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Appraisal of WaSH (Water-Sanitation-Hygiene) Infrastructure using a Composite Index, Spatial Algorithms and Sociodemographic Correlates in Rural India

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ABSTRACT. Rationale: A great wealth of studies expound on the impact of water and sanitation facilities on sustainable human development. But even though water-sanitation nexus is acknowledged in WaSH (Water-Sanitation-Hygiene) literature, they are seldom assessed collectively. In rural India, open defecation is still a major threat to human health, as much as potable water quality. Unfortunately, no study yet exists that attempts to assess the WaSH sector in a holistic sense. Objective: Present study was aimed to integrate multiple WaSH parameters into a composite WaSH Quality Index (WaSHQI) for rural India, within a geospatial framework, and understand potential effects of different sociodemographic factors that are likely to influece WaSH profile development. Methods: District-wise data for (i) within-premises latrine facility, (ii) water source type (safe/treated tap), (iii) water source location (near home/away from home), and (iv) wastewater drainage (closed/open) were mapped at nationwide scale. Gini Coefficients were computed for each parameter to elucidate spatial inequality. The parameters were integrated in various combinations to compute a composite index for each district called, WaSHQI. In the process, four hypothetical scenarios were generated (grading from most conservative to most liberal). The WaSHQI was later (a) merged with spatial algorithms (Moran's I and LISA)) to identify WaSH-hotspots and (b) correlated with a range of sociodemographic factors (e.g., literacy, household density, caste). Results: Under a conservative aproach (presumably the most hygienic WaSH scenario), a vast expanse through central India were significantly (p < 0.001) lagging in multiple WaSH facilities and appeared as major hotspots that deserve urgent management actions. On the other hand, northwestern states (Punjab and Haryana) registered a better WaSH profile owing to a number of progressive social reforms. Significant (p < 0.01) correlations between the WaSHQI and literacy levels, especially that of female, in the hotspots called for more in-depth region-specific investigations in future. Rural WaSH sector in India is marked by intense spatial inequality/heterogeneity, calling for spatially-optimized interventions. Using multiple geospatial alrorithms and statistical analyses the study demonstrated the spatially interconnected nature of the WaSH and argued that policy decisions have to address the parameters collectively. Future Implications: WaSHQI can offer the decision-makers a semi-quantitative approximation of overall WaSH infrastructural inadequacy at any level of administrative hierarchy anywhere in the world. However, some efforts to exapand/diversify the potentials WaSHQI (accounting for additional socioeconomic parameters) could be pursued on the premise of developing a WaSH informatics system to track regional progress/lag over time.

Keywords: WaSH quality index, LISA, Moran's I, Gini coefficient, open defecation, wastewater drainage, literacy

1. Introduction

Ensuring adequate supply of safe potable *W*ater, access to basic *S*anitation, that leads to public health and *H*ygiene (WaSH) form the crux of sustainable human development paradigms around the world (Schwemlien et al., 2016). In recent times, appraisal of WaSH facilities has emerged as a critical concern to the government, owing to myriad issues over water-borne diseases ensuing from lack of appropriate WaSH facilities, especially in middle- and low-income countries (Fewtrell and Colford, 2005; Yates et al., 2015). In India, poor/inadequate WaSH infrastructure, and associated unhygienic practices, not only accentuate human health hazards (diarrhea, dysentery etc.) but affect overall social dynamics, especially in rural areas (Mara et al., 2010).

After 25 years of global monitoring (1990 ~ 2015) of WaSH performance by the Joint Monitoring Program (JMP), established by the WHO-UNICEF as part of the Millennium Development Goal (MDG), it might plague the decision-makers to realize that still about 800 million people do not have 'at-home' water sources; 2.4 billion people (37% of global population) lack access to improved sanitation facilities, with about one billion (15% of global population) practicing open defecation (WHO-UNICEF, 2015). Majority of the latter population resides in South- and Southeast Asian countries.

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Appallingly, India claims the lion's share of the same: 66% of the global population practicing open defecation, among which 90% live in the rural areas (Routray et al., 2015). India hosts the highest density of open defecators in the world, twice the global average (Coffey et al., 2014) which aggravates shallow groundwater quality, water distribution networks, and soil systems, which in turn undermines public health system (Patil et al., 2014).

In the current era of the UN's Sustainable Development Goals (2015 ~ 2030), a daunting task is to gage progress towards the global WaSH target under SDG 6: *improved water and sanitation for all by 2030*. In rural India, importance of basic sanitation facilities and safe potable water on sustainable human development is yet to be fully realized by Chaudhuri and Roy, (2017a). The JMP estimates indicated that only about 30% of the Indian rural populace enjoy access to improved sanitation facilities. Rampant open defecation practices in rural areas lead to numerous diseases (Clasen et al., 2014; O'Rielly and Louis, 2014), including diarrhea (Kumar and Das, 2014) and stunting (Spears et al., 2013) among children. Lack of appropriate WaSH facilities has also been linked to morbidity as well as mortality (Shakya et al., 2015). India hosts the largest global tally of diarrheal deaths for children less than 5 years of age (Patil et al., 2014). The above observations call for a nationwide WaSH informatics system, to continuously monitor, develop, revise and implement well-informed policy measures in regions lacking WaSH infrastructural facilities as well as identify regions (hotspots) that would require in-depth studies in future to identify major challenges therein.

An interesting trait of the studies made in WaSH sector in India is that, they approached issues of water and sanitation

Table 1. State-wise Number of Districts, Villages, Rural Households and Rural Population as % of State Population in India

State/UT*	No. of Districts	No. of Villages	No. of Rural Households	Rural Population (% of Total State Population)
Jammu & Kashmir (J&K)	22	6337	1,553,433	73
Himachal Pradesh (HP)	12	17,882	1,312,510	90
Punjab (PN)	21	12,168	3,358,113	63
Chandigarh*	1	5	7,140	3
Uttarakhand (UK)	13	15,745	1,425,086	70
Haryana (HR)	21	6,642	3,043,756	65
NCT of Delhi*	9	103	79,574	2
Rajasthan (RJ)	33	43,264	9,494,903	75
Uttar Pradesh (UP)	72	97,814	25,685,942	78
Bihar (BR)	38	39,073	16,862,940	89
Sikkim (SK)	4	425	93,288	75
Arunachal Pradesh (AR)	16	5,258	200,210	77
Nagaland (NG)	11	1,400	277,491	71
Manipur (MN)	9	2,515	385,520	71
Mizoram (MZ)	8	704	105,812	48
Tripura (TR)	4	863	616,582	74
Meghalaya (MG)	7	6,459	430,573	80
Assam (AS)	27	25,372	5,420,877	86
West Bengal (WB)	19	37,469	13,813,165	68
Jharkhand (JH)	24	29,492	4,729,369	76
Odisha (OR)	30	47,675	8,089,987	83
Chhattisgarh (CG)	27	19,567	4,365,568	77
Madhya Pradesh (MP)	50	51,929	11,080,278	72
Gujarat (GJ)	26	17,843	6,773,558	57
Daman & Diu*	2	19	12,744	25
Dadra & Nagar Haveli*	1	65	36,094	53
Maharashtra (MH)	35	40,959	13,214,738	55
Andhra Pradesh (AP)	23	26,286	14,234,387	67
Karnataka (KA)	30	27,397	7,946,657	61
Goa (CA)	2	320	128,208	38
Lakshadweep*	1	6	2,710	22
Kerala (KL)	14	1,017	4,149,641	52
Tamil Nadu (TN)	32	15,049	9,528,495	52
Puducherry*	4	90	95,018	32
Andaman & Nicobar Islands*	3	396	58,530	62

*Union Territories (UT). There are currently 7 UTs in India.
**Letters in the parentheses indicate state acronyms used in the study.

Table 2. State-wise Scheduled Caste and Scheduled Tribe Population as Percentages of Total Rural Population

State Name	% SC	% ST
Andhra Pradesh (AP)	19.24	9.28
Arunachal Pradesh (AR)	0.00	74.07
Assam (AS)	6.80	13.67
Bihar (BR)	16.61	1.37
Chhattisgarh (CG)	12.81	36.87
Goa (GA)	1.71	15.88
Gujarat (GJ)	6.57	23.12
Haryana (HR)	22.53	0.00
Himachal Pradesh (HP)	26.01	6.06
Jammu & Kashmir (J&K)	8.24	15.44
Jharkhand (JH)	12.58	31.40
Karnataka (KA)	20.01	9.15
Kerala (KL)	10.41	2.47
Madhya Pradesh (MP)	15.73	27.16
Maharashtra (MH)	12.18	14.63
Manipur (MN)	2.73	45.56
Meghalaya (MG)	0.49	90.11
Mizoram (MZ)	0.06	96.58
Nagaland (NG)	0.00	92.84
Odisha (OR)	17.78	25.72
Punjab (PN)	37.45	0.00
Rajasthan (RJ)	18.51	16.88
Sikkim (SK)	4.45	36.57
Tamil Nadu (TN)	25.45	1.77
Tripura (TR)	16.14	41.20
Uttar Pradesh (UP)	22.97	0.66
Uttarakhand (UK)	21.27	3.76
West Bengal (WB)	27.49	7.81

*Data cited for 29 states of India.

**Letters in the parentheses indicate state acronyms used in the study.

individually, rather than collectively. In other words no study till date attempted to combine water and sanitation into a composite measure to assess holistic spatial dimensions of the problem. An additional issue therein is, majority of the studies ignored parameters (e.g., wastewater drainage) that should enjoy equal importance in WaSH policy making. In addition, majority of the studies were based on survey-based results over smaller spatial extent (e.g., single village or village clusters) which made the findings rather contextual.

In light of above observations, the present study proposes to devise a composite WaSH quality Index (WaSHQI), by integrating multiple parameters to capture nationwide spatial dimensions in the WaSH infrastructural facilities in rural India and map them to visualize any recognizable patterns (heterogeneity/inequality). Fundamental idea pursued through this study was to identify the WaSH hotspots (where facilities are starkly lacking), with statistical significance, to offer the policy-makers viable means to strategize optimal interventions to achieve nationwide homogeneity in rural public service systems. To achieve the goal the study was divided into five components including (a) thematic mapping of district-wise percentages (raw data) of rural households having different attributes for latrine (within premises), potable water (source type and location), and wastewater drainage (closed or open) facilities; (b) obtaining a numerical sense for inter- and intra-state spatial inequality in the above-mentioned parameters (c) assimilating the parameters into a single index (WaSHQI) to obtain a nationwide overview of the rural WaSH sector; (d) integrate WaSHQI with various global (Moran's I) and local (Local Indicators of Spatial Association) spatial algorithms to map WaSH infrastructural inadequacies within a defined window of statistical significance ($0.05 < p < 0.001$), and (e) understand likely influences of different sociodemographic traits (e.g., literacy) on WaSH profile development. A major impetus to conduct such a study was to explore possibilities to developing a robust WaSH informatics system that can be a major tool for the policy-makers to track WaSH developmental trajectory across space and time.

2. Materials and Methods

There are 29 states in India and seven Union Territories. In 2011, the rural population accounted for about 69% of the national total (GoI, 2014). In states of Himachal Pradesh, Bihar, Assam and Odisha, rural population accounted for about 83% of the states' total population. According to Census 2011 database, there were over 597,000 villages in India with over 207,116,576 rural households (Table 1). States of Uttar Pradesh (UP), Madhya Pradesh (MP), Rajasthan (RJ), Odisha (OR), Maharashtra (MH), Bihar (BR) and West Bengal (WB) account for about 51% of the villages in the country. The Provisional Total suggested over 833 million people (~ 70% of the total population) dwelled in the rural areas in India.

A considerable fraction of the Indian rural demography comprises of the reserved sections: the Scheduled Caste (SC) and Scheduled Tribes (ST). By census definition, the SC and ST represent various "officially designated reserved population of historically disadvantaged people". In modern assessments, they are often deemed untouchables as well and in some states, labeled as dalits (the oppressed) (Kumar, 1992). Officially, these reserved sections came into being in the post-independent era by the Constitution Order of 1950. As per the census 2011 database, the SCs and STs, respectively, represent about 16.6% (18.45% in case of rural) and 8.6% (11.25% for rural) of the total national population (Table 2). By far, the State of Uttar Pradesh (UP) hosts the highest population of SCs in the country followed by West Bengal (WB), Bihar (BR), Andhra Pradesh (AP), Tamil Nadu (TN), Maharashtra (MH), Rajasthan (RJ), and Karnataka (KA).

Lack of adequate WaSH infrastructure is a ubiquitous issue throughout India. According to the census estimates, over 69% of rural households in India lacked latrine facilities within premises in 2011 (Table 2). About 22% rural households lacked water sources within premises while 63% lacked wastewater drainage facility.

Present study derived cross-sectional data from the Census of India database for 2011 (GoI, 2014). Census data is by far the most authentic and complete governmental database listing information from households to village, constitutional

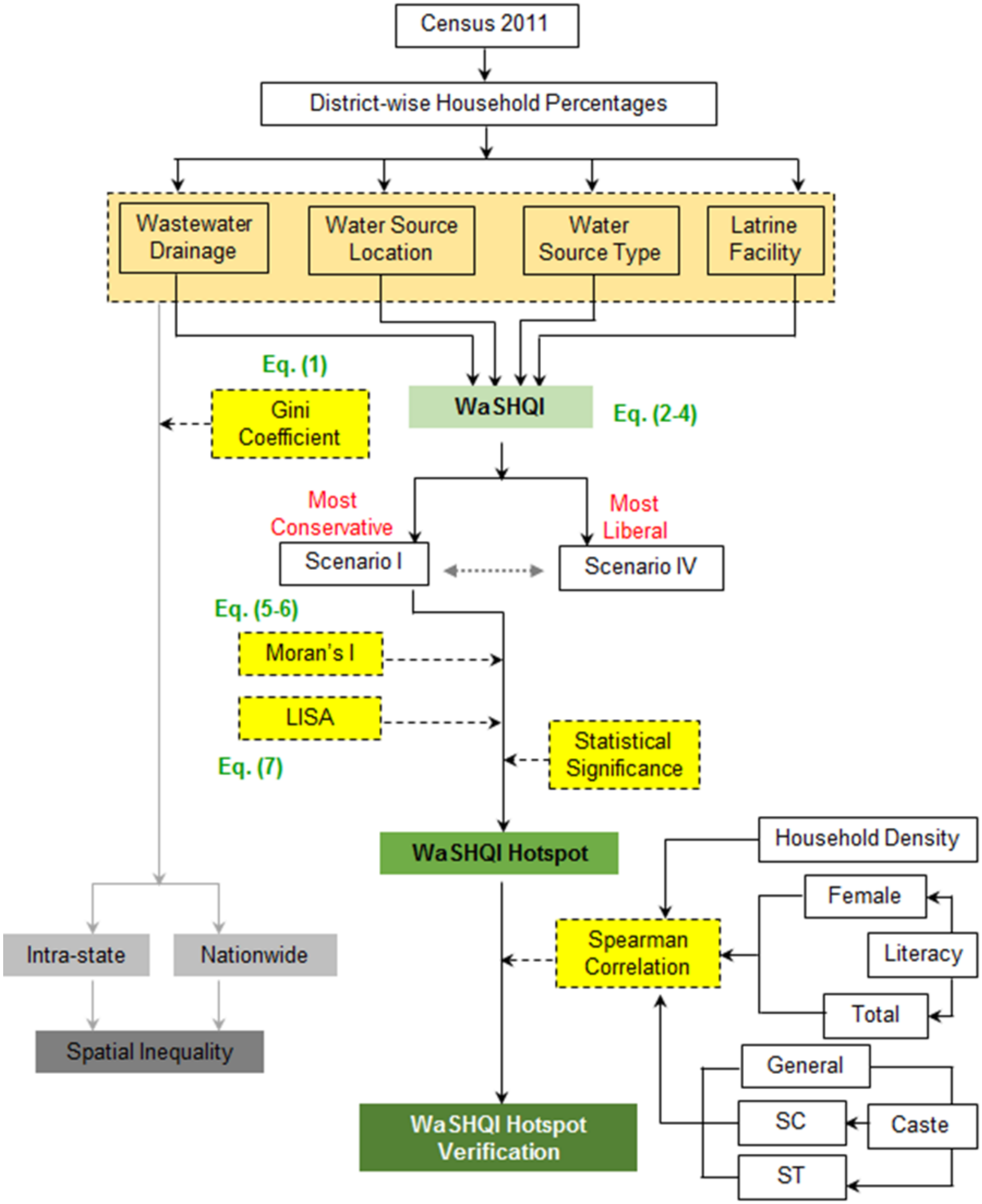

Figure 1. Framework of analytical methods followed in the study.

Note: Yellow boxes contain the main spatial/statistical methods used. Corresponding equations in the text are marked in green.

Table 3. Nationwide Gini Coefficient Computed for Different WaSH Infrastructural Facilities, Considering all Districts in India

Parameter Type	Within Premises	Away From Premises
Water Source (location)	0.42	0.26
Latrine (location)	0.69	0.38
	Closed	Open
Wastewater Drainage (type)	0.46	0.31
	Safe	Treated Tap
Water Source (chemical quality)	0.38	0.62

*Open Defecation is considered as Away From Premises facility.
**Higher the Gini value higher the spatially inequality.

performances, census data were extracted from the Census database (H-series: Household Amenities) for district-wise percentages of rural households with (a) within-premises latrine facilities, (b) water source types, (c) water source locations (at-home and near-home), and (d) wastewater drainage facility (open and closed). The "within-premises latrine facility" data were also obtained from Census, 2001 database for temporal assessment. However, this data was only available at state level.

In addition, information for a number of sociodemographic attributes were obtained from the Census 2011 database, including district-wise (a) number of rural households and household densities, (b) Scheduled caste (SC) and Scheduled Tribes (ST), as representative of the reserved population, and (c) literate population (total and female). The SC/ST groups were considered as a major sociodemographic driver in the present study owing to their lower literacy (elaborated in Appendix 2) that leads to lack of environmental awareness and/or sense of hygiene and thus to inappropriate WaSH practices that may put the whole village community at risk.

The initial part of the analysis comprised of spatial mapping of district-wise household percentages of different WaSH infrastructural facilities (thematic mapping) (Figure 2, 4 ~ 6). For each parameter, districts were color-coded on the map using a roughly 25% interval, to present a visual appraisal of the existing scenario. The thematic mapping of WaSH parameters essentially laid out the foundations to all subsequent advanced spatial analyses.

Following thematic mapping, Gini coefficients were calculated to estimate spatial inequality in the geographic distribution of different WaSH facilities, using the following equation (Figure 1):

$$G = \frac{1}{2n^2u}\sum\nolimits_{j-1}^{n}\sum\nolimits_{i=1}^{n}\left|Y_j - Y_i\right| \quad (1)$$

where G = Gini coefficient

n = sample size (number of districts)

u = average value of the study parameter

$|Y_j - Y_i|$ = absolute value of the difference between districts

Gini coefficient values range between 0 (perfect equality in WaSH facilities; i.e., no heterogeneity) and 1 (perfect inequality; extreme heterogeneity) (Wagstaff et al., 1991), with following categories for G: < 0.20: *good equality*; 0.20 ~ 0.30: *fair equality*; 0.30 ~ 0.40: *reasonable equality*; 0.40 ~ 0,50: *high inequality*; > 0.50: *stark inequality* (Fang et al., 2013).

Table 4. Nationwide Percentages of Rural Households Have Different Types of Wash Facilities

Latrine: Within-premises (30.74)*		Latrine: Away from Premises (69.2)	
Flush/Pour flush:	19.43	Public latrine	1.94
• Piped sewer	2.20	Open defecation	67.32
• Septic tank	14.70		
• Other	2.53		
Pit:			
• Slab/Ventilated	8.19		
• Without slab/Open pit	2.35		
Safe Water Source (82.73)**		**Within-premises Water Source (77.94)****	
Tap:	30.82	At-Home	35.00
• Treated	17.86	Near-Home	42.94
• Untreated	12.96	Away from Home	22.06
Hand pump	43.63		
Tube well/Bore well	8.28		
Others (river, tank, spring)	17.27		
Within-premises Wastewater Drainage Facility (36.76)***			
Open	5.75		
Closed	31.01		
None	63.24		

*within-premises latrine facility.
**total safe water source (Tap + Hand Pump + Tube well/Bore well).
***within-premises wastewater drainage facility (Open + Closed); within-premises water source (At-Home + Near-Home); near-home water source indicates water source available with 500 meter of household.

Fundamental idea of computing the Gini coefficient was to obtain a semiquantitative appraisal of the magnitude of spatial inequality in WaSH facilities in India, as a whole, as much as highlighting inter-state differences (*how inequal the states are from each other?*). To achieve such dual purpose Gini Coefficients were calculated in two different ways, by considering each WaSH parameter:

a) For all the districts taken as a whole for India (resulting in one nationwide Gini coefficient for each WaSH parameter respectively) (Table 3) and

b) For districts within each state to obtain state-wise Gini coefficient

While the first approach resulted in a single value for each WaSH parameter and was used to estimate nationwide spatial inequality. The latter yielded state-wise values for each parameter that were appended to state maps to elucidate inter-state inequalities. Such portrayal will help visualizing the zonal structure of spatial inequality across the nation that may help the policy makers implement spatially-optimized interventions to achieve nationwide WaSH homogeneity.

The WaSH Quality Index (WaSHQI) was computed by considering four WaSH parameters: (1) drinking water source ('safe' and 'treated tap'); (2) drinking water source location ('at-home' and 'near-home'); (3) within-premises latrine facility; (3) wastewater drainage facility ('open' and 'closed') using following equations:

$$\text{WaSHQI} = \frac{\sum (Q_n \times W_n)}{\sum W_n} \tag{2}$$

where Q_n = District-wise observed value for each WaSH parameter

W_n = Weight factor for each WaSH parameter

The weight factor (W_n) for each WaSH parameter was determined using following equation:

$$W_n = K \times S_{i...4} \tag{3}$$

where W_n = Weight factor for each WaSH parameter

K = Proportionality constant

S = Standard value for each WaSH parameter

The weight factor (W_n) for each WaSH parameter varies directly with corresponding standard value (S) assuming that higher the 'S', the higher the WaSHQI, and 'better' the WaSH infrastructure. For the present purpose, the national total for each WaSH parameter was taken as its standard value (Table 4). The proportionality constant (K) was derived as follows:

$$K = \frac{1}{\sum_{i=1}^{4} S_i} \tag{4}$$

The WaSHQI values were scaled between 0 and 100, and divided into five categories namely, WaSHQI < 20 = Very Poor; 20 ~ 40 = Poor; 40 ~ 60 = Moderate; 60 ~ 80 = Fair; > 80 = Excellent. For each district, WaSHQI values were generated for four scenarios, considering various combinations of subcategories (open/close drainage) of WaSH parameters.

A fundamental premise tested through conceptualization of WaSHQI was to explore potentials of developing a range of scenarios, by combining different sub-categories of each WaSH parameter, grading from Most Conservative (most ideal) to Most Liberal (somewhat acceptable). For example, having latrine, water source and closed wastewater drainage facilities within premises may be regarded as the most desirable WaSH scenario (Most Conservative) from health and hygiene perspective. Such idealistic accommodations, however, may be highly demanding based on socioeconomic framework and level of availability of governmental support. Under the circumstances, the district/village may want to resort to relatively relaxed accommodations (Liberal Approach). Four such hypothetical scenarios were computed and presented cartographically as visual summary of viable WaSH management options.

More than often, a major need for the policy-makers is to have a clear understanding of the underlying spatial structure (heterogeneity) in the WaSH infrastructure. In other words, if any statistically significant geographic pattern can be identified in WaSH facilities which might be used with certain level of confidence to implement zone-wise management strategies to optimize resource use. To characterize spatial heterogeneity in WaSH parameters across the nation, Moran's I and Local Indicators of Spatial Association (LISA) were computed, using district-wise WaSHQI values, which might aid in smart decision-making by prioritizing zones (cluster of districts/states) that will require urgent management actions in days ahead.

Moran's I was computed using the following equation:

$$\text{I} = \frac{n}{S_o} \frac{\sum_{i=1}^{n} \sum_{j=0}^{n} W_{ij} \left(x_i - X \right) \left(x_j - X \right)}{\sum_{i=1}^{n} \left(x_i - X \right)^2} \tag{5}$$

where n = total number of observations (districts) of WaSHQI

i and j = spatial location of districts with respect to each other

W_{ij} = spatial weight matrix

S_o = product sum of the spatial weight matrix

x_i = WaSHQI value at location i,

x_j = WaSHQI value at location j

X = mean of value x

The product sum of the spatial weight matrix, S_o was computed as:

$$S_o = \sum_{i=1}^{n} \sum_{j=1}^{n} W_{ij} \tag{6}$$

Moran's I is a global indicator of spatial association that yields a single statistic for the entire area (India as a whole, in this case) by averaging out the local variations (e.g., district-wise WaSHQI variability), which can lead to local 'non-stationarity' phenomena (Anselin, 1995). Moran's I is essentially an extension of Pearson's product-moment correlation coefficient with the numerator representing a covariance function while the denominator represents the sample variance (Moran, 1950). Analogous to Pearson's correlation coefficient, values of Moran's I can vary from +1 (strong positive spatial autocorrelation between the spatial units) to −1 (strong negative spatial autocorrelation) through 0, which suggest random pattern between adjacent spatial units (districts) (Ping et al., 2004). Positive spatial autocorrelation implies that districts with high WaSHQI values are contiguous within a defined neighborhood, while negative spatial autocorrelation indicates clustering of low WaSHQI values (Chaudhuri et al., 2012; Chaudhuri and Ale, 2014). A scatterplot was generated in the process with four quadrants depicting four different types of spatial autocorrelation between the districts. The scatterplot was obtained by using Monte-Carlo randomization allowing for 999 permutations.

Building upon the premise of Moran's I, Local Indicator of Spatial Association (LISA) illustrates the spatial autocorrelation phenomena with two maps: one depicts the clustering of (dis)similar WaSHQI districts, while the other yields the statistical significance associated with each cluster. As the name suggests, LISA represents local scenario of spatial autocorrelation within a defined neighborhood, using following equation:

$$\text{LISA} = Z_i \sum_{i=1}^{n} W_{ij} Z_j \quad (7)$$

where Z = standardized variable of interest

For both Moran's I and LISA, a first-order queen contiguity between the adjoining spatial units was assumed to derive the spatial weight matrix. The spatial weight matrix (W_{ij}) was row-standardized and, by convention, equaled to zero.

To understand potential influences of various sociodemographic traits on WaSH profile development in rural India, Spearman Rank correlations were performed between district-wise WaSHQI values and corresponding sociodemographic attributes namely, district-wise (a) rural household density, (b) ratio of general:reserved population (SC + ST), (c) percentages of total literate population, and (d) percentages of female literate population. District-wise correlation analyses were conducted in two ways, (a) entire India and (b) within the hotspot of WaSH infrastructural inadequacy as identified by the LISA. Fundamental purpose of including the reserved population (SC and ST) in the analyses was to obtain a first-hand clue for the policy-makers if regions (districts/states) with greater abundance of the same, as compared to general population, also are the regions challenged by WaSH infrastructural inadequacy. To best of our knowledge no such attempts have yet been made at nationwide scale in India. Such

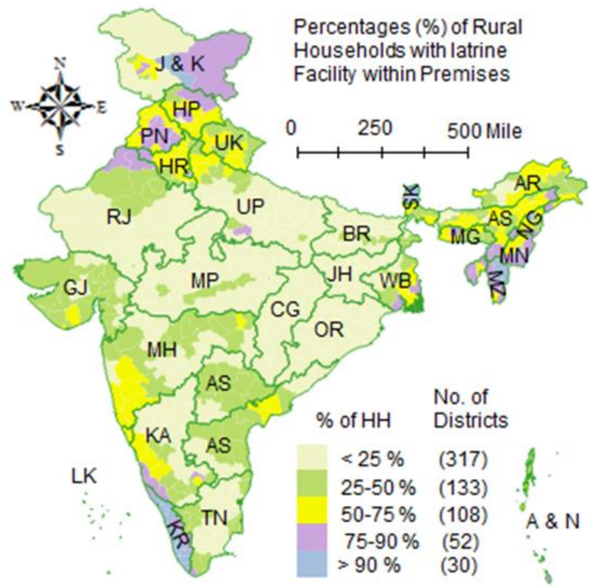

Figure 2. Nationwide spatial distribution of district-wise percentages of rural households having latrine facility within premises.

Note: "HH" = Household. Vide relevant text for state acronyms.

assessment may provide useful insights to understanding how social processes may influence (undermine or support) WaSH infrastructural development.

Thematic cartography was carried out using the ESRI ArcGIS software suits. For Moran's I and LISA, an open-sourced platform called GeoDa was used. Gini coefficients and WaSHQI computations were performed on MS Excel and results were presented graphically (e.g., nationwide Gini coefficients) using Grapher v.6, and/or appended to spatial maps using ArcGIS Spatial Data Join function for visual appraisal.

3. Results and Discussions

3.1. Thematic Mapping

Thematic depiction of latrine facilities revealed (a) an appalling inadequacy of within-premises latrine facilities in the rural areas and (b) raging spatial heterogeneity across the nation (Figure 2). For example, over 300 districts in India lacked within-premises latrine facilities for more than three-fourth of their rural households Rajasthan (RJ), Madhya Pradesh (MP), Uttar Pradesh (UP), Bihar (BR), Jharkhand (JH), Chhattisgarh (CG), and Odisha (OR). About 200 districts had latrine facilities for over half of their rural households. These relatively "better" districts occurred in three spatial clusters: (a) the north-east region (NER): comprising of states of Assam (AS), Arunanchal Pradesh (AR), Nagaland (NG), Manipur (MN), Mizoram (MZ), Tripura (TR) and Meghalaya (MG); (b) the north-west: comprising the states of Himachal Pradesh (HP), Uttarakhand (UK), Punjab (PN), and

Haryana (HR); and (c) Kerala (KL) in the southern India.

However, a redeeming feature in the rural WaSH sector was 11% drop, between 2001 and 2011, in households resorting to open defecation (Figure 3a). The improvement came mostly by rise in abundance of flush/flush pour latrine types (7% households in 2001 to 19% in 2011). Steepest rises were noted from states of Jammu and Kashmir (K&K), HP, PN, UK, HR, Sikkim (SK) and the NER (Figure 3b). On the other hand, abundance of pit latrines did not improve appreciably: from 10% to 11% over a decade (Figure 3b). Overall, 14 states had over 50% of rural households with latrine facilities within premises in 2011 as compared to only about 8 states in 2001 which marked some significant development (Figure 3). However, for most states, rate of improvement appeared slow. For example, in JH, CG, BR, UP, and MP, the decadal rise amounted less than five percentage points.

An apprehension that recently surfaced in rural WaSH sector is the physical existence of latrines built on governmental enterprises. In other words, corruption at different levels of local/regional bureaucracy, leading to rampant tampering with governmental records and relevant funds to attain Open Defecation Free (ODF) status. Several instances were noted where government-subsidized latrines exist only on papers as the bureaucrats often tend to falsify official records and hog the funds for themselves (Tyagi, 2017). Ground-truthing shot up appalling scenarios. For example, audit report by the Controller and Auditor General (CAG) of India released in December 2015 found that 2008 and 2013, governments of at least 16 states have exaggerated the data by over 190% of the actual constructions (The Hindu, 2016). On certain occasions, public school grounds have been turned into open-latrines where hundreds of villagers regularly relieve themselves. This gains added significance in view of child/infant mortality (Hathi et al., 2017) and stunting (Rah et al., 2015) in rural India owing to open defecation.

In addition, regular monitoring (and maintenance) of the government-subsidized latrines to assess/maintain their functional status, is seldom performed. In a nationwide survey conducted by the Ministry of Drinking Water and Sanitation in 2012 ~ 2013, about 1.39 crore (30%), out of total 7.41 crore, household toilets in India appeared defunct/dysfunctional (Bansal, 2016). This indicates that, even though latrines are being built on governmental enterprises, they fall out of use after a while and villagers effectively revert back to their original practices (open defecation).

Lack of latrine facilities within premises was, however, not the only concern to the rural WaSH sector. Assessment of within-premises wastewater drainage (WWD) facility distinguished two spatial clusters: (a) the northwestern states comprising of HR, PN, and parts of UP where > 75% of rural households had WWD facility within premises, and (b) rest of India with a grieving lack (Figure 4a). In states of MP, RJ, and the NER, over half, while in West Bengal (WB), OR, JH and CG, over 75% of the rural households lacked WWD within premises. Overall, about 450 districts lacked WWD for over 50% of their rural households.

To add to the grievance, majority of rural households had open WWD (Figure 4b). Excepting Goa (26% of rural households), HP (20%), KL (18%), and GJ (11.5%), closed WWD facilities were insubstantial in rest of India. Overall, only about 37% of all rural households had any form of WWD facility within premises, which underscored the general lack of awareness about health and hygiene at household levels. Such ignorance is a major threat to public health in India that eventually exposes a vast majority of the population to diarrheal diseases (Kumar and Joseph, 2012; Gupta et al., 2017). In the past few years, diarrhea has emerged as the third leading cause of child (< 5 years) mortality in India, accounting for up to about 13% of the all annual deaths among children (Lakshminarayanan and Jayalakshmy, 2015).

But apart from lack of appropriate latrine and WWD facilities within premises, other critical concerns in the rural WaSH sector in India involve safe (chemical-biological quality) and sustainable water supply (location of water sources) infrastructure. About 610 districts had access to drinking water sources within premises (at-home + near-home) for over half their rural households (Figure 5a). In states of PN, HR, UP, TN and KL, over 90% rural households enjoyed such privileges. But a distressing fact was that, about 43% rural households in the country still had to rely upon near-home (at distances < 500 m from home) water sources. In 20 states, the near-home type dominated over the at-home type with the highest differences (> 25 percentage points) observed in states of NER, MP, CG, JH, OR, and RJ (Figure 5b). To add to the grievance, about 23% rural households had to access water sources away-from-home (distances > 500 m).

Accessing water at external sources could have tremendous negative environmental and/or health outcomes in multiple ways:

- Hauling water from distant sources raises chances of contamination and salinization (via pathogen attack, dust etc.) and thus elevates human health risks.
- Lack of at-home water sources tend to prohibit latrine usage within premises (Alexander et al., 2016). In other words, *it* is often a major reason in rural areas to take to open defecation. Cleansing after defecation is a lengthy ritual in rural India that may range from washing the clothes to ablution. It is therefore a common practice for the villagers to defecate at locations in vicinity of sustainable water supply (e.g., stream, pond etc.) (Chaudhuri and Roy, 2017b). Such practices, however, only accentuate risks of water quality degradation, ultimately telling upon human health.

But other than physical impacts of having to access water at external sources, there could be myriad social issues that should be factored into WaSH policy making as well:

- It aggravates chances of physical abuse for women (Kumar, 2015), who are usually the ones in a rural family assigned with such chores, which leads to long-term psychological trauma.

- It raises likelihood of conflict and violence (over the first right to water) among the villagers that undermines rural social dynamics. It largely ensues from caste hierarchy in India - women from lower castes are humiliated and are usually the last ones to get access.
- In arid-semi arid regions of western India (states of Rajasthan and Gujarat in particular), women have to travel about 5 ~ 6 kilometers or more on average every day to get to the water source that takes up most of their day time. Often it would have require several trips to fulfill daily water needs. A common threat on such trips is animal attacks e.g., (snake/ scorpion bites).
- Even women in their late pregnancy are expected to fetch water, which affects their health, as much as that of the fetus. Such compulsive behavior may even lead to miscarriage.
- Travelling for water on daily basis interferes with

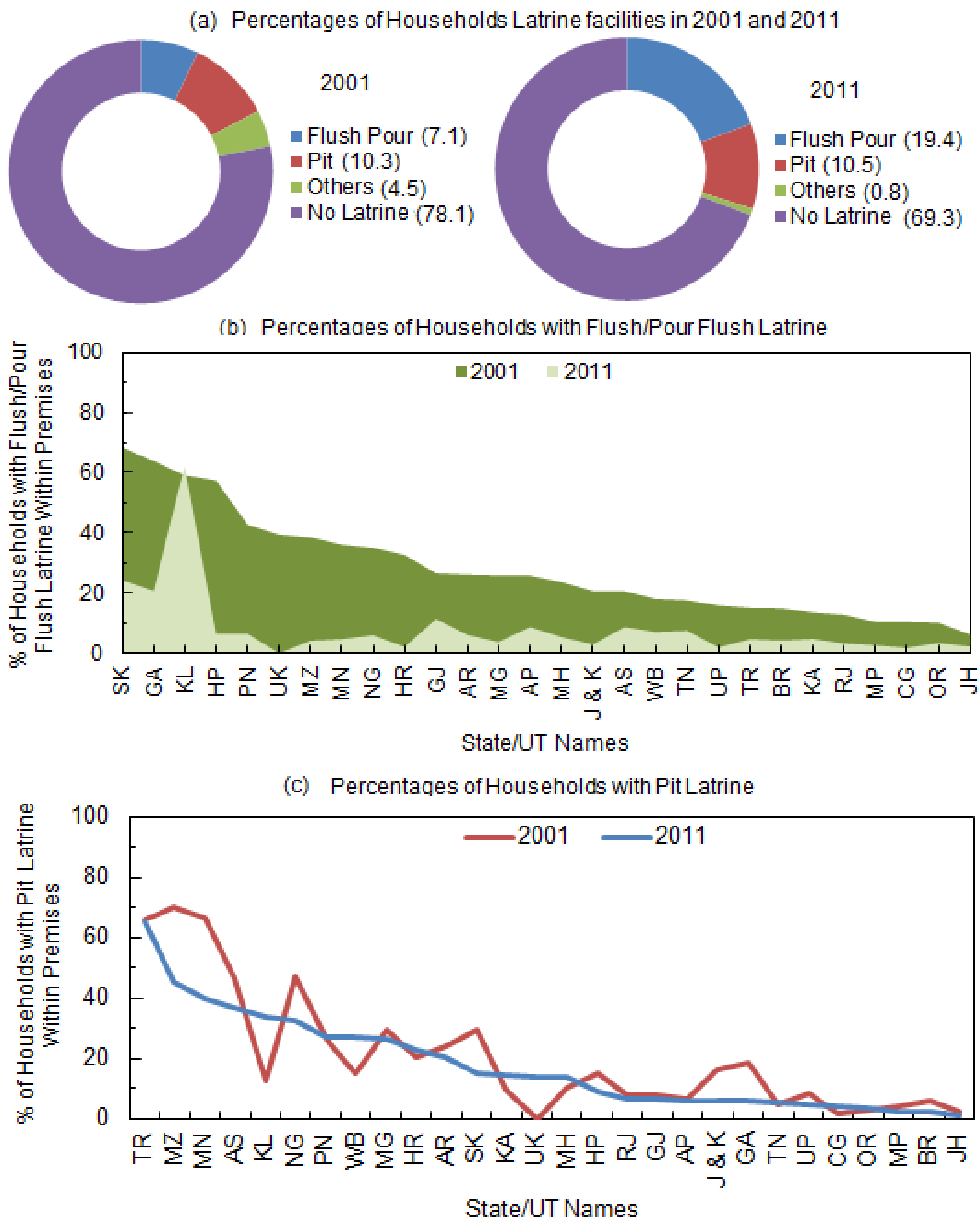

Figure 3. Comparison of % of rural households with different types of latrine facilities between 2001 and 2011: (a) nationwide, (b) & (c) state-wise.
Note: Vide relevant text for state acronyms.

- education, which impedes literacy and in turn lowers awareness levels about hygienic WaSH practices.
- Girls, since their early childhood, are expected to accompany their mothers as well, which bears heavy on the health, education, and eventually development.
- In certain regions of the country (state of Maharashtra in particular), people tend to marry multiple times out of the argument "more women more water" (Water Wives). In other regions, whereas, people hesitate to marry off their daughters due to lack of sustainable source of water. On both occasions, however, the rural social dynamics get hampered.

Current rural developmental paradigms in India advocate for an *inclusive growth* model (Chaudhuri, 2017). Such approaches aim for collective upliftment of rural livelihood by accounting for diverse challenges ranging from poverty to literacy, public health, women empowerment etc. Access to sustainable water supply should at the core of this model for its influence on human health and collective social wellbeing (e.g., gender inequality and low female literacy levels).

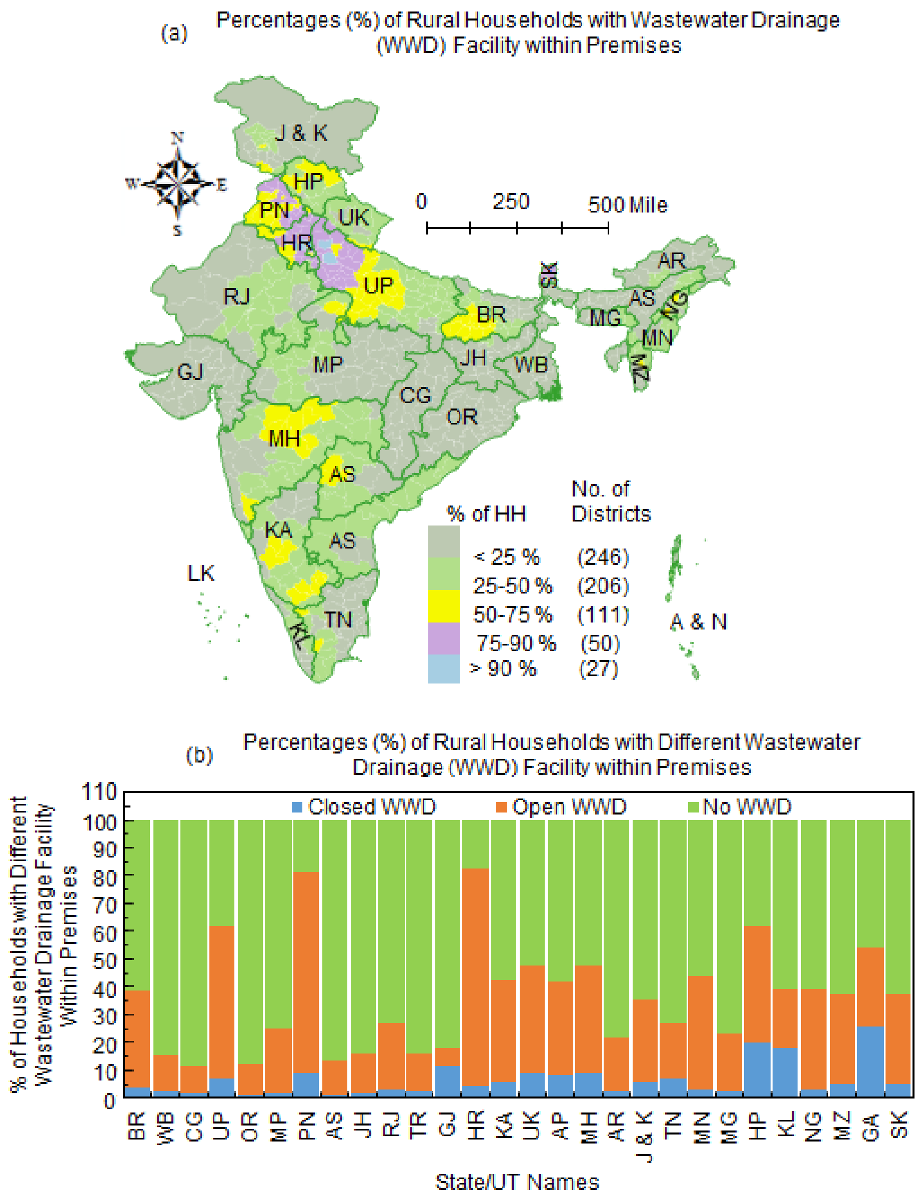

Figure 4. (a) Nationwide spatial distribution of district-wise percentages of rural households having wastewater drainage (WDD) facility within premises, and (b) state-wise percentages of rural households with different WWD facilities.
Note: "HH" = Household. Vide relevant text for state acronyms.

Interestingly, health and wellbeing is a key facet in the UN's framework of Sustainable Development Goal (SDG 3), just as gender inequality (SDG 4) and literacy (SDG 3). These issues also form the pillars of the inclusive growth model proposed for rural India, as much as in other developing nations, and would require mutually reinforcing policy measures.

But concerns about the rural water sector in India is not just about access to a sustainable source. A major hitch is the chemical quality as well. And herein lay a puzzling fact about the governmental estimates. As per the census 2011 database, 75% of the districts in India had access to *safe* drinking water sources for over 50% of their rural households. About 240 districts had it for over 90% (Figure 6a). The latter districts mainly occurred in states of UP, HR, PN, and HP in the northwest, while TN and parts of Telengana (TS) and Karnataka (KA) in the south.

This might appear promising at first glance. But in reality, governmental accounts may be questioned on the premise of

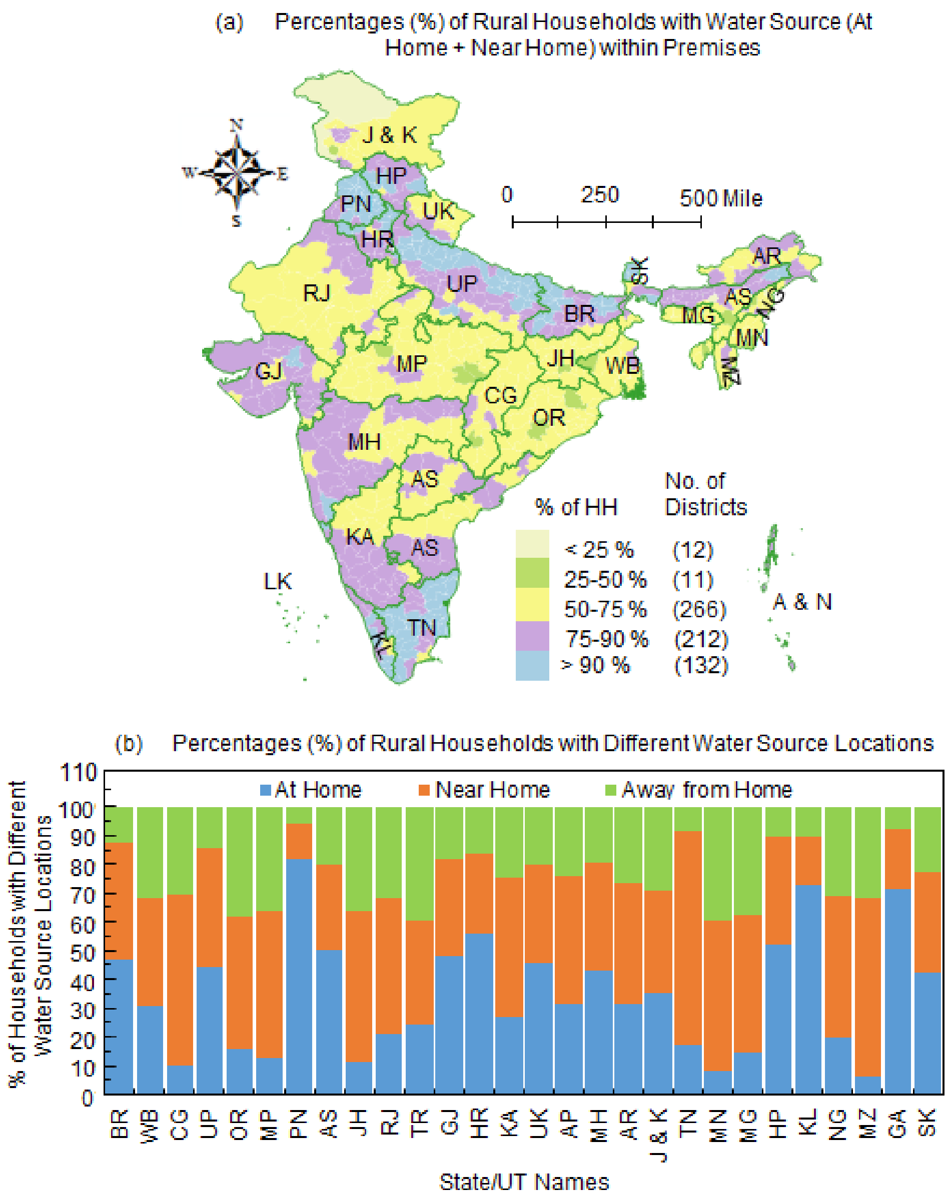

Figure 5. (a) Nationwide spatial distribution of district-wise percentages of rural households having within-premises water source (At Home + Near Home), and (b) state-wise percentages of rural households with different water sources locations.
Note: "HH" = Household. Vide relevant text for state acronyms.

the very concept of safe water in India (Chaudhuri and Roy, 2017b). In India safe water sources include a variety of sources: tap (treated + untreated), hand pump and tube well/ bore well. Majority of these sources, however, are either unsafe (e.g., untreated tap water) by definition, or so being sourced to groundwater (e.g., hand pumps and bore/tube wells). Groundwater contamination/salinization is a well-documented fact in India (Chaudhuri and Roy, 2016). High levels of arsenic (Guha Mazumder et al., 2016) fluoride (Dahariya et al., 2015), iron (Behera et al., 2012; Achary, 2014), nitrate (Trivedi et al., 2012), salinity (Lorenzen et al., 2011), and various microbial species (Megha et al., 2015) are reported from across the nation that lower the potable water quality of groundwater resources and thus questions its safety. Additional concerns over groundwater include lack of regular monitoring for quality and steady depletion. These factors further challenge its long-term sustainability for water sources.

To avoid ambiguity, treated tap should ideally be taken as the only safe water source. State-wise percentages of rural households having access to treated tap water sources, however, portrayed a grim scenario throughout the nation (Figure 6b). Excepting states of HP and Goa, treated tap water sources accounted for less than 50% of all potable water infrastructure in the country. In states of WB, BR, CG, JH, OR and several

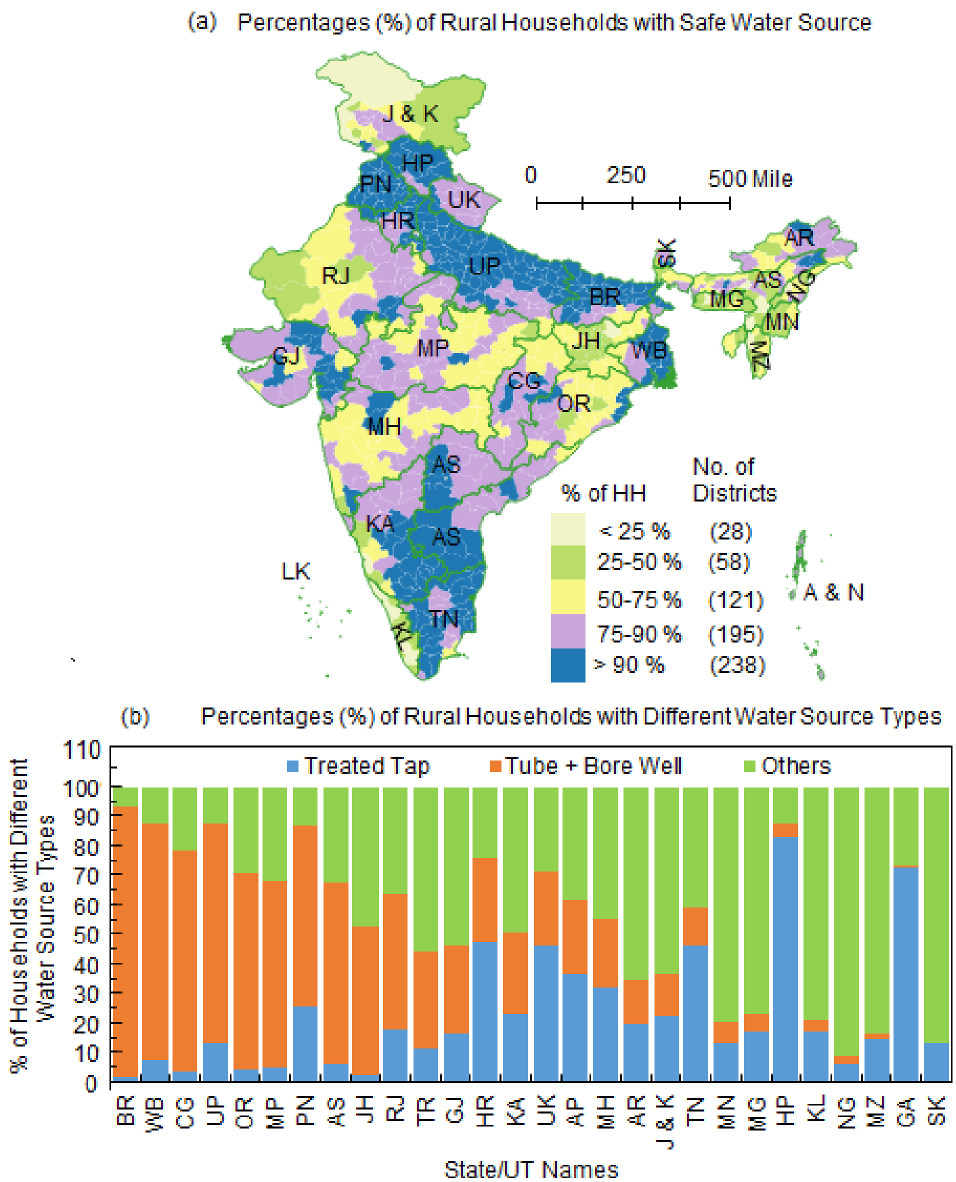

Figure 6. (a) Nationwide spatial distribution of district-wise percentages of rural households having safe and (b) state-wise percentages of different water source types.

Note: "HH" = Household. Vide relevant text for state acronyms.

NER states, treated tap water accounted for < 10% of all water sources, indicating potential health hazards.

3.2. Gini Coefficient: Assessing WaSH Spatial Inequality

Thematic mapping of WaSH infrastructure shot up broader views raging spatial heterogeneity in WaSH facilities. Gini coefficients provided a semi-quantitative measure of the magnitude of the heterogeneity (inequality, in other words) within and between the states (Figure 7a ~ d). Good to Reasonable Equality were observed all across central Indian states of CG, BR, JH, OR, MP, RJ and KA, for most WaSH facilities, except Safe Water. This might appear gratifying on account of homogeneity in infrastructural facilities. Comparison of Figure 7 with Figures 2 and 4 ~ 5, however, revealed that these states were homogenous only due to appallingly low WaSH facilities which demonstrates grieving lags across vast rural reaches of the nation that require urgent intervention to comply with the national motto "improved WaSH for all". High inequality in majority owed largely to the lack of safe water sources. On the other hand Gini coefficients for PN, HR, UK and HP, in the northwestern regions, displayed Good to Reasonable Equality with significantly higher percentages of WaSH facilities including greater availability/accessibility of safe water sources.

To summarize spatial inequality, Gini coefficients, were further computed using all districts across the country and aggregated at the national level. Nationwide Gini revealed high inequality for water source and WWD within premises, which showcased a patchy WaSH management action across the nation (Table 3). On the other hand, facilities away from premises appeared with reasonable equality implying, despite numerous progressive reforms implemented by the Government of India, a large fraction of rural households in India still have to rely upon external facilities. For latrine, open defeca-

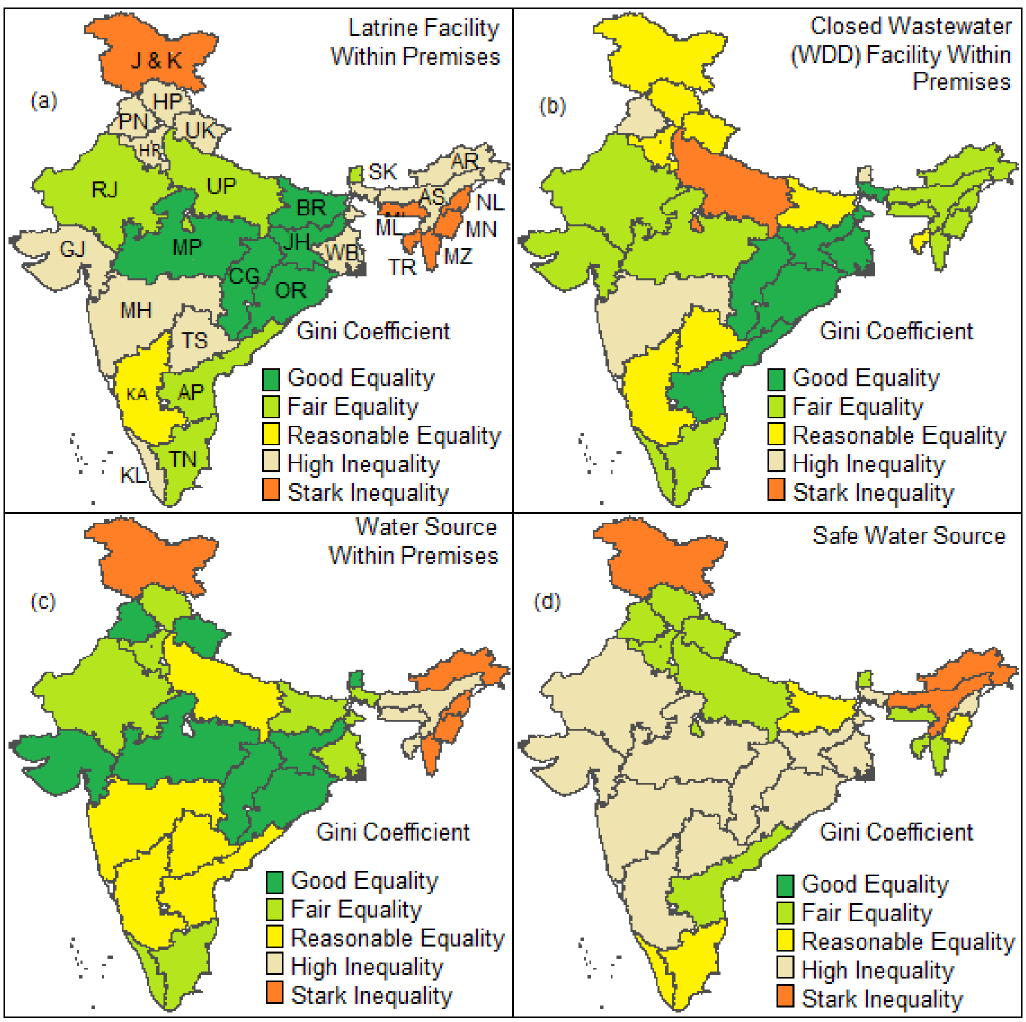

Figure 7. State-wise Gini Coefficients computed using corresponding district-wise percentages of WaSH facilities to illustrate spatial inequality.

Note: Map legend represent Gini inequality classes as described in the corresponding text. Vide relevant text for state acronyms.

tion (equivalent to away from home facility) appeared with reasonably equality. Similar trend was also observed for treated tap and safe water sources.

A grave impediment to implementing nationwide uniform WaSH reform policies is the spatial inequality in the WaSH sector. Drawing from that, spatial attributes of WaSH identified through the present analysis should form the cornerstone of any future WaSH informatics system, based on which reform policies are to be spatially-optimized. State-wise Gini coefficients can be especially useful to estimate intra-state inequality, arguing for identification of major factors leading to such spatial differences and devise appropriate interventions to vie for a more 'homogenized' public services system.

3.3. WaSHQI: Towards a Composite Index

The WaSHQI was computed to generate four scenarios (Figure 8a ~ d) for each district, using subcategories of the four WaSH parameters in various combinations, sequentially grading from "most conservative" (scenario I) to "most liberal" (scenario IV) as follows:

Scenario I (Most Conservative): Treated tap water + at-home water source + within-premises latrine + within-premises closed WWD

Scenario II (Conservative): Treated tap water + within-premises water sources (at-home + near-home) + within-premises latrine + within-premises WWD (closed + open)

Scenario III (Liberal): Safe water + at-home water source + within-premises latrine + within-premises closed WWD

Scenario I (Most Liberal): Safe water + within-premises water source (at-home + near-home) + within-premises latrine + within-premises (closed + open) WWD

The propelling force for drawing up such a gradational scale of assessment was to anticipate potential (health/hygiene) impacts of different WaSH facilities. For example, due to inherent ambiguity over safe water source, it was only

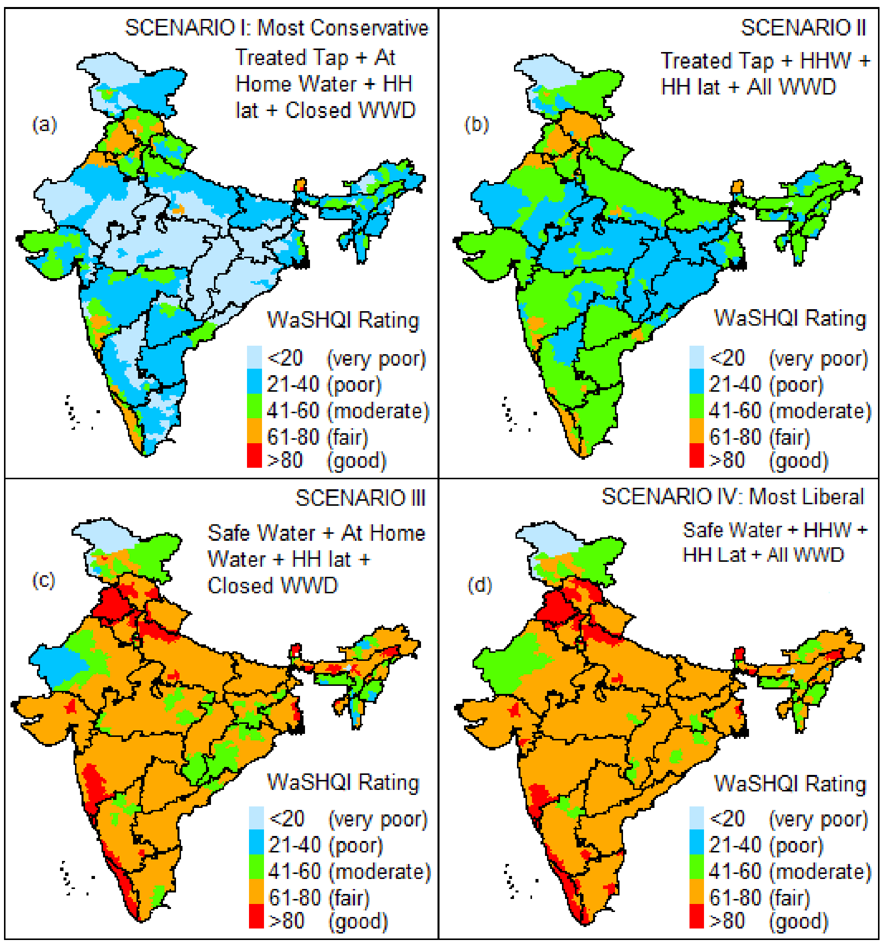

Figure 8. District-wise WaSHQI values computed under four scenarios ranging from (a) scenario I: most conservative to (d) scenario IV: most liberal.

Note: HH Lat: within-premises latrine; HHW: within-premises water source (at-home + near-home); All WWD: within-premises wastewater drainage facility (open + closed).

included in liberal approaches (scenarios III ~ IV). By the same token, treated tap was evaluated within conservative approaches (scenario I ~ II). Following similar argument, the most conservative approach (scenario I) included a combination of closed WWD and at-home water source, besides latrine facility within premises. Fundamentally, the idea was "how ideally the rural WaSH sector can be developed in days ahead so as to minimize health hazards to support sustainable human development"? This formed the fundamental basis of our conservative approach that combined the ideal WaSH facilities.

The conservative approaches (scenario I ~ II), infrastructural inadequacy appeared a dismal reality throughout the nation, especially in central India (Figure 8a ~ b). About 580 districts ranked as very poor/poor on the WaSHQI rating in (scenario I (Figure 8a). States of OR, CG, JH and MP appeared with such traits in their entirety. Only a handful of states—PN, HR, UK, KL, and Sikkim (SK)—ranked fair under the conservative approaches: a matter that should be probed further to identify the beneficent factors and develop possible means to replicate them through rest of the nation.

The WaSH scenario lunged on an improving trajectory as treated tap water was replaced by safe water through scenarios III ~ IV (Figure 8c ~ d). With introduction of such flexibility in the framework, most part of the country begun ranking fair to good. Interestingly, certain regions still continued to rank poor to moderate even under liberal approaches. For example, several districts across states of OR, CG, JH, RJ, J and K and the NER, ranked moderate, which implied that regardless of parameters selected, these regions have persistent inadequacies that need urgent actions. About 90 districts in the country ranked as moderate or worse even under the most liberal approach (scenario IV). In contrast, vast areas through PN, HR, HP, KL and TN ranked fair to good (Figure 8d). Overall, the WaSHQI cartograms revealed that certain regions in India may be faring well while some others are starkly lagging behind (Ghosh and Carincross, 2015). This also underscored need of a WaSH informatics system, maintained and revised with latest monitoring updates that will map nationwide WaSH inadequacies to prioritize regions for management action.

Better WaSH conditions in the northwest may have resulted from several factors: (a) availability water sources in close vicinity (Pal and Gupta, 2008), (b) adoption of a participatory approach marked by flourishing of Community Led Total Sanitation (CLTS) programs, and (c) improving rural economy due to recent agricultural boom (e.g., commercial fruit cultivation) through the 2000s. The latter entailed higher literacy/awareness levels for basic hygiene principles, in turn prompting them to adopt to appropriate sanitation practices. Interestingly, a recent campaign named, "No Toilet No Bride" in states of HR and PN, have had positive impacts on people's attitude towards adopting safe WaSH practices, prompting them to build latrine facilities within premises. The campaign, launched by the state governments in 2005, used various forms of social/public media to prompt the families having marriage-age girls to demand latrine facility of the potential suitors. The campaign's ingenuity largely led to about a 15%

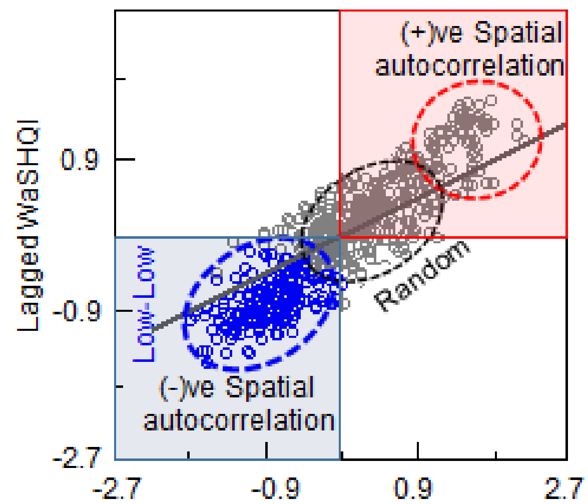

Figure 9. Moran's scatterplot for Scenario I (most conservative) depicting main types of spatial autocorrelation between the districts.

rise in male investment in building sanitation facilities within premises (Stopnitzky, 2012). The effect of the campaign appeared four times larger in marriage markets where women are scarce as compared to that where women are abundant.

Overall, composite index approaches, such as WaSHQI, have following merits: (i) ability to incorporate data from multiple sources in an objective, rapid and reproducible fashion (ii) effective in communicating overall status of WaSH to the government, experts, researchers, NGOs, as well as public, (iii) flexibility to accommodate a wide variety of input parameters owing to simplistic design, (iv) can be used for any administrative unit along the hierarchy, (v) tolerance to missing data values, (vi) ideal for regional comparisons etc. Including the entire spectrum of administrative hierarchy, from household to state level, WaSHQI can provide easy yet informative insights. Due to ease of computation and open-sourced database, this method can be replicated in anywhere without major alteration.

3.4. Moran's I and LISA: District-wise Spatial Autocorrelative Structure in WaSH

Computation of Moran's I yielded, +0.72 (Figure 9) and +0.25, respectively, for the 'most conservative' (scenario I) (Figure 10a) and 'most liberal' (scenario IV). Clustering of high-high and low-low districts, occuring on diagonally oppostite quadrants of the Moran's scatterplot with a statistically significant Moran's I implied storng positive spatial association between districts with similar WaSH infrastructural traits (Figure 5a). The scatterplot also indicated that a vast number of dstricts in the country lacked any identifiable spatial disposition as they occurred rather randomly. Overall, the Moran's scatterplot, provided some initial clues that WaSH policy reforms (and interventions) would need a spatial component, rather than be uniform across the nation. Being a global statistic, however, Moran's I failed to address some central issues typically encountered in decision-making such as:

- Which districts are clustered in terms of their WaSHQI values?
- Is the clustering phenomena statistically significant?
- Are there any spatial outliers?

To seek answers to the above-mentioned questions, LISA was computed for scenario I and IV, as they represented the potential end-members of WaSH infrastructural development, to capture the entire spectrum of WaSH (Figure 10). The LISA, built upon the spatial foundation set by Moran's I, depicted the clustering phenomena in terms of statistically significant spatial contiguity among the districts with high/low WaSHQI values, giving rise to four spatial patterns:

(i) High-High clustering (positive spatial autocorrelation): High-WaSHQI districts in spatial contiguity with high-WaSHQI districts

(ii) Low-Low (negative spatial autocorrelation): Low-WaSHQI districts spatially contiguous

(iii) Spatial outliers: High-WaSHQI districts contiguous with low-WaSHQI districts and vice versa

(iv) Random: Districts devoid of spatial clustering

The LISA practically divided the country into two distinct spatial cluster of districts marked by contrasting WaSH characteristics. The better part, denoted by the High-High clusters (positive spatial autocorrelation between districts having mutually high WaSHQI rating), primarily occurred in two regions (a) HR, PN and HP in the northwest and (b) KL and parts of TN in the south, including 104 districts in total (Figure 9a). The less promising part, as mapped by the Low-Low clusters (negative spatial autocorrelation) on the

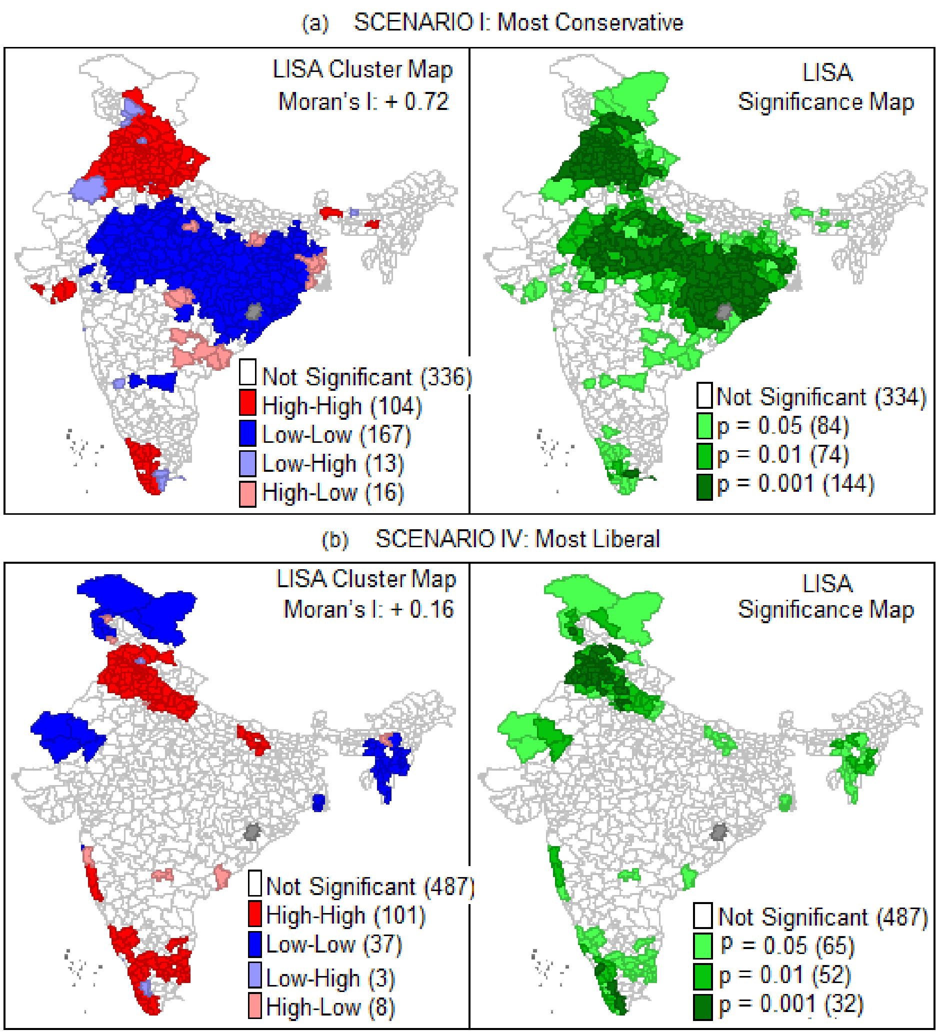

Figure 10. Moran's I and LISA for (a) scenario I: Most Conservative and (b) scenario IV: Most Liberal, to understand spatial clustering phenomena.

Note: Moran's I and LISA were computed using district-wise WaSHQI values.

other hand, extended from West Bengal (WB) in the east to RJ in the west across OR, CG, JH and MP encompassing about 170 districts through central India.

LISA for Scenario I conformed to the earlier findings (Figure 8a): under a more conservative approach, WaSH infrastructural facilities are highly variable (heterogeneous), marked by intense spatial inequality. Interestingly, 29 districts, mostly occurring in the states of WB, Telengana (TS), and AP, emerged as spatial outliers (High-Low or Low-High district clusters), which indicated that districts with dissimilar WaSH traits occurred in spatial contiguity. This obviates further investigation in future so as to understand underlying factors leading to such anomalous spatial assemblages.

The significance map associated with the LISA depictions established the spatial clustering phenomena within a given window of statistical significance ($0.05 < p < 0.001$) that should assist the decision-makers develop/implement policy reforms with certain degree of confidence (Figure 10a). For example, 114 districts, where the spatial clustering phenomena occurred with highest level of statistical significance, $p < 0.001$, may be looked in with greater emphasis so as to identify the major socioeconomic/demographic factors giving rise to such anomalous spatial assemblage. Knowledge earned through this could be translated in other parts of the country on the premise of adopting similar WaSH management interventions.

As discussed earlier, due to its liberal approach, scenario IV *approved* of any combination of parameters, which implied that majority of the districts were expected to pass for infrastructural adequacy and therefore will be clustered. The LISA illustration, however, brought up a rather perplexing view: even though a vast region, through the central and southern states, ranked fair on the WaSHQI rating (Figure 6d), no statistically significant spatial clustering was, however, evident in its LISA counterpart (Figure 10b). In fact, majority of the districts (487 districts) did not show any statistically significant clustering. This indicated that simple thematic cartography alone can be over-ambitious if used for policy-making, which demands statistical confidence. And herein lay the central idea of integrating WaSHQI with spatial algorithms: to help the decision-makers look beyond traditional maps and identify the hotspots with statistical significance and devise/implement policy interventions accordingly.

Overall, 89 districts from states of OR, CG, JH, BR, MP and RJ were selected as WaSH hotspots for correlation analyses (Figure 11). What prioritized these districts was: they appeared as Low-Low clusters in Scenario I (Most Conservative), with highest level of significance ($p < 0.001$). Ideologically, the Most Conservative scenario should be the most desirable WaSH situation and districts lagging on such should receive special attention.

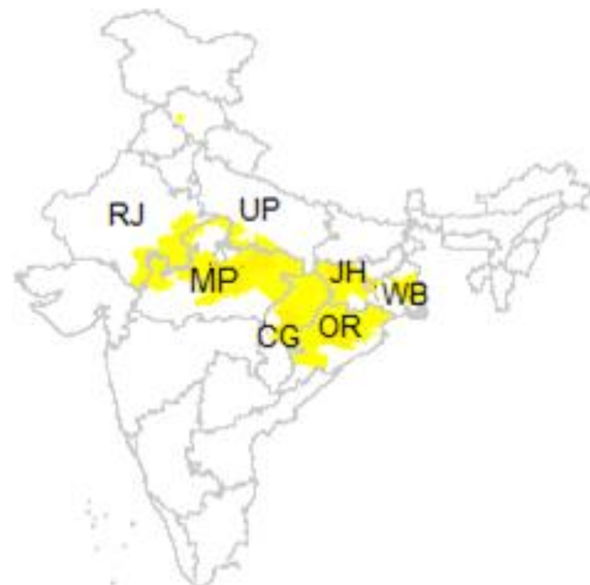

Figure 11. Study area selected by LISA analysis for Spearman correlation analysis.
Note: RJ: Rajasthan; MP: Madhya Pradesh; UP: Uttar Pradesh; CG: Chhattisgarh, JH: Jharkhand; OR: Odisha; WB: West Bengal.

3.5. Correlation to Sociodemographic Traits

Spearman Rank correlation analyses performed between the district-wise WaSHQI values and a number of sociodemographic attributes at the nationwide scale revealed significant positive association (ρ: 0.40; $p < 0.05$) between WaSHQI and corresponding percentage of total rural literate population (Table 5) only, which indicated how literacy plays a positive role in building mass awareness among the rural population and nurture right mental dispositions to adopting improved WaSH-practices, such as building latrines and/or WWD facilities at home.

On the other hand, significant negative correlation was found between district-wise WaSHQI values and rural household density (ρ: −0.38; $p < 0.05$), which probably indicated space-crunch in congested areas may bar latrine construction (Manisha et al., 2016). The WaSHQI values varied directly with (a) general to reserved (SC + ST) population ratio (ρ: 0.44; $p < 0.01$), (b) percentage of total rural literate (ρ: 0.49; $p < 0.01$) (Table 5). Positive correlations between WaSHQI and caste indicated that regions dominated by reserved population, tend to lack appropriate WaSH support. This probably leads from the fact that the reserved populations frequently include the tribal groups who have been historically marginalized -socially, economically, culturally, and educationally; and as a result lack in appropriate mental/intellectual dispositions for hygiene/environmental benefits of improved WaSH facilities (Banda et al., 2007). It is also not uncommon to find that even when government-subsidized facilities are available in these regions, they are of little use to the reserved population, who on account of various sociodemographic factors are often housed on village periphery. Under the circumstances, shear distance between their home and these facilities act as a demotivating factor to using them (Bonu and Kim, 2009).

A major revelation to be apparent was significant positive association between WaSHQI and rural female literate population (ρ: 0.55; $p < 0.01$), which strongly corroborated with previous studies suggesting that higher female literacy entails increased awareness and right attitudes for hygienic WaSH practices at home (Gius and Subramanium, 2015; Coffey et al., 2017). Open defecation is unsafe for rural women in India as it aggravates chances of abuse (Gius and Subramanium, 2015) besides multiple health and educational consequences. To avoid such undesirable circumstances, rural women either tend to group up for open defecation or urge the family heads to build latrine at home. The latter tendency increases with increasing literacy/awareness that raises sense of dignity and self-esteem. However, building latrines at home incurs additional expenses and such demands are frequently turned down. In fact, building appropriate latrine facilities at home seldom enjoys priority to prospective homeowners as it is still considered rather a luxury than necessity. Such tendencies are more apparent with lower literacy levels.

Rural literacy (7+ years) levels are still far from desired levels with pronounced gender gap. According to the census of India database, about 57.9% of rural females were literate in 2011 as compared to about 77.1% of males (GoI, 2014). Nationally, about 64.6% females were literate against about 80% males. Appallingly, among the reserved populations (SC and ST), female literacy levels averaged around 40% (of reserved female population) (Figure 12).

Low literacy is a major impediment (Manisha, 2016) against implementing safe WaSH practices (Behera, 2014). A plethora of mutually reinforcing factors undermines the rural literacy sector. Majority of the rural tribal population in the country still consider their children as economic assets and would prefer for them to work to support the familial expenses instead of *wasting* valuable time on education, which is deemed rather a luxury. An issue in this regard is school hours, which frequently conflict with the daily work hours of the children, making the parents disinterested and eventually keeping the children from attending schools on regular basis and/or drop out in early childhood. As added aggravation, the schools in the tribal areas largely lack adequate infrastructural facilities (buildings, library, teachers etc.). In this regard, free mid-day meal plan for students in government-subsidized schools is a major incentive for the poor parents to have their children attending school. It is however, owing to corruption and misappropriation of funds in local administration, that meal plans are not implemented with desired rigor in rural areas, except for in papers, that acts against the attendance. Often the meal itself appears of poor quality (rotten/undercooked/old etc.) that disenchants the students. For girls, an issue commonly encountered in most rural schools is lack of separate toilet facilities. For girls of menstruating ages this is a major dissuasive factor to attending schools on regular basis. Often the travel-time to school appears too high, thus acting against the students' will to attend schools as not all villages have schools, particularly girls' schools. For girls, travel also aggravates chances of physical/psychological abuse, which makes the parents apprehensive.

Table 5. Comparative Evaluation of Spearman Rank Correlation Coefficients Computed between Washqi and Different Sociodemographic Attributes for India (Considering all Districts) and the Study Area (Selected 89 Districts) Identified as Hotspots by LISA Analysis

India (nationwide)		Study Area (LISA Hotspot)	
Household density	0.22	Household density	0.33*
General/(SC + ST)	0.19	General/(SC + ST)	0.44*
% Total literate	0.36*	% Total literate	0.49**
% Female literate	0.40*	% Female literate	0.55**

*significant at $p < 0.05$
**significant at $p < 0.01$

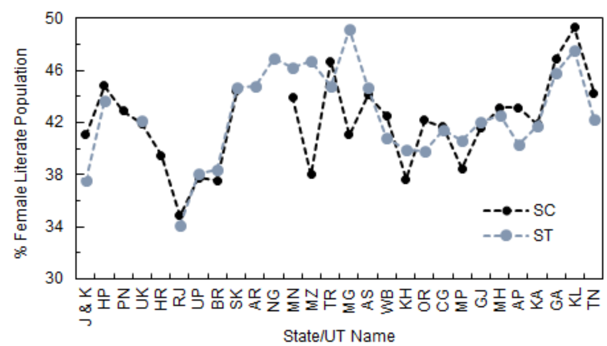

Figure 12. State-wise rural female literate population for SC and ST sections expressed as corresponding state-wise total SC and ST population in 2011.
Note: Solid red line indicates the national tally for SC and STs that hovers around 41%. Several states lack SC population. Vide relevant text for state acronyms.

In addition, the teaching staff in the tribal schools often lack right mental disposition to appreciate the tribal ways of life (customs, taboos, religious beliefs, superstitions etc.), which effectively scares the children away. Rooted in this, tribal groups foster strong reservations against receiving education from the outsiders (school teachers in villages often come from urban areas), which they believe will *anger* their deities. In addition, many tribal clans believe that formal education will make their children more defiant. Such behavior is especially apprehended for the female, who may become less docile under the influence of *modernity* and challenge rural norms. Schooling also leads to out-migration-from villages to urban areas- in search of prosperous livelihoods. Such aspirations are believed to severe familial ties and result in estrangement and thus disapproved. Overall, a large number of factors, mostly rooted in social beliefs and taboos, make schooling a threat to sociocultural practices and thus discouraged.

Last but not the least, scientific facts about WaSH and health benefits are not always taken seriously in rural schools, as it often contradicts with rural social/religious customs/ beliefs or the teachers are not adequately trained themselves for such purposes (Chaudhuri and Roy, 2017a). Such ignorance/ incompetency, however, keep WaSH from receiving due importance in the academic curricula. This fails to inculcate a positive sense of hygiene among students, even those who attend schools regularly. Unfortunately, all these issues also act against the proposed inclusive growth model of rural development, as discussed earlier, and undermines the public health sector.

Overall, the results brought up several mutually reinforcing facets of rural life in India that play decisive roles in influencing literacy among rural communities and in turn, awareness levels for adopting hygienic WaSH practices (Figure 13). Interestingly, many of the facets also lend themselves to the UN's Sustainable Development Goals. Just to mention, India is heavily lagging on several SDGs and would require urgent policy measures in days ahead. By the same token, this could be a major incentive for the government to enacting stringent WaSH regulations that will address multiple concerns simultaneously. Moreover, it fits well into recently proposed inclusive growth model for upliftment of rural livelihoods. Inclusive growth is essentially a constellation of ideas that aims for holistic rural development and WaSH is an integral part of it dealing with community health and hygiene, environmental sustainability, gender equality and education. This is something the policy-makers have to be aware of: WaSH cannot be envisaged in standalone manner. It can only be achieved within the broad framework of rural life.

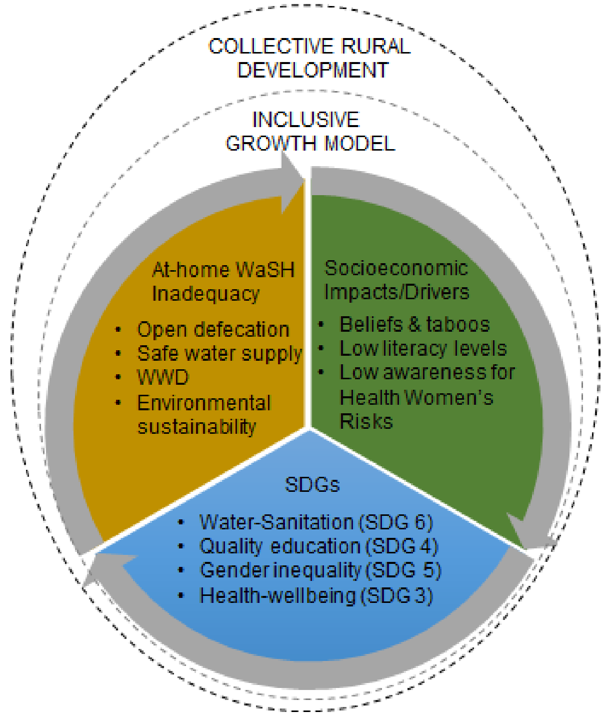

Figure 13. Mutually reinforcing facets of the rural WaSH sector in India and their collective effect on various Sustainable Development Goals as envisioned within an inclusive growth model for collective rural development in India.

4. Limitations and Future Recommendations

Present study explored a method to evaluate nationwide WaSH profile using the most authentic, cross-sectional open-sourced database. It is a major advancement proposed over its predecessors that resorted mostly to survey-based approaches whose implications were largely constrained by smaller geographic dimensions. Secondly, the study took an index approach to showcase collective inadequacy in multiple WaSH attributes. Condensing multiple parameters into a single composite score, has been widely used in water quality studies (Shah et al., 2017), environmental sustainability (Esty et al., 2005), and vulnerability (SOPAC, 2005). However, no such attempt has yet been made in the WaSH sector. Such an approach can lay the foundations to a robust WaSH informatics system to help the policy-makers (i) identify regions of multiple inadequacies with a semi-quantitative estimate, (iii) evaluate nationwide spatial inequality therein, and (iii) track progress (or lag) in the WaSH development trajectory over time with statistical confidence. Findings were summarized in a series of maps to elucidate spatial dimensions of WaSH attributes using GIS that has emerged as a major tool in policy making around the world (Lee et al., 2016; Guigoz et al., 2017).

Several challenges were realized during the conceptualization of WaSHQI, which, however, only pointed out the possible means to extend/diversify WaSHQI for more effective decision making and offered intriguing research directions for future. For example, the effectiveness of WaSHQI might be significantly enhanced by incorporating specific information on district-/village-wise percentages of households affected by water-borne diseases (e.g., diarrhea), specifically tied to WaSH infrastructural inadequacy.

Another improvement in the WaSHQI-performance could potentially be achieved by considering WaSH dataset, stratified by the sociodemographic categories (SC/ST/general), religious sects (Hindus/Muslims/Sikhs/Christians/Jains etc.), and rural household conditions (availability of household amenities). An additional improvement could be to integrate economic details specific to the demographic/religious groups and literacy levels (especially for the reserved sections of the society) within the spatial framework of WaSHQI, in other words, more parameters that potentially influence WaSH development, could be brought in to highlight social behavior that deter hygienic sanitation practices in rural India. Moreover, present study was entirely based on cross-sectional data which lacks the time component. Incorporating longitudinal data (e.g., WaSH data from multiple census years, whenever available) to assess progress or slip-back over time, might also bolster the decision-making process.

A confounding issue to devising an effective WaSHQI, however, may arise from determination of the weight (S) of the WaSH parameters. To minimize apparent subjectivity therein, S was determined by a comparative assessment between the observed value of the parameter and corresponding national standard, in view that each district should consciously attempt to upscale it if lagging from the national tally while districts that equals or better the same should be acknowledged with due credit. Therefore, in effect, determination of S resulted from expert decision, which could obviously be improved in future by exploring more robust numeric means to vie for objectivity.

5. Conclusions

Through the course of the study it appeared that vast stretches between central to west India (comprising of states of CG, CG, BR, OR, MP, RJ) severely lacks multiple WaSH facilities, including improved latrine facilities at home. On the other hand, states of northwest India (HR, PN, HP etc.) appear with better traits marking intense spatial heterogeneity that needs to be addressed with spatially-optimized policy reforms in days ahead.

However, a major realization that emerged was that, latrine facilities cannot be the sole concern of the decision-makers. Rural WaSH sector in India is plagued by a variety of issues. For example, the central Indian states severely lack closed wastewater drainage facility within premises that aggravates human health risks. To aggravate the situation, true identity of safe drinking water sources is yet to be resolved in India. In recent years, water quality has emerged as an important consideration in decision-making in view of ensuring human health and sustainable development around the world (Tan et al., 2015). By the same token, considerations about safe and sustainable water supply should sit at the core of WaSH policy-making in India or elsewhere.

One way or the other, lack of appropriate WaSH infrastructure is not only affecting health/environmental outcomes in rural India, but also influencing social dynamics in a variety of ways that need to be addressed with urgency. The study hinted upon importance of literacy as it plays a central role in building awareness, especially among the rural reserved population. For rural women, importance of literacy cannot be emphasized enough, and should be a major stand on behalf of the government to ensure/promote hygienic WaSH practices in days ahead. In this regard, a great deal of effort needs to be divested to address the age-old social taboos among the rural populace against formal school education. Apparently, governmental efforts to instill the urge of adopting hygienic sanitation practices is yet to gain desired momentum in rural areas owing to a variety of reasons that need closer scrutiny in days ahead.

Using a single statistic to characterize the WaSH sector, in a country as vast and diverse as India, might be simplification of the underlying complexities (e.g., overlapping spheres of literacy, economy, social practices, and age-old taboos). This study, however, can mark a modest beginning to establish a nationwide WaSH-informatics system. The WaSHQI can be taken as an easy-to-use yet effective tool to monitor trajectory of WaSH infrastructural development, within a collective framework. Multiple scenarios may provide the policy-makers with a certain degree of flexibility to select optimal management interventions based on timeframe and resource availability. Such approaches can especially be useful to the rural health care administration to decide on the desired rigor of the policy reforms to meet the needs.

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