Mediation effect of diversity and availability of high transit service on transit oriented development and spread of COVID-19

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Abstract
The impact of the novel coronavirus disease (COVID-19) continues unabated. Still, it seems that apart from contact and respiratory transmission, the design and development pattern of an area does echoes to be a contributing factor in virus spreadability. The present study considers land use and transportation system parameters under TOD mode of 16 BRT station provinces in Bhopal, India, and COVID-19 cases data were collected from April 2020 to August 2020. Further, the Pearson correlation and mediational analysis were employed to determine the relationship between TODness and COVID-19 spread cases. The bootstrapping method was used to evaluate the mediation effect and describe why and under what conditions they are related. The study shows that TODness and COVID-19 spread cases are positively correlated. The results show a considerable correlation at \( p < 0.05 \) is 0.405 of the dispersed along with TODness of an area in the analysed 16 BRT station areas. In particular, dispersed demonstrated a high-level correlation of 0.681 with TOD areas, whereas a moderate correlation of 0.322 with non-TOD areas was mediated by diversity and the number of available transit service indicators. Diversity and availability of high-quality transit services effectively spread the virus, whereas population density and public transport mediation effects are insignificant. Outcomes from this study may help government authorities and policymakers devise a strategy and adopt preventive measures in subsequent waves of the pandemic.

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Graphical abstract

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1 Introduction

The novel coronavirus disease (known as COVID-19, introduced by the contamination of SARS-CoV-2), first recognized in December 2019 in China, is spreading across countries and metropolitan networks. Globally, almost all the countries have undergone complete lockdown for 1 week to several weeks at first, depending upon its ill effects. It is accepted that the COVID-19 infection began at a city “wet” market in Wuhan, a flourishing city in China’s urbanizing rapidly with a modern focus (Chakraborty et al., 2020).

The first instance of the COVID-19 case in India was accounted for on 30 January 2020, which originated in China. India has the most confirmed number of COVID-19 cases in Asia and, in April 2021, became the second-most noteworthy number of confirmed cases worldwide after the USA, with more than 20.4 million announced instances of COVID-19 contamination and above 299,000 passing’s as of 23 May 2021 (Novel Coronavirus (COVID-19) Cases, JHU CSSE, 2020). In mid-September, cases were at the peak in India with more than 90,000 cases and have since come down to under 15,000 starting in January 2021. The migrant worker’s contribution to the scattering of COVID-19 is very high, which triggers the virus to disperse quickly at the regional level. Upward high-rise density is an essential trait of urban areas focused across the globe. However, though the aggregation of more individuals in less space can undoubtedly decrease the size of society’s environmental footprints, a circumstance where individuals are progressively squeezed against one another in complex multi-storey constructed buildings connected through worldwide progressions of voyagers, merchandise, and thoughts (and frenzy) convolutes the need to control contamination, obviously at present it is spreading rapidly worldwide. The stressing
angle is this and was notable prior to the current emergency. We have had precise information on the interchange between disease and density and the related subtleties and intricacies since the 1920s. Urban areas unite individuals to make energetic business sectors. Dense and enormous urban communities sustain financial success by encouraging productive social and monetary collaborations and individuals’ information.

Until COVID-19 has no effective treatment, several efforts are made to understand the dynamics of infection. Based on the available pandemic information, researchers have been active in understanding the factors that anticipate its spread. The modelling of any virus propagation depends on the multiple factors related to the disease. Some research stated that the COVID-19 virus is related to the factors such as temperature, humidity, wind speed, population density, travel history, and urban mobility (Basir et al., 2020; Khadi & Khelfaoui, 2020; Sachin, 2020). However, some consider population density to be the reason for the spread of SARS-CoV-2 because it builds individual-to-individual contact potential. It is a natural process. However, it neglects to clarify why the numbers of COVID-19 cases differ between the cities, notwithstanding similar city-level densities. Foundational well-being and social and monetary differences have put minorities and economically vulnerable communities in more danger than others. There is an immediate necessity to build up a region-level study that can catch vulnerable communities’ heterogeneity. While (Bhadra et al., 2021) find a moderate association between Covid-19 spread and population density. (Sy et al., 2021) findings suggest that dense areas increase contact rates necessary for disease transmission. SARS-CoV-2 R0 estimates need to consider this geographic variability for proper planning and resource allocation, particularly as epidemics emerge and old outbreaks resurge. (Hamidi et al., 2020) stated that higher densities have significantly lower virus-related mortality rates than counties with lower densities. The Johns Hopkins—Utah stated that the metropolitan populace is one of the main indicators of contamination rates while county density had no huge relationship with disease rate. (Khavarian-Garmsir et al., 2021) found that density alone cannot be considered a risk factor. Some studies recommend that mode choices will presumably be changed post-covid-19, with an obvious shift away from public vehicles to walking, cycling or personal vehicle expected, temporarily. The review proposes that Mumbai, Delhi, and Kolkata might encounter more modest movements from public vehicle modes when contrasted with Ahmedabad, Chennai and Hyderabad. Different implementable measures have been appraised by the respondents towards tending to the issues while going through public transportation (Transport and Communications Bulletin for Asia and the Pacific No. 90, 2020). (Marra et al., 2022; Tira-chini & Cats, 2020) stated that people perceive public transportation as unsafe during pandemic times resulting in an unprecedented decline in public transport demand and revenue generation. (Park & Kim, 2021) developed a model for determining the risk of COVID-19 infection on public transportation, considering exposure time, mask efficiency, ventilation rate, and distance.

In any event, briefly, COVID-19 has changed many countries’ essences and, for the most part, impacted the discussion of how we should administer urban life in the wake of a pandemic. This brings into focus the need to learn urban planning practices and conceivably assess urban experimentation in crisis. Our lifestyle depends on physical interaction. We are social animals; it is the way we are created, work, and flourish. With the more significant part of the total populace living in an urban area, it is where we track down the most chances to make ideas, trade information and commend remarkable societies. With the centralization of individuals, thoughts, and such, they are the powers to be viewed in our worldwide economies. The pandemic’s inceptions and its hopeful eradication are likely urban ones. Generally, old urban areas and their markets have been the focal points for
social connection and social and financial action. They are also where some general medical problems have begun, and society has commonly taken those lessons to authorize great social and general well-being headways. Since the coronavirus transmits through human contact, it is essential to study the design parameter of an area. The familiar assumption is that COVID-19 transferred rapidly in the high-density area, whereas there are fewer chances in the low-density region.

The main research gap is to study the relationship between TOD practice and COVID-19 cases to identify whether design and development play a role in the spread of COVID-19 or not. For our objective, the formulated research question is what are the governing parameters for the design and development of a TOD area that plays a role in COVID-19 spread? The study also provides some insight about COVID-19 and TOD, which helps analyze how the TOD area acts in pandemics and the most mediated parameters, improving the correlation between COVID-19 and TOD.

2 Methodology

Initially, the indicators were identified, which are essential for the TOD study according to the study area (Khare et al., 2021a, 2021b). After processing the indicators in the GIS environment, the TODness value was evaluated for all the selected BRT stations using the TOD index value by employing the Multicriteria Evaluation (MCE) technique. Further, Pearson correlation analysis was used to analyze the connection between TODness and COVID-19 cases. This examination was directed in JASP 3.0 and a considerable $p$-value of 0.05. Subsequently, the SEM module was referred to as the hypothesized mediational model utilizing bootstrapping method in JASP 3.0. Then mediation analysis of highly correlated TOD indicators was done. Mediation examination explores whether and how much the impact of a variable $X$ on variable $Y$ is clarified by the variable $M$ (Biesanz et al., 2010). The correlation coefficient calculation is the most regularly embraced method used for passing the judgment on the statistical connection between two variables, which measures the level of (direct) affiliation (Bewick et al., 2003). The bootstrapping assessment was utilized to examine the mediation impact with 10,000 bootstrap samples. The mediation effects were viewed as considerable if, in the indirect effect, the confidence interval did not involve the value of zero.

3 Study area and data used

Bhopal is a city located in the centre of India. It is the capital and administrative centre of Madhya Pradesh (Deshmukh et al., 2016). The Transit Station (TS) selected in the study is the BRT station (Fig. 1). According to the summary of the most widely used indicators in the TOD study, 13 indicators have been picked based on the study area’s different attributes, shown in Table 1 (Khare et al., 2020).

The COVID-19 pandemic data (Covid important information, District Bhopal (MP), 2021), BMC (Bhopal Municipal Corporation) boundary, number of houses, and population data are taken from the BMC. For defining the pattern of Bhopal, census data and field
Fig. 1 Study area showing Bhopal municipal boundary with BRT stations
| Indicators                              | Data source                                                                 | Mean  | SD    | SE   |
|----------------------------------------|-----------------------------------------------------------------------------|-------|-------|------|
| COVID-19 cases                         | District office, Bhopal                                                     | 10.963| 8.065 | 2.016|
| Number of high-frequency transit service| Bhopal Municipal corporation, Regional transport office                      | 1.011 | 0.136 | 0.034|
| Intersection density                   | Bhopal Municipal corporation, Google Earth                                 | 0.977 | 0.451 | 0.113|
| Vehicle kilometre travelled (VKT)      | Questionnaire survey                                                        | 1.021 | 0.212 | 0.053|
| Journey (residents) made by Motor vehicle (%) | Questionnaire survey                                                    | 1.043 | 0.416 | 0.104|
| Journey (residents) made by local transport (%) | Questionnaire survey                      | 1.026 | 0.279 | 0.070|
| Method of the journey (residents)      | Questionnaire survey                                                        | 1.027 | 0.328 | 0.082|
| Walk/cycle (%)                         | Bhopal Municipal corporation, District Census Handbook Bhopal                | 0.860 | 0.849 | 0.212|
| Population density                     | Bhopal Municipal corporation                                              | 0.888 | 0.702 | 0.175|
| Employment density                     | Bhopal Municipal corporation                                              | 0.962 | 0.333 | 0.083|
| Walkable path                          | Bhopal Municipal corporation, Google earth                                | 0.932 | 0.610 | 0.153|
| Mixed use                              | Bhopal Municipal corporation, Google earth                                | 0.652 | 0.186 | 0.247|
| Diversity                              | Bhopal Municipal corporation, Google earth                                | 0.980 | 0.207 | 0.052|
| Business density                       | Bhopal Municipal corporation                                              | 0.983 | 0.214 | 0.054|
survey data were used as described in Table 1. GIS software is used for the spatial analysis of the data.

4 Results

4.1 Multicriteria analysis

The GIS-based Multicriteria evaluation (MCE) method can be considered a method that combines the spatial and non-spatial data as input and transforms it into a subsequent outcome in the form of output (Ghanbari et al., 2020). The decision maker’s preferences and geographical data can be combined into a unidimensional value of alternate choices. For evaluating multiple goals, MCE can achieve decision-making by analysing different objectives (Malczewski, 2006). Additionally, it can monitor various changes made among these alternatives, subsequently contributing to selecting an appropriate option for the function (Eastman, 1999). After the criteria are selected, in the MCE method, each factor is given weightage through two critical steps, i.e. standardization and determination (Singh et al., 2017). Standardization of performance measures is needed because all the performance measures are different in units, and to make comparisons possible, decide the suitability values of the factors to a common. Using the MCE (Fig. 2), we find the TODness index value of all the selected TS by providing TOD indicator values (Table 1). Here we assume that BRT stations scored a value of 0.60 or above follows TOD, whereas other stations that scored less than 0.60 act as non-TOD areas. As shown in Table 2, the first eight areas that scored above 0.60 are TOD and eight are non-TOD areas (Khare et al., 2021a, 2021b).

4.2 Regression analysis

The correlation coefficient (r) value finding is the most frequently used method to determine the statistical relationship between two variables, primarily computing the degree
of involvement (Bewick et al., 2003; Bhadra et al., 2021). In the present analysis, indicators that have a significant relationship with Coronavirus cases are vital. This importance is a significant point for the forecast. A few indicators have a relationship power of 0.031–0.588 (Table 3). The essential point is that some indicators statistically correlate substantially with the number of COVID-19 cases. The importance of statistical significance here decides the consideration of these indicators in the regression analysis (Truong & Truong, 2021). Here population density, diversity, number of high-quality transit services available, and resident method of travel (Public Transport) indicators are highly correlated with the COVID-19 cases with \( r \) values 0.429, 0.588, 0.449, and 0.442, respectively. Figure 3 shows the distribution of COVID-19 cases along TOD and Non-TOD areas. 0 and 1 represent non-TOD and TOD areas. The investigation likewise intended to check a mediational model in which TOD indicators have been assumed to mediate the relationship between TODness and COVID-19 cases. Before looking at such prospects, we proposed a set of regression analyses (Table 4) to help decide precisely what combination of TODness, TOD indicators, and COVID-19 cases should be analysed. For instance, if TODness were not identified with Coronavirus cases, then due to the absence of motivation, determination for the possible mediation of this

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**Table 2** TODness index of all the selected 16 BRT areas (Khare et al., 2021a, 2021b)

| BRT stations           | TOD Index | COVID-19 cases | BRT Stations   | TOD Index | COVID-19 cases |
|------------------------|-----------|----------------|----------------|-----------|----------------|
| New Market             | 0.74      | 26.75          | Habibganj      | 0.56      | 11.98          |
| Board office           | 0.71      | 4.93           | Gandhi Nagar   | 0.48      | 4.51           |
| New-Ashok Garden       | 0.70      | 26.68          | Koh-E-Fiza     | 0.48      | 24.20          |
| Piplani                | 0.65      | 14.83          | Beema Kunj     | 0.46      | 6.44           |
| Bhopal Railway station | 0.63      | 12.80          | Halalpur       | 0.45      | 7.20           |
| People mall            | 0.62      | 3.76           | Aura Mall      | 0.44      | 5.58           |
| Karond square          | 0.62      | 4.07           | C-21 Mall      | 0.40      | 8.20           |
| Sai board              | 0.60      | 6.39           | Ashima Mall    | 0.39      | 7.10           |

**Table 3** Correlation of each TOD indicator with COVID-19 cases in Bhopal city, India

| Parameters                                      | \( r \) | \( p \) |
|------------------------------------------------|--------|--------|
| Population density                             | 0.429  | 0.098  |
| Employment density                             | 0.335  | 0.204  |
| Diversity                                      | 0.588  | 0.217  |
| Mixed use index                                | 0.031  | 0.910  |
| Walkable catchment area                        | 0.117  | 0.666  |
| VKT                                            | 0.348  | 0.187  |
| Journey (residents) made by motor vehicle (%)  | 0.396  | 0.129  |
| Journey (residents) made by local transport (%)| 0.442  | 0.087  |
| Method of the journey (residents) walk/cycle (%)| 0.131  | 0.629  |
| Number of high-quality transit services available| 0.449 | 0.081  |
| Intersection density                           | 0.279  | 0.295  |
| Walkable path                                  | 0.210  | 0.434  |
| Business density                               | 0.049  | 0.856  |
A set of regression analyses were used to choose indicators for the mediation analysis to consider the relationship among measures of the same category (Kadi & Khelfaoui, 2020). This lessens the number of investigations of the examination, which decreases the study-wise error rate.

**4.3 Mediation analysis**

Despite the fact that assessing bivariate relations between variables can loan understanding into whether a hypothesized relation holds or whether an analysis seems to work, it cannot address the question of why, how, and for whom the relationship has or the program works. Exploring third factors like mediation depicts how or why a relationship between two variables is impacted by the third variable (Coskun et al., 2021; Zhu et al., 2020). Mediation analyses have been directed to assess a hypothetical model of the relation among the associated indicators, i.e. TODness value and COVID-19 cases, because

![Distribution of COVID-19 cases among study areas (0 represents Non-TOD and 1 is TOD area having a TODness value more than 0.60)](image)

**Table 4** Descriptive statistics and Correlation coefficient between TODness and COVID-19 cases

|                      | Mean  | SD   | SE   | r     |
|----------------------|-------|------|------|-------|
| COVID-19 cases       | 10.963| 8.065| 2.016|       |
| TODness              | 0.558 | 0.115| 0.029| 0.405 |
| TOD area             |       |      |      | 0.6806|
| Non-TOD area         |       |      |      | 0.3223|
both the indicators have significant linkage with one another. Now two possible results may be apparent. Hence, we speculated that highly correlated indicators might mediate the relationship between TODness and COVID-19 cases. If a highly correlated indicator is an influential variable, it can mediate the relation between TODness and COVID-19 cases. Then again, if TODness is a compelling variable, it can remove the facilitator role of highly correlated indicators [Diversity, Population density, Number of high-quality transit services available, Residents’ method of the journey (Public Transport)].

Second, TODness may mediate exceptionally related indicators and COVID-19 cases. Table 5 shows the mediation analysis among TODness, highly correlated TOD indicators and COVID-19 cases. Exploring mediator impacts additionally pursues satisfying a few late Government announcements to control COVID-19 spread like a declaration of lockdown, movement of public transport put on brakes and seize up the mass gathering, isolation and so on.

Here the hypothetical mediation model is demonstrated in Fig. 4 below. During our examination, $X$ is the TODness, $Y$ is the COVID-19 cases, and $M$ is the mediator indicators (important for TODness assessment and highly correlated with Coronavirus cases). The flow direction denotes effects, i.e. $d$ represents the direct effect of $X$ on $Y$, and $I_1 \times I_2$ is called the indirect effect. The sum of the indirect and direct effects is called total effect: mediation analysis decomposes an existing effect into these two terms (Biesanz et al., 2010).

The indirect effect is a decisive factor for mediation analysis (Cypryanska & Nezlek, 2020) which uses a series of processes. The bootstrap method was employed with 10,000 samples in JASP 3.0 to present the finest explanation of mediation. Independent investigations were conducted for every arrangement of TODness, COVID-19 cases, and highly correlated indicators. The analysis shows a 95% confidence interval and $p < 0.05$ for the effects. Firstly, how TOD performance measures might mediate the relationship among COVID-19 instances and TODness. The correlation analysis found that COVID-19 cases were related to all the performance measures but were significantly related to only diversity, population density, number of high-quality transit services available and resident’s mode of the journey (public transport).

Consequently, all four analyses were simulated, one in which each highly correlated indicator was the mediator, TODness was the predictor, and COVID-19 cases were the outcomes. The result of these analyses was quite clear (Fig. 5). For population density as a mediator (Fig. 5a), the total effect of 27.64 was broken down into an indirect effect of 10.64 (CI = −0.757 to 5.789) and a direct effect of 17 (CI = −3.100 to 7.526); wherein the direct effect is more than indirect, indicating partial mediation.

Diversity partially mediated the relationship among TODness and COVID-19 (Fig. 5b). The total effect of 3.57 (CI = −1.205 to 7.410) was breakdown into direct and indirect effect of −4.9 (CI = −15.720 to 3.574) and 8.47 (CI = 1.882–19.136), respectively. Here direct effects were opposite in sign to ($I_1 \times I_2$). The indirect effect refers to inconsistent mediation. But in this case, mediation is there and acts as a suppressor variable.

For public transport as a preferred mode of travel as a mediator (Fig. 5c), the total effect of 3.524, were breakdown into direct and indirect effects of 3.4 (CI = −0.636 to 7.215) and 0.1247 (CI = −1.588 to 2.501), respectively. Here the direct effect has a very less indirect effect.

For the availability of high-frequency transit services as a mediator (Fig. 5d), the total effect of 3.52 was breakdown into direct and indirect effects of 2.2 (CI = −2.832 to 6.253)
Table 5  Mediation analysis between TODness, diversity, population density, number of high-quality transit services available, residents’ mode of the journey (public transport) and COVID-19 cases

| Mediator variable                  | Mediation analysis                                                                 | Impact | Estimate | Standard error | Z-value | Confidence interval (95%) |
|-----------------------------------|------------------------------------------------------------------------------------|--------|----------|----------------|---------|---------------------------|
| Diversity                         | TODness and COVID-19 cases                                                         | Direct effects | −4.940 | 3.643 | −1.356 | −15.720 | 3.574 |
|                                   | TODness → Diversity → COVID-19 cases                                               | Indirect effects | 8.446 | 3.418 | 2.471 | 1.882 | 19.136 |
|                                   | TODness → COVID-19 cases                                                           | Total Effects | 3.506 | 1.979 | 1.771 | −1.205 | 7.410 |
| Population density                | TODness and COVID-19 cases                                                         | Direct effects | 2.160 | 2.224 | 0.971 | −3.100 | 7.526 |
|                                   | TODness → Population density → COVID-19 cases                                       | Indirect effects | 1.346 | 1.281 | 1.050 | −0.757 | 5.789 |
|                                   | TODness → COVID-19 cases                                                           | Total Effects | 3.506 | 1.979 | 1.771 | −1.467 | 7.225 |
| Public transport (Mode of travel) | TODness and COVID-19 cases                                                         | Direct effects | 3.380 | 1.750 | 1.932 | −0.636 | 7.215 |
|                                   | TODness → Public Transport → COVID-19 cases                                         | Indirect effects | 0.126 | 0.929 | 0.136 | −1.588 | 2.501 |
|                                   | TODness → COVID-19 cases                                                           | Total Effects | 3.506 | 1.979 | 1.771 | −1.377 | 7.311 |
| Availability of high frequency transit services | TODness and COVID-19 cases                                                         | Direct effects | 2.184 | 2.107 | 1.036 | −2.832 | 6.253 |
|                                   | TODness → No. of transit service available → COVID-19 cases                         | Indirect effects | 1.322 | 1.159 | 1.140 | 0.050 | 5.259 |
|                                   | TODness → COVID-19 cases                                                           | Total Effects | 3.506 | 1.979 | 1.771 | −1.414 | 7.252 |
and 1.32 (CI = 0.050 to 5.259), respectively. The mediator is said to be partial mediation in that standardized path a is greater than path b.

For TODness as the predictor variable and COVID-19 as outcomes, diversity and number of high-quality transit service availability are the only possible mediator. The analyses found that the indirect effect on population density and public transport was insignificant. And Fig. 6 shows the dissemination of the COVID-19 cases with TODness and highly
**Fig. 6** Graphical representation of (a) diversity, (b) population density, (c) public transport and (d) number of high-quality transit services available as a mediator with TODness and COVID-19 cases. The blue lines represent the object, whereas the red lines are the ghost lines to make the comparison easier.
correlated indicators of Diversity, Population density, Number of high-quality transit services available, and ‘Resident’s mode of journey (public transport).

5 Discussion

In the present study, the TOD’s role in COVID-19 spread was attempted for the first time as per the literature available. In the previous research, only the effect of individual variables like population density, public transit ridership, etc. explained. In this study, a combination of variables was considered and analysed on the station level and attempted to study the role of multiple variables for the first time. The study outcomes showed that diversity explains 59% of the variance. In contrast, population density is 43%, public transport as a travel mode 44%, and the number of high-frequency transit services available explain 45% of the variance in COVID-19 propagation. The other TOD indicators include employment density, mixed-use of the land, walkable catchment area, VKT, travel behaviour (Number of trips per day %), motor vehicle, walkable path, walking or cycle, economic development, intersection density were not found to be related significantly. A considerable correlation of 0.405 ($p < 0.05$) was found for the spread with TODness of an area in the 16 analysed BRT station areas. Especially, spread displayed a high correlation of 0.681 along with TOD area whereas a moderate correlation of 0.322 with non-TOD area mediate by diversity and number of transit service available indicators. Here we also found the correlation between COVID-19 and each indicator of TOD, which makes an area development transit-oriented to calculate the correlation of COVID-19 with other parameters too, which presence affects COVID-19 spread rate in terms of design parameters of an area.

COVID-19 put the question on TOD characteristics: high population density and less personalized vehicle use oriented, but the actual offender lies in crowding, poverty, pollution, and other socio-economic factors. Enlighten the network contacts consideration contributes to the virus spread more and not the use of public transit. Here TODness positively correlated was found with the COVID-19 cases for a case study performed on 16 BRTS areas in Bhopal city, India. However, in mediation analysis, it was observed that population density, mixed-use of land, and public transport as one the travel modes of individuals do not play any significant role.

So, it is clear that corona virus will not kill TOD practices because moderate to high density, more use of public transport, and mixed-use of land are the key factor of TOD. So still TOD has seen as a desirable urban planning option for all generations because the relation is mainly mediated by diverse land use (automatically attract several people and give multiple reasons for gathering as different land use present in one area) and again for the availability of high-frequency transit service, so people have the choice to move). Tables 2 and 4 observe that COVID-19 cases are more highly correlated with the TOD area than the non-TOD area because the TOD area scored high in diversity. And TODness–COVID-19 relationship is significantly mediated by diversity; that is why TOD areas having high diversity value will have more chances of increasing the number of COVID-19 cases. From the findings summed up above, population density does not significantly impact the spreading of the virus. If the virus is impervious to density, the design pattern may be expected to play an intervening job between population density and infection spread. If so, then the chances of the virus spreading cases in the low-density zones ought to be low.

The findings also observed that the new market TS scored the first rank in TODness, having more number of COVID-19 cases; also, Bhopal city’s main commercial place
known as CBD (Central Business District) scored highest in diversity criteria. Whereas Board office TS scored second TODness rank (newly developed CBD of Bhopal) mainly office cum commercial area with fewer COVID-19 cases, as remote work (work from home) orders reduce the need to commute every day. Similarly, the new Ashoka garden TS scored third in TODness, second highest in diversity and COVID-19 cases in the residential low-medium income group area.

In India, the reasons behind the COVID-19 virus’s rapid spreading are because people did not follow the protection measures like wearing masks, handwashing, social distancing, etc. They freely enjoy parties, leisure spaces, shopping, political event, etc. The viral outbreak of COVID-19 cases in the dense urban environments and slums areas in sprawling metropolitan cities like Mumbai, Delhi, Chennai, Kolkata, Ahmedabad, and others forces the administrator to rethink the standards of planning and design of urban areas. The Covid-19 emergency has changed currently individual’s transportation ways of behaving in emotional ways, with enormous decreases in public vehicle use and huge development in cycling take-up. Proof from past emergencies shows that in the prompt outcome of emergencies, transport ways of behaving will change as individuals rethink the expenses and advantages of various vehicle modes. Decision-making will be somewhat determined by individuals’ impression of risks, and whether or not such insights are all around established. As lockdowns are announced, arrangements will be essential in deciding if mobility changes set off by Covid-19 are positive or negative, as far as their effects on energy use, security and long-haul ecological and well-being results (Sung & Monschauer, 2020). While it is true that large population concentration provides cities with the scale that ensures the economic viability of capital-intensive infrastructure, it is becoming apparent that when densities breach their critical mass, they have negative consequences on economic, environmental, health, and social sustainability.

Now, the time has come to revisit India’s Urban and Regional Development Plans Formulation and Implementation (UDRPFI) Guidelines and examine how they can lead the way in shaping a new urban form and density pattern less susceptible to natural disasters. Urban planners and the Town Planning agencies at the metropolitan level shall take the view of urban density as a complex interaction between several forces and the way the daily work and their living coup with the new standard because the idea is not to over-regulate developments but to distinguish between a good urban density and a bad one. They should advocate for rich, dense places, where people can shelter in place, work remotely, and also have access to food and other needs at the time of crisis, as opposed to poor dense sites, which push people to go out onto the streets, forces them to walk miles to reach stores and onto crowded transit with one another. People must reflect on what kind of cities they are living in and how more integrated land-use policies coupled with behavioural change could help them to correct. In the quest for a new paradigm in planning standards, cities must also look for ways to make urban public spaces more flexible and fluid. Innovative concepts such as pop-up parks and temporary local public spaces are the need of the hour in this new world of required social and physical distancing. Urban planning guidelines shall provide room for experimentation in the form of the temporary redesign of public physical environments in an emergency to make it easier for communities to stay informed and safe while having access to fresh air in the dense cities that we have landed ourselves into. Such design is important on the grounds that our habits are set off by hint built into our physical environment. And if everything appears and feels the same, we will constantly return to old practices. Suppose we can make the necessary changes in the urban planning guidelines, adopt a new norm in urban density, and design quick, temporary solutions to alter and
adjust our built environments. In that case, we can trigger better, more effective physical behaviour and help our authorities deal with disasters and emergencies efficiently.

Even with moderate to high-density development and less use of private motorized vehicles as a key point of TOD, TOD contributes to a connected and sustainable healthy lifestyle. Ultimately it is suggested that we must rethink TOD and the importance of infrastructure, contributing to the integration of transit and land development. However, it seems that with the spread of COVID-19 and the future pandemic threat, we must prepare for it. However, to our knowledge, our results are one of the first to show that land-use diversity is an important driver of COVID-19 transmission, even in areas where residents rely more on private modes of transportation. Moreover, even though transmission is less in lower-density areas. Further research is needed on the overall burden of COVID-19 across the spectrum of population density. Land-use diversity has been found as a potential indicator of infection spread, suggesting that in densely populated diverse areas, more stringent policies or implementations of distancing may be considered. These findings reinforce that strategies and planning for COVID-19 should be based on the differences in population parameters between counties in the same region (Martins, 2021). An overall conclusion that can be drawn from this study is that density should be considered in the different epidemiological models as it contains complementary information to population size. However, considering density at a “microscopic” level can be more informative than the “macroscopic” density considered in most of the studies (Pascoal & Rocha, 2022). However, to our knowledge, our results are one of the first to show that land-use diversity is an important driver of COVID-19 transmission, even in areas where residents rely more on private modes of transportation. Moreover, even though transmission is less in lower-density areas. Further research is needed on the overall burden of COVID-19 across the spectrum of population density.

TOD is still an opportunity to consider extending investment into suburbs and positioning TOD properties in these less dense markets defined by sprawl. TOD could do a lot very quickly to expand density and build walkable areas where they needed the most. When we try to correlate the virus and the cities, none of the most straightforward solutions fits all explanations. Because cities have multiple dissimilarities in population size, area, climate, economic development, job offers, type of population, etc. it is important to investigate its propagation pattern characteristics of the area where it was first noticed. It is known that initial lockdowns, movement restrictions (work from home, closing school, alternative ‘days’ office working, etc.) controlled the virus’s spread in many places. These practices play an important role in flattening the curve. But it might be possible that these cities have other dimensions, which makes some areas more or less vulnerable.

6 Conclusion

In the present study, the role of TODness on COVID-19 spread was attempted for the first time as per the literature available. In this study, a combination of 13 parameters was considered and analysed the role of each parameter was on 16 BRT stations. The study outcomes showed that diversity explains 59% of the variance. In contrast, population density is 43%, public transport as a travel mode 44%, and the number of high-frequency transit services available explains 45% of the variance in COVID-19 spread. Thus, the present study suggests that a positive trend was observed when the correlation analysis was performed among COVID-19 spread and TODness of the area. Land-use
diversity is the first and most important factor that contributes to virus spread. This can be explained by diverse land use in a single point, such as residential, commercial, recreational, shopping, education, and public utility. It attracts multiple users and increases the chance of mass gathering and chances of people coming in contact with each other and with the virus. Also, the number of high-frequency transit services available as a TOD indicator mediated the TODness and COVID-19 cases. However, in the present study, only 5 months data from April 2020 to August 2020 were used because the virus started to spread in the area during this period. Future studies can be enhanced by using a longer period of COVID-19 cases data and considering a much broader area may be at the district, state, or country level, to enlighten the issue further. Although, taking the regional data for evaluation can be questionable in terms of the accuracy or viability of the data. But present study justifies that the availability of frequent transit services will attract people for more regular movements, increasing the chance of virus spread. And the investigation portrays that online ticketing and improved quality of public transportation are two prime requirements of public transport users. The pandemic has brought about prominent upgrades in nearby air quality in urban communities and an impression, maybe, of a greener future. We have an amazing chance to change urban mobility by advancing manageable and decarbonized transport. Public transportation is broadly viewed as the mainstay of maintainable mobility. Restoring the area with public well-being, better frequency and inclusion, and an adaptable foundation could assist with making extraordinary additions in tending to the ascent in GHG outflows and the always-expanding clog in Indian urban communities. Thus, the present study helps the urban land planners adopt a novel framework for the area’s design and development pattern to contain and control the spread of COVID-19.

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Declarations

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

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