# Energy, drinking water and health nexus in India and its effects on environment and economy

Vikrant P. Katekar, Sandip S. Deshmukh and A. Vasan

## ABSTRACT

This paper examines energy, drinking water and health nexus in India, and its consequences for the environment and economy. To establish this nexus, K-means cluster analysis and Davies–Bouldin validation index are employed to group 32 Indian states and union territories. The classification was performed based on 16 criteria, and the number of optimal clusters arrived at is 8. The nexus between energy, drinking water and health must be cautiously dealt with to ensure the social and economic growth of the nation. The criterion analysis of the states within these clusters indicates that states and union territories facing energy crises are usually deficient in safe drinking water services; consequently, people of those regions suffer from ill-health, which increases the economic burden on people through the loss of work productivity. With a deficient cash reserve, the communities are incapable of fulfilling the demand for energy and safe drinking water. However, while installing desalination plants to fulfil the need for safe drinking water, their environmental impact must be taken into account, as these systems have high energy consumption and significant environmental impact.

**Key words** | carbon footprint, cluster validation, desalination, distillation, K-means clustering, waterborne diseases

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## HIGHLIGHTS

- This work examines energy, drinking water, and health nexus in India, and its effects on climate change.
- States/union territories facing energy crises are usually deficient in safe drinking water services. Consequently, people suffer from ill-health, which increases their economic burden.
- With a deficient cash reserve, the communities are incapable of fulfilling the demand for energy and safe drinking water

## NOMENCLATURE

| | |
|---|---|
| AN | Andaman and Nicobar Islands |
| AP | Andhra Pradesh |
| AR | Arunachal Pradesh |
| AS | Assam |
| BCM | Billion cubic metre |
| BR | Bihar |
| BWRO | Brackish water reverse osmosis |
| CG | Chhattisgarh |
| CH | Chandigarh |
| COP | Conference of parties |
| CVAP | Cluster validity analysis platform |
| DB | Davies–Bouldin |
| DL | Delhi |
| E | Energy index |



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|---|---|
| ED | Electrodialysis |
| EDR | Electrodialysis reversal |
| FO | Forward osmosis |
| GA | Goa |
| GDP | Gross domestic product |
| GJ | Gujarat |
| H | Health index |
| HP | Himachal Pradesh |
| HR | Haryana |
| IEA | International Energy Agency |
| IEEJ | The Institute of Energy Economics, Japan |
| IRENA | International Renewable Energy Agency |
| JH | Jharkhand |
| JK | Jammu and Kashmir |
| JMP | Joint Monitoring Program |
| KA | Karnataka |
| KL | Kerala |
| LD | Lakshadweep |
| MD | Membrane distillation |
| MEB | Multi-effect boiling |
| MED | Multiple-effect distillation |
| MH | Maharashtra |
| MHFW | Ministry of Health and Family Welfare, Government of India |
| ML | Meghalaya |
| MN | Manipur |
| MP | Madhya Pradesh |
| MSF | Multi-stage flash |
| MVC | Mechanical vapour compression |
| MZ | Mizoram |
| NITI | National Institution for Transforming India |
| NL | Nagaland |
| OR | Orissa |
| PB | Punjab |
| PY | Pondicherry |
| RJ | Rajasthan |
| RO | Reverse osmosis |
| SDG | Sustainable development goal |
| SK | Sikkim |
| SWRO | Seawater reverse osmosis |
| TN | Tamil Nadu |
| TR | Tripura |
| TS | Telangana |
| UK | Uttarakhand |
| UN | United Nations |
| UNDP | United Nations Development Program |
| UNICEF | United Nations International Children's Emergency Fund |
| UP | Uttar Pradesh |
| UT | Union territory |
| W | Drinking water index |
| WB | West Bengal |
| WHO | World Health Organisation |

## INTRODUCTION

For every living being, water and air are the two necessary substances for the survival of life on Earth. Safe drinking water, sanitation and hygiene at home are essential requirements for human health, and all countries have a responsibility towards this goal (World Health Organisation 2009). Safe drinking water deficiency is one of the critical challenges in India. More than 44 million Indians suffered from enteric fever and viral hepatitis during 2014–2016 due to consumption of unhygienic water (WELFARE 2017), and providing sufficient energy access to everyone ensures safe drinking water (Deshmukh *et al.* 2014).

As per the National Portal of Government of India (2020), India is the seventh largest country in the world and covers an area of 3,287,263 $km^2$. The topographical boundaries start from the Great Himalayas in the north, and go southwards flanked by the Bay of Bengal on the east and the Arabian Sea on the west. The nation is located between latitudes 8° 4′ and 37° 6′ N, and longitudes 68° 7′ and 97° 25′ E. It measures around 3,214 km from north to south between the extreme latitudes and about 2,933 km from east to west between the extreme longitudes. The nation has a land border of about 15,200 km, and the total length of the coastline including Lakshadweep, Andaman and the Nicobar Islands is 7,516 km. For effective administration, the nation is administered through 28 states and 8 union territories, as shown in Figure 1.

As per the 2011 Census data, the nation has to fulfil all the necessary demands of more than 1,210 million people such as energy, food, water, education, health, employment,


**Figure 1** | Political map of India. (Source: Political map of India, available in the public domain; Press Information Bureau, Government of India, https://pib.gov.in/).

to attain effectual socio-economic progress (Jambhulkar *et al.* 2015). The nation is rapidly growing, with the fifth largest economy by nominal GDP in the world. Nominal GDP in the year 2019–20 was 209.19 lakh crore (Joshi *et al.* 2019). To investigate the diversity and associated challenges in energy–drinking water–health issues in the states and union territories, these may be constituted into appropriate clusters. This also paves the way for facilitating effective implementation of policies of the central government and other relevant agencies from time to time (Wang *et al.* 2009;

Raju & Nagesh Kumar 2014). However, multiple challenges remain, which are explained in the next section.

## SIGNIFICANT CHALLENGES AT THE NATIONAL LEVEL

The World Economic Forum's Global Competitiveness Index ranks different nations globally based on socio-economic factors and ranked India 60th out of 148 countries in the year 2013–14. India would lose $6.15 trillion due to non-communicable diseases and mental disorders by 2030 as per a Harvard School of Public Health assessment. The World Bank estimates that 21% of infectious diseases in India are related to the consumption of unsafe water, and diarrhoea alone causes more than 1,600 deaths daily. To handle these challenges, two basic requirements, access to clean energy and safe drinking water to every individual, must be fulfilled by the central and state governments (Ambade *et al.* 2009).

From the various reports published by the Government of India, associated with energy accessibility, safe drinking water availability, and public health, it has been observed that these are critically interlinked factors, forming a multi-faceted nexus issue. It is commonly noticed that people facing energy crises are usually short of safe drinking water services, and hence they suffer from waterborne diseases. Consequently, they bear a loss of work productivity and earnings. With a low income, people are unable to fulfil the demand for energy and safe drinking water, as shown in Figure 2.

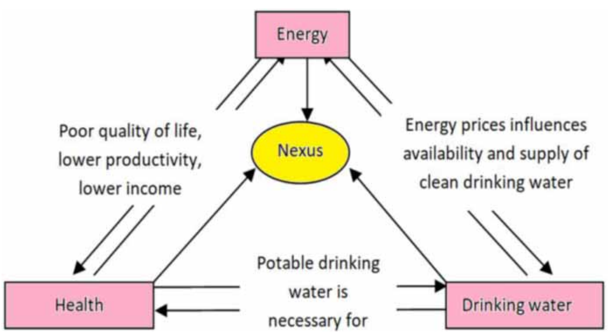


**Figure 2** | Energy/drinking water/health nexus.

This nexus issue has to be dealt with comprehensively to boost countries' economic growth as well as to reduce poverty. The literature shows that many investigators across the globe have used the nexus approach to solve significant crises of society. Avatar *et al.* (2019) investigated the population–urbanisation–energy nexus and concluded that the use of science and technology is required at the policy level, the geographical location of energy resources affects energy distribution and its cost. Rasul (2016) demonstrated the food–water–energy nexus. Authors have depicted that free water and subsidised power is not sufficient for rural and slum development. Kro (2017) studied the nexus of water–poverty–health expenditure and stated that poor people are prone to suffer from toxic substances through drinking water, as they cannot afford water of good quality for drinking and cooking. Bidoglio *et al.* (2018) described the nexus of water–energy–food–ecosystems. They stated that the governmental model must contain the creation and diffusion of technology for nexus administration, and public–private partnership is essential to develop inventive models, technologies, strategies and policies for nexus control. Wakil *et al.* (2017) studied the energy–water–environment nexus and found that this nexus is vital to attain the Conference of Parties goal (COP-21). For prospect sustainability, new membrane materials were investigated for water desalination. They also forecast that thermally driven desalination technology hybridisation could increase desalination efficiency by 20–25%. Ibrahim *et al.* (2019) discussed the water–energy–land–food nexus. They stated that the sensitivity analysis of the nexus showed a 13% decrease in its efficiency. Mercure *et al.* (2019) demonstrated the energy–water–food nexus to understand global demand for agricultural commodities; the need of new agricultural policies avoid only direct land-use and to handle the issue of climate change, deforestation, and change in the water cycle. Mannan *et al.* (2018) presented the energy–water–food nexus to understand the fundamental methodology to determine environmental burdens. Li *et al.* (2017) investigated the water–energy nexus for the utilisation of ocean energy for seawater desalination. Terrapon-Pfaff *et al.* (2018) demonstrated the water–energy–food nexus and concluded that organised action for integrating the water and food requirement into energy scheduling at the neighbourhood level is vital to avoid trade-offs and to improve progressive outcomes and impact of power ventures. Wicaksono & Kang (2018) gave a water–energy–food nexus for optimisation of resource allocation to maximise the security of resources. Review of the literature shows that the interlinking of energy, drinking water and human health in the Indian context is not holistically dealt with by any investigators to handle the problem of energy and safe drinking water security for the sustainable development of the nation. The present work investigates the energy, drinking water and health nexus in India using a clustering approach.

The paper describes the existing energy, drinking water and people's health scenario in the Indian context, interlinking factors between energy, drinking water and health using numerical indices and K-means clustering algorithm. The paper also provides information on water desalination, its environmental impact and the cost associated with desalinated water. Finally, the work concludes with region-wise investigations and policy recommendations.

## METHODOLOGY AND DATA COLLECTION

To find appropriate literature on energy scenarios, clean drinking water availability, its access to people and public health in India, relevant research papers have been collected and studied to understand the nexus between energy, drinking water and health in the nation and its implications for climate change. Special attention has been given to internationally published reports on India from various distinguished organisations such as the UN, WHO, UNICEF, IEA, IRENA, IEEJ and Government of India dealing with energy, drinking water and health, with their policies and guidelines to discover their relevance for this proposed nexus study. Collected research papers and reports have been interpreted carefully, and the most significant findings of each one are noted down. The state-wise data are collected from the portals of Government of India such as geographical area, population (urban, rural), GDP, literacy rate, people living below the poverty line, primary energy mix, cases and deaths reported due to waterborne diseases, electrification done, per capita energy consumption, human development index, people with access to clean cooking fuel, total annual replenishable groundwater resources and public expenditure on health (refer to Tables 1 and 2).

**Table 1** | Data for different Indian states/UTs

| Sn | Name of the state/UT[a] | Geographical area (sq. km) | Total population | State GDP (lakh crore) | Grand total (installed capacity) | Per capita energy consumption (kWh) | Per centage of households with access to safe drinking water (2011) | State-wise cases due to cholera in India 2014–2016 | State-wise cases due to acute diarrhoeal diseases reported during 2014–2016 | State-wise cases due to enteric fever (typhoid) reported during 2014–2016 | Total number of deaths due to waterborne diseases during 2014–2016 | Total annual replenishable groundwater resource (in billion cubic metre) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Andaman and Nicobar Islands | 8,249 | 380,581 | 0.066 | 57.49 | 370 | 85.5 | 0 | 23,547 | 1,127 | 1 | 0.31 |
| 2 | Andhra Pradesh | 162,970 | 49,577,103 | 10.81 | 26,500.26 | 1,319 | 90.5 | 0 | 1,194,005 | 170,249 | 12 | 35.89[b] |
| 3 | Arunachal Pradesh | 83,743 | 1,383,727 | 0.234 | 951.72 | 648 | 78.6 | 9 | 11,715 | 4,574 | 7 | 4.51 |
| 4 | Assam | 78,438 | 31,205,576 | 4.09 | 1,819.05 | 339 | 69.9 | 0 | 88,736 | 19,328 | 296 | 28.52 |
| 5 | Bihar | 94,163 | 104,099,452 | 6.86 | 6,733.47 | 272 | 94 | 0 | 392,224 | 204,366 | 10 | 29.34 |
| 6 | Chandigarh | 114 | 1,055,450 | 0.318 | 40.55 | 1,128 | 99.3 | 10 | 49,891 | 12,237 | 116 | 0.02 |
| 7 | Chhattisgarh | 135,191 | 25,545,198 | 3.62 | 23,799.85 | 2,016 | 86.3 | 55 | 157,064 | 74,632 | 56 | 12.42 |
| 8 | Delhi | 1,483 | 16,787,941 | 8.56 | 2,425.56 | 1,574 | 95 | 228 | 135,907 | 30,015 | 264 | 0.31 |

*(continued)*

**Table 1** | continued

| Sn | Name of the state/UT[a] | Geographical area (sq. km) | Total population | State GDP (lakh crore) | Grand total (installed capacity) | Per capita energy consumption (kWh) | Per centage of households with access to safe drinking water (2011) | State-wise cases due to cholera in India 2014–2016 | State-wise cases due to acute diarrhoeal diseases reported during 2014–2016 | State-wise cases due to enteric fever (typhoid) reported during 2014–2016 | Total number of deaths due to waterborne diseases during 2014–2016 | Total annual replenishable groundwater resource (in billion cubic metre) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 9 | Goa | 3,702 | 1,458,545 | 0.772 | 53.17 | 2,466 | 85.7 | 0 | 14,245 | 724 | 4 | 0.24 |
| 10 | Gujarat | 196,024 | 60,439,692 | 18.85 | 36,866.57 | 2,279 | 90.3 | 88 | 641,451 | 45,970 | 2 | 18.57 |
| 11 | Haryana | 44,212 | 25,351,462 | 9.4 | 6,292.89 | 1,975 | 93.8 | 0 | 224,780 | 36,442 | 14 | 10.78 |
| 12 | Himachal Pradesh | 55,673 | 6,864,602 | 1.82 | 10,761.63 | 1,340 | 93.7 | 0 | 310,789 | 38,093 | 81 | 0.56 |
| 13 | Jammu and Kashmir | 42,241 | 12,267,032 | 1.38 | 3,734.78 | 1,282 | 76.8 | 0 | 534,341 | 46,904 | 0 | 4.25 |
| 14 | Jharkhand | 79,714 | 32,988,134 | 3.83 | 4,716.75 | 915 | 60.1 | 5 | 93,547 | 41,731 | 0 | 6.31 |
| 15 | Karnataka | 191,791 | 61,095,297 | 18.05 | 29,266.46 | 1,367 | 87.5 | 29 | 930,369 | 97,493 | 22 | 17.03 |
| 16 | Kerala | 38,863 | 33,406,061 | 9.62 | 2,979.96 | 763 | 33.5 | 7 | 476,686 | 2,038 | 33 | 6.69 |
| 17 | Madhya Pradesh | 308,350 | 72,626,809 | 9.78 | 28,426.39 | 989 | 78 | 94 | 740,236 | 129,998 | 165 | 35.04 |
| 18 | Maharashtra | 307,713 | 112,374,333 | 32.24 | 42,386.32 | 1,307 | 83.4 | 107 | 1,051,445 | 137,617 | 58 | 33.95 |
| 19 | Manipur | 22,327 | 2,570,390 | 0.231 | 152.05 | 326 | 45.4 | 0 | 33,193 | 4,942 | 24 | 0.44 |
| 20 | Meghalaya | 22,429 | 2,966,889 | 0.33 | 368.45 | 832 | 44.7 | 0 | 165,404 | 14,128 | 31 | 1.78 |
| 21 | Mizoram | 21,081 | 1,097,206 | 0.176 | 97.99 | 523 | 60.4 | 17 | 13,602 | 3,085 | 16 | 0.03 |
| 22 | Nagaland | 16,579 | 1,978,502 | 0.215 | 106.67 | 345 | 53.8 | 6 | 15,062 | 8,267 | 0 | 0.62 |
| 23 | Orissa | 155,707 | 41,974,219 | 5.85 | 12,464.04 | 1,622 | 75.3 | 0 | 775,824 | 73,330 | 140 | 17.78 |
| 24 | Pondicherry | 492 | 1,247,953 | 0.359 | 38.01 | 1,784 | 97.8 | 0 | 92,379 | 1,943 | 12 | 0.19 |
| 25 | Punjab | 50,362 | 27,743,338 | 6.44 | 8,224.8 | 2,028 | 97.6 | 0 | 195,281 | 37,896 | 54 | 22.53 |
| 26 | Rajasthan | 342,238 | 68,548,437 | 11.33 | 22,016.91 | 1,166 | 78.1 | 2 | 897,209 | 116,470 | 8 | 11.94 |
| 27 | Tamil Nadu | 130,058 | 72,147,030 | 20.91 | 33,218.61 | 1,847 | 92.5 | 8 | 367,815 | 33,853 | 9 | 21.53 |
| 28 | Telangana | 112,077 | 35,003,674 | 11.08 | 13,252.68 | 1,551 | 96.8 | 0 | 871,497 | 133,838 | 19 | 35.89[b] |
| 29 | Tripura | 10,486 | 3,673,917 | 0.461 | 1,157.52 | 470 | 67.5 | 0 | 95,278 | 5,398 | 10 | 2.59 |
| 30 | Uttar Pradesh | 243,290 | 199,812,341 | 17.91 | 28,079.45 | 585 | 95.1 | 4 | 1,066,342 | 495,698 | 663 | 77.19 |
| 31 | Uttarakhand | 53,483 | 10,086,292 | 2.93 | 4,868.07 | 1,454 | 92.3 | 0 | 110,942 | 33,904 | 27 | 2.04 |
| 32 | West Bengal | 88,752 | 91,276,115 | 14.7 | 16,153.17 | 665 | 92.2 | 157 | 2,045,451 | 161,264 | 329 | 29.25 |

[a]UTs such as Ladhak, Dadra, Nagar Haveli, Daman and Diu along with Lakshadweep, Sikkim are not considered.
[b]It is assumed that the total annual replenishable groundwater resource for Andhra Pradesh and Telangana is equal.

**Table 2** | Values of indices for different states/union territories

| Sn | Name of state/UT[a] | Human development index | Public expenditure on health (Rs.) | Energy index (E) | Drinking water index (W) | Health index (H) |
|---|---|---|---|---|---|---|
| 1 | Andaman and Nicobar Islands | 0.739 | 3,407,106 | 0.31 | 0.15 | 0.07 |
| 2 | Andhra Pradesh | 0.65 | 74,299,271 | 1.12 | 0.10 | 0.03 |
| 3 | Arunachal Pradesh | 0.66 | 11,199,034 | 0.55 | 0.21 | 0.01 |
| 4 | Assam | 0.614 | 53,770,407 | 0.29 | 0.30 | 0.00 |
| 5 | Bihar | 0.576 | 66,685,781 | 0.23 | 0.06 | 0.01 |
| 6 | Chandigarh | 0.775 | 4,225,950 | 0.96 | 0.01 | 0.06 |
| 7 | Chhattisgarh | 0.613 | 44,871,975 | 1.71 | 0.14 | 0.01 |
| 8 | Delhi | 0.746 | 59,027,640 | 1.33 | 0.05 | 0.01 |
| 9 | Goa | 0.761 | 9,601,472 | 2.09 | 0.14 | 0.01 |
| 10 | Gujarat | 0.672 | 88,164,653 | 1.93 | 0.10 | 0.01 |
| 11 | Haryana | 0.554 | 43,849,236 | 1.67 | 0.06 | 0.01 |
| 12 | Himachal Pradesh | 0.725 | 20,544,690 | 1.13 | 0.06 | 0.05 |
| 13 | Jammu and Kashmir | 0.688 | 35,454,949 | 1.09 | 0.23 | 0.05 |
| 14 | Jharkhand | 0.599 | 31,292,593 | 0.77 | 0.40 | 0.00 |
| 15 | Karnataka | 0.682 | 72,295,591 | 1.16 | 0.13 | 0.02 |
| 16 | Kerala | 0.779 | 68,824,749 | 0.65 | 0.67 | 0.01 |
| 17 | Madhya Pradesh | 0.606 | 80,651,222 | 0.84 | 0.22 | 0.01 |
| 18 | Maharashtra | 0.696 | 122,250,772 | 1.11 | 0.17 | 0.01 |
| 19 | Manipur | 0.696 | 6,045,568 | 0.28 | 0.55 | 0.01 |
| 20 | Meghalaya | 0.656 | 7,639,627 | 0.70 | 0.55 | 0.06 |
| 21 | Mizoram | 0.705 | 5,558,640 | 0.44 | 0.40 | 0.02 |
| 22 | Nagaland | 0.679 | 6,164,974 | 0.29 | 0.46 | 0.01 |
| 23 | Orissa | 0.606 | 5,714,627 | 1.37 | 0.25 | 0.02 |
| 24 | Pondicherry | 0.738 | 5,269,367 | 1.51 | 0.02 | 0.08 |
| 25 | Punjab | 0.723 | 36,378,787 | 1.72 | 0.02 | 0.01 |
| 26 | Rajasthan | 0.629 | 98,143,384 | 0.99 | 0.22 | 0.01 |
| 27 | Tamil Nadu | 0.636 | 99,761,913 | 1.56 | 0.08 | 0.01 |
| 28 | Telangana | 0.669 | 63,914,252 | 1.31 | 0.03 | 0.03 |
| 29 | Tripura | 0.658 | 7,364,735 | 0.40 | 0.33 | 0.03 |
| 30 | Uttar Pradesh | 0.596 | 189,671,521 | 0.50 | 0.05 | 0.01 |
| 31 | Uttarakhand | 0.684 | 22,471,783 | 1.23 | 0.08 | 0.02 |
| 32 | West Bengal | 0.641 | 79,211,955 | 0.56 | 0.08 | 0.02 |

[a]UTs such as Ladhak, Dadra, Nagar Haveli, Daman and Diu along with Lakshadweep, Sikkim are not considered.

Furthermore, information on desalination techniques, the energy consumption and cost for desalination technologies, their environmental footprints, and efficacy of renewable energy for desalination have been collected. Water, energy and health indices are defined, estimated and compared to investigate the existence of interlink between energy–drinking water, drinking water–health and health–energy to compile diverse sections in the paper. Finally, the nexus between energy, drinking water and health has been established. Figure 3 shows the steps used to carry out this study, which is self-explanatory.

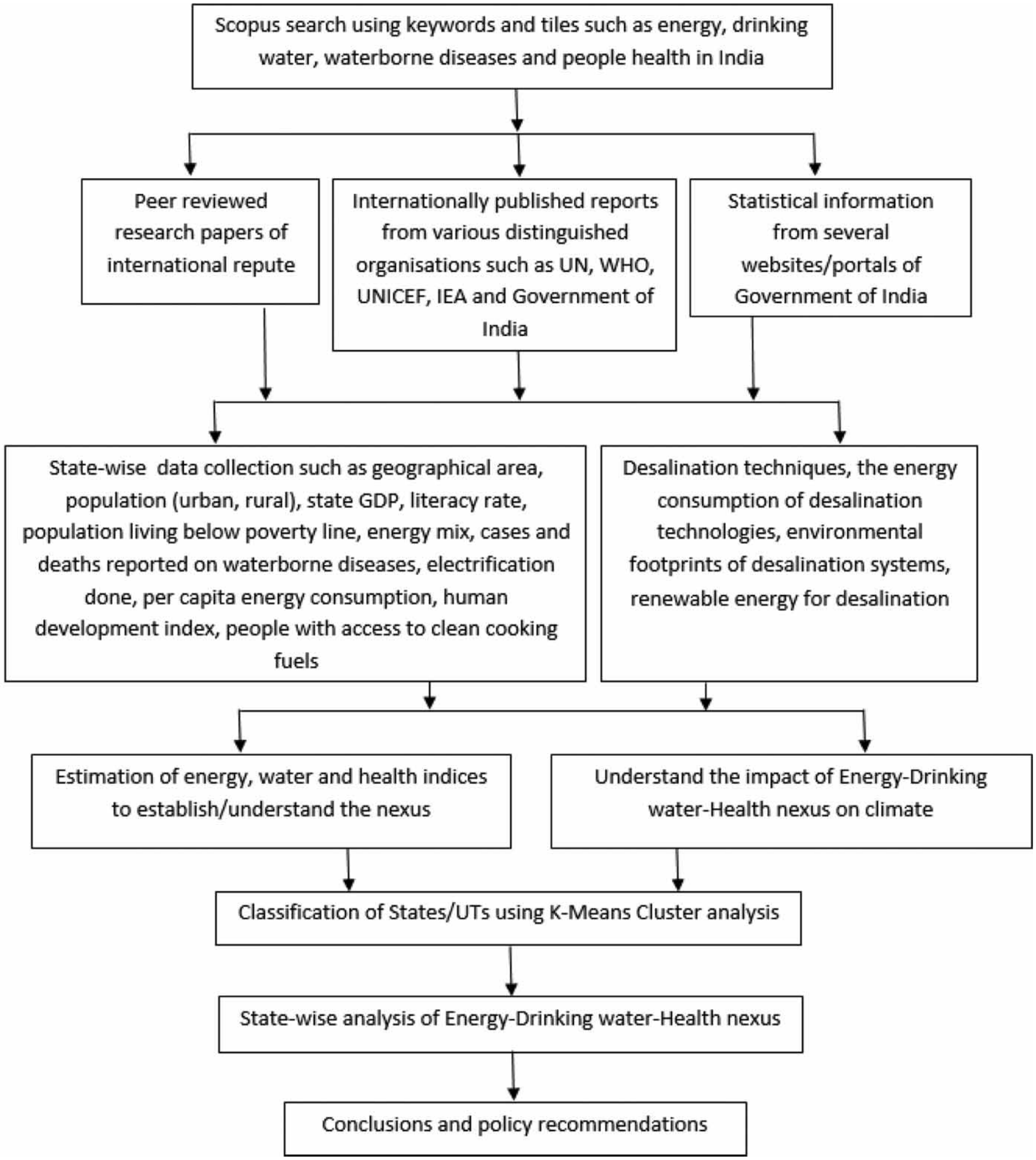


**Figure 3** | Steps used for investigations.

## PRESENT ENERGY SCENARIO OF THE NATION

As per the report of the Economic Survey of India (2019), presently India consumes only 6% of the world's primary energy to fulfil the energy demand of more than 1,300 million people. The nation has low per capita energy consumption (1,181 kWh per person per year or 140 W per person in 2019) which is less than half of the world's average (2,674 kWh per person per year or 309 W per person). The primary energy mix of the nation and the world in 2015 is shown in Figure 4 (Lakshmi *et al.* 2019).

The National Institution for Transforming India (NITI Aayog) and The Institute of Energy Economics, Japan (IEEJ) (2017) jointly surveyed India's energy sector recently. This survey report states that India, home of 18% of the world's population, aims to reduce its energy poverty sustainably, to attain economic growth, and to control environmental pollution below the internationally set benchmark. This report forecasted that the total energy demand of India would increase by 25% by 2040, which will exert enormous pressure on natural energy resources.

To attain these objectives, the government of India sets ambitious goals such as (NITI Aayog & IEEJ 2017):

- installation of renewable energy capacity to 175 GW by 2022,
- 24 × 7 electricity to all households by 2022,
- residential housing to all by 2022,
- development of 100 smart cities,
- 10% reduction of oil and gas imports by 2022 as compared with import demand in 2014–15,
- provision of clean cooking fuels to all.

Figure 4 shows that a large proportion of the energy demand of the nation is fulfilled by burning coal. The use of natural gas is found to be less (6.51%) as compared with the rest of the world (23.82%). The share of coal in the primary energy mix for India and the world is 58 and 29%, respectively, whereas that of natural gas is 6.5 and 24%, respectively. Uses of other energy sources for electricity generation are found to be almost the same in the primary energy mix of the nation and the world. However, it has been projected that the nation has a lot of potential to increase the share of natural gas in its primary energy mix (Tiewsoh *et al.* 2019). Figure 5 shows the state-wise total installed capacity of the nation (Lakshmi *et al.* 2019).

As per the records of the Ministry of Power, per capita, the electricity consumption of the nation in the year 2018–19 was 1,181 kWh. Dadra, Nagar Haveli, Daman, and Diu have the highest and Bihar has the lowest per capita energy consumption in the nation (Lakshmi *et al.* 2019).

As per the Census 2011, the population of India was 1.2 billion, and as per the report of the Population Foundation of India, the population of the nation will be 1.7 billion in

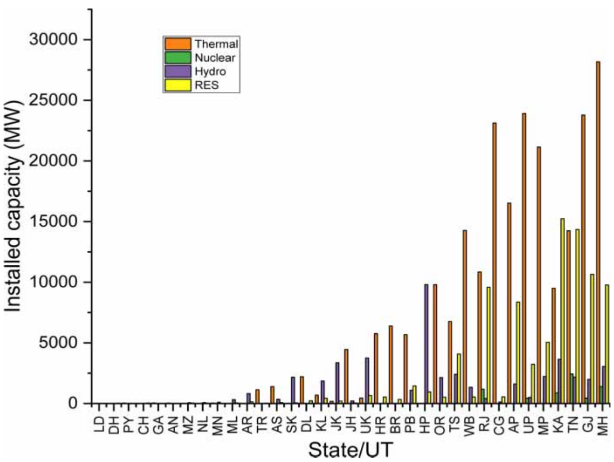


**Figure 5** | Installed capacity as per the fuel used (Lakshmi *et al.* 2019).

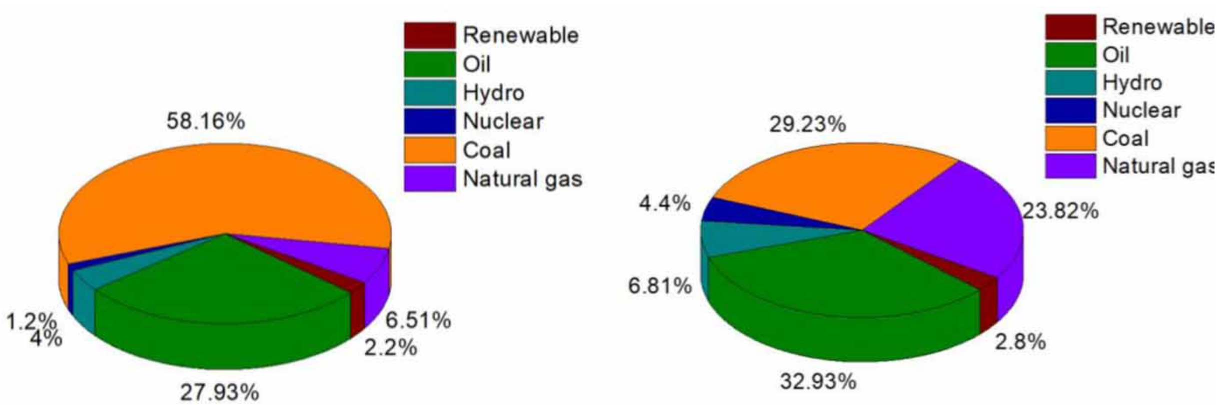


**Figure 4** | Comparison of the share of energy sources in India and the world in 2015 (Lakshmi *et al.* 2019).

2047. The Indian urban population will grow from 31% (2011) to 51% (2047). The increasing population of the nation will increase the burden on energy resources, and fossil fuel import expenditure (Katekar & Deshmukh 2020a). At the same time, the energy demand of industry would increase from 16% (2011) to 34% (2047). The forecasted primary energy mix of the nation in 2047 is shown in Figure 6. It shows that coal will remain the dominant fuel in the primary energy mix in 2047 with 40% of the contribution, followed by oil with 27.62% of the share (NITI Aayog & IEEJ 2017).

As compared with the primary energy mix of 2011, the contribution of nuclear, renewable, oil and natural gas will increase by 3, 3, 2 and 2%, respectively; however, the contribution of coal and agricultural waste will be reduced by 7 and 4%, respectively, as shown in Figure 7. The nation's own fossil fuel reserves are depleting rapidly, which will alter the fossil fuel import dependence, as shown in Figure 8 (NITI Aayog & IEEJ 2017).

## PRESENT DRINKING WATER SCENARIO IN INDIA

Safe drinking water scarcity is one of the significant difficulties in India. India has 4% of the world's freshwater resources to meet the demand of more than 1,300 million people (Katekar & Deshmukh 2020b). NITI Aayog introduced the Composite Water Management Index (CWMI) in 2018 to establish the regional water administration across the states of the nation (NITI Aayog & Development 2019). Annual utilisation of water resources in the nation is 447 billion cubic metres (BCM) from groundwater sources and 690 BCM from surface sources. However, it is possible to store 214 BCM of surplus monsoon runoff water in the groundwater reservoirs (NITI Aayog & Development 2019). Figure 9 indicates the state-wise different drinking water sources available in India. The highest treated tap water supply is available in Chandigarh (CH), and the most increased untreated tap water supply is in Sikkim. Highest and lowest covered wells are found in Kerala and Chandigarh, respectively. Highest and most inadequate uncovered wells are located in Lakshadweep and Chandigarh, respectively. Maximum use of hand pump and tube wells is found in Bihar and Dadra, Nagar Haveli, Daman and Diu. Full use of river water is recorded in Manipur. Meghalaya uses the most spring water to fulfil the drinking water demand of people of the state (Census 2011).

Presently, more than 820 million people living in 12 major river basins of India are facing a high to extreme water stress situation (NITI Aayog & Development 2019). Of these, 495 million people alone live in the Ganga river basin. Recently, the Government of India launched '*Jalshakti Abhiyan*' in 256 water-stressed districts. The government is focusing on the responsible use of water for agriculture, groundwater recharge, and the use of new technology for water management. NITI Aayog report (2019) says that,

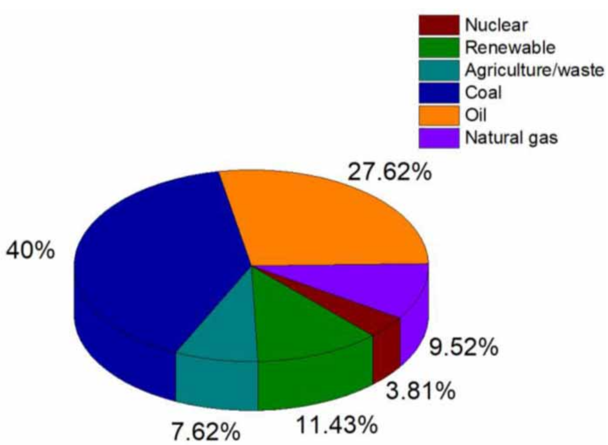


**Figure 6** | Primary energy mix in 2047 (forecasted) (NITI Aayog & IEEJ 2017).

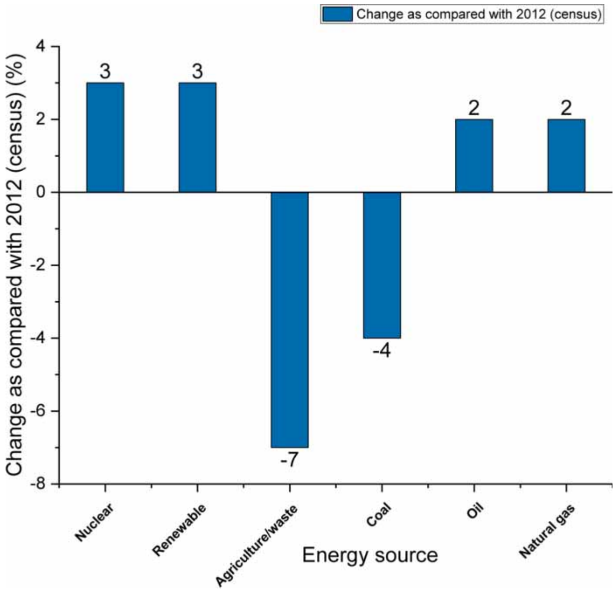


**Figure 7** | Changes in demand for fuel in 2047 (NITI Aayog & IEEJ 2017).

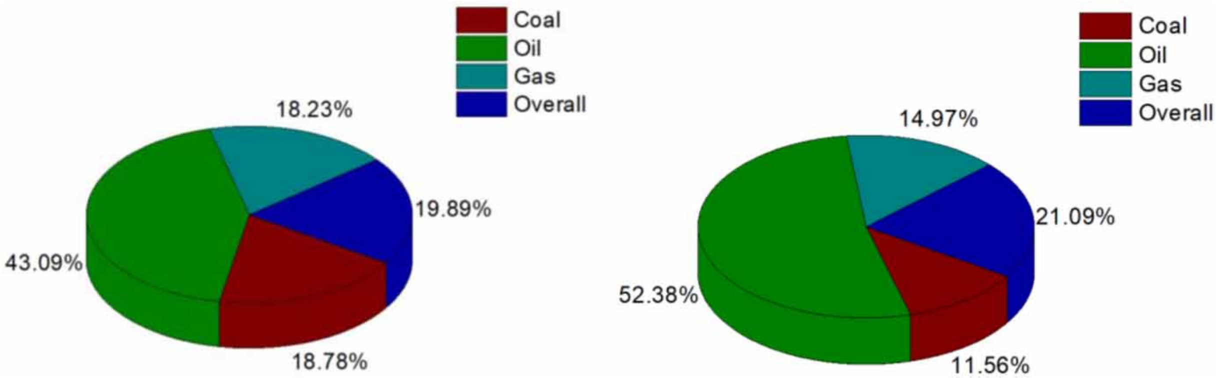


**Figure 8** | Fuel share in 2047 as compared with 2012.

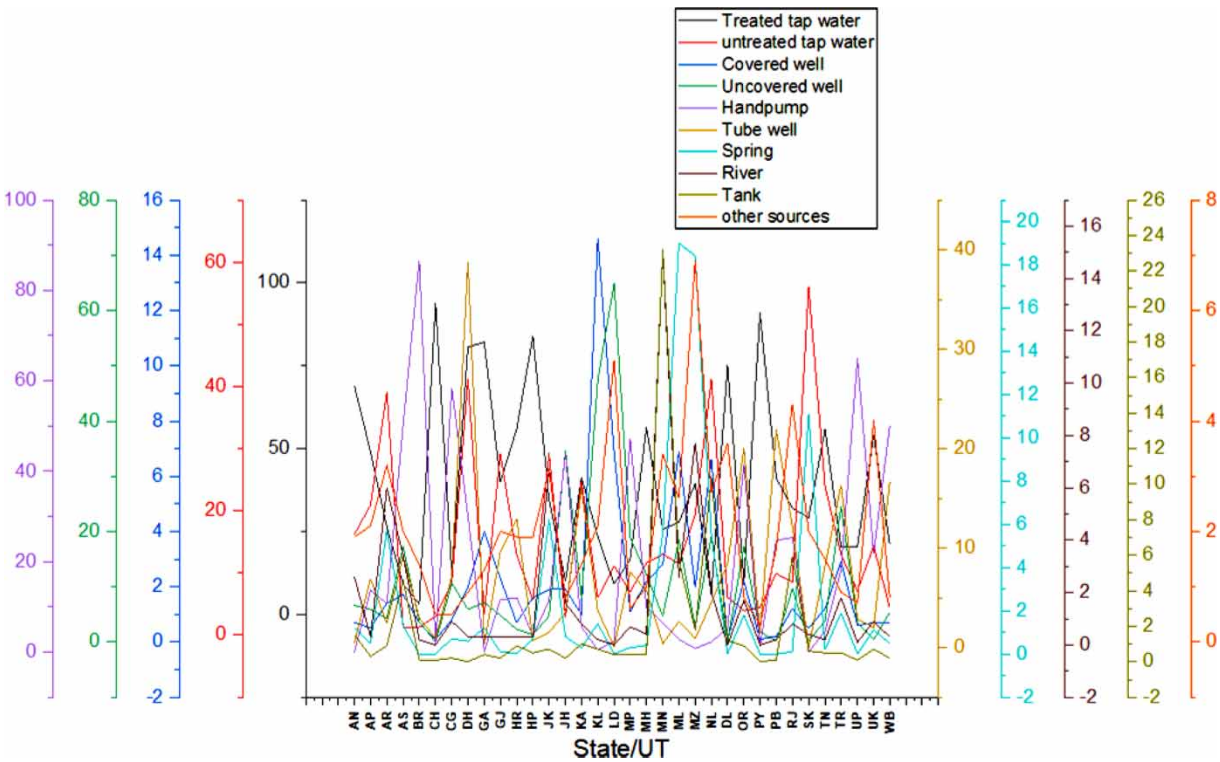


**Figure 9** | State-wise different drinking water sources available in India (as per Census 2011).

presently, no Indian city can provide $24 \times 7$ water supplies to its entire urban population. As per the Census 2011, the government is attempting to supply treated tap water, but its proportion is drastically variable across the nation (0.9–99.6%). Figure 10 shows the locations where the treated tap water supply is less than 25% (Eris *et al.* 2019).

The expected water demand–supply gap will be 50 BCM for the domestic sector by 2030, and industrial water demand will increase by three times by 2030. Another big challenge is that 40% of India's thermal power plants are situated in water-stressed regions, and of them, 70% of power plants will face high water stress by 2030. Presently, 11% of Indian land is desertified due to water shortages. Eighty-two per cent of the rural households in India do not have an individually piped water supply system at their home. Seventy per cent of India's surface water is

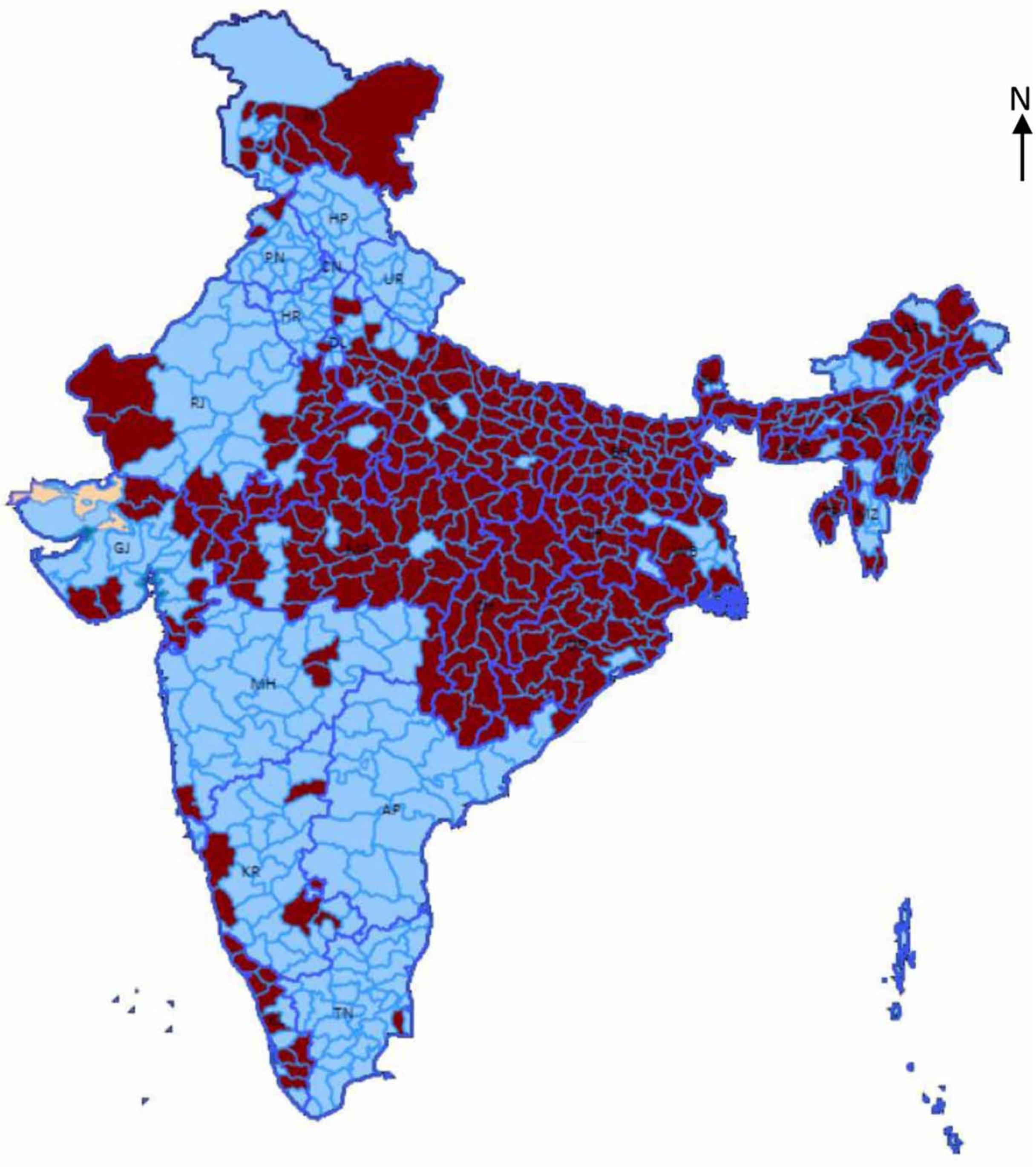


**Figure 10** | The region where treated tap water supply is less than 25% (Census 2011).

contaminated, and 163 million people live without access to clean water close to their homes (NITI Aayog & Development 2019). Average per capita water availability is expected to reduce to 1,341 $m^3$ by 2025 and 1,140 $m^3$ by 2050. This value is close to the official water scarcity threshold of 1,000 $m^3$. It is forecasted that Rs. 2,000,000 crores investments are required to bridge the demand–supply gap by 2030; consequently, the nation will lose 6% of GDP due to water crises by 2030 (NITI Aayog & Development 2019).

## HEALTH AND WATERBORNE DISEASES

Water is the nectar present on the Earth. Clean, safe drinking water is the foremost need of all living beings to sustain life. The United Nations Sustainable Development Goals (SDGs) demonstrate the pathway to achieve a better and more sustainable future for people from every corner of the world. SDGs focus on global challenges such as poverty, inequality, climate change, environmental degradation, peace and justice. There are a total of 17 SDGs, of which, SDG-6 is associated with drinking water and sanitation.

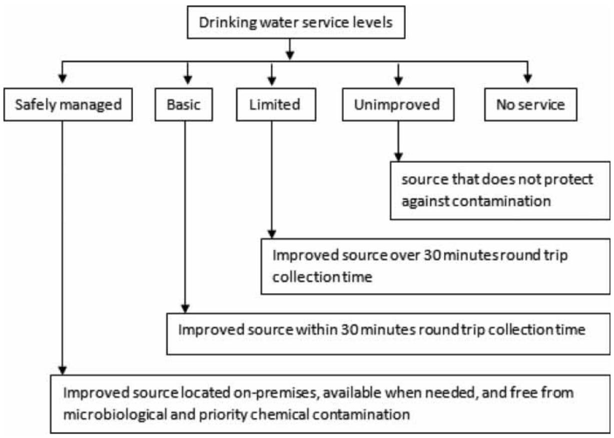


**Figure 11** | Different water service levels (WHO-UNICEF).

SDG-6 states that '*Water sustains life, but safe drinking water defines civilisation*'. By 2030, nations must: ensure safe and affordable drinking water, adequate sanitation and hygiene facilities, execute integrated water resources administration at all levels, safeguard and restore water-related ecology, extend support to developing countries for water along with sanitation administration, and strengthen the involvement of local communities for water and sanitation management (Dinka 2018).

WHO-UNICEF Joint Monitoring Program (JMP) defined five different water service levels for community drinking as shown in Figure 11.

A report of WHO (2019) declares that safe and readily accessible drinking water is vital for public health, whether it is used for cooking, drinking or recreational purposes. The Institute of Medicine recommends that a man must consume roughly 3.7 litres, and a woman must drink 2.7 litres of potable water per day to maintain good health (Abbaspour 2011).

High water pollution makes the task of potable water supply to the communities extremely difficult. The quality of drinking water is altered in many ways, such as changes in nutrients, sedimentation, and by addition of compounds such as heavy metals, non-metallic toxicants, persistent organics and pesticides (Chouler & Di Lorenzo 2015). Figure 12

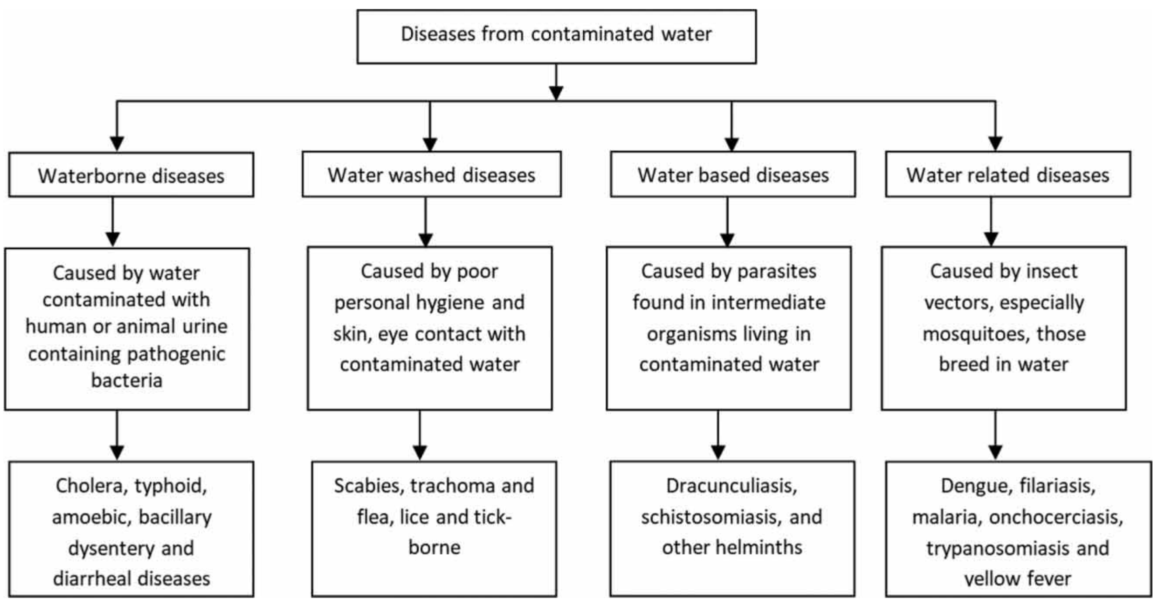


**Figure 12** | Classification of diseases due to impure water consumption (Schuster-Wallace et al. 2008).

illustrates various types of human diseases caused by drinking contaminated water (Schuster-Wallace et al. 2008).

The WHO states that the maximum permissible limit of salinity in drinking water is 500 ppm, and for exceptional cases, it may be up to 1,000 ppm. However, most of the surface or groundwater available on Earth has salinity up to 10,000 ppm. Seawater usually has a salinity in the range of 35,000–45,000 ppm (El-Ghonemy 2012). In addition to this, pollutants in water come in many forms such as deoxygenating materials, toxic materials, and solid materials such as vehicle tyres, shopping trolleys, old shoes, and plastics. These pollutants severely affect biological conditions in water and also deoxygenate the water. Such infected water transmits severe diseases. Figure 13 illustrates the guidelines for safe drinking water given by the WHO.

Many people in India rely on untreated surface water or groundwater; consequently, they are at risk of waterborne diseases. Lakshadweep (22.8%) and Chandigarh (99.3%) are the states with the lowest and highest percentages of households with access to safe drinking water, respectively.

Marginalised and illiterate people are less careful about drinking water quality and hygiene. The human development index is an integrated index incorporating life expectancy, education and per capita income. The United Nations Development Program (UNDP) report (2018) states that the human development index (HDI) of the nation in 2018 was 0.647 as compared to 0.640 in the year 2017. The report also says that

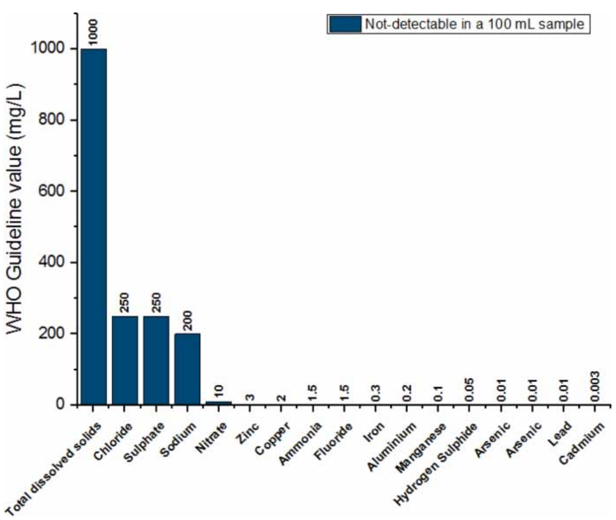


**Figure 13** | WHO guidelines for safe drinking water. *Note: Turbidity 5 NTU, colour 15 TCU, may not be toxic but could result in consumer complaints.

inequality and deprivation are still very high in the nation, which is badly affecting the quality of life and human health. The smallest and largest human development index is found to be 0.554 and 0.779 for Haryana and Kerala, respectively (Programme 2018).

As per the WHO report, cholera, which is one of the severe waterborne diseases whose symptoms are not quickly identified, affects both children and adults, and can kill suddenly if a patient is not medically treated quickly. As per the report of the Ministry of Health and Family Welfare of Government of India (MHFW), during the year 2014–16, a total of 841 cases of cholera were reported. The highest cases were registered in Delhi (228), and the lowest cases were found in Rajasthan (2) (WELFARE 2017). Similarly, diarrhoea is another infection caused by consumption of contaminated water. It is usually found in infants and children, mainly in the rural areas. As per the report of Government of India, the total number of cases of diarrhoea reported during 2014–16 was 1,3,923,275. The highest and lowest cases were found in Lakshadweep (4,387) and West Bengal (2,045,451), respectively. Diarrhoeal disease took the life of 1,540 people during this period. The highest number of people died in Uttar Pradesh (303) (WELFARE 2017). Typhoid or enteric fever is commonly found to be a waterborne disease attacking people in almost all seasons. A total of 2,222,695 cases and 512 deaths due to enteric fever (typhoid) were reported during 2014–16. The highest numbers of patients (495,698) and deaths (313) were reported in Uttar Pradesh and the smallest numbers of cases were reported in Lakshadweep (50) (WELFARE 2017).

Similarly, viral hepatitis is a liver infection caused by drinking infected water. A total of 142,148 cases and 446 deaths were registered due to viral hepatitis in the nation during 2014–16. The most cases were found in Bihar (28,578), and the most deaths were reported in West Bengal (115). During this time, 16,288,959 people were affected, and 2,498 died due to waterborne diseases in the nation. The highest percentage of cases were found in Dadra, Nagar Haveli, Daman and Diu (10.42%); however, the highest number of deaths was registered in Uttar Pradesh (663) (WELFARE 2017). Health expenditure of the nation or state covers the provision of health services, but it does not include water and sanitation. Presently, the nation has a total health expenditure of Rs. 1,581,949,168.

The highest public health expenditure is found for Uttar Pradesh (Rs. 189,671,521).

## ESTABLISHMENT AND INVESTIGATION OF E-DW-H NEXUS

Nexus is the relationship between two or more entities. The nexus approach has been used by many researchers to solve significant problems of societies. To establish and judge the nexus between some factors, some measurable parameters called nexus indices need to be estimated. This section defines nexus indices, evaluates their magnitude and establishes the nexus among them.

### Indices for E-DW-H nexus

#### Energy index (E)

The average value of an entity per person per year is termed as per capita. Energy consumption per capita indicates the total energy consumed per person per year in the nation. The energy index of a state or union territory is the ratio of per capita energy consumption of a state or union territory to the per capita energy consumption of the nation. A higher value of energy index (E) is always desirable, which indicates better accessibility of energy to people of that region.

$$E = \frac{\text{Per capita energy consumption of state}}{\text{Per capita energy consumption of country}} \tag{1}$$

#### Drinking water index (W)

Drinking water index (W) indicates the fraction of the total population that does not have access to safe drinking water. Its magnitude varies between 0 and 1. A lower value is always desirable, as it indicates a smaller number of people of a given state/union territory without access to safe drinking water.

$$W = \frac{\text{Total population without acesss to safe drinking water}}{\text{Total population of state/UT}} \tag{2}$$

#### Health index (H)

Health index (H) indicates the fraction of the total population suffering from waterborne diseases. Its value varies from 0 to 1. This index must be as low as possible. Its lower value indicates a smaller number of people of a given state/union territory suffering from waterborne diseases.

$$H = \frac{\text{Total population suffering from waterborne diseases}}{\text{Total population of state/UT}} \tag{3}$$

To establish the nexus between energy, drinking water and health, the above indices are calculated for different states and union territories and are shown in Table 2 from 2014 to 2016. Per capita, the energy consumption of the nation has been considered as 1,181 kWh. The energy index is found to be highest for the state of Goa (E = 2.09), and indicates that the people of Goa have better access to electricity; hence, people of Goa have higher per capita energy consumption, whereas the people of Bihar have the lowest access to electricity (E = 0.23) in the nation. Similarly, drinking water index is lowest for Chandigarh (W = 0.01). It shows that 10% of the people of Chandigarh do not have access to safe drinking water, which is the lowest in the nation. However, 77% of people of Lakshadweep (W = 0.77) do not have access to safe drinking water, which is the highest in the nation. The people of Sikkim (H = 0.08) are facing the most massive issue of waterborne diseases, and no cases of waterborne diseases were reported in Assam from 2014 to 2016.

### Cluster analysis

Cluster analysis is the activity of grouping of available objects such that objects are in the same group (Bolshakova & Azuaje 2003). K-means clustering algorithm is applied to 32 Indian states (out of 36, due to the non-availability of some input data information in the public domain for the remaining four regions) to form homogeneous clusters based on 16 evaluation criteria; namely, geographical area, total population, state GDP, grand total (installed capacity), per capita energy consumption, percentage of households with access to safe drinking water (2011), state-wise cases due to cholera in India 2014–16, state-wise cases due to acute diarrhoeal diseases reported during 2014–16, state-wise cases due to enteric fever (typhoid) reported during 2014–16, total number of deaths due to waterborne diseases during 2014–16, total annual replenishable groundwater resource, human development index, public expenditure in health, energy index, drinking water index and health index (Xie & Beni 1991).

K-means cluster analysis classifies N data sets into K homogeneous clusters (Jain & Dubes 1988) intending to decrease within-cluster sums of squares of differences. Data sets are iteratively moved from one group to another on this basis until the specified termination criterion is met (Chen *et al.* 2002). The total square error value $D_K$ for cluster K is the sum of the errors from the individual clusters (Dunn 1974). Cluster validity analysis platform (CVAP) is used for the algorithms (Wang 2007). K-means is iterated for three to ten clusters. Table 3 presents states in each sub-cluster and their numbers. It is observed from Figure 14 that the sum of squared errors decreased from 16.39 to 6.02, with the increase in the number of clusters. It has been observed from Table 3 that with the increase in the number of clusters, only one state exists as a sub-cluster. The reason behind this is that it contains a higher value of either energy or drinking water or health index. For example, in cluster 4, UP holds an independent sub-cluster.

Another research question is, what is the optimal size of clusters for chosen N data sets? In this regard, cluster validation algorithms play a significant role (Raju *et al.* 2012). Davies–Bouldin is chosen in the present study to serve the purpose (Davies & Bouldin 1979; Raju & Nagesh Kumar 2014). In the present study, the Davies-Bouldin validation index provided the optimal cluster size of 8, as shown in Figure 15.

## Energy–drinking water–health nexus

Energy, drinking water and health indices tabulated in Table 3 are compared for different states and union territories to investigate the nexus between them. This section discusses the interlinking of energy and drinking water, drinking water and health, as well as energy and health. Finally, the nexus between all these factors is also elaborated.

### Interlink of energy and drinking water

The International Energy Agency (IEA) (2019) outlines energy access as a reliable and affordable supply for both clean cooking facilities and electricity, which is sufficient to operate essential energy services (Bhujade *et al.* 2017). Lack of energy access results in poor access to clean drinking water. Consequently, people are not able to use desalination systems, or they prefer not to use boiled drinking water daily. Thus, neglecting the contamination in drinking water, people use freely available water to fulfil their daily water demand for cooking and drinking. Figure 16 shows that Lakshadweep (LD), Kerala (KL), Meghalaya (ML), Nagaland (NL) and Jharkhand (JH) are regions with low per capita energy consumption. Hence, people of these territories have poor access to clean drinking water. However, Chandigarh (CH), Pondicherry (PY), Punjab (PB), Telangana (TS) and Uttar Pradesh (UP) have higher per capita energy consumption indicating better access to safe drinking water.

### Interlink of drinking water and health

Water accessibility is defined as how the community or individual families practically access drinking water. All living beings from the water to land need water intake to avoid dehydration, but consumption of contaminated water is harmful and can lead to fatalities. Figure 17 shows that people of Lakshadweep (LD), Meghalaya (ML), Manipur (MN), Sikkim (SK), and Andaman and Nicobar Islands (AN) have poor access to safe drinking water; therefore, more people are suffering from waterborne diseases. Nevertheless, interestingly, the people of Andaman and Nicobar Islands (AN), Himachal Pradesh (HP), Pondicherry (PY) and Chandigarh (CH) have better access to safe drinking water, yet, higher numbers of cases of waterborne diseases are registered.

### Interlink of energy and health

Energy is the critical element for the socio-economic development of every community. All types of energy require water for their production, directly or indirectly; energy is needed to supply drinking water to communities.

**Table 3** | Clustering of states/UTs using K-means algorithm

| No. of clusters | Sub-cluster No. | Index of states in each sub-cluster | No. of states in each sub-cluster | % Number of states in each sub-cluster |
|---|---|---|---|---|
| 3 | 1 | AP, BR, GJ, KA, MP, MH, OR, RJ, TN, TS, UP, WB | 12 | 37.50% |
| | 2 | AN, AR, AS, JH, KL, MN, ML, MZ, NL, TR | 10 | 31.25% |
| | 3 | CH, CG, DL, GA, HR, HP, JK, PY, PB, UK | 10 | 31.25% |
| 4 | 1 | AP, BR, CG, GJ, KA, MP, MH, OR, RJ, TN, TS, WB | 12 | 37.50% |
| | 2 | UP | 1 | 3.13% |
| | 3 | AN, AR, AS, JH, KL, MN, ML, MZ, NL, TR | 10 | 31.25% |
| | 4 | CH, DL, GA, HR, HP, JK, PY, PB, UK | 9 | 28.13% |
| 5 | 1 | AR, AS, JH, KL, MN, ML, MZ, NL, TR | 9 | 28.13% |
| | 2 | AP, BR, GJ, KA, MP, MH, OR, RJ, TN, TS, WB | 11 | 34.38% |
| | 3 | UP | 1 | 3.13% |
| | 4 | AN, CH, HP, JK, PY | 5 | 15.63% |
| | 5 | CG, DL, GA, HR, PB, UK | 6 | 18.75% |
| 6 | 1 | AP, GJ, KA, MP, MH, RJ, TN | 7 | 21.88% |
| | 2 | CG, DL, GA, HR, OR, PB, TS, UK | 8 | 25.00% |
| | 3 | UP | 1 | 3.13% |
| | 4 | BR, WB | 2 | 6.25% |
| | 5 | AR, AS, JH, KL, MN, ML, MZ, NL, TR | 9 | 28.13% |
| | 6 | AN, CH, HP, JK, PY | 5 | 15.63% |
| 7 | 1 | BR, WB | 2 | 6.25% |
| | 2 | DL | 1 | 3.13% |
| | 3 | AR, AS, JH, KL, MN, ML, MZ, NL, TR | 9 | 28.13% |
| | 4 | AP, GJ, KA, MP, MH, RJ, TN | 7 | 21.88% |
| | 5 | UP | 1 | 3.13% |
| | 6 | AN, CH, HP, JK, PY | 5 | 15.63% |
| | 7 | CG, GA, HR, OR, PB, TS, UK | 7 | 21.88% |
| 8 | 1 | AN, CH, HP, JK, PY | 5 | 15.63% |
| | 2 | UP | 1 | 3.13% |
| | 3 | WB | 1 | 3.13% |
| | 4 | CG, GA, HR, OR, PB, TS, UK | 7 | 21.88% |
| | 5 | AP, GJ, KA, MP, MH, RJ, TN | 7 | 21.88% |
| | 6 | DL | 1 | 3.13% |
| | 7 | AR, AS, BR, JH | 4 | 12.50% |
| | 8 | KL, MN, ML, MZ, NL, TR | 6 | 18.75% |
| 9 | 1 | GJ, MH, TN | 3 | 9.38% |
| | 2 | AN, CH, HP, JK, PY | 5 | 15.63% |
| | 3 | KL, MN, ML, MZ, NL, TR | 6 | 18.75% |
| | 4 | CG, GA, HR, PB, UK | 5 | 15.63% |
| | 5 | AR, AS, BR, JH | 4 | 12.50% |
| | 6 | AP, KA, MP, OR, RJ, TS | 6 | 18.75% |
| | 7 | WB | 1 | 3.13% |
| | 8 | DL | 1 | 3.13% |
| | 9 | UP | 1 | 3.13% |
| 10 | 1 | DL | 1 | 3.13% |
| | 2 | CG, HR, OR, TS | 4 | 12.50% |
| | 3 | AP, KA, MP, RJ | 4 | 12.50% |
| | 4 | KL, MN, ML, MZ, NL, TR | 6 | 18.75% |
| | 5 | UP | 1 | 3.13% |
| | 6 | WB | 1 | 3.13% |
| | 7 | GJ, MH, TN | 3 | 9.38% |
| | 8 | AN, CH, HP, JK, PY | 5 | 15.63% |
| | 9 | GA, PB, UK | 3 | 9.38% |
| | 10 | AR, AS, BR, JH | 4 | 12.50% |

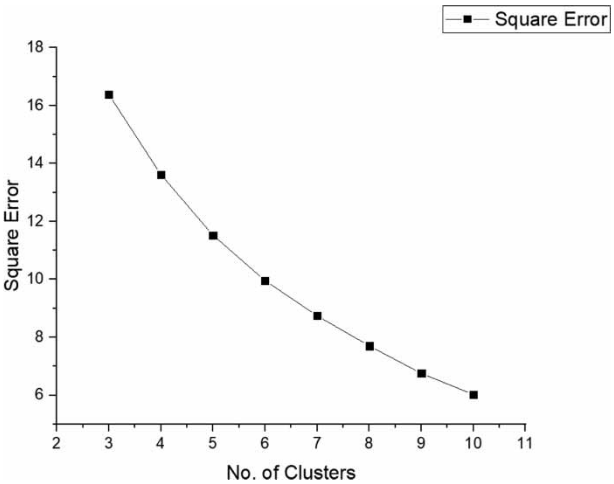


**Figure 14** | Square error value for each cluster.

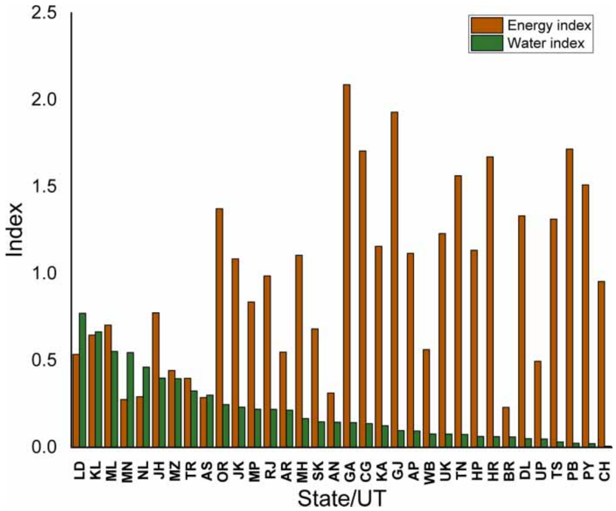


**Figure 16** | The relation between energy and drinking water.

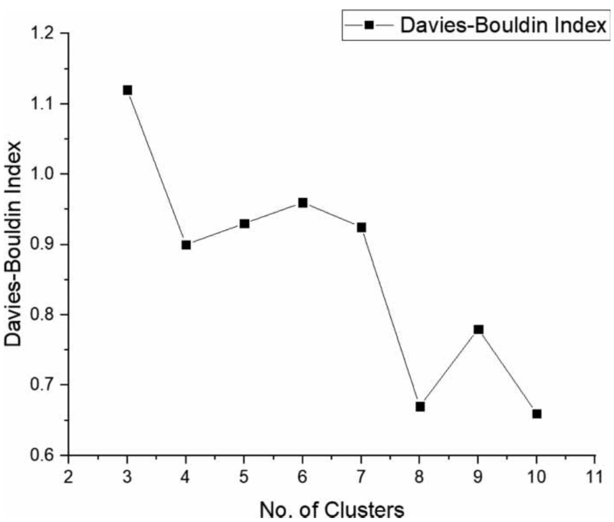


**Figure 15** | Davies–Bouldin index for each cluster.

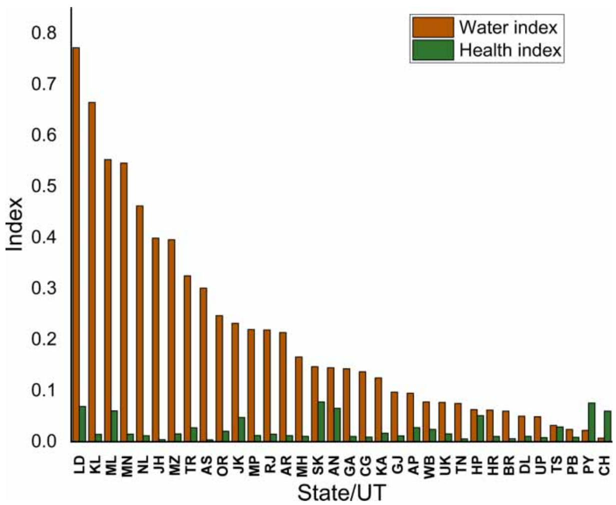


**Figure 17** | The relation between water and health index.

Thermal/electric energy is essential for the desalination of impure water. Nature-based technology for water purification is not usually suitable on a large scale as the quality of drinking water cannot be assured. Figure 18 shows that Andaman and Nicobar Islands (AN), Tripura (TR), Mizoram (MZ), Lakshadweep (LD) and West Bengal (WB) are the top five states which have lower per capita energy consumption; consequently, people do not use water purification/desalination systems and hence a more significant number of people are suffering from waterborne diseases. The people of Goa (GA), Gujarat (GJ), Punjab (PB), Chhattisgarh (CG) and Haryana (HR) have higher per capita energy consumption, hence the influence of waterborne diseases in these regions is found to be less.

Figure 19 shows the interrelation between the income of the state and the proportion of people suffering from waterborne diseases. Andaman and Nicobar Islands (AN), Chandigarh (CH), Madhya Pradesh (HP), Jammu and Kashmir (JK), Lakshadweep (LD), Meghalaya (ML), Pondicherry (PY) and Sikkim (SK) have lower GDP; hence, a greater number of people are suffering from waterborne diseases.

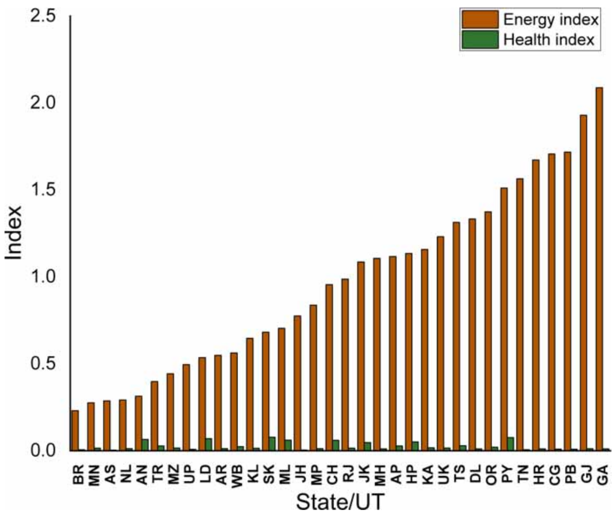


**Figure 18** | The relation between energy and health index.

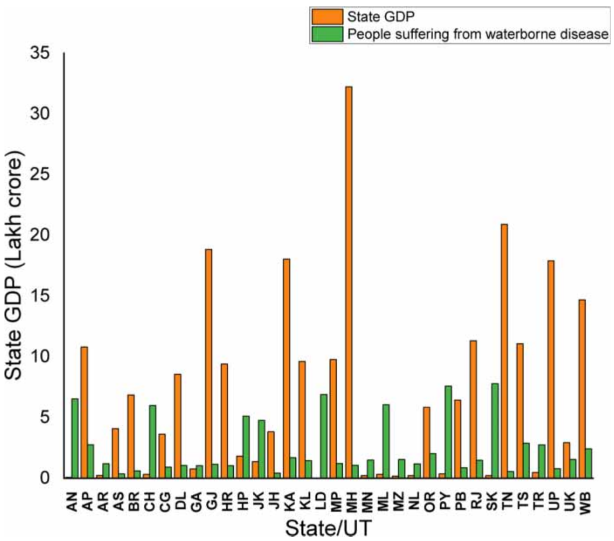


**Figure 19** | State-wise GDP and people suffering from waterborne diseases.

States like Gujarat (GJ), Karnataka (KA), Maharashtra (MH), Telangana (TS), Uttar Pradesh (UP) and West Bengal (WB) have higher state GDP; hence, there is a lower influence of waterborne diseases. People living in states with higher GDP have a greater income to spend on water-related services. Sometimes, the state government is capable of providing safe drinking water at the doorstep at an affordable cost, or people can afford a desalination system such as reverse osmosis for water purification at their home.

## Investigation of energy–drinking water–health nexus

From the preceding sections it can be seen that strong inter-linking exists between energy, drinking water and people's health. The average value of energy, drinking water and health index for the nation is estimated at 0.97, 0.21 and 0.03, respectively. This indicates that 21% of people in the nation do not have access to safe drinking water sources, and 3% of people are suffering from waterborne diseases. Figure 20 shows that Lakshadweep (LD), Kerala (KL), Meghalaya (ML), Manipur (MN), Nagaland (NL), Jharkhand (JH), Mizoram (MZ) and Tripura (TR) have lower per capita energy consumption and poor access to safe drinking water. Hence, more people are suffering from waterborne diseases. Similarly, states like Chandigarh (CH), Pondicherry (PY), Punjab (PB), Telangana (TS), Uttar Pradesh (UP), Delhi (DL), Bihar (BR) and Haryana (HR) have higher per capita energy consumption. People of these regions have better access to safe drinking water, and hence a lower proportion of people are suffering from waterborne diseases.

From this assessment, it can be recognised that there exists a substantial nexus between energy, drinking water and health. The states/union territories facing energy crises usually are deficient in safe drinking water services; consequently, people of those regions suffer more from ill-health due to drinking infected water, which increases the economic burden on them through the loss of work

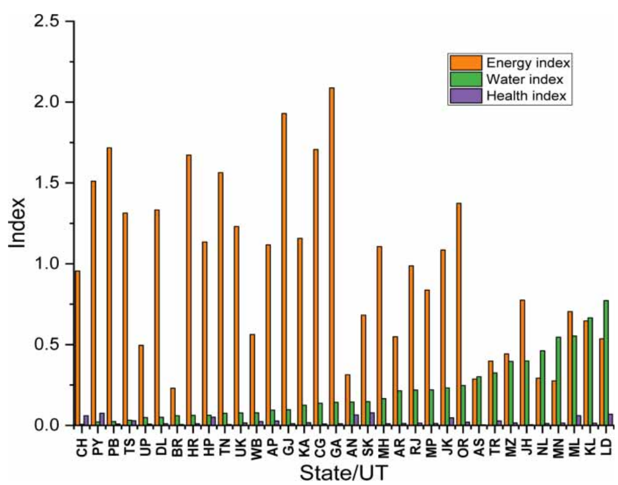


**Figure 20** | Comparison of energy, drinking water and health nexus.

productivity. With a deficient cash reserve, the communities are incapable of fulfilling the demand for energy and safe drinking water. Hence, this nexus must be carefully dealt with to gain the social and economic growth of the nation. Table 4 illustrates the consolidated summary of this nexus observation.

From Table 4, it can be observed that states/UTs fitting in the sub-cluster numbers 1, 2, 3 have higher per capita energy consumption, higher numbers of population with access to safe drinking water, and a lower proportion of people suffering from waterborne diseases. They are doing better to handle the issue of waterborne diseases. States/UTs fitting in sub-cluster numbers 4, 5, 6 are doing moderately in addressing the issue of waterborne diseases. However, states/UTs included in the sub-cluster numbers 7 and 8 have lower per capita energy consumption, a lower number of people with access to safe drinking water, and a higher proportion of people suffering from waterborne diseases. The state governments of these states have to make more effort to ensure energy and drinking water security in their state for sustainable development and environmental protection.

## EFFECT ON CLIMATIC CHANGE

To provide sufficient and safe drinking water to more than 1,300 million Indians is a significant challenge as water demand is increasing rapidly day by day due to population growth, industrialisation and urbanisation. Water pollution and climate change have affected the natural hydrological cycle that also generates water scarcity (Cheng *et al.* 2011). The government is taking several steps to improve the drinking water supply to people, such as water conservation, advancement in water collection and distribution systems, periodic repair and maintenance of water supply infrastructure. These efforts improve the quality of existing water resources. Another alternative to increase the drinking water supply is water desalination and water reuse (Elimelech & Phillip 2011). Table 5 shows that RO is the most energy-efficient technology, and its added advantage is that it does not consume any thermal energy; hence, its environmental impact is lowest as compared with other methods of desalination. Forward osmosis is also an emerging technology, but it consumes heat energy in addition to electric power.

Table 5 shows that desalination plants are energy-intensive. They need considerable thermal and electric energy; consequently, they contribute to greenhouse gases and leave a carbon footprint on the environment (Speirs *et al.* 2010). These desalination technologies have lower thermal efficiency, 10–15%; consequently, their energy consumption and environmental impact are inherently high (Leach & Deshmukh 2012). It is estimated that nearly 0.71 kWh of energy is required for a desalination process to produce 1 cubic metre of freshwater from brackish water; subsequently, this results in the burning of at least 1 ton of oil to produce 20 tons of desalinated water, which places an enormous burden on the environment (Reddy & Sharon 2016). Another problem with conventional desalination is

**Table 4** | Consolidated summary of the investigation

| Name of identified cluster | Sub-cluster No. | Index of states in each sub-cluster | Nexus information |
|---|---|---|---|
| 8 | 1 | AN, CH, HP, JK, PY | Doing better to handle the issue of waterborne diseases |
| | 2 | UP | |
| | 3 | WB | |
| | 4 | CG, GA, HR, OR, PB, TS, UK | Doing moderate to handle the issue of waterborne diseases |
| | 5 | AP, GJ, KA, MP, MH, RJ, TN | |
| | 6 | DL | |
| | 7 | AR, AS, BR, JH | Needs to take more efforts to handle the issue of waterborne diseases |
| | 8 | KL, MN, ML, MZ, NL, TR | |

**Table 5** | Energy consumption and carbon footprint of desalination technologies (El-Ghonemy 2012; Liu *et al.* 2015; Stillwell & Webber 2016)

| Desalination technology | Total electric energy (kWh/m$^3$) | Heat consumption (kJ/kg) | Total electric equivalent (kWh/m3) | Carbon footprint (kg $CO_2$) |
|---|---|---|---|---|
| MSF | 3–5 | 250–330 | 21–59 | 1.98–34.68 |
| MED/TVC | 1.5–2.5 | 145–390 | 15–57 | 1.19–26.94 |
| MVC | 8–15 | – | 7–15 | NA[a] |
| RO | 2.5–7 | – | 0.5–6 | 1.75–2.79 |

[a]NA, not available.

the disposal of desalination by-products. Their salinity is about twice that of untreated saline water. Concentrated brine, chemicals used in pre-treatment and membrane-cleaning exert high environmental risks to living organisms when these by-products are discharged into rivers or seawater (Elimelech & Phillip 2011).

To reduce the burden of fossil fuel expenditure and its environmental impact on desalination, renewable energy is a viable solution (Katekar & Deshmukh 2020c). Figure 21 shows possible combinations of the use of renewable energy with water desalination technologies (Shatat & Riffat 2014).

To fulfil the demand for potable water in an extremely rural and remote area where there are shortages of electricity and the problem of frequent power cuts, a solar still is a very convenient device (Dhurwey et al. 2019). The solar still converts saline water into drinkable water using solar energy. Solar still functions are analogous to the hydrological cycle of nature (Figure 22) (Deshmukh et al. 2008). This technology comes under the low-carbon economy as it has a negligible impact on greenhouse gas. Solar still can remove inorganic, bacteriological, organic, non-volatile contaminants from water (Hanson et al. 2004). The solar still is also used for small industrial applications (Mate et al. 2017). The chemical quality parameters for water obtained from a solar still are found to be within the limit recommended by the WHO standard for potable water (TDS < 500 ppm) (World Health Organization 2009; Ramteke et al. 2016; Malaeb et al. 2017).

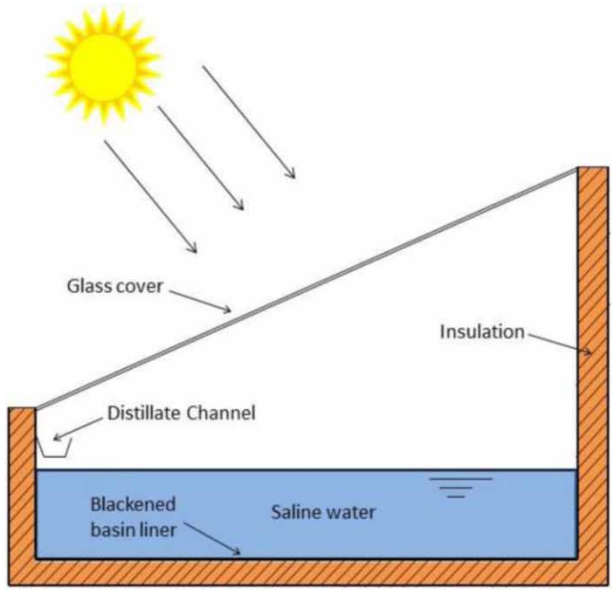


**Figure 22** | Solar still (Somanchi et al. 2015).

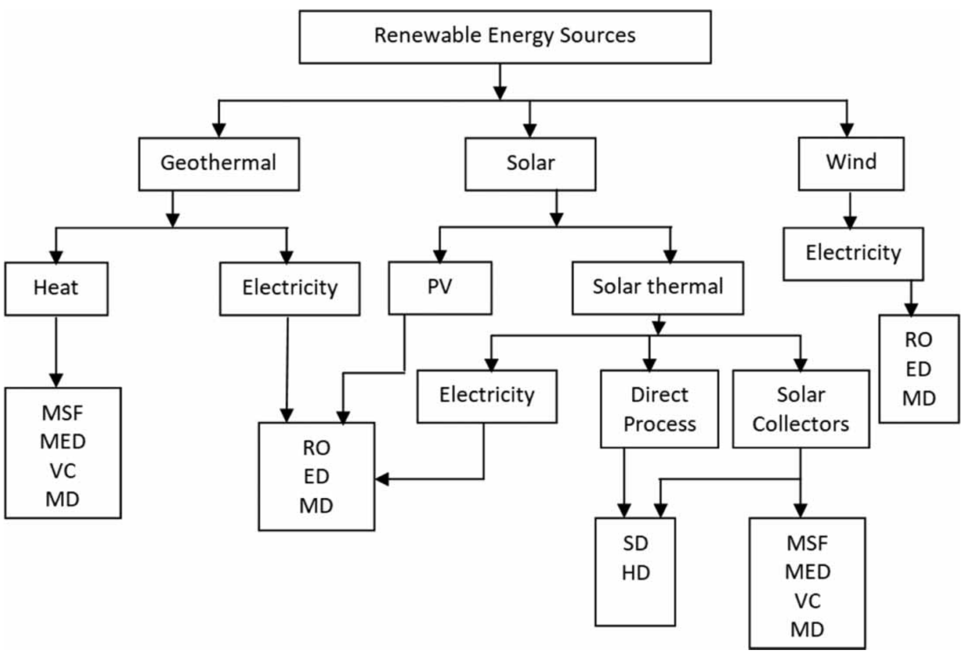


**Figure 21** | Renewable energy resources with water desalination (Shatat & Riffat 2014).

## COST OF DESALINATION

Another challenge associated with conventional desalination is the cost of purification. The International Renewable Energy Agency (IRENA) estimates that seawater desalination using MSF consumes typically 80.6 kWh of heat energy and 2.5–3.5 kWh of electrical energy per $m^3$ of desalinated water. Large-scale RO requires 3.5–5.0 kWh of electricity per $m^3$ of desalinated water. The cost of desalination has been decreasing the last few years up to US$ 0.5/$m^3$, while its market price is between US$ 1 and 2/$m^3$. Table 6 shows the cost of desalination/$m^3$ of product water. It illustrates that the cost of desalination reduces with an increase in the desalination capacity of the plant. In thermal technologies, for lower capacity up to 1,200 $m^3$ per day, vapour compression desalination is found to be most economical; whereas, for high desalination capacity, multi-effect desalination is found to be cost-effective.

**Table 6** | Cost of desalinated water in various thermal processes (El-Ghonemy 2012)

| Desalination process | Desalination plant capacity ($m^3$ per day) | Desalination cost per $m^3$ (US$) |
|---|---|---|
| Multi-effect distillation (MED) | < 100 | 2.5–10 |
| | 12,000–55,000 | 0.95–1.95 |
| | > 91,000 | 0.52–1.01 |
| Multi-stage flash (MSF) | 23,000–528,000 | 0.52–1.75 |
| Vapour compression (VCD) | 1,000–1,200 | 2.01–2.66 |

Figure 23 gives the cost comparison of brackish water and seawater desalination using RO plant. As brackish water has lower salinity than seawater, its desalination is cheaper. RO was found to be the most economical technology for large-scale seawater desalination, followed by MSF and MED. The investment cost of a large-scale RO plant is somewhere in the range of 500–1,000 million dollars, depending on the size, and it can generate freshwater in the range of US$ 0.45–0.55/$m^3$(Wittholz et al. 2008).

The economics of a desalination system running on renewable energy depends on the cost of renewable energy (Deshmukh & Deshmukh 2006). Currently, the cost of renewable desalination is higher as compared with the cost of conventional desalination running on grid electricity or fossil fuels (Leach et al. 2014). However, the prices of renewable technologies are quickly decreasing day by day (Anwar & Deshmukh 2018). It is forecasted that the future expected electricity cost beyond the year 2025 for most of the typical solar systems would be between US$ 0.04 and 0.1/kWh for annual energy isolation of 2,500 kW/$m^3$ (Shouman et al. 2015). The estimated water cost for desalination with photo-voltaic powered seawater desalination using a reverse osmosis (PV/SW-RO) system will be about US$ 1.21 $m^3$ while it will be between US$ 1.18 and 1.56 for conventional RO desalination. Table 7 shows various renewable energy-driven water desalination systems with their energy consumptions and the cost of production water.

In the Indian context, it is usually observed that the poor often pay high costs for energy; sometimes, they do not have

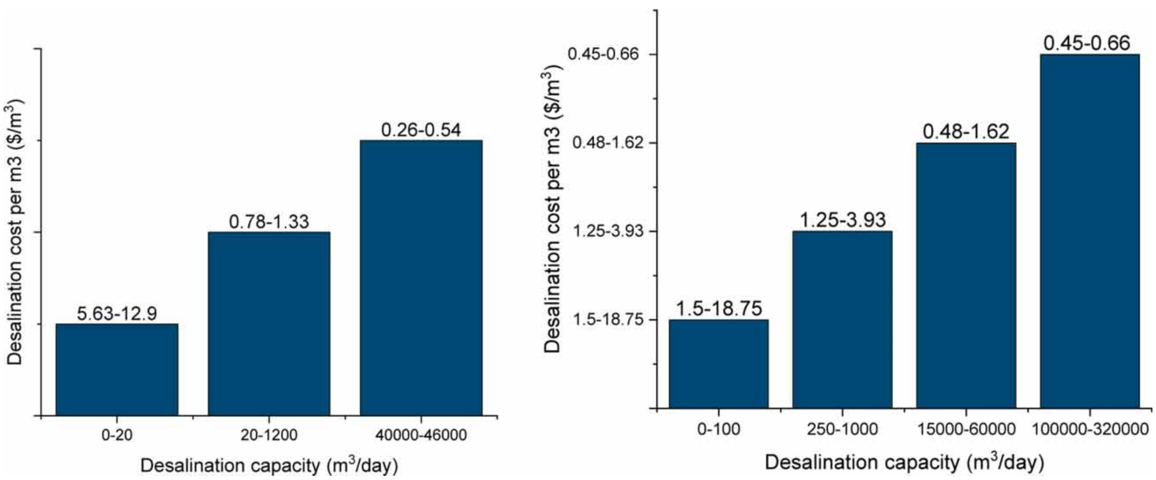


**Figure 23** | Price of desalinated water produced using RO plants (Shatat & Riffat 2014).

**Table 7** | Various renewable water desalination systems with energy consumption and the cost of the product (Shouman *et al.* 2015)

| Option | Capacity ($m^3$/d) | Cost of distillation (\$/$m^3$) |
|---|---|---|
| Solar stills | <0.1 | 1.3–6.5 |
| Solar-MED | 1–100 | 2.6–6.5 |
| Solar/CSP-MED | >5,000 | 2.3–2.9 |
| Photovoltaic-RO | <100 | 11.7–15.6 |
| Wind-RO | 50–2,000 | 6.5–9.5 (capacity <100 $m^3$/d); 6.5–9.1 2–5.2 (capacity 1,000 $m^3$/d) |
| Wind-MVC | <100 | 5.2–7.8 |

sufficient money to use energy services. The latest reports on the Indian economy 2019 state that 25.7% of the total rural population and 13.7% of the total urban population are living below the poverty line. The state-wise percentage of people living below the poverty line is given in Figure 24.

Low-income families with a lack of cash reserves are unable to pay quickly for their energy expenditure. The energy price is increasing and has reached a maximum for almost all sectors of the nation. High energy bills and energy burden on the communities hurt the economy of the nation both in the domestic sector and external sector (Bergasse *et al.* 2013). In many places, state or central government is not capable of supplying safe drinking water at the doorsteps of households, particularly in rural, remote and semi-urban areas. People in these regions cannot afford a personal desalination plant due to its intensive energy consumption and higher maintenance cost. Hence, they drink mostly untreated water from open sources, which forces them to live under the risk of waterborne diseases.

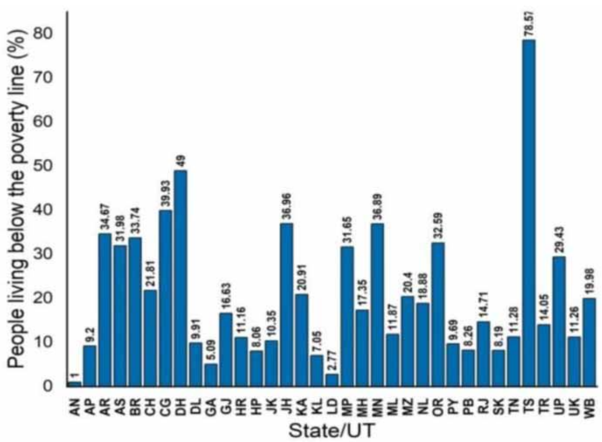


**Figure 24** | The number of people living below the poverty line.

## SUMMARY AND CONCLUSIONS

This study investigates the energy, drinking water and health nexus in India, keeping in view its critical role in climate change. This review has been summarised, and the subsequent conclusions have been drawn:

- The total number of people suffering from waterborne diseases in the nation from 2014 to 2016 was 16,288,959 and 2,498 deaths occurred due to consumption of contaminated water.
- The average value of energy, drinking water and health index for the nation is estimated at 0.97, 0.21 and 0.03, respectively.
- It has been found that states/union territories facing energy crises usually are deficient in safe drinking water services; consequently, people in those regions suffer more from waterborne diseases, which increases the economic burden through the loss of work productivity. With a deficient cash reserve, the communities are incapable of fulfilling the demand for energy and safe drinking water.

As far as the authors are aware, this is the first study where the K-means clustering algorithm, along with the Davies–Bouldin index, is applied to the classification of 32 Indian states based on 16 criteria. Observations that can be made from the study are:

- Sum of squared error decreased from 16.39 to 6.02.
- Eight clusters are found to be suitable based on the Davies–Bouldin index approach.
- It should be noted that the observations derived are based on data collected from various sources, selected clustering related algorithms and views of authors.
- From this analysis, it has been observed that the state governments of Arunachal Pradesh, Assam, Bihar, Jharkhand, Kerala, Manipur, Meghalaya, Mizoram and

Tripura need to make greater efforts to handle the issue of waterborne diseases.

From this assessment, it has been recognised that there is a substantial nexus between energy, drinking water and health, which must be carefully dealt with to gain the social and economic growth of the nation.

### Recommendations

To combat the problem of safe drinking water scarcity, the following are some recommendations:

- To provide safe drinking water to all, multilevel governance, the involvement of local non-government organisations (NGOs) and active public participation are crucial for the formulation of national and regional water policies.
- To increase safe drinking water affordability to the ordinary family, the cost of water provision services must be reduced. It can be possible using technological innovation, improvement in water supply management, good governance, increasing transparency in water distribution, and efficiency improvement of water desalination systems.
- The government should support efforts to raise awareness of the importance of preserving water resources and support studies to monitor drinking water quality and alternative treatment methods.
- Production of freshwater using renewable desalination technology is a workable solution in remote areas that lack conventional energy sources like heat and electricity.
- Economical solar distillation, as well as solar desalination systems, must be developed to provide clean and safe drinking water at the doorstep of people residing in rural and remote areas.

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## DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

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