Exploration of urban sustainability of India through the lens of sustainable development goals

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Abstract:

Sustainable Development Goal (SDG) index is a recognized metric for measuring progress in the UN SDGs. However, national or multinational-level analyses are more prevalent than sub-national types. We analysed the performance of 14 SDGs for 56 Indian cities (grouped into 6 regions) with available 77 indicators (2020-2021). Pearson's correlation, hierarchical clustering, data envelopment analysis etc. were used to infer existing status, interactions, efficiency, and interrelationships. Finally, we offer policy suggestions coupled with limitations to mitigate the drawbacks of the Indian city SDG framework. The findings reveal the asynchronous nature of SDGs. 18% of Indian cities register a poor track record of converting environmental performance into socioeconomic prosperity while 55% of cities are lagging in performance than respective states. A significant degree of inequality reigns among cities of various regions towards achieving SDGs. In a race to be economically powerful, the environment is being adversely affected. So, mainstreaming the environment into development planning is urgently warranted.

Keywords: data envelopment analysis; hierarchical clustering; India; SDG index; sustainable development goals; urban sustainability;

1. Introduction

India has a vast number of large cities, which contribute to the nation's massive population. There are 39 cities in the country with populations exceeding one million people. Two of these cities, Mumbai and Delhi, have populations of more than 10 million. While these megacities contribute millions to the country's population, the country also features smaller but densely populated cities, such as 396 cities with populations of 100,000 to 1 million people and 2,483 cities with populations of 10,000 to 100,000. Rural areas account for 65% of the population, while urban areas account for 35% of the population. This means the current (2020) rate of urbanization is 2.3% (World Bank 2022). In numerous respects, cities have been viewed as critical to advancing the sustainable development goal. Because of their population density, economic significance, prosperity, and resulting worldwide resource requirements, cities have a deep and far-reaching impact on the environment and society beyond their borders. Cities, on the other hand, are centres of information, technology, and innovation, making them critical participants in any transition to sustainability.

The Sustainable Development Goals (SDGs) are a blueprint for long-term planning toward social, economic, and environmental well-being that were accepted by all 193 UN member countries in 2015. Transformative transformation is required to address the SDGs' interrelated concerns. To establish egalitarian, inclusive, and sustainable ecosystems where all life may thrive, we must re-evaluate how societies work, how economies move, and how we engage with our planet. These goals have been approved by national governments, but they will only be achieved with the help of subnational governments. Cities all around the world are learning from one another as they incorporate the SDGs into existing planning processes, overcome data and communication gaps caused by administrative silos, and give leadership in identifying and resolving local needs to achieve long-term, large-scale change. Meaningful monitoring and target setting, based on measures that reflect relative and absolute progress toward sustainability, will be critical to cities' success in achieving the SDGs. Downscaling objectives and indicators to the city level to help planning and policy in a local context, however, remains a difficulty. Very recently, the IPCC report (IPCC 2021) has given cognisance to the role of compound extremes and multiple climate change drivers operating in tandem in maximising disaster impacts in 12 Indian cities. Among the warnings, intensity and frequency of hot extremes, such as warm days, warm nights, and heat waves; and decreases in the intensity and frequency of cold extremes, such as cold days and cold nights are of severe importance for Indian cities. Important from these 12 cities, that might go underwater, are Mumbai, Mangalore, Cochin, Vishakhapatnam, Chennai etc. Hence, this study has been conceptualised to understand and explore the contemporary conditions of Indian city SDGs, their interrelationship within SDGs as well as with some other city performance frameworks, SDG efficiency, and drawbacks coupled with policy suggestions to mitigate them in future.

2. Literature review

There have been a handful of works regarding this in the last few years. Simon et al. (2015) have synthesised a co-production work between researchers and local authority officials in 5 diverse cities: Bengaluru, Cape Town, Gothenburg, Greater Manchester, and Kisumu, for urban SDGs. In another work, Arfvidsson et al. (2017) tested the urban sustainable development goal 11 using 5 cities from Europe, Africa, and Asia. Patel et al. (2017) have explored the relationship between data and governance regarding SDG 11 for Cape Town. Koch & Ahmad (2018) have used SDG 11 to measure progress toward an inclusive, safe, resilient and sustainable city using German and Indian cities as case studies. Zinkernagel et al. (2018) have reviewed the evolution of indicators for monitoring sustainable urban development using SDGs and conclude that the SDG indicators provide the possibility of a more balanced and integrated approach to urban sustainability monitoring. Weymouth & Hartz-Karp (2018) have proposed a step-by-step process for the implementation and integration of the SDGs in cities. Nagy et al. (2018) have analysed sustainability on a local level (Romanian metropolitan area) by measuring 16 SDGs. In recent years, various reports have been published on the SDG assessment of municipalities or cities in Europe (Lafortune et al. 2019), the USA (Lynch et al. 2019), Spain (REDS, 2020), Italy (Cavalli et al. 2020), Brazil (ICS & SDSN 2021), Bolivia (Andersen et al. 2020) etc. Croese et al. (2020) have reviewed the prospect of localizing the SDGs from urban resilience strategies of the 100 Resilient Cities (100RC) network and Cape

Town. Giles-Corti et al. (2020) have examined the extent to which the UN indicators will help cities evaluate their efforts to deliver sustainability and health outcomes. Kutty et al. (2020) have proposed a system thinking approach towards several ongoing smart city initiatives with SDGs for transition to the sustainable smart city using keyword-based search in the Scopus database. Butcher et al. (2021) have done a content analysis of the intersections between 'urban' and 'equality' references across SDGs, that can ensure 'leave no urban citizens behind'. Grossi & Trunova (2021) reflect on the SDGs agenda and Key Performance Indicators (KPIs) for sustainable and smart cities as a possible measurement tool for these multiple values using Moscow as a case study. Sharifi (2021) has prepared a bibliometric literature review from the Web of Science of 1991-2020 concerning urban sustainability assessment in the world. Wiedmann & Allen (2021) have also composed a bibliometric literature review from the Web of Science of 1990-2020 regarding cities and SDGs and concluded that SDG monitoring and assessment of cities should take advantage of both consumption-based (footprint) accounting and benchmarking against planetary boundaries and social thresholds to achieve greater relevance for designing sustainable cities and urban lifestyles. Fox & Macleod (2021) have reflected SDG 'localization' derived from an action research project of Bristol. Schraven et al. (2021) have composed a comprehensive bibliometric analysis of 35 city labels to examine their (co-)occurrences during 1990-2019 from Scopus towards sustainable urban development. Engström et al. (2018) have emphasised accounting for the international spillovers of cities' SDG actions. Masuda et al. (2021) have developed an analytical framework covering key components for local-level mainstreaming of the SDGs and then, applied this to Shimokawa & Kitakyushu cities. In recent work, Roy et al. (2022) have shown the interrelationships between environmental resource usage and globalization, which is a key characteristic feature of urban areas. Singh et al. (2021) have reviewed city plans as well as peer-reviewed and grey literature to examine climate change adaptation action for 53 Indian cities with >1 million population.

They have established that 67% of these adaptation actions are merely in the implementation stage, i.e., a long way from achieving sustainability.

Following these, several significant research gaps are identified: (a) there are no studies that use the full spectrum of SDG framework for urban sustainability, and (b) except for reports from SDSN, almost all studies are composed of only one or a few of SDGs, (c) most of the studies on urban sustainability are focused on one topic (e.g., climate change), (d) most of the existing studies only use prevailing analyses instead of incorporating new tools (e.g., data envelopment analysis), (e) there are no such studies for lower-middle highly populated rapidly urbanizing countries like India, that encompasses the features we have mentioned earlier etc. These deficiencies triggered us to compose a comprehensive study that can ensemble solutions for all of these scopes, even with the present data-scarce state (of urban SDG analysis). This work is aimed at understanding the following from the perspective of major cities of India:

- Achievements and shortfalls in terms of SDGs,
- Interrelationships among SDGs,
- Efficiency in utilizing environmental scores towards socio-economic achievements,
- Relative SDG performance with their respective Indian states,
- Interrelationships with other indices of performance,
- Policy suggestions to mitigate the potential drawbacks in the city SDG framework of India.

3. Methodology:

We have collected the SDG scores of 56 Indian cities from NITI Aayog (NITI Aayog 2022). Out of 56, 44 urban units have a population of more than one million. The remaining 12 cities have populations of fewer than a million people. We have not included three SDGs (viz. SDG

14, 15 & 17) as the overall scoring of these SDGs are not available in the dataset. The 77 indicators included here, covers various topics related to urban sustainability, such as - clean energy, climate action, economic growth, education, forests, governance, health, industry, infrastructure, nutrition, poverty reduction, inequality reduction, urban development, water and sanitation, women empowerment etc. We have also collected six indicators relating to Indian cities. These are - carbon footprint (CF) (Moran et al. 2018), population (Pop) (World Population Review 2022), City Competitiveness index (CCI) (CCR 2017), Ease of Living index (EoLi) (EOL 2020), Cost of Living Index (CoLi), and Pollution index (PI) (Numbeo 2022).

To understand the interrelationships between various SDGs, we have used Pearson's correlation. For the assembly of correlation (via correlogram) between various SDG scores for every city included in this study, using the 'pheatmap' (version 1.0.12) packages with R (4.1.5). We have used OriginPro 2021 to create the heatmap of individual and grouped SDGs.

Along with this, we have prepared the hierarchical clustering analysis (HCA) between 2 groups of features, viz. environmental SDGs and socioeconomic SDGs of the cities. We have used within-cluster-sum of squared (WSS) to find cluster numbers via the Silhouette method through Euclidean distance using a single linkage. The Silhouette method determines how well each point fits into its cluster and measures the quality of the clustering. The length of a line segment connecting two locations in Euclidean space is called the Euclidean distance. We have used the 'cluster' (version 2.1.2), 'dendextend' (version 1.15.2), and 'factoextra' (version 1.0.7) packages with R (4.1.5).

The performance assessment approach of data envelopment analysis (DEA) is used to determine the relative efficiency of decision-making units (DMUs). For a given level of socioeconomic development (represented here by socioeconomic SDGs), efficient cities use the fewest environmental resources (represented here by environmental SDGs), whereas inefficient cities use the most environmental resources for the same level of socioeconomic development (represented here by socioeconomic SDGs). The efficiency of a city can be assessed by comparing two environmental SDG inputs and 12 socioeconomic SDG outputs. Based on the applicability of our purpose, we employed input-oriented DEA with the slack-based model (SBM) (Tone 2001) and the variable return to scale (VRS) assumption, which minimises their inputs while maintaining consistent outputs, i.e., the same outputs with less input. According to the concept of returns to scale (RTS), we categorized efficient DMUs into three distinct zones: (a) increasing returns to scale (IRS) zone, (b) constant returns to scale (CRS) zone, and (c) falling returns to scale (DRS) zone. For these analyses, we used the 'deaR' (version 1.2.3) package with R (4.1.5).

The efficient frontier, which splits cities into two divisions, was used to explore a city's relative situation. We've also calculated improvement goals for less efficient cities that are guided by more efficient cities, which can help us better understand the overall scope for improvements among cities in India as well as abroad. An efficient city, in this context, is one in which inputs are kept to a minimum, but constant levels of success are achieved (outputs). The efficiency coefficient of each city (DMU), which ranges from zero to 1, is computed. DMUs with a one-to-one efficiency ratio are deemed efficient and form the efficiency frontier. The remaining DMUs (with an efficiency < 1) are considered inefficient, and targets for improvement can be assigned. The number of DMUs should be 3 times the sum of the inputs and outputs to have sufficient discriminating power (Banker et al. 1989). Another stipulation is that the number of DMUs equals the sum of the number of input and output variables. The input variables are two and the output variables are twelve in this study, and 56 DMUs meet both criteria, culminating in a model with sufficient discriminating power.

According to the concept of returns to scale (RTS), DEA can also categorise efficient DMUs into 3 distinct zones. DMUs can expand their outputs (here, socioeconomic SDGs) at a faster rate than their inputs in the rising returns to scale (IRS) zone (here, environmental SDGs). The input/output ratio (here, environmental/socioeconomic SDG ratio) of DMUs is constantly maintained in the constant returns to scale (CRS) zone. In the decreasing returns to scale (DRS) zone, DMUs' inputs (here, environmental SDGs) are reduced more, while their outputs shrink considerably less (here, socioeconomic SDGs). This study is crucial because it reveals how difficult it is for DMUs (in terms of environmental SDGs) to improve their socioeconomic SDGs. If lambda sum = 1, DMU is in the CRS subzone; if lambda sum > 1, DMU is in the DRS subzone; if lambda sum <1, DMU is in the IRS subzone (Seiford & Zhu 1999).

Due to the nature of the available city SDG dataset (single point, single year), most of the advanced analysis methods, like – different types of regressions, future projection etc. could not be applicable in this study. All the pertinent results related to this study are provided in supplementary file 2.

4. Results

4.1. Performance of city SDGs

We need to understand the performance of Indian cities in SDGs. We have grouped SDGs into 3 categories, based on the 'wedding cake' conceptualization (Folke et al. 2016). This includes economy-related SDGs (viz. SDG 8-10 & 12) on top. These are embedded in society-related SDGs (viz. SDG 1-5, 7, 11 & 16). This group in turn depends on environment-related SDGs (viz. 6, 13-15). Based on this (Fig 1 a-b), the best economically perming cities are Pune, Bhopal, Shimla, Raipur, and Bengaluru. The gap between the best (70.5, Pune) and the worst (38, Dhanbad) performing cities in economic SDGs is 32.5. The average performance of Indian cities in this economic SDG is 57.48. It means, 46.42% of cities have lesser economic SDG scores than the national average. Socially most performing cities are Kochi, Coimbatore, Tiruchirappalli, Panaji, and Shimla. The gap between the best (81.37, Kochi) and worst (53.25, Meerut) performing cities in societal SDGs is 28.12. The average performance of Indian cities in this societal SDGs is 67.33. It means, 46.42% of cities have lesser societal SDG scores than the national average. The top 5 cities for environmental performance would be – Kochi, Thiruvananthapuram, Shimla, Panaji and Shillong. The gap between the best (95.5, Kochi) and worst (47, Dhanbad) performing cities in environmental SDGs is 48.5. The average performance of Indian cities in these environmental SDGs is 68.49. It means, 50% of cities have lesser environmental SDG scores than the national average. Since societal and economic development is well connected and interlinked, we have combined them to yield socio-economic development. Likewise, when we perform the same, we get the best socioeconomically performing cities such as - Shimla, Coimbatore, Pune, Chandigarh, Ahmedabad etc. The gap between the best (72.68, Shimla) and worst (49.5, Dhanbad) performing cities in societal SDGs is 28.12. The average performance of Indian cities in this socioeconomic SDGs is 62.4. It means, 42.85% of cities have lesser socioeconomic SDG scores than the national average. Now, if we see the composite score of all SDGs, the best performing cities are Shimla, Coimbatore, Chandigarh, Kochi, and Panaji. The gap between the best (76, Shimla) and the worst (52, Dhanbad) performing cities in composite SDG is 24. The average performance of Indian cities in this composite SDGs is 64.65. This means, 41.07% of cities have lesser composite SDG scores than the national average. We have summarised a comparative table for different features of individual indicators of each SDG (see Table S.1 in supplementary file 1). The descriptive statistics, based on individual SDGs and indicators data have also been calculated (see Table S.2 & S.3 in supplementary file 1).

For regional aggregation, we have chosen 6 regions. The distribution of 56 cities studied are – central (23%), eastern (11%), north-eastern (12%), northern (18%), western (18%) & southern (18%) regions (see Table S.4, Fig S.1 in supplementary file 1). If we delve into this regional aggregation (Fig 1c), it is seen that for environmental SDGs, southern and western cities perform better than the national average, while eastern, north-eastern, central and northern cities' performance is lesser than that. For economic SDGs, western and central cities perform better than the national average. But, northern, southern, north-eastern, and eastern cities perform lesser. For societal SDGs, southern, western, and northern cities perform better than the national average, whilst north-eastern, central and eastern cities perform less. To sum up, Indian cities of southern, western and northern regions perform better than the national average whilst cities of central, north-eastern, and eastern regions perform less.

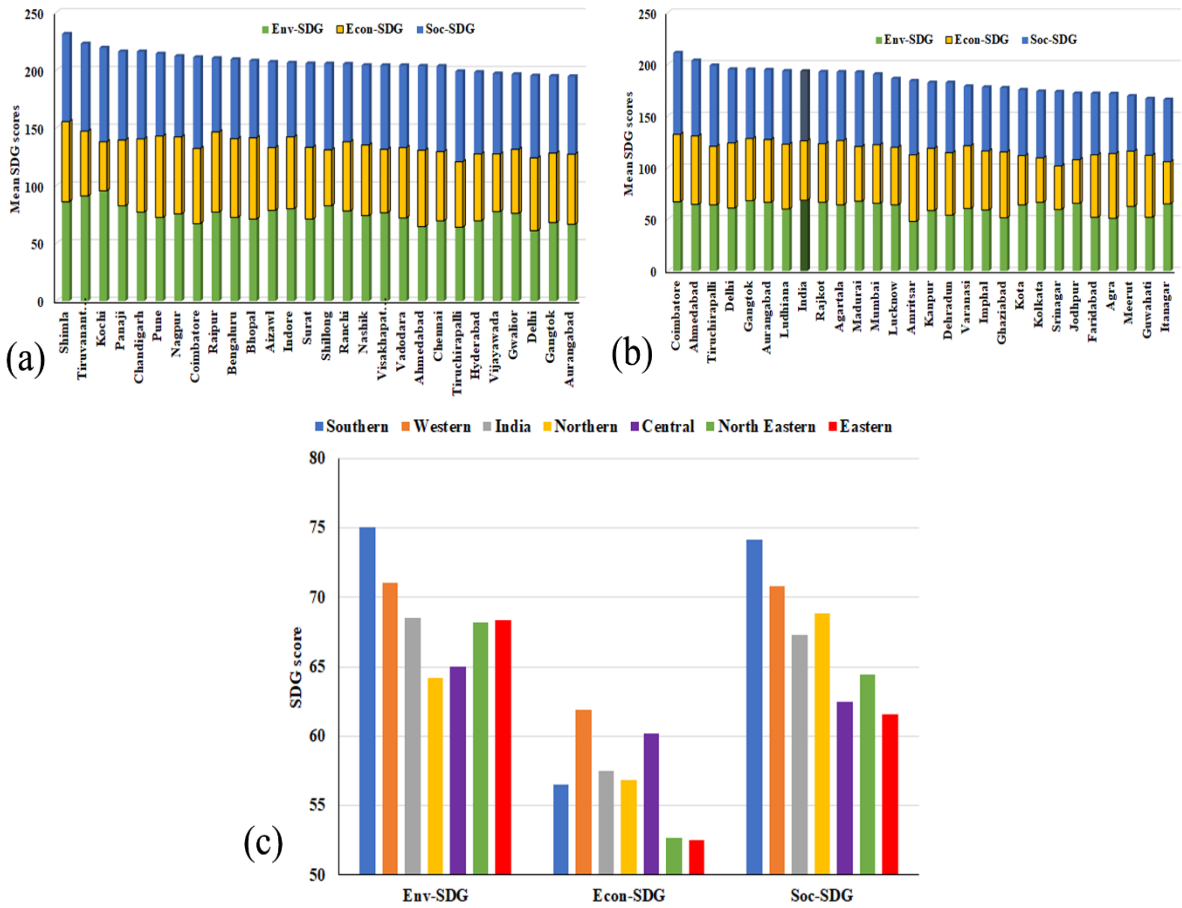
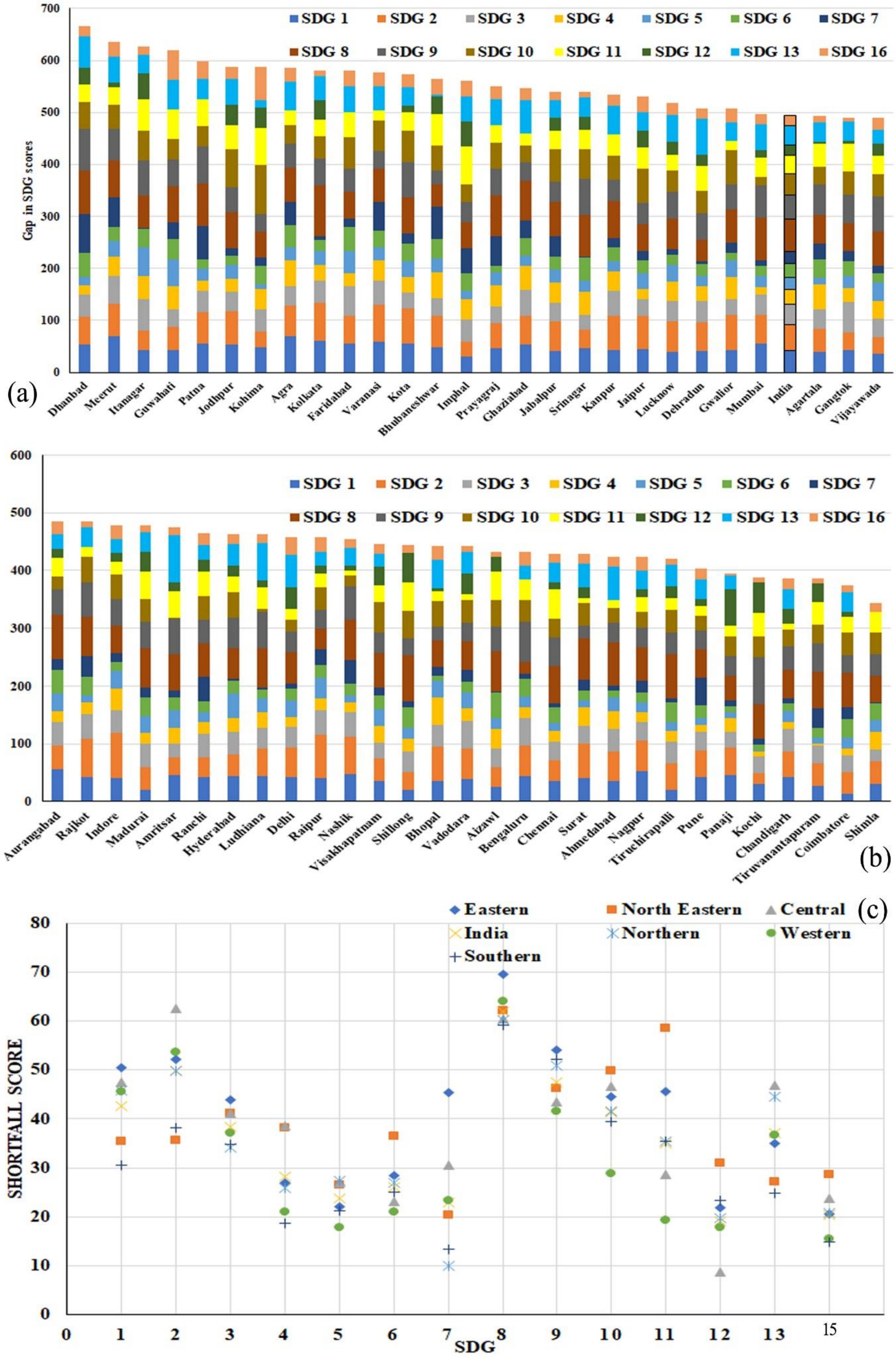


Fig 1. Achieving 3 types of SDGs for 56 Indian cities (a-b) and 6 regions (c). The SDG groups are environmental, economic and societal SDGs. The average score of 3 SDG groups for 6 regions of Indian cities (c).

Now, we understand the shortfalls of individual SDGs for Indian cities (Fig 2 a-b). Based on this, the lowest-performing cities with the highest cumulative gap are Dhanbad, Meerut, Itanagar, Guwahati, and Patna. The national average shortfall in Indian cities is 35.30. The cities with the highest lag in environmental SDGs would be Dhanbad, Amritsar, Agra, Ghaziabad, Faridabad etc. The national average shortfall in Indian cities for environmental SDGs is 31.5. The cities with the highest lag in economic SDGs would be Dhanbad, Itanagar, Srinagar, Jodhpur, Kochi etc. The national average shortfall in Indian cities for economic SDGs is 42.51. The cities with the highest lag in societal SDGs would be Meerut, Bhubaneshwar, Guwahati, Patna, Varanasi etc. The national average shortfall in Indian cities for societal SDGs is 32.66. If we delve into the SDG shortfall of city-regions (Fig 2. c), we see that the average national shortfall would be 35.31. Among 6 regions, 3 regions, viz. southern (30.76), western (31.69) & northern regions (35.25), have a lesser shortfall than the national average. However, the remaining 3 regions, naming central (37.8), north-eastern (38.39) & eastern regions (40.04) have a higher shortfall.



(a)
Gap in SDG scores
SDG 1 SDG 2 SDG 3 SDG 4 SDG 5 SDG 6 SDG 7
SDG 8 SDG 9 SDG 10 SDG 11 SDG 12 SDG 13 SDG 16
0 100 200 300 400 500 600 700
Dhanbad Meerut Itanagar Guwahati Patna Jodhpur Kohima Agra Kolkata Faridabad Varanasi Kota Bhubaneshwar Imphal Prayagraj Ghaziabad Jabalpur Srinagar Kanpur Jaipur Lucknow Dehradun Gwalior Mumbai India Agartala Gangtok Vijayawada
(b)
SDG 1 SDG 2 SDG 3 SDG 4 SDG 5 SDG 6 SDG 7
SDG 8 SDG 9 SDG 10 SDG 11 SDG 12 SDG 13 SDG 16
0 100 200 300 400 500 600
Aurangabad Rajkot Indore Madurai Amritsar Ranchi Hyderabad Ludhiana Delhi Raipur Nashik Visakhapatnam Shillong Bhopal Vadodara Aizawl Bengaluru Chennai Surat Ahmedabad Nagpur Tiruchirapalli Pune Panaji Kochi Chandigarh Tiruvanantapuram Coimbatore Shimla
(c)
Eastern North Eastern Central
India Northern Western
Southern
SHORTFALL SCORE
0 10 20 30 40 50 60 70 80
SDG
0 1 2 3 4 5 6 7 8 9 10 11 12 13 15

Fig 2. Shortfalls in achieving SDGs for 56 Indian cities (a-b) and 6 regions (c). The average shortfall of individual SDGs for 6 regions (central, eastern, north-eastern, northern, southern, & western) of Indian cities (c), for the national average score.

The gap in SDG score (i.e., inequality) of individual cities indicates if the sustainable development has taken synchronously or not. If we assemble different cities as per increasing order of difference between highest and lowest SDG scores, they (SDGs) would be – Composite SDG > 6 > 3 > 4 > 5 > 1 > 2 > 9 > 12 > 16 > 11 > 7 > 8 > 13 > 10. We can see that the top 5 SDGs with less inequality in average SDG score for cities are combined SDG, SDG 6, 3, 4 & % 5. On the other hand, the bottom 5 are SDG 10, 13, 8, 7, & 11. These city SDGs have a large gap in scores among different cities. If we assemble cities of different regions as per increasing order of difference between highest and lowest SDG scores, they (SDGs) would be – Composite SDG > 5 > 3 > 8 > 9 > 16 > 6 > 4 > 1 > 10 > 14 > 12 > 2 > 7 > 11. We can see for Combined SDG, and SDG 5, 3, 8, and 9 have the lowest gap in regional SDG scores with one another. On the other hand, SDGs 11, 7, 2, and 12 have the highest difference among regions. From this, as per the decreasing order of regions with the highest shortfall while comparing with another region would be – Eastern cities (for SDG 1, 3, 7, 8, 9, & Composite) > North-eastern cities (for SDG 6, 10, 11, 12, 16) > Central cities (for SDGs 2, 13, 14) > Northern cities (for SDG 5). Cities of the western and southern regions don't show the highest lag in any SDGs in comparison with cities from other regions of India. We can sum up the main results of SDG performance of Indian cities with respective regions (Table 1).

Table 1. Performance of Indian cities in sustainable development goals.

SDG	**National avg.**	**Highest performers (cities)**	**Inequality (city score)**	**Lowest performers (cities)**	**Highest perfor**	**Inequality**	**Lowest perfor**

					mer (region)	**(region score)**	**mer (region)**
	57.3	Coimbatore, Madurai, Shillong,	56	Agra, Meerut, Kolkata,	South	20	East
	50.14	Kochi, Imphal, Kohima,	58	Indore, Raipur, Kolkata,	North-East	26.9	Central
	61.62	Shimla, Amritsar, Panaji,	40	Itanagar, Gangtok, Faridabad	North	9.8	East
	71.69	Thiruvananthapuram, Kochi, Chandigarh,	46	Bhubaneshwar, Agra, Bhopal,	South	19.94	Central
	76.19	Kochi, Thiruvananthapuram, Kohima,	53	Itanagar, Guwahati, Hyderabad,	West	9.6	North
	74	Bhopal, Kochi, Panaji,	39	Faridabad, Dhanbad, Srinagar,	West	15.33	North-East
	77.16	Shimla, Srinagar, Itanagar,	74	Dhanbad, Patna, Bhubaneshwar,	North	35.44	East

8	38	Bengaluru, Raipur, Panaji,	76	Kolkata, Dhanbad, Patna,	South	10.4	East
9	52.5	Surat, Bhopal, Bhubaneshwar,	59	Kochi, Dhanbad, Patna,	West	12.4	East
10	58.55	Amritsar, Ludhiana, Mumbai,	92	Kohima, Jodhpur, Gwalior,	West	20.96	North-East
11	65.01	Nashik, Surat, Chandigarh,	66	Imphal, Kohima, Itanagar,	West	39.13	North-East
12	80.89	Guwahati, Patna, Faridabad,	62	Panaji, Kochi, Itanagar,	Central	22.3	North-East
13	62.98	Kochi, Shillong, Thiruvananthapuram,	82	Amritsar, Dehradun, Ludhiana,	South	22.03	Central
16	79.53	Panaji, Gangtok, Kochi,	62	Kohima, Guwahati, Patna,	South	13.82	North-East
	64.67	Shimla, Coimbatore, Chandigarh,	24	Dhanbad, Itanagar, Meerut,	South	9.1	East

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4.2. Interactions among city SDGs

We infer the interrelationships among individual and SDG groups via heatmap, correlation and hierarchical clustering. For individual SDGs (Fig 3a, also Fig S.2 in supplementary file 1), 2 major clusters are seen, one with SDG 4, 5, 6, 7, 12 & 16; another with SDG 1, 2, 3, 8, 9, 10 & 13. We have also performed Pearson's correlation for individual SDGs as well as composite SDG scores (Fig 3b). Here we can see two major clusters. One is composed of SDGs 1, 2 & 7. Another cluster is composed of 4 sub-clusters. They are SDG 8 & 9; SDG 6 & 11; SDG 4, 10 & 16; and SDG 3, 5 & composite score. SDG 12 does not belong to any of the clusters. It is seen that except for SDG 10 & 11, there is a negative correlation between SDG 12 and all the rest. If we arrange the individual SDGs as per count of negative correlation with any other SDG or composite score, it would be SDG 12 > 9 > 2 > 8 > 11 > 13 > 6 > 10 > 16 > 1 > 4 > 5 > 7 > composite > 3. These indicate a handful of trade-offs (i.e., not synergy) among various city SDGs in India. For example, the top 5 negative correlated SDGs are SDG 2 (zero hunger) - 11 (sustainable cities & communities), SDG 2 - 12 (responsible consumption and production), SDG 11- 13 (climate action), SDG 1 (no poverty) - 12, SDG 10 (reduced inequalities) - 13. To sum up, we can see that achieving socioenvironmental targets in cities is getting hindered by economic targets and vice-versa. For SDG groups (Fig 3c, also Fig S.3 in supplementary file 1), we can see that environmental and social SDGs form a cluster that is distant from economic SDG scores. We have executed Pearson's correlation for SDG groups along with composite SDG scores (Fig 3d). Here, we can see that environmental, social and composite SDGs come within a cluster, but economic SDG does not. It is also seen that socioenvironmental SDGs have no high level of positive correlation with economic SDGs. Also, the social SDGs have the highest positive correlation with composite SDGs.

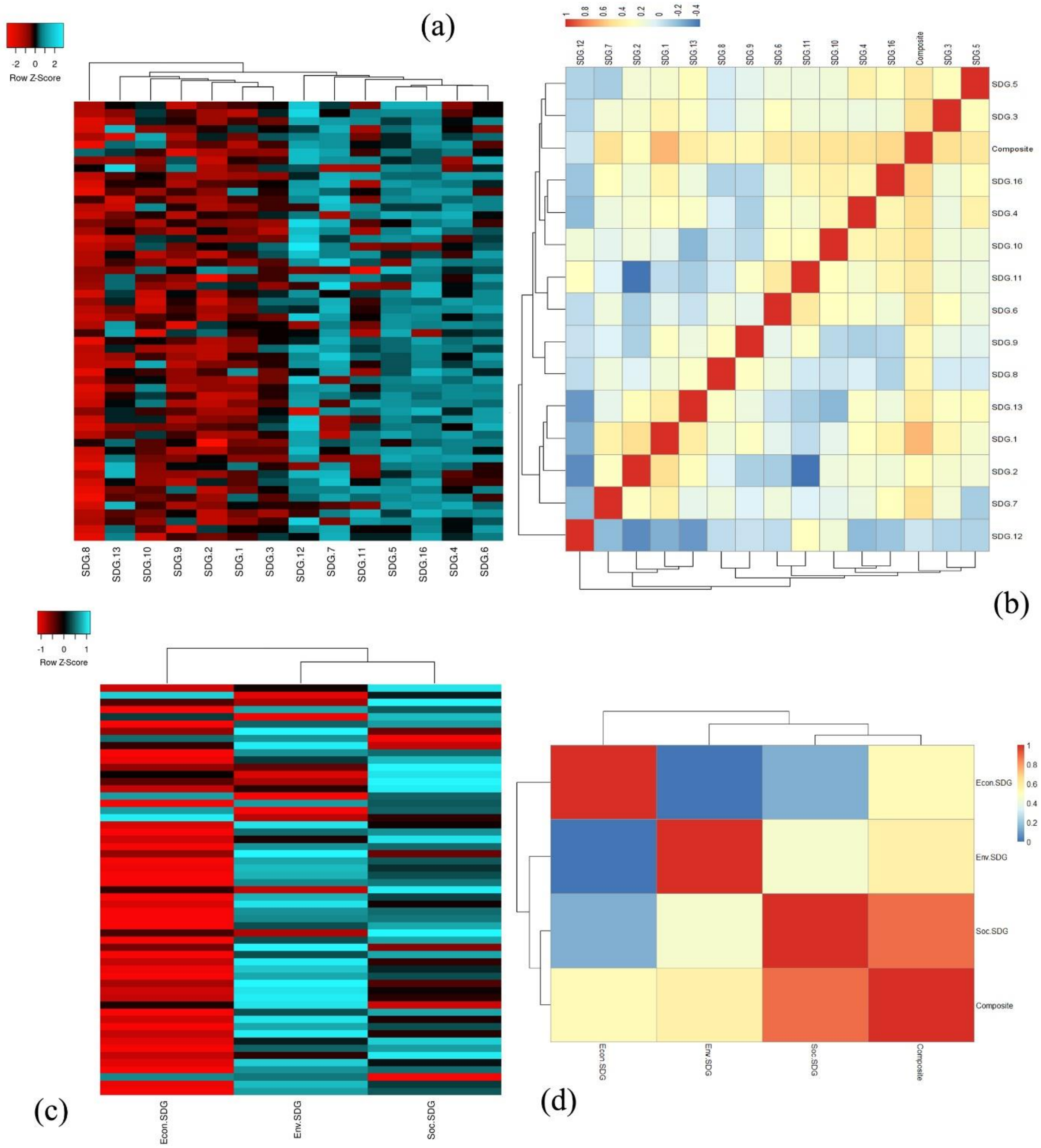

Fig 3. Interrelationships among SDGs for different cities of India.

(a) Heatmap of individual SDGs; (b) Pearson's correlation (correlogram) of individual SDGs; (c) Heatmap of environmental, social and economic SDGs; (d) Pearson's correlation (correlogram) of environmental, social and economic SDGs;

We have performed the hierarchical clustering analysis (HCA) using 2 groups of data. First, we have used environmental SDG scores as input and economic SDGs & societal SDGs as output (Fig 4.a, also Fig S.4 in supplementary file 1). Second, we have used a similar framework, but individual SDG scores as input as well as output (Fig 4.b, also Fig S.5 in supplementary file 1). In both cases, we have determined the optimum number of clusters as 5. From the first method, we can see on the left side that only 2 cities form the highest environmental performing cluster (sky-blue colour), and only a handful form the cluster of lowest environmental performance (blue colour). The middle 3 clusters (orange, grey, and red coloured), which can be interpreted as better, intermediate and lower environmental performance, are composed of an almost similar number of cities. This means, from the perspective of environmental SDGs, Indian cities fall into various categories with a similar number of members. On the right side, 3 clusters (orange, sky blue and red coloured) are formed by only a handful of cities, viz. 4, 6 & 10 in number, respectively. The remaining 2 clusters (grey and blue coloured) are composed of an almost similar number of members. A similar situation is seen in the second method (Fig 4. b), i.e. when we consider individual SDG scores instead of average grouping scores. These results indicate that higher environmental SDG performance is not corresponding to better performance in economic and societal SDGs. This is evident when we track the performance of each city independently. Likewise, better performance in economic and societal SDGs does not mean that the cities have achieved similarly environmental SDGs.

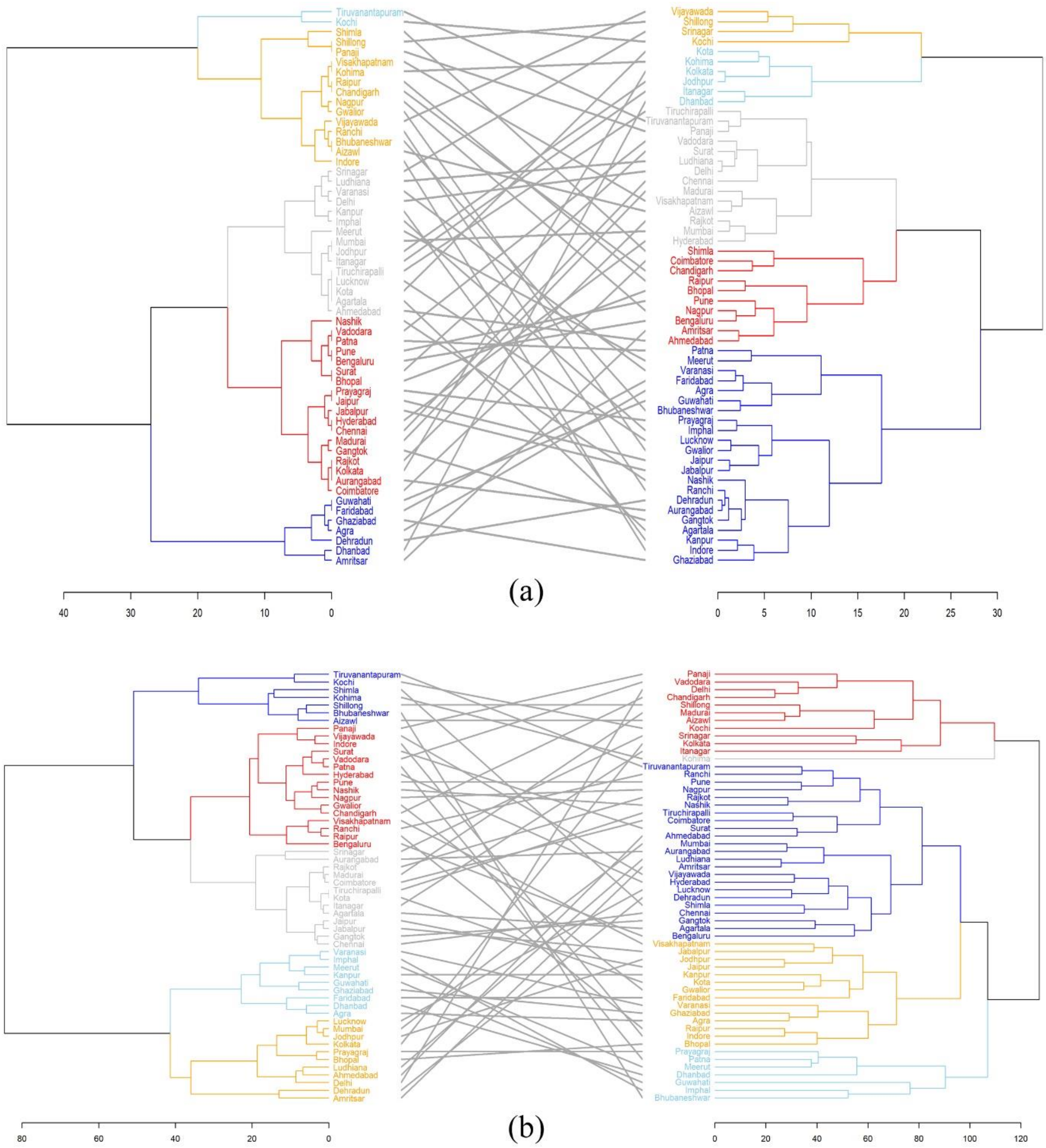

Fig 4. Hierarchical clustering analysis for cities of India (via tanglegram).

(a) Environmental SDGs (*left*) and socioeconomic SDGs (*right*), using average scores. (b) SDG 6 & 13 (*left*) and SDG 1-5, 7-12, 16 (*right*), using individual SDG scores.

4.3. Efficiency of city SDGs

We next employ data envelopment analysis (DEA) to assess the connecting efficiency of 56 Indian cities. For this, we have used individual SDG scores of 56 cities. Environmental SDGs were used as input and societal & economic SDGs were used as output. This exploration is focused on finding out the efficiency of Indian cities in translating better environmental features into socio-economic prospects or lack thereof. The efficient & inefficient cities are 10 (i.e., 17.85%) and 46 (82.14%), respectively (Fig 5. a).

Linear combinations of indicator values in a group of comparable cities are used to generate improvement targets. Improvement targets point to the modifications that must be created to improve an inefficient DMU efficiency. Peer cities are thought to be following best practices, therefore inefficient cities should aim to emulate their behaviour as much as feasible. Only a handful (n=8, i.e., 14.28%) of cities have acted as peers for ≥3 times (Fig 5. b). They, along with the times of appearance as references, are – Amritsar (9), Dehradun (6), Coimbatore (6), Tiruchirappalli (3), Srinagar (3), Ghaziabad (3), Dhanbad (3) and Delhi (3). The inefficient cities concerning their efficient frontiers are shown here (Fig 5. c).

The idea of a return to scale provides insight into the environmental efficiency of DMUs' socioeconomic development (i.e., cities). It determines if the ratio of inputs (environmental SDGs) to outputs (socioeconomic SDGs) for a DMU is more productive or less productive. From the result, we can see that only Jaipur belongs to the DRS sub-zone. This means Jaipur shows decreasing socioeconomic return in terms of SDGs for more environmental input. Only 3 (i.e., 5.35%) cities (viz. Indore, Lucknow & Ranchi) belong to the IRS sub-zone. This means these 3 cities show higher socioeconomic returns for environmental input. All the remaining (i.e., 52 or 92.85%) cities belong to the CRS sub-zone. This means a majority of Indian cities, at this stage show, an equal amount of socioeconomic return from environmental input.

The results clearly show that there are 10 (or 17.85%) cities that are inefficient in this translation (Fig 5.d). These cities, along with their efficiency scores, are – Meerut (0.74), Jodhpur (0.79), Indore (0.815), Jabalpur (0.817), Ranchi (0.853), Lucknow (0.858), Kolkata (0.86), Kota (0.88), Jodhpur (0.931), and Madurai (0.936).

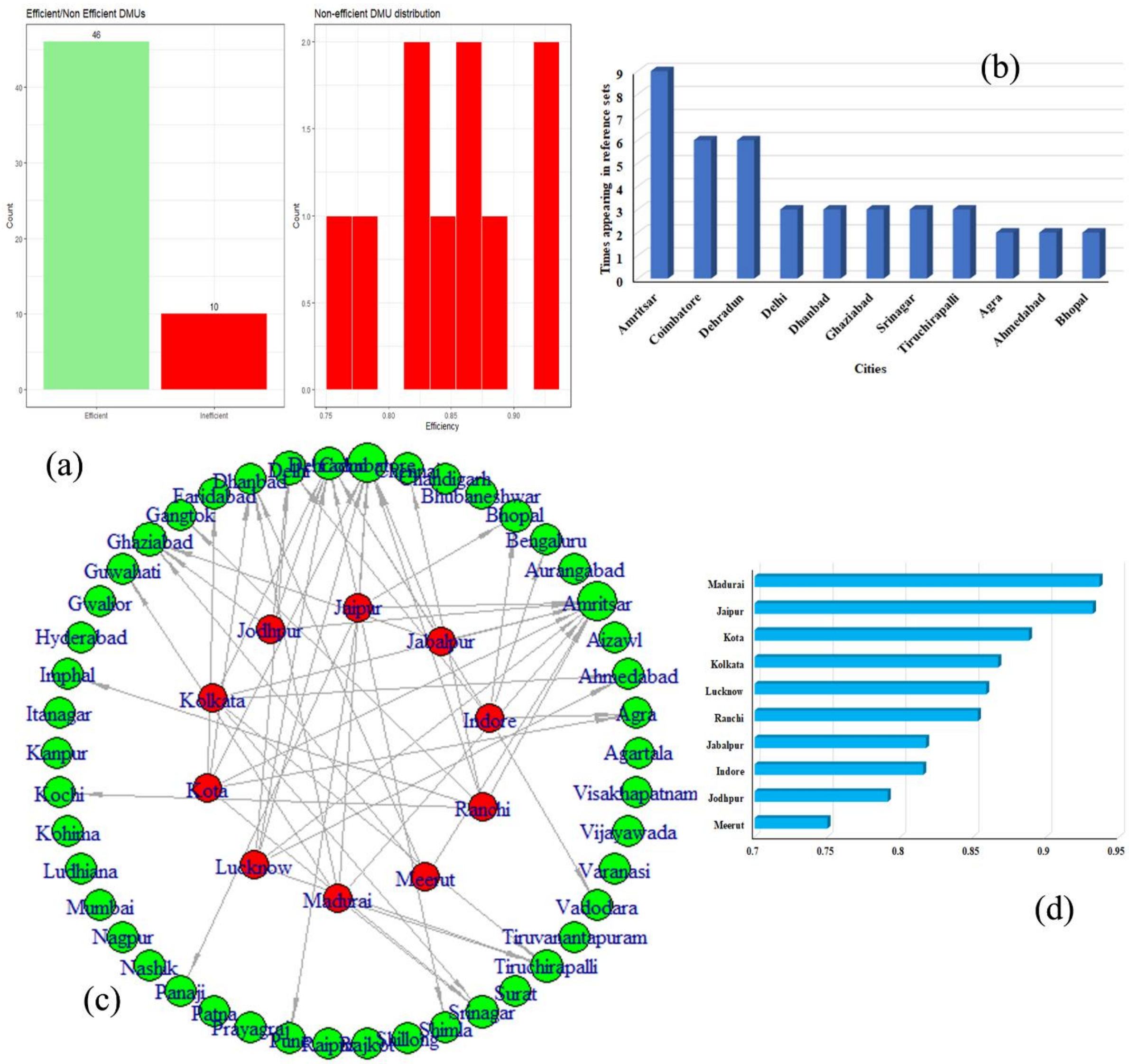

Fig 5. The efficiency of converting environmental SDGs into socioeconomic SDGs.

(a) Grouping of efficient and non-efficient DMUs (cities, n=56) of India; and Distribution of efficiency score for non-efficient DMUs (cities of India). (b) Ranking of efficient DMUs (cities) acting as peers (≥2 times) in reference sets. (c) Non-efficient DMUs (10 cities, *red, inner circle*) and their respective reference efficient DMUs (46 cities, *green, outer circle*). (d) Efficiency scores (0.74 to 0.93, here) for 10 inefficient cities in India.

4.4. SDG performance of Indian cities vs Indian states

We need to understand whether the SDG performance of cities is better or worse than their state SDG scores. To understand this, we have created a comparative index of the relative SDG performance of cities. The relative performance of the city in SDG = (city SDG score/ state SDG score). We can also multiply this ratio by 100 to convert the performance scale into a percentage (%). We have done this for each of 56 cities for each SDG as well as composite SDG score (see Fig S.6 in supplementary file 1). It is a general assumption that cities are responsible for the betterment of states or the forward advancement of states since districts have much lesser facilities than cities in terms of employment generation, access to education, health services etc. Hence, in this case, most of the cities are supposed to perform better than their respective states. However, the results show a completely different picture. If we group the relative performance into 3 groups, we can see that only 19 relative performance scores (i.e., 2.26%) in any one of the SDGs are similar to the state performance (=1). Of the remaining, 460 relative performance scores (i.e., 54.76%) are worse performers than the state (<1), whilst the remaining (i.e., 361 or 42.97%) are better than the state performance (>1). From this, we can interpret that in the case of most of the cities, other regions in their state (especially villages or smaller cities) must have performed better to bring up the average state SDG performance better than these highlighted cities. The top 10 cities that have outperformed their state in a specific SDG would be Patna (SDG 4, 13), Ranchi (2, 13), Shillong (9), Dhanbad (2), Agartala (5), Kohima (9), Delhi (5), and Bhopal (9). The worse 10 cities that have lesser performance than their state in a specific SDG would be Kolkata (SDG 8), Kohima (10), Mumbai (8), Dhanbad (8), Shillong (8), Patna (8), Amritsar (13), and Tiruchirappalli (8). However, we think that the inclusion of more representative cities would have been helpful to conclusively understand this outcome.

4.5. Interrelationships with other city performance indices

In this section, we try to infer if any relationships exist between SDG scores of Indian cities with some other indicators. Based on the availability of data, we have composed a heatmap (Fig 6. a) to understand the distribution of data. We have also coupled it with clustering to infer associations among different indices. From the heatmap, it is seen that there are some data gaps, especially in CF, CoLi, CCI & PI. The rest of the indices have a good abundance of data to infer relationships. We have applied clustering based on the average linkage with Euclidean distance. The length of a line segment connecting two locations in Euclidean space is called the Euclidean distance. It can be seen that 4 indicators (viz. CCI, CoLi, PI, & EoLi) are closely associated with SDG in cities. Then, Pop and CF are clustered in order.

From the correlogram (Fig 6. b), there are a few things to be seen. First, some relationships with a lesser degree of positive associations exist. They are between CF-SDG, EoLi-PI, CoLi-PI, EoLi-CF, EoLi-Pop, PI-CCI etc. Second, some relationships of the intermediate degree of positive associations exist. They are between SDG-CoLi, SDG-CCI, SDG-CoLi, EoLi-CoLi, etc. Third, some relationships with a higher degree of positive associations exist. They are SDG-EoLi, EoLi-CCI, PI-CF, PI-Pop, CF-Pop, CF-CCI, CF-CoLi, Pop-CCI, Pop-CoLi, CCI-CoLi etc. Fourth, only three negative correlations exist, which are SDG-CF, SDG-Pop, & SDG-PI, to an increasing degree. If we focus on the relationships regarding city SDGs, it is easily understandable that the level of pollution index (PI), carbon footprint (CF), and population (Pop) are negatively correlated with city SDGs. The pollution index is a measure of the city's overall pollution. Air pollution is given more weight than water pollution/accessibility, the two main pollution issues. Other types of pollution are given a low priority (Numbeo, 2022). So, higher pollution levels would hinder the achievement of environmental SDGs, and in turn also other socio-economic achievements. The carbon footprint of consumption would work on a similar path. An increase in population would trigger the higher requirement of environmental resources as well as lesser performance in environmental SDGs, which is coupled with a lack or higher competition in access to goods and services related to socio-economic development, i.e., in societal and economic SDGs. The Ease of Living Index assesses the well-being of Indian city dwellers based on four main pillars: Quality of Life (35% weightage), Economic Ability (15%), Sustainability (20%), and Citizens Perception Survey (30%). It means the cities that are easier to live in would be placed higher in SDG scores. The City Competitiveness Index (CCI) measures the competitiveness of Indian cities across a variety of metrics. It employs Michael Porter's Diamond Model framework (Porter, 1998), which defines competitiveness as the sum of factor conditions, demand conditions, the backdrop for firm strategy and rivalry, as well as connected and supporting sectors. It is made up of four pillars that are divided into 12 sub-pillars to map all of the city's important dimensions. These four pillars are - factor conditions, demand conditions, the context for strategy & rivalry, and related & supporting industries. We can see the more competitive the cities are, the better the SDG performance. The cost-of-living index (CoLi) is measured relative to New York City. It is a measure of the relative cost of consumer products, such as - groceries, restaurants, transportation, and utilities. This means inhabiting cities with overall better performance in SDGs usually costs more.

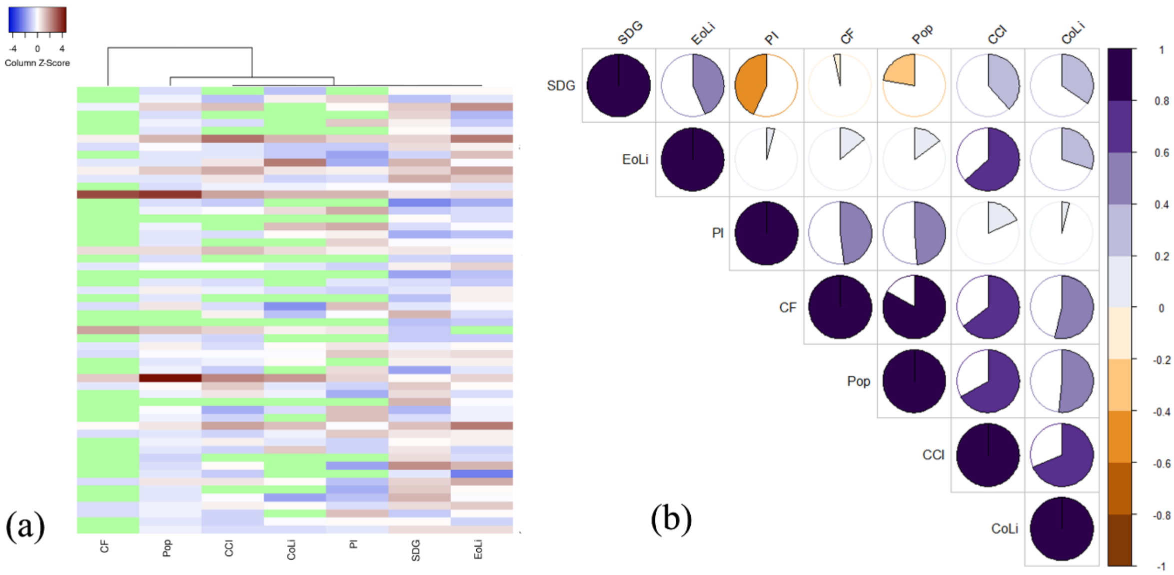

Fig 6. Interrelationship of city SDGs with other indicators. The other 6 indicators are carbon footprint (CF), population (Pop), city competitiveness index (CCI), cost of living index (CoLi), ease of living index (EoLi), and pollution index (PI). (a) Clustered heatmap (data gap represented by light green cells), (b) Correlogram (negative to positive).

5. Limitations and policy recommendations

This work has a few limitations, which could also be viewed as prospects for future research as well as scopes for policy implementations coupled within.

First, pertinent and reliable city SDG data management. The dataset prepared by NITI Aayog is full of data gaps, especially regarding individual indicators of SDG. Also, 3 SDGs (14, 15 & 17) are practically omitted from the dataset. SDG 14 (life below water) is completely absent. NITI Aayog has suggested that SDG 14 is excluded since its only important for coastal areas. We suggest that when consumption-based impacts are measured (via footprint, LCA etc.), major cities do have indirect yet significant connections with life below water (i.e., SDG 14). SDG 15 has only 2 indicators included, which don't even have rounded overall scores. NITI Aayog has also suggested that SDG 17 (partnerships for the goals) is not relevant at the urban local body level. We can also argue that to understand synergy & trade-offs, negative and positive feedback among SDG 1-16, and SDG 17 is essential. This has hindered us in many ways to explore deeper into urban sustainability assessment. Authority with whom the data management has been entrusted (here, NITI Aayog) should resolve this. *Second*, less comprehensive dataset. If we compare the city SDG dataset of India with Europe or the US city SDG dataset, we could find a potential drawback. For 4 SDGs, namely SDG 7, 9, 11 & 15 the number of indicators used for Indian city SDG indexing fall short by 1 (than the USA), 1 (Europe), 6 (Europe) and 2 (Europe) indicators (see Fig S.7 in supplementary file 1). It is a general understanding that robustness can be achieved via data abundance. Hence, it is suggested to incorporate more indicators, especially for those SDGs. *Third*, short dataset. Indian city SDG dataset is composed of only 1 set of data. This specifically stops the temporal assessment as well as a future projection which are of absolute necessity if India wants to comply with the UN SDG by 2030 for urban locations. *Fourth*, of the nearly 400 cities inhabited by million+ citizens, this dataset only includes 56 cities. For many states, there is only a single representative city whilst there are dozens more. Though these cities might not be of national scale importance, these should be included to enrich heterogeneity and representation of Indian city SDG. *Fifth,* is the suitability of urban SDG. At least 35% of urban citizens in India are living in slum areas (2018 data, World Bank 2022). Hence, to practically implement the 'leave no one behind' agenda in urban areas of India, the SDG framework should be an inclusive, equity-based measurement of SDG progress. We suggest that initiating people and authorities of these regions are of utmost importance if the Indian urban SDG don't want to be selectively applicable. *Sixth,* is the need for co-creation, i.e., stakeholder dialogue and engagement. The goal of these urban SDGs is to prioritise performance over in-depth, locally relevant examinations of the causes of complex challenges like urban inequality and poverty. Each urban local government should choose an appropriate indicator set that is both realistic and feasible on the one hand, and challenging and helpful in promoting its urban sustainability transition or even more substantive transformation on the other, ideally in consultation with its respective regional and national departments and ministries, as well as national associations of local governments. In a variety of circumstances, the UN-recommended SDG indicators may prove difficult to implement and ill-suited for local applicability. And here comes the scope of co-creating urban SDGs. *Seventh*, philosophical challenges of urban SDGs. There is a clear risk that sectoral interests will take precedence over the agendas' longer-term objectives. Most local governments are still organised by sector, which makes it difficult to do the integrated, cross-cutting, and collaborative work required to achieve UN SDG agendas. *Eighth,* embracing complexity in the system framework. The potential conflicts, synergies, and trade-offs between the actions aimed at achieving the SDGs must be accounted for in these studies. This should include a discussion of the agendas' 'blind spots', or subjects that aren't covered or aren't given enough consideration. *Ninth*, is the adoption of transformation pathways. The ability to monitor and evaluate progress and alter the course of action as needed will play a role in realising the transformative potential of these agendas at the local level. On the other hand, when available, city governments can use their existing monitoring systems to supplement them with applicable and locally adapted SDG indicator frameworks. *Tenth*, integrating governance. A key aspect of the UN SDG is the integrated nature of sustainability, i.e., the importance of addressing the social, environmental and economic dimensions of sustainability in unison. This requires multi-level collaboration and real- data-enriched and adaptive governance. It includes horizontal collaboration (between entities and actors at the same level), vertical collaboration (between actors at different levels, such as national, regional, and local), and collaboration among different types of actors. If needed, based on various features of cities, like – culture, geographical location, employment generation etc., each city can make their customized framework of law & rules to implement and abide by. *Eleventh*, financing city sustainability.

Local governments or higher authorities need to come up with feasible financial plans. These funds could emerge from positive outcomes of various sustainability projects which are economically efficient and then be inserted again for betterment. If need be, city authorities can borrow funds from national or international funding agencies. This aspect is of special significance for lower-middle-income economies like India.

6. Conclusion

This study has examined the performance, interrelationship, and efficiency of SDGs in 56 major Indian cities. To sum up the important results of this study, as for the SDG performance, regarding environmental SDGs, the as per the order of performance, southern > western > eastern > north-eastern > central > northern region cities. For economic SDGs, this order would be western > central > northern > southern > north-eastern > eastern region cities. For societal SDGs, this order would be southern > western > northern > north-eastern > central > eastern region cities. For overall SDG score, this order would be southern > western > northern > central > north-eastern > eastern region cities. We also see there is a significant degree of inequality among cities of various regions towards achieving SDGs. Based on the inequality of various SDGs, the order would be eastern > north-eastern > central > northern region cities. From the Pearson correlation, we see that SDG 12 does not form any cluster with any other SDGs, as well is negatively correlated to all SDGs (excluding SDG 10 & 11). Based on the number of positive correlations with any other SDGs, the order is 3 > composite > 7 > 5 > 4 > 1 > 16 > 10 > 6 > 13 > 11 > 8 > 2 > 9 > 12. This gives proof of the variable degree of synergy among various SDGs related to Indian cities. From the nature of clustering, accomplishing socioenvironmental goals is hampered by economic goals in Indian cities, and vice versa. Environmental and social SDGs comprise a cluster that is separated from economic SDGs for both individuals and grouped SDGs. Higher environmental SDG performance does not equate to better success in economic and societal SDGs, according to the results of hierarchical clustering. Similarly, improved success in the economic and sociological SDGs does not imply that cities have achieved equivalent outcomes in the environmental SDGs. The results from DEA clearly show that there are 17.85% of cities are with a poor track record of converting environmental performance into socioeconomic prosperity. Furthermore, in their current state, the bulk of Indian cities exhibit an equal degree of socioeconomic return from environmental input (i.e., in the CRS zone). We think this proves a serious scope for decoupling economic growth from the environment, meaning the path towards better socioeconomic development must not come from an environmental cost. When we see the relative SDG performance score of cities with their respective states in India, we see that nearly 55% of cities are worse performers than the state. This suggests that other regions in Indian states (especially villages or smaller towns) must have performed better than these highlighted cities to improve the average state SDG performance. From the interrelationship with other performance scores, a few results come up about Indian cities. Higher levels of pollution and consumptive carbon footprint would obstruct the attainment of environmental SDGs, as well as other socioeconomic goals. An increase in population would result in a greater demand for environmental resources and lower performance in environmental SDGs, which would be accompanied by a lack of or increased competition in access to goods and services related to socio-economic development, i.e., in societal and economic SDGs. SDG scores are higher in cities that are easier to live in. The better the SDG performance, the more competitive the cities are. It is frequently more expensive to live in cities with greater overall SDG performance.

We think this work is the first of its kind, based exclusive on India, dealing with urban sustainability based on the UN SDG framework, on a comprehensive scale. This study has many new contributions, not seen in previous studies in similar urban sustainability research domains: (1) including almost all of the SDGs in the city sustainability framework, instead of the traditional usage of 1-2 SDG indicators, (2) examining the links utilising different tools (i.e., analyses) than those commonly used, as evidenced by the literature, (3) exploring interrelationships among various SDGs at an individual city level, (4) interpretation of efficiency of Indian cities, (5) formulation of relative SDG performance measurement, not prevalent in concerning literature, (6) exploring connections of some other performance indices with SDG scores, etc.

While not exhaustive, the results came out intertwined with the thoughts provided in this work could provide evidence-based observations on issues that should be considered for a more open and comprehensive process in the formulation and implementation of these global UN SDG objectives at the local level. The agendas' complexity and breadth, as well as their inclusive and participatory goals, necessitate an integrated governance approach that facilitates the formation of partnerships and dialogues between different levels of government (both horizontally and vertically within a single urban agglomeration), across sectors, and with various societal groups. Innovation and cross-sectoral collaboration are essential to achieve the aims of the SDG agendas. Only 8 years are remaining (2022-2030) to achieve the UN’s SDG 2030 agenda (see Fig S.8 in supplementary file 1). The urban areas of India need special focus as the nature of the socioeconomic stage of development as well as ongoing and potential biophysical resource scarcity problems would affect the city-dwellers harder. We think the singular focus on economic development is about bringing inequalities in access to various societal services, coupled with the scarcity of a range of biophysical resources, which are vital for the everyday life of urban citizens. Local government and administrators should be able to understand critical aspects of a city's social, economic, and environmental performance through city-level sustainability assessments so that cities can be planned and managed to meet the needs of all residents while ensuring that environmental pressures do not exceed key thresholds. The SDGs can help with such judgments by offering a widely legitimate, goal-oriented framework and dashboard of objectives and indicators that encompass social inequality issues more comprehensively than prior sustainability assessment frameworks. Cities are the primary drivers of the global consumption of goods and services, hence the metrics utilised in SDG evaluation must be consumption-based. Cities' impacts or environmental threshold coherence offers significant wasted potential for influencing sustainable urban development. Interdisciplinary research is needed to measure, explain, and assist alleviate the effects of urban consumption. This initial step necessitates ongoing collaboration among earth system, natural, environmental, system, and economic scientists to better understand the interlinkages among urban activities, consumption-based environmental footprints, and city planetary boundaries (for PB of Indian city Mumbai, Hoornweg et al. 2016), as well as dynamic interactions and system reactions. We suggest that, if the sustainability of Indian cities is not taken seriously, it might thwart the regional as well as national progress of India to achieve sustainable development goals by 2030.

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