences, Mumbai, served as the nodal agency for conducting these surveys. The state and district-level accessibility and availability of household improved sources of drinking water, distance from house to water sources (time), latrine facilities, drainage facilities, access to hand wash facilities, kitchen facilities, access to improved cooking fuel facilities, house type and access to electricity data were adopted from the NFHS-5 (2019–21) household dataset.

3.2. Indicators

Drinking water, Sanitation and Hygiene are the major indicators of SDG-6 (Ensure availability and sustainable management of water and sanitation for all). We have taken nine indicators based on previous literature and considered the local situation under the three main WASH dimensions [6,38,54]. The selected dimensions and indicators of WASH coverage are shown in Table 2 **[Table 2 pasted].**

3.3. Methods

In this study, nine indicators representing three main components of Water, Sanitation, and Hygiene were utilized. The percentage of households' access to all the identified indicators under each component was aggregated to create composite indices for Water, Sanitation, and Hygiene. The purpose of constructing these composite indices was to illustrate WASH inequality at both state and district levels. For which the following formula is used:

$$\mathrm{Index_{id}} = \frac{\mathrm{i_d} - \mathrm{i_{min}}}{\mathrm{i_{max}} - \mathrm{i_{min}}}$$

Where $\mathrm{i_d}$ is the actual value of the selected indicators of the districts, and $\mathrm{i_{max}}$ and $\mathrm{i_{min}}$ are the maximum and minimum values among the districts in terms of each selected indicator. Here the values vary from '0' to '1', indicating the worst and best situation of the states and districts, respectively, among all other states and districts in terms of each selected aspect of drinking water, sanitation, and hygiene. The average access to improved drinking water sources and availability close to households is taken as the water index. The average access to latrine facilities and access drainage facilities is taken as the sanitation index. Moreover, the hygiene index is the average access to hand wash facilities, kitchen facilities, improved cooking fuel facilities, a house suitable for living, and access to electricity. Then, three subcomponents were aggregated through the following formula:

$$\mathrm{WASH_{composite}} = \sqrt[3]{\mathrm{I}_{\textit{Drinking water}} * \mathrm{I}_{\textit{Sanitation}} * \mathrm{I}_{\textit{Hygiene}}}$$

The % coverage of all indicators in each state and UTs is shown in tabular format. Where less than 70 is not satisfactory, 70–80 is aspirant, 80–90 is performer, 90–99 is front runners, and more than 99 is the achiever. After that, all indicators of each criterion (not satisfactory, aspirant, performer, front runners and achiever), the performance of state and UTs highlighted through the composite bar

Table 1
Detail of reviewed studies.

Sr. #	Authors (Year)	Study area	Methods	Findings
Global Studies				
1	Giné Garriga & Pérez Foguet [39]	Kenya	WASH poverty index.	Aggregating the three sub-indices (WPI, SPI, HPI) into one composite index reduces the validity of the final outcome, as the sub-indices provide more reliable information when examined separately.
2	Garriga et al. [40]	Tanzania, Kenya, and Mozambique	Water supply coverage index, management index, maintenance index, water quality index, seasonality index, sanitation coverage index, open defecation index, and handwashing index.	The study focuses on testing the validity of WASH indices as targeting and prioritization tools for local planning, emphasizing the importance of considering both hardware (infrastructure) and software (hygiene knowledge and behaviors) aspects in addressing WASH issues effectively.
3	Roche et al. [41]	25 countries in Sub-Saharan Africa	Water and sanitation coverage rates were estimated separately for urban and rural populations and for wealth quintiles.	Combined MDG coverage in Sub-Saharan African countries was 20 %, and combined basic SDG coverage was 4 %; an estimated 921 million people lacked basic SDG coverage.
4	Emenike et al. [42]	Nigeria	Multinomial logistic regression model.	Water access within the study area is mostly limited to private sources because of the level of quality and accessibility.
5	Ezbakhe & Perez-Foguet [43]	Kenya	Two multi-criteria decision analysis.	Adapted Multi-Attribute Utility Theory and Elimination Et Choix Traduisant la Realité methodologies to integrate data uncertainty, resulting in similar district rankings and prioritization, essential for reducing inequalities in access to WASH services.
6	Wang et al. [44]	Nepal	Pearson correlations tests, binary logistic regression models.	Between 1996 and 2016, the percentage of households with access to improved toilet facilities increased from 5.6 % to 40.5 %, while access to improved water facilities rose from 19.3 % to 27 %. Despite progress, many households still lack these services, particularly in Far Western and Mountain regions.
7	Ohwo [45]	16 countries in Sub-Saharan Africa	Review-based article.	In sub-Saharan Africa, disparities in access to improved drinking water and sanitation persist between urban and rural areas. While 87 % of urban dwellers have access to improved water sources, only 56 % of rural residents do. Similarly, 40 % of urban populations have access to improved sanitation facilities, compared to only 23 % in rural areas.
8	Setty et al. [32]	36 countries	Qualitative Study.	The study found high overall confidence in working towards Goal 6 (water and sanitation), but only 7 % of respondents were very confident across all target areas. Funding was cited as a significant determinant, and there were disparities in confidence and learning needs among different constituencies.
9	Zerbo et al. [46]	Sub-Saharan Africa	Simple quantitative analysis.	WASH coverage in Sub-Saharan Africa is low, especially in rural areas. Urban coverage is better but still unequal, with poor urban areas underserved. Unsafe WASH contributes significantly to diarrheal disease mortality in Sub-Saharan Africa.
10	Mattos et al. [31]	Respondents surveyed to an online poll in UNC Water and Health Conference	Frequency graph.	In high-income countries, significant knowledge gaps exist in WASH-related data collection, particularly concerning underserved populations. Rural and urban areas face distinct challenges, including environmental injustice, funding constraints, and technical issues.
11	Rahaman et al. [36]	Bangladesh	Analysis of data on indicators 6.1.1 and 6.2.1.	Shahidbug slum only 38.64 % of people have access to a safely managed drinking water service, and only 1.18 % of people have access to safely managed sanitation services.
12	Abrams et al. [47]	South Africa	Transdisciplinary approach exploring WASH.	Inadequate and inequitable access to WASH in rural areas and small towns in South Africa due to climate change impacts, including extreme

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Table 1 (*continued*)

Sr. #	Authors (Year)	Study area	Methods	Findings
				weather events, unreliable transport infrastructure, high inequality, and the legacy of apartheid.
13	Quispe-Coica & Pérez-Foguet [33]	Peru	Development of a methodology to disaggregate information and form WASH ladders at the subnational level.	The study proposes a methodology to disaggregate information and form WASH ladders at the subnational level. Findings highlight the importance of overcoming challenges related to data validation, interpolation techniques, and incorporation of data uncertainty into the model results.
14	Wada et al. [48]	Nigeria	Mixed-methods approach.	The study revealed significant disparities in WASH facilities between public and private schools in a low-income Nigerian community. None of the public schools provided sanitation and hygiene services, while all private schools did. Private-school students showed better WASH knowledge and attitude.
15	Shehu & Nazim [34]	Nigeria	Qualitative research method.	The study highlights the impact of poor policy making in Nigeria on water insecurity, hygiene, health, and safety. Inadequate access to WASH leads to diarrheal and intestinal diseases, hunger, illness, misgovernance, and conflict.
16	Calderón-Villarreal et al. [49]	Bangladesh, Kenya, Uganda, South Sudan, and Zimbabwe	Bivariate and multivariate analyses.	Most refugee households had high levels of access to improved water (95 %), but low access to waste disposal (64 %), sanitation privacy (63 %), basic sanitation (30 %), and hand hygiene facilities (24 %). Inequalities were significant across social and geographic strata, with poorer access for households with disabled or elderly members, fewer members, and women of reproductive age.
17	Marchesi et al. [37]	Brazil	Simple quantitative analysis.	About 20 % of the Brazilian maritime island inhabitants (over 730,000 people) need access to an improved drinking water supply. Another 60 % (over 2.2 million) need access to improved sanitation. Inequalities within and between the Brazilian Federal States are substantial, both in urban and rural areas, mainly in the North and Northeast Brazilian regions.
18	Dickin & Gabrielsson [50]	Global level	Review-based study.	Existing approaches to measuring WASH inequalities have limitations, particularly in relation to gender and social differences. Better use of existing datasets and the development of a broader range of indicators are needed to accurately measure and monitor WASH inequalities.
Indian Studies				
19	Chaudhuri & Roy [51]	India	Bray-curtis dissimilarity index, gini coefficient, moran's I, and local indicators of spatial association.	The study found significant rural-urban inequalities in access to WASH facilities in India. Rural areas exhibited lower access to treated tap water, improved water sources, and at-home water sources compared to urban areas.
20	Saroj et al. [52]	Indian metro cities	Descriptive statistics, order logit regression model.	The study analyzed WASH performance in six major Indian cities using data from the India Human Development Survey (2004-05 and 2011–12). Overall, WASH performance improved, with Mumbai showing the most significant improvement. However, significant inequalities persisted, attributed to housing conditions, economic status, education level, socio-religious affiliation, and occupational status.
21	Ghosh et al. [54]	India	WASH poverty composite index, atkinson's inequality index, gini coefficient, moran's I, and local indicators of spatial association.	The study found moderate to very high spatial dependence of every dimension of WASH poverty across Indian districts. Clusters of districts in central and eastern Indian states showed higher levels of WASH poverty, while districts along the western coast, including Delhi

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Table 1 (*continued*)

Sr. #	Authors (Year)	Study area	Methods	Findings
				and neighboring states, had relatively lower levels.
22	Biswas et al. [6]	India	Percentage distribution, normalization, and arithmetic mean methods.	States with 100 % achievement included Chandigarh, Dadra & Nagar Haveli, Ladakh, Lakshadweep, Sikkim, and Goa. Delhi was the only UT categorized as "Aspirant Stage," while others fell into the "Front Runner Stage" (66–99 % achievement).
23	Ghosh et al. [27]	India	Global moran's I, local indicators of spatial association, quadrant analysis, atkinson's inequality index, Pearson correlations, and linear & non-linear regression model.	The study found that 46 %–60 % of districts had lower coverage of Individual Drinking Water Supply (IDWS) facilities, with greater deprivation among SC/ST communities. Surprisingly, 45 %–49 % of districts with higher IDWS facility coverage still experienced greater SC/ST deprivation.
24	Roy [53]	India	Univariate and bivariate analysis, hotspot analysis, spatial autocorrelation, and binary logistic regression	The study found the prevalence of limited access to drinking water and sanitation facilities was higher in Madhya Pradesh (12.28 %) and Manipur (22.65 %). The spatial distribution of limited access to drinking water and sanitation facilities was spatially clustered among a few central and western Indian states. In the binary logistic regression, education, wealth index, and place of residence were significantly associated with limited drinking water and sanitation services.

Table 2
Selected dimensions and indicators of water, sanitation, and hygiene coverage.

Sub-components	Indicators	Explanation
Drinking Water	Access to improved sources of drinking water	Households (%) access improved sources of drinking water
	Drinking water availability close to households	Households (%) access drinking water close to the house.
Sanitation	Access to latrine facilities	Households (%) having latrine facilities
	Access to drainage facilities	Households (%) having drainage facilities
Hygiene	Access to hand wash facilities	Households (%) having hand wash facilities
	Access to kitchen facilities	Households (%) having kitchen facilities
	Access to improved cooking fuel facilities	Households (%) having access to improved cooking fuel facilities
	Access to the house suitable for living	Households (%) having access to a house suitable for living
	Access to electricity	Households (%) having access to electricity

chart.

We also used Moran's I statistics to analyze the geographical dependency and spatial heterogeneity of WASH. Moran's I scatter plot and the global Moran's I index, developed in 1948, have been used to illustrate spatial dependency [55]. The global Moran's I index can be represented as follows:

$$I = (N / W) \ * \Sigma\Sigma w_{ij} (x_i - \overline{x}) \left(x_j - \overline{x}\right) \Big/ \Sigma(x_i - \overline{x})^2$$

Where N: is the number of spatial units indexed by i and j, W: is the sum of all wij, x: the variable of interest (WASH), $\overline{x}$: is the mean of x and wij: a matrix of spatial weights. The value for Moran's I can range from −1 to 1 where: 1: the variable of interest is perfectly dispersed, 0: the variable of interest is randomly dispersed, and 1: the variable of interest is perfectly clustered together. Along with computing Moran's I, most statistical software will compute a corresponding p-value that can be used to determine whether or not the data is randomly dispersed or not. The inequality of WASH is shown mathematically with the help of the Gini coefficient. Where the value ranges between 0 and 1. 1 means perfect WASH inequality, and 0 means perfect WASH equality.

Mapping was done using QGIS 2.18.25 software. Moran's I was performed in GeoDa software. Furthermore, StataSE 16 and MS Excel have been used for analysis and graphical representation. The methodological framework of the present research work is given in Fig. 1 **[Fig. 1 pasted]**.

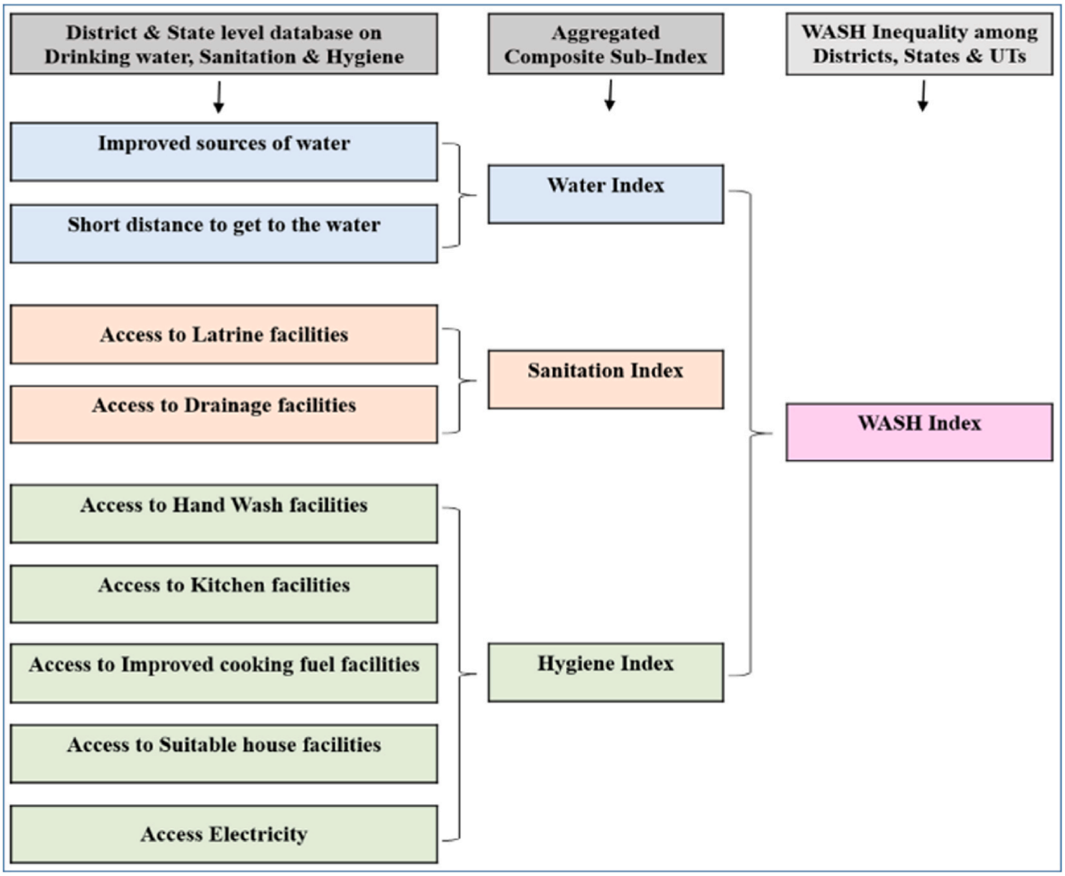

Fig. 1. Methodological framework of the study.

4. Result and discussion

4.1. Inequality of WASH coverage among Indian districts and states

The present study investigated the water, sanitation, and hygiene scenario across Indian districts using composite indices to provide a comprehensive understanding of the coverage of these essential facilities. The study used four composite indices: drinking water composite index (Figure-2: a), sanitation coverage composite index (Figure-2: b), hygiene composite index (Figure-2:c), and WASH composite index (Figure-2:d). **[Fig. 2 pasted]**

The drinking water composite index (Figure-2: a) revealed that the northern districts of India have very high coverage of drinking water facilities. The middle part of India has medium to high coverage of drinking water facilities, whereas the western districts of Rajasthan and the north-eastern districts of Assam and Meghalaya have low to medium coverage, respectively. The southern districts of India have varying coverage, ranging from low to very high. The sanitation coverage composite index (Figure-2: b) showed that most Indian districts have low to medium coverage of sanitation facilities, with the worst situation being observed in Western and Central Indian districts. Low to medium coverage of sanitation facilities was also observed in the rest of the districts. The hygiene composite index (Figure-2: c) revealed high to very high coverage of hygiene facilities in most Indian districts, indicating positive progress towards achieving WASH targets. The WASH composite index (Figure-2: d) indicated that most districts have high to very high coverage of WASH facilities, which is expected to aid India in achieving its SDG-6 targets. Eastern Indian states' poor WASH conditions are related to their greater rates of housing poverty, poorer conditions for household quality of life, and lower levels of socioeconomic and human development [38]. The findings highlight the need for more targeted interventions to improve sanitation coverage in Western and Central Indian districts. In Rajasthan, the state's arid and semi-arid climate, coupled with low rainfall, poses significant challenges to water availability [56–58]. Additionally, the state's rural areas often face water scarcity due to the overexploitation of groundwater resources, inadequate infrastructure, and inefficient water management practices [59]. Similarly, in the north-eastern districts of Assam and Meghalaya, the hilly terrain and remote location make it challenging to provide access to clean drinking water to all households [60,61]. The low coverage of sanitation facilities in Western and Central Indian districts may be due to several factors, including inadequate infrastructure, poor waste management practices, and lack of awareness about the importance of proper sanitation practices [51,62–64]. Additionally, the cultural and social norms in some communities may pose challenges to the adoption of

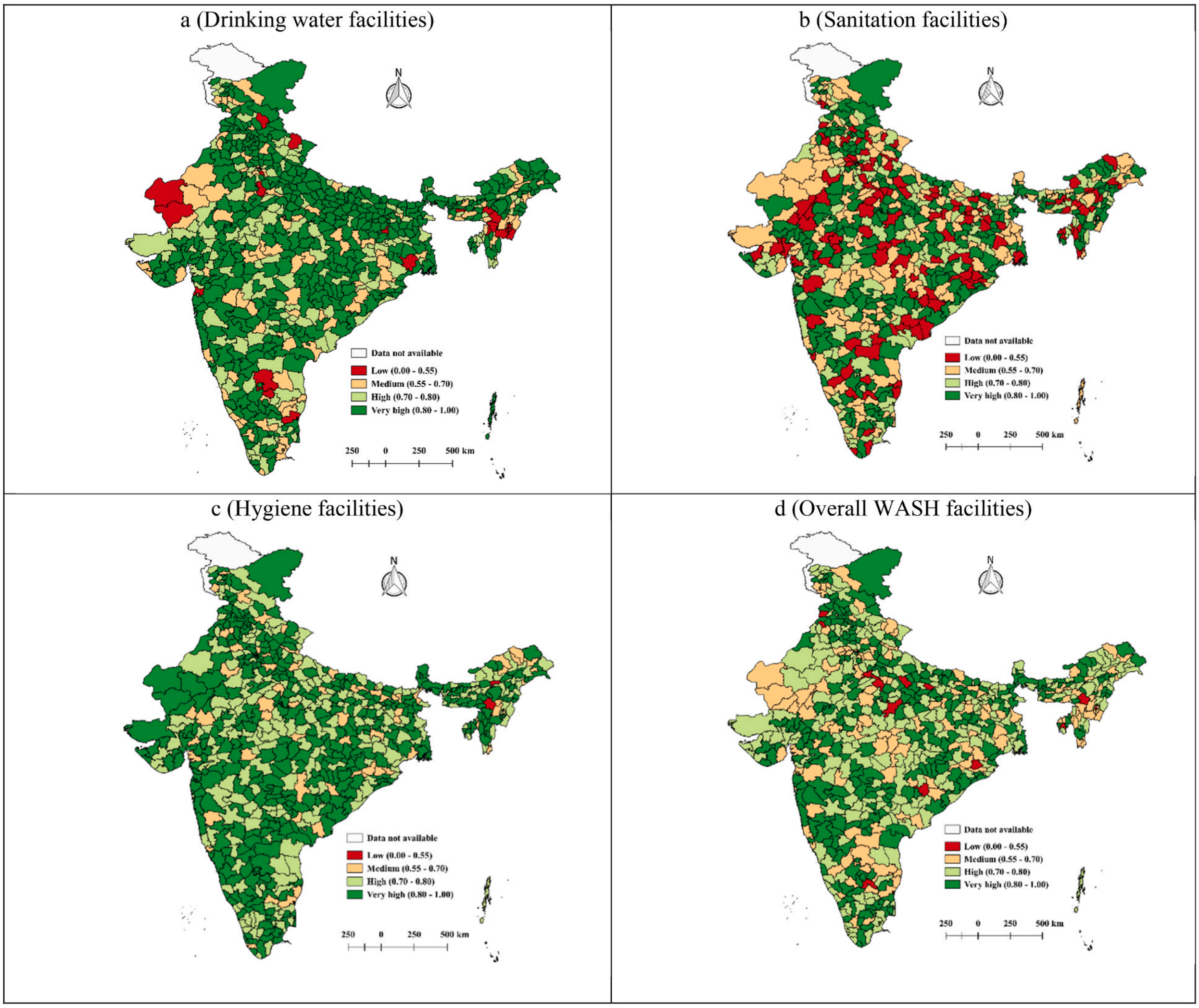

Fig. 2. (a–d): District-level spatial distribution of (a) drinking water, (b) sanitation, and (c) hygiene (d) WASH coverage.

improved sanitation practices, such as the use of toilets [65–67]. It is important to note that the factors contributing to the low coverage of WASH facilities can vary across different regions and communities. Therefore, addressing these challenges would require context-specific and community-led interventions that take into account the local social, economic, and environmental factors.

Table 3 presents the Gini coefficient values for drinking water facilities, sanitation, hygiene, and overall WASH coverage across States and UTs in India. The Gini coefficient values for drinking water facilities, sanitation, hygiene, and overall WASH coverage were found to be 0.07, 0.29, 0.25, and 0.21, respectively. These values suggest that there is very minimal disparity among states and UTs in terms of access to these facilities **[Table 3 pasted] .**

Furthermore, the findings reveal that the difference between the highest and lowest-performing states in India in terms of access to drinking water, sanitation, hygiene, and overall WASH facilities is relatively small. The difference in access to drinking water, sanitation, hygiene, and overall WASH facilities between the highest and lowest-performing states is only 1.1 %, 1.53 %, 0.61 %, and 0.79 %, respectively. This indicates that the overall WASH coverage in India is almost equally distributed across all states and UTs, highlighting significant achievements in the provision of these essential services.

Table 3
Gini coefficient values for WASH facilities in India.

WASH Indicators	Gini coefficient
Improved access of drinking water facilities	0.07
Improved access of sanitation facilities	0.29
Improved access of hygiene facilities	0.25
Overall WASH facilities	0.21

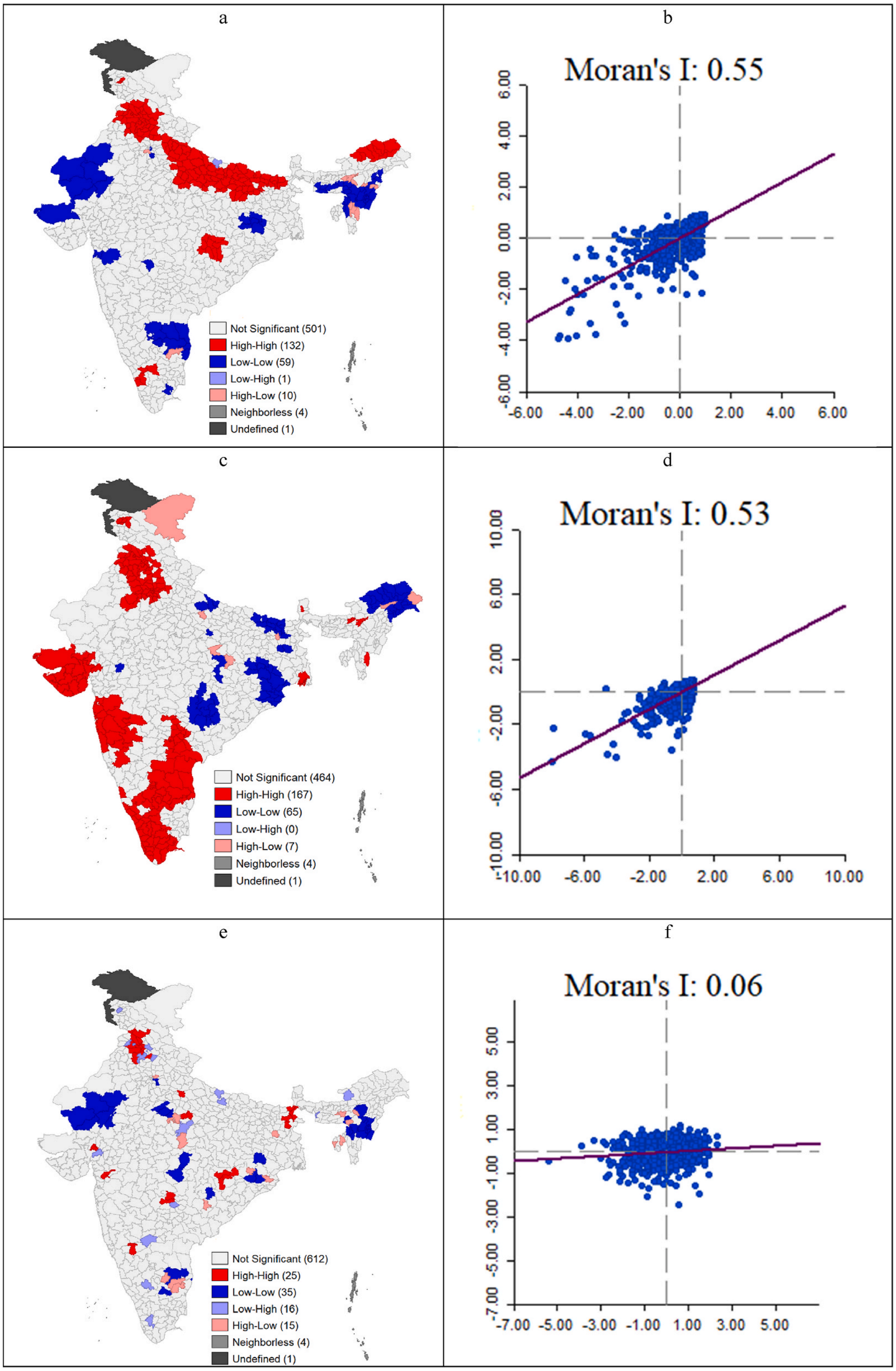

Fig. 3. (a–f): Local spatial pattern (LISA map) and Moran's Scatter Plot showing spatial relationships of water coverage (a, b), accessibility to suitable living facilities (c, d), and overall WASH coverage (e, f).

These results are consistent with other studies that have shown improvements in WASH coverage in India over the past few decades. For example, a report by the Ministry of Drinking Water and Sanitation noted that the percentage of households with access to improved sanitation facilities increased from 21.9 % in 2001 to 64.9 % in 2017. The report also highlighted the success of the Swachh Bharat Mission, a national campaign launched in 2014 to improve sanitation and hygiene practices in India [68–70].

However, it is important to note that despite these achievements, challenges remain in ensuring universal access to WASH facilities, particularly in rural areas and among marginalized communities. For example, a report by Water Aid India found that around 163 million people in India still lack access to clean water close to their homes, while around 732 million people do not have access to basic sanitation facilities [71].

4.2. Spatial dependence and heterogeneity of inequality-adjusted WASH poverty

In this study, the spatial patterns of WASH (water, sanitation, and hygiene) facilities in India were examined using a set of 9 indicators. The results showed that only 2 indicators, "improved sources of water coverage facilities" and "access to the house suitable for living", exhibited significant spatial dependency among India's districts, as indicated by high global Moran's I index and LISA (Local Indicators of Spatial Association) maps. The remaining 7 indicators did not show any specific clustering patterns or spatial dependency **[Fig. 3 pasted] .**

The LISA map (Fig. 3: a) of "improved sources of water coverage facilities" identified 132 districts in the north, east, and northeast states of Arunachal Pradesh with relatively higher levels of coverage of improved water sources facilities surrounded by similar characterized districts (high-high zone). In contrast, clusters of 59 districts situated in western India, south-east India, and north-east Indian districts, including Meghalaya, Tripura, Manipur, Mizoram, and Nagaland, exhibited poor facilities of improved water sources coverage (low-low zone). The LISA map (Fig. 3: c) of "access to the house suitable for living facilities" identified 167 districts with relatively higher levels of coverage of access to the house suitable for living facilities surrounded by similar characterized districts (high-high zone) in southern districts, western Gujarat and Maharashtra districts, and northern districts including Punjab, Haryana,

Table 4
An overview of India's progress in achieving WASH coverage across various indicators.

States & UTs	Improved sources of water	Short distance to get to the water	**Water Index**	Access Latrine	Access Drainage	**Sanitation Index**	Access Hand Wash	Access Kitchen	Access Improved cooking fuel	Suitable House	Access Electricity	**Hygiene Index**	**WASH Index**
Jammu & Kashmir	91.91	89.94	90.93	94.12	70.48	82.30	95.40	95.00	69.19	96.97	99.27	91.17	88.13
Himachal Pradesh	96.30	93.95	95.13	93.25	91.57	92.41	98.24	97.49	51.73	98.39	99.43	89.06	92.20
Punjab	97.91	98.22	98.07	96.99	98.41	97.70	94.91	94.15	76.66	98.94	99.57	92.85	96.20
Chandigarh	97.02	97.95	97.49	97.17	99.58	98.38	93.82	98.06	95.81	98.89	99.73	97.26	97.71
Uttarakhand	95.16	91.92	93.54	93.46	74.69	84.08	98.77	95.06	59.17	95.75	99.39	89.63	89.08
Haryana	90.19	90.29	90.24	96.31	96.17	96.24	97.89	80.15	59.51	99.14	99.54	87.25	91.24
NCT of Delhi	84.42	96.84	90.63	97.12	98.94	98.03	98.62	98.92	98.94	99.72	99.87	99.21	95.96
Rajasthan	85.81	83.27	84.54	77.44	76.77	77.11	98.38	77.18	41.38	96.50	97.92	82.27	81.31
Uttar Pradesh	96.04	95.22	95.63	76.80	87.26	82.03	96.76	95.73	49.52	94.33	89.77	85.22	87.63
Bihar	97.16	96.89	97.03	61.04	81.16	71.10	96.19	92.47	37.79	88.67	95.61	82.15	83.42
Sikkim	93.82	99.38	96.60	99.52	87.93	93.73	94.94	99.55	78.40	98.49	99.30	94.14	94.82
Arunachal Pradesh	94.06	97.64	95.85	98.19	62.83	80.51	96.49	99.61	53.19	71.39	94.75	83.09	86.48
Nagaland	83.00	91.80	87.40	99.48	71.95	85.72	98.06	99.74	43.00	92.04	98.55	86.28	86.46
Manipur	41.94	84.84	63.39	99.03	71.32	85.18	97.70	99.42	70.43	98.54	97.78	92.77	80.45
Mizoram	90.50	97.42	93.96	99.82	95.93	97.88	99.13	99.73	83.77	95.19	97.97	95.16	95.66
Tripura	88.25	88.46	88.36	98.64	35.96	67.30	96.00	95.89	45.34	93.65	97.94	85.76	80.47
Meghalaya	76.86	86.92	81.89	94.80	77.66	86.23	93.34	96.71	33.68	95.44	91.97	82.23	83.45
Assam	85.22	94.61	89.92	94.11	58.58	76.35	97.59	96.60	42.13	97.07	92.71	85.22	83.83
West Bengal	92.58	88.61	90.60	87.62	41.63	64.63	87.70	88.04	40.22	95.71	97.04	81.74	78.99
Jharkhand	83.13	78.29	80.71	66.28	68.90	67.59	97.65	90.48	31.89	90.19	93.85	80.81	76.37
Odisha	90.58	82.18	86.38	66.08	40.19	53.14	98.56	79.68	34.74	88.66	96.25	79.58	73.03
Chhattisgarh	95.46	82.66	89.06	84.40	74.93	79.67	96.63	94.21	33.00	88.29	98.51	82.13	83.62
Madhya Pradesh	87.96	72.49	80.23	73.63	70.74	72.19	96.18	92.73	40.05	92.78	98.05	83.96	78.79
Gujarat	90.41	93.14	91.78	80.48	77.02	78.75	94.97	93.67	66.85	98.33	97.18	90.20	86.91
Dadra & Nagar Haveli	66.36	89.88	78.12	90.20	72.84	81.52	97.30	97.25	79.94	98.86	99.57	94.58	84.74
Maharashtra	89.31	90.74	90.03	81.59	83.50	82.55	97.42	96.06	79.72	98.27	97.45	93.78	88.78
Andhra Pradesh	79.22	78.67	78.95	83.48	67.95	75.72	99.62	91.05	83.62	98.36	99.11	94.35	83.00
Karnataka	87.03	92.32	89.68	82.08	83.85	82.97	94.81	98.48	79.73	97.42	98.80	93.85	88.83
Goa	97.99	99.92	98.96	96.23	95.60	95.92	99.18	99.66	96.50	99.63	100.00	98.99	97.95
Lakshadweep	88.58	99.12	93.85	100.00	97.92	98.96	97.22	98.64	59.43	99.51	99.66	90.89	94.57
Kerala	93.59	98.91	96.25	99.61	88.05	93.83	94.46	98.58	72.07	99.67	99.50	92.86	94.31
Tamil Nadu	85.59	89.05	87.32	77.34	73.84	75.59	96.53	89.09	82.87	97.90	98.98	93.07	85.33
Puducherry	89.75	94.66	92.21	89.94	88.11	89.03	97.43	95.13	92.34	97.76	99.75	96.48	92.57
Andaman & Nicobar	90.32	95.92	93.12	96.22	72.45	84.34	92.36	98.66	79.77	97.79	97.49	93.21	90.22
Telangana	93.03	89.74	91.39	87.10	80.50	83.80	97.99	96.24	91.76	98.66	99.34	96.80	90.66
Ladakh	84.17	76.90	80.54	99.38	47.69	73.54	93.24	98.32	76.26	94.26	99.45	92.31	82.13

(blue)	Achiever (>99)
(green)	Front Runner (90-99)
(yellow)	Performer (80-90)
(pink)	Aspirant (70-80)
(red)	Not Satisfactory (<70)

and NCT Delhi in India. Conversely, clusters of 65 districts situated in districts of Arunachal Pradesh, Orissa, Bihar, and Chhattisgarh, exhibited poor facilities of access to the house suitable for living facilities (low-low zone). The overall WASH coverage LISA map (Fig. 3e), which included all nine indicators, showed that 35 districts, including Orissa, Nagaland, Manipur, and western districts of Rajasthan, were demarcated by low-low zone, indicating a lack of access to overall WASH facilities in that region in India.

The findings suggest that there are substantial variations in access to WASH facilities in India, with some districts exhibiting significantly better facilities than others. The reasons behind the lack of access to WASH facilities may include factors such as economic status, geographic location, infrastructure development, and government policies [72,72–77]. The identification of districts with poor facilities can inform policymakers and stakeholders to target interventions to improve access to WASH facilities in these areas.

The variations in the levels of coverage of improved water sources and access to suitable living facilities across different districts in India could be due to several factors. Firstly, geographical location and natural resources may play a significant role. For example, the northern and northeastern states of India, including Arunachal Pradesh, may have a more challenging terrain, which could make it difficult to access clean water sources or build suitable living facilities [78–80]. Similarly, areas with high rainfall may be more prone to flooding, making it challenging to maintain clean water sources or suitable housing [81–83]. Secondly, socio-economic factors such as poverty and inequality may also contribute to the disparities in coverage. Districts with higher levels of poverty may lack the resources or infrastructure to invest in water and sanitation facilities or build suitable housing [52,84,85]. Additionally, marginalized communities such as those living in slums or tribal areas may face additional barriers to accessing these facilities [86]. Thirdly, government policies and initiatives may also impact the coverage of these facilities. For example, states that have implemented successful water and sanitation programs such as Gujarat and Maharashtra may have higher levels of coverage, while those that have not prioritized these issues may have lower levels of coverage [87–90].

4.3. India's achievements towards WASH coverage

The paragraph describes the status of drinking water, sanitation, and hygiene facilities in different Indian states and union territories. The data is presented in Table 4 and Fig. 4.

Table 4 shows that the North States and UTs have the highest coverage of drinking water facilities, with 90–99 % coverage. Manipur, on the other hand, has a not satisfactory situation in terms of drinking water coverage. In terms of sanitation facilities, Himachal Pradesh, Punjab, Chandigarh, Delhi, Rajasthan, Sikkim, Mizoram, Goa, Lakshadweep, and Kerala are front runner States and UTs, while Manipur, West Bengal, Jharkhand, and Odisha show not satisfactory results. In terms of hygiene facilities, the NCT of Delhi is the only "Achiever" Union Territory. Overall, Himachal Pradesh, Punjab, Chandigarh, Haryana, NCT of Delhi, Sikkim, Mizoram, Goa, Lakshadweep, Kerala, Puducherry, Andaman & Nicobar Islands, and Telangana are the front-runner states and UTs, while West Bengal, Jharkhand, Odisha, Madhya Pradesh are aspirant states.

Fig. 4 shows the status of each state and union territory in a total of nine indicators. Andaman & Nicobar Islands have the highest number of indicators [7] in the achiever situation, while Himachal Pradesh, Punjab, and Chandigarh have seven indicators in the front runner's situation. Tamil Nadu and West Bengal have the highest number of indicators [4] in the performer situation, and three indicators of Madhya Pradesh are in the "aspirant" situation. Jharkhand and Orisha have the highest number of indicators [3] in the not satisfactory situation, and Arunachal Pradesh, Bihar, Tripura, and Assam have two indicators each in the not satisfactory situation. Overall, Rajasthan, West Bengal, Jharkhand, Odisha, Chhattisgarh, Madhya Pradesh, and Andhra Pradesh need more improvement on

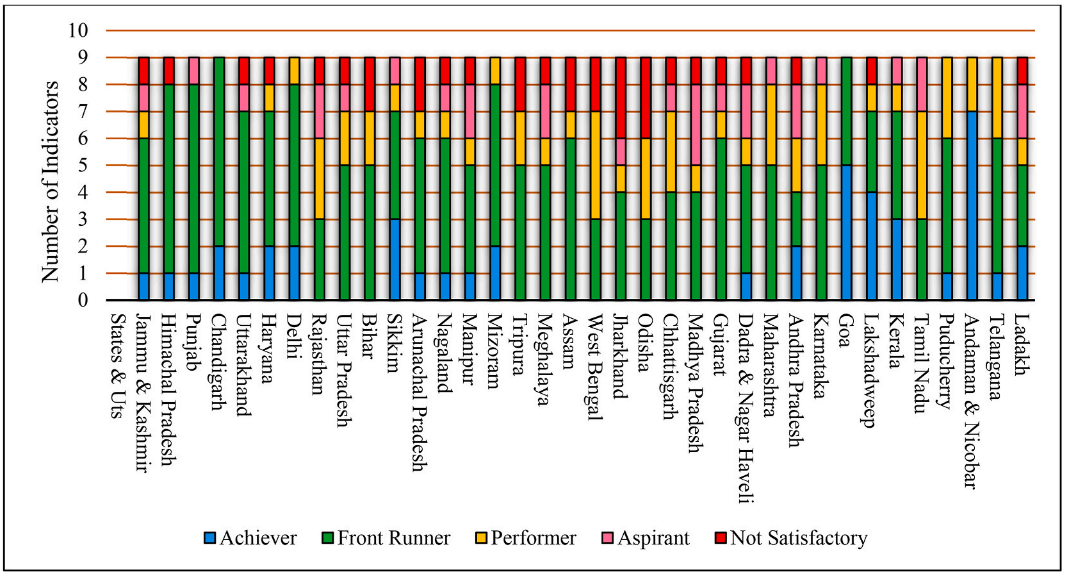

Fig. 4. Overall performance of different indicators of drinking water, sanitation and hygiene across different Indian states.

WASH. Low income, inadequate investment, high population density, low levels of education and income, and certain climatic and geographic regions are among the key factors contributing to inadequate coverage of water and sanitation services [57,61,64,65].

However, it can be inferred that the availability of resources, infrastructure, and government policies and initiatives can play a significant role in determining the status of WASH facilities in different states and union territories. For example, the North States and UTs may have better access to drinking water facilities due to their geographical location and availability of resources. Similarly, the States and UTs in the front-runner and achiever categories may have implemented effective policies and initiatives to improve WASH facilities, while those in the "aspirant" and not satisfactory categories may need to prioritize and invest in WASH infrastructure and programs. Factors such as poverty, education, and cultural practices may also contribute to the lack of access and well access to facilities in certain areas.

Several policy interventions are recommended to ensure universal access to improved drinking water, sanitation, and hygiene facilities in India. Firstly, there needs to be a significant investment in water supply and sanitation infrastructure, particularly in regions with low coverage, focusing on building and maintaining water supply systems, sewage networks, and waste treatment facilities. Secondly, community engagement and awareness campaigns should be prioritized to educate communities about the importance of proper sanitation and hygiene practices while also engaging them in planning, implementing, and maintaining water and sanitation facilities. Targeted interventions are essential to address the specific needs of marginalized communities, including those living in rural areas, slums, and tribal regions, which may involve providing subsidies or financial incentives for the construction of toilets and sanitation facilities in households that cannot afford them. Embracing innovative water purification, sewage treatment, and waste management technologies is also crucial, including adopting decentralized wastewater treatment systems, water recycling, and smart sensors for monitoring water quality. Strengthening coordination between government departments, local authorities, and non-governmental organizations to ensure effective policy implementation and resource allocation, along with fostering partnerships with international organizations and research institutions, is vital to access funding, technical expertise, and best practices in water and sanitation management, learning from successful initiatives implemented in other countries and adapting them to the local context. In Western countries, advanced techniques such as smart water management systems, decentralized wastewater treatment, water recycling and reuse, green infrastructure, and public-private partnerships (PPPs) have been widely adopted to improve water and sanitation services, optimize resource utilization, and ensure sustainability. These approaches, effective policy coordination, and international collaboration offer valuable insights and strategies for addressing India's water and sanitation challenges.

5. Limitation of the study

One limitation of our study is the need for standardized composite indicators to assess WASH conditions. While the WHO provides a set of key indicators for monitoring and assessing WASH conditions, there is no specific composite index defined by any organization. Our study developed a composite index based on nine main indicators obtained from the NFHS-5 survey to assess the WASH scenario across Indian districts. However, this approach may only partially capture some aspects of WASH conditions, and the absence of standardized composite indicators may limit the comparability of our findings with other studies. Additionally, the NFHS-5 survey is a sample survey and does not cover the entire population of India. Furthermore, the most recent census conducted in India was in 2011, and there currently needs to be updated data, which may affect the accuracy and reliability of our analysis. Due to the lack of recent census data, we had to rely on the NFHS-5 data for our analysis, which might not fully represent the current WASH scenario in India.

6. Conclusion

In this study, we employed a composite index to assess the water, sanitation, and hygiene scenario across Indian districts, utilizing nine indicators categorized under the main components of WASH. The composite index was developed to highlight WASH inequalities at the state and district levels, allowing us to identify areas in need of targeted interventions. While no organization provides a specific composite indicator for WASH, the use of this composite index provided a comprehensive understanding of WASH coverage and disparities in India. Our study reveals significant variations in WASH coverage, particularly in Western and Central Indian districts. Although minimal inequality in the distribution of WASH facilities across States and UTs was observed, there remains a small difference between the highest and lowest-performing states. Despite considerable progress in improving WASH coverage in India, challenges persist, particularly in rural areas and among marginalized communities. Our findings underscore the importance of context-specific and community-led interventions to address these challenges, considering local social, economic, and environmental factors. The study has important policy implications, emphasizing the need for continued efforts to improve access to WASH facilities, especially in areas with low coverage, and the necessity for targeted interventions to support marginalized communities. Overall, our study provides valuable insights into the WASH scenario across Indian districts, contributing to the ongoing efforts to achieve universal access to these essential services and ultimately supporting the realization of Sustainable Development Goal 6 in India.

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We did not receive any grants from any funding agency in public, commercial, or non-profit sectors for conducting this study.

Data availability statement

This study analyses a nationally representative survey database available freely in the public domain and can be accessed using standard protocols. The data is available on the Demographic Health Survey website, http://dhsprogram.com.

Ethical statement

Ethical approval was not applicable for this secondary data analysis of the nationally representative survey NFHS-5 as the data is available in the public domain; deanonymized data was retrieved via standard protocols from the Demographic Health Survey website, http://dhsprogram.com. The survey was performed as per the standard ethical guideline and informed consent was obtained from the participants.

CRediT authorship contribution statement

Sourav Biswas: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Resources, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Mihir Adhikary:** Writing – review & editing, Writing – original draft, Validation. **Asraful Alam:** Writing – review & editing, Writing – original draft, Validation, Supervision, Conceptualization. **Nazrul Islam:** Writing – review & editing, Writing – original draft, Validation, Supervision. **Ranjan Roy:** Writing – review & editing, Writing – original draft, Validation, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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