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Impact of social lockdown due to COVID-19 on environmental and health risk indices in India

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ABSTRACT

Coronavirus disease (COVID-19) spread across the globe through the human transmission. The World Health Organization suggested social distancing to curb the community spread. After national social lockdown started in India, air quality improved drastically. This further hypothesized to influence the environment and human health, and this study is positively the first to weigh it using multiple indices. The calculated environmental indices are photochemical ozone creation potential (POCP), acidification potential (AP), and eutrophication potential (EP). The cancer risk, chronic health index (CHI), and acute health index (AHI) were considered to calculate the health risk. The spatial trend change in the air pollution reflecting on these indices are calculated for four Indian megacities Delhi, Bangalore, Hyderabad, and Kolkata. Temporal variation was accounted for monthly (2019 vs 2020), one-week and two-weeks period during the social lockdown. The results showed a significant decrease in environmental and health risk during the lockdown due to a corresponding decrement in air pollution. The decrease in the particulate matter was found to play a vital role in altering the air pollution mediated risks of interest. Delhi showed a maximum difference in POCP and Acute HI by recording a dip of 70.79% and 43.53% respectively in 2020 during lockdown. The maximum reduction in health risk indices was 41%, 31%, 17%, 19% for Delhi, Bangalore, Hyderabad, and Kolkata. Bangalore recorded the maximum decline in EP, Cancer risk, Chronic HI by 66.66%, 58.62%, and 58.76% in 2020 compared to 2019. A maximum fall in AP was seen in Kolkata by 57.23% in 2020 among all cities. The connection between these drop-in indices and the cause of air pollutants were well discussed. This present paper gives more in-depth insights into air pollution's effect on environmental and health parameters by connecting and converging various air pollution aspects into a single scale. This study also enlightens the importance of controlling air pollution to have a better environment and healthy life to attain sustainable development.

1. Introduction

Coronavirus disease (COVID-19) is an infectious disorder triggered by a coronavirus. The World Health Organization identified it in late 2019. Many individuals infected by the COVID-19 virus globally develop mild to severe lung illness, which may be significant for the aged and others with existing medical conditions such as coronary disease, asthma, a chronic pulmonary disorder, and cancer (Your Health, August 14, 2020). The infection spreads mostly by saliva droplets or discharges from the nose transferred by an infected person through a healthy person's body as the infected person sneezes or coughs. The best ways to prevent and avoid transmission are by being well informed about the disease it causes and how the virus spreads, maintaining personal hygiene and maintaining social distancing to avoid contact with others. As told by the World Health Organization, crowded places should be avoided to ensure maximum safety from this virus now spread worldwide. There is no vaccine still available for protection against COVID-19. (WHO, March 29, 2020).

The first human cases of COVID-19 were first reported in Wuhan city, China, in December 2019. (WHO, March 29, 2020) Later with people traveling from China to different parts of the world, the virus took the cover of almost the entire globe. To ensure citizens' maximum safety and minimize the spread of the disease through human contact with an infected person, national governments worldwide imposed nationwide social lockdowns in their respective countries. The same was done in

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List of abbreviations

COVID-19	Coronavirus Disease
AP	Acidification Potential
EP	Eutrophication Potential
POCP	Photochemical Ozone Creation Potential
HI	Health Index
WHO	World Health Organization
GIS	Geographic Information System
CPCB	Central Pollution Control Board,
IWD	Inverse Distance Weighting
REL	Reference Exposure Level
BTEX	Benzene, Toluene, Ethylbenzene and Xylene
SAFAR	System of Air Quality Weather Forecasting and Research
IARC	International Agency for Research on Cancer
AQI	Air Quality Index
EI	Environmental Impact
HR	Health Risk

India after the first case of COVID-19 was reported in India on January 30, 2020, in Kerala. The Indian government declared a nationwide social lockdown on March 25, 2020, till April 14, 2020, realizing the virus's spread through community transmission. The first social lockdown for 21 days from March 25 till April 14 was followed by social lockdowns 2.0 from April 15 till May 3 and then by social lockdown 3.0 from May 1 till May 17, after which there was an extension of the social lockdown till May 31, 2020. Later, from June 8 onwards, there was a phased reopening of the social lockdowns after 75 days of complete social lockdown (Devesh Kumar, 2020). According to guidelines issued by the government for the nationwide social lockdown in India, all domestic and international air travel, train travel, public transport, movement of individual vehicles, institutions, markets, construction works, industrial and commercial activities, and other major activities that demand social interaction were prohibited (The Hindu Net Desk, April 15, 2020).

Due to social lockdown nationwide and the shutting down of mainly all activities, the citizens faced a drastic change in their daily lives. The nation's economic progress started going on a downward path (Stephanie Segal, Dylan Gerstel, 2020). On the other hand, what took an edge by improving its conditions during social lockdown was the environment. Slowing down all daily activities reduces pollution of air, water, noise, and degradation of nature, creating a positive impact on the environment. Multiple studies repeatedly state that India's air quality observed the most drastic change, especially in urban and megacities such as Delhi, Mumbai, etc. All these cities faced the highest air pollution and mediated diseases in the past years. Because of the social lockdown, as all roads of big cities became empty and factories stopped letting out harmful chemicals into the air, the air quality recorded a substantial improvement. Similar observations were made with other countries, too, connecting the COVID-19 and bettering environmental pollution and associated health risks. A study reported in China indicated that the primary contaminants such as SO_2, NO_x, $PM_{2.5}$, and VOCs decreased by 26%, 47%, 46%, and 57%, culminating in a 25.4%–48.1% decrease in $PM_{2.5}$ concentrations across the YRD area. However, throughout the lockdown time, the average $PM_{2.5}$ varied from 15 to 79 $\mu g/m^3$ and bounced simultaneously by 20.5%. (Li et al., 2020). A similar study showed that in Kazakhstan, concentrations of $PM_{2.5}$ decreased by 21%, with spatial differences between 6 and 34% relative to the average of the same days in 2018–2019, CO and NO_2 decreased by 49% and 35%, respectively. Concentrations of O_3 rose by 15% compared to the previous 17 days before lockdown. The benzene and toluene amounts were 2–3 times greater than in the same 2015–2019 seasons. (Aiymgul Kerimray et al., 2020).

This fact is well verified in India with multiple studies carried out on air pollution. Research indicates a substantial improvement in air quality and could be expected even during unfavorable meteorology if the air quality is strictly implemented. In most cases, $PM_{2.5}$ had a maximum reduction (Shubham et al., 2020). The impacts correlated with the growth of any cities' development are inevitable, and in this study, the vice versa is hypothesized. The movement halted due to the social lockdown from midnight of March 24, 2020, ceasing vehicular emission and encouraging their employees to work from home. Vehicles on the road had been significantly limited from further rising the pollution from automobiles, thus reducing the impact on the environment and health. (Sarath Guttikunda, 2020).

A study done on air quality of Mumbai and Delhi, the two most polluted cities of India, observed a substantial decrease in NO_2 (40–50%) compared to the same period last year (Khurram S., Muddassar S., Syed Ghulam M., 2020). A similar study done on 41 cities of India suggested a 13% NO_2 reduction during the lockdown (March 25–May 3rd, 2020) compared to the pre-lockdown (January 1st–March 24th, 2020) period. During the 2020 lockdown period, temporal analysis revealed a gradual reduction in NO_2 in all the cities. The results also indicate spatial differences, i.e., the NO_2 levels decreased exponentially, as the city center's distance increased. In comparison with the decrease in NO_2 for most of the cities, during the 2020 lockdown period we observed an increase in NO_2 for towns in Northeast India and attributed it to vegetation fires. (Krishna P., Vadrevu, 2020). A number of studies were carried out in India and other countries globally, connecting COVID -19 social lockdown with air pollution. However, so far, there were no studies on estimating the social lockdown's influence on environmental impact and health risk indices, which were dominantly influenced by air pollution considering the country, India.

At this point, the fact is that air is considered one of the essential requirements for a living being to have a long and healthy life. However, with the degrading air quality at an alarming rate, not only human beings but even plants and wild animals living in distant ecosystems suffer significantly because of the negative impacts of air pollution. Few studies show the positive correlation between air pollutants and environmental impact and health risk indices. Rapid industrialization, urbanization, and vehicular emissions are primary air pollution sources that release CH_4, PM_{10}, $PM_{2.5}$, NO, NO_2, NO_x, SO_2, CO, NH_3, and O_3. These have resulted in the rise of global warming, depletion of the ozone layer, photochemical smog formation, aerosol, and acid rain (Ahmad A., Pratiksha S., 2013). Air pollution has ruthlessly distressed natural bio-network and ecosystems and has severe consequences on human beings' health. Coarse particulate matter (PM_{10} -Particulate matter equivalent to or smaller than 10 μm in diameter) is known to induce health issues in the nasal and upper airways. Fine particles ($PM_{2.5}$ –Particulate matter with a diameter of fewer than 2.5 μm) reach deeper into the lungs and cause heart attacks, strokes, asthma, and bronchitis, as well as an early death from cardiac failure, lung disease, and cancer (Yelda Aydın T., Mustafa K., 2020).

Nitrogen oxides (NO_x) can cause asthma and bronchitis to worsen and intensify, contributing to a higher risk of heart failure. Ozone (O_3) is a well-established respiratory irritant at ground level (where it becomes generally considered smog). Sulfur dioxide (SO_2) induces skin inflammation, worsens asthma, improves lung pressure, and stimulates the cardiovascular system. A compelling reason for controlling air pollutants, such as particulate matter (PM), nitrogen oxide (NO_x), sulfur dioxide (SO_2), ozone, etc., is their damaging effect on human health. A study (Daniele F., Francesco R., 2020) showed an increase in VOC. They ended up reporting a correlation with inflammatory responses and a high incidence of respiratory and cardiac affections in Italy. Nine out of every ten people across the planet breathe toxic dust. Today's air pollution presents the most significant environmental danger of early mortality, affecting as much as 5 million premature deaths per year (EDF). The data from different stations located all over India proved the presence of CH_4, PM_{10}, $PM_{2.5}$, NO, NO_2, NO_x, SO_2, CO, NH_3, O_3, Benzene, Ethyl Benzene, Xylene, Ozone and Toluene in ambient air at different cities (CPCB).

This paper aims to estimate the influence of COVID-19 enabled social lockdown in environmental impact and health risk in selected four megacities in India. Both of these were calculated in terms of indices, which are well explained in the methodology section. The specific tasks include 1) data collection on air pollutants and compilation, 2) calculation of indices showing the impact on the environment and health risk 3) interpretation of the results using multiple tools such as GIS mapping and statistical analysis.

Therefore, considering the changes in the health of the air in India brought disaster by the pandemic and the following social lockdowns, we have analyzed and studied various indices that measure the air quality and also its effects on the environment and health of people, recorded in four megacities of India. Few COVID-19 and air pollution studies in India are stated in Table 1, but none focuses on environmental impact and health risk analysis.

2. Methodology

2.1. Selection of cities and data collection

This paper examined the influence of social lockdown on environment and health risk indices through air quality aspects in India's cities during the COVID-19 breakdown. Because the estimated level of air pollutants in India is far higher than in other countries, this study's research region was restricted to four urban megacities Delhi, Kolkata, Bangalore, and Hyderabad, India. We selected the cities based on the history of air pollution (the chosen cities are India's populated topmost towns having industries holding a high economy and thus having a strong working community with compelling travel). Also, for an efficient study, we considered data availability in these cities.

We obtained the air quality data from a central pollution control board website that acquired it from several monitoring stations operating continuously in each city. Table S1 lists the station names, say 38 in Delhi, 7 in Kolkata, 10 in Bangalore, and 6 in Hyderabad, from which the data were acquired to calculate the environmental impact and health risk indices.

The 14 air pollutants, i.e., fine particulate matter ($PM_{2.5}$), coarse particulate matter (PM_{10}), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), ammonia (NH_3), carbon monoxide (CO), and ozone (O_3), were collected through Central Pollution Control Board (CPCB). Continuous atmospheric air quality data was tracked at the various control stations in each city. Amount of Benzene, Ethyl Benzene, Xylene, and Toluene were also collected. By comparing the data of meteorological parameters of 2019 and 2020 for the same time interval, a basic assumption was made which indicates that meteorological data for 2020 are similar to 2019. Further, the influence of meteorological parameters on the air pollution was ruled out in this study.

2.2. Calculation of environmental impact and health risk indices

From the air pollution data, photochemical ozone creation potential (POCP), acidification potential (AP), and eutrophication potential (EP) are used to calculate the impact on the environment. The cancer risk, chronic health index (CHI), and acute health index (AHI) were considered to calculate the health risk. For calculating the cancer risk for different age groups, the assumption that 100% population is between the age of 2–16 years and 16–70 years is used. To calculate cancer risk for the mixed age group (cancer risk mix), the census report 2011 was used as the base. It fixed the ratio of 0.06, 0.34, and 0.6 for the age group of populations 0–2, 2–16, and 16–70 years, respectively, and as indicated in Table S4.

2.3. Data analysis and mapping

The collected air quality data and calculated indices were analyzed using a simple statistical averaging method and spatiotemporal mapping to show the environmental impact and health risk indices' changes due to social lockdown. For better understanding, the research tasks have been segmented into i) monthly average analysis of 2019 vs 2020 ii) before and during COVID-19 social lockdown in 2020, for all the cities. These segmental studies improve the study's reliability and enhance the opportunity to explore more about the influence of COVID-19 social lockdown on the environment and health. The average monthly data from March 25 to April 24, 2020, was compared with 2019. The

Table 1
List of studies in India.

Sl. No	Focus	Target Air Pollutants	Outcome	Environmental/Health Analysis	Reference
1	The effect of restricted human activities due to the COVID-19 pandemic on air quality in 22 cities of India was estimated	NO_2 $PM_{2.5}$ PM_{10} O_3 SO_2 CO	A substantial improvement in air quality expected even during unfavorable meteorology if strict air quality control plans are implemented. In most cases, $PM_{2.5}$ had maximum reduction. Considerable decrease in concent rations of air pollutants leading to a fourfold drop in Complete ER. $PM_{2.5}$ could rise because of unfavorable meteorology but average concentration would still fall within CPCB limits.	Only environmental analysis. Air quality data analyzed in different regions of India.	Shubham et al., 2020
2	The focus of the study is to conduct a critical analysis of social environmental pollutants in India due to COVID-19 pandemic disease.	NO_2 $PM_{2.5}$ PM_{10} O_3 SO_2 CO	The results revealed a statistically significant reduction in all contaminants, except ozone, in all mega-cities.	A study done on the impacts of COVID-19 lockdown in different regions, environmental pollutants were analyzed over two time periods March–April 20 2019 and March–April 2020 and 10th - 20th March 2020 (before lockdown) and March 25 to 6th April 21 2020 (during lockdown).	Suresh Jain and Tanya Sharma, 2020
3	Study on the effects of meteorological factors on COVID-19 cases in India	NO_2 $PM_{2.5}$ PM_{10} Aerosols	Early lockdown in India slowed down the spread of contagious disease COVID-19. More than 45% fall was found in AOD and NO_2 values during the lockdown period.	Degradation in the air quality, especially in the north Indian region created a health emergency by producing respiratory diseases due to increased particulate matter. This enhanced the number of deaths due to COVID-19 and also increased its spread through aerosols.	Sarvan Kumar, 2020

continuous 24-h spatial statistics were gathered for all cities during 2019 and 2020, and the average was used to assess differences in indices.

The before and during COVID-19 social lockdown again is categorized as a one-week average, and two-weeks average termed as one-week average and two-weeks average. To confirm with the deviating air quality, the weekly average of seven days data from March 4 to 11, 2020, as contrasted to the seven days average for March 25 to 31, 2020, to discern the results immediately before and during the first phase of COVID-19 social lockdown. In the two-weeks analysis, the air quality data was collected for 14 days before social lockdown (4–17 March 2020) and 14 days during the social lockdown (March 25 - April 7, 2020).

To strengthen the argument that the shift in the indices is due to social lockdown mediated change in air quality, the trend analysis of air pollutants and the corresponding indices are plotted together for 4th - 3rd April 2020 for further interpretation and assessment on the associated pattern change.

2.4. Interpretation and assessment

To associate these indices with social lockdown due to COVID-19, the monthly, one-week, and two-weeks average of indices were converted to spatiotemporal mapping using the ArcGIS 10.8 map toolbox IWD Interpolation. This was achieved by measuring air pollution in growing regions before and during the lockdowns. The spatial-temporal distribution of various air pollutants among cities was significantly heterogeneous. The concentrations of six air pollutants were much smaller than the normal day concentrations, which showed the positive impact of traffic restrictions on emission mitigation. Also, time-trend terminology and city-specific impacts were used to account for temporal and geographic shifts.

To study the effects of various changing air pollutants on the indices included in the paper and observe the pattern change of indices concerning air pollutants, a trend analysis was done with time for a month, from March 4 to April 3. In this pattern analysis, the objective was to analyze how every air pollutant influences the indices of environmental impact and health risks. The same trend has been represented graphically and is given below. Data recorded on studying the trends are plotted on bar graphs for all the four cities using GIS mapping. The analysis was done for 2019 vs 2020, one-week and two-weeks averages for before and during the social lockdown 2020. Three separate times were examined for the complete social lockdown effect on the environment and people's health. It gives perspectives of different times to judge the effects more precisely. The disparity in the environmental indices and health risk indices are compared between cities and with years. In the GIS mapping, the color code used ranges from green to red. The darkest green shade represents the minimum values of indices recorded at places and red color showing the maximum values. The shades of colors ranging between green and red show the indices' range between the maximum and minimum. GIS mapping for all individual indices has been done for each of the four cities. This gives a better insight into the changing values of the environmental and health risk indices in all the four cities' stations.

It is necessary to notice that there is significant concern regarding this condition in India so far. The regions are analyzed by spatiotemporal analysis in the association between susceptibility to air pollution and COVID-19 infection. They are also prone to scrutiny and extreme restrictions which are rare for determining the effects of social lockdown on the air quality.

3. Results and discussion

3.1. Trend analysis of air pollutants versus individual environmental and health risk indices

A total of 14 pollutants are considered for environmental impact and health risk assessments, namely, PM_{10}, $PM_{2.5}$, NO, NO_2, NO_x, SO_2, CO, NH_3, O_3, CH_4, Benzene, Ethyl Benzene, Xylene, and Toluene.

The spectrum in Fig. 1 and Fig. S1(a-b) shows the variance in air pollutants concentration and the resultant EI and HR indices. A detailed illustration of all the index corresponding to their air pollutants is shown in Fig. S2(a-i). From March 4 to April 3, 2020, the evolving trends covered the days before and during the social lockdown. The maximum air pollutant level can be seen between March 16 to March 22 with an average of 641.66 $\mu g/m^3$ and the lowest after March 24, 2020, with approximately 184 $\mu g/m^3$. The highest was around 700 $\mu g/m^3$ on March 10, while the lowest around 150 $\mu g/m^3$ on March 28. Delhi, which faces the most increased air pollution and resultant smog, could witness better air quality and India's clear sky. To cope with the argument, social lockdown enabled a drastic improvement in air quality from March 22 due to the complete closure of industries, traffic, and other activities. In transportation and industrial locations, air quality has improved close to 60%. Central and Eastern Delhi has experienced a maximum improvement in air quality. On the 2nd and 4th day of lockdown, about 40%–50% improvement in air quality was observed. (Susanta et al., 2020) The consequence of the unprecedented change in air quality is positively reflected in EI and HR indices. The highest peak of all indices can be seen on March 10, and as the social lockdown continues, the average decrease in the impact was ~71%.

The majority of the indices' variance is almost similar, having a pattern of ups and downs as in air pollutants except for POCP and Acute HI, discussed in the next section. NO_x and particulate matters strongly impact EI and HR indices. The calculations of all the index can be done using Table S2.

3.1.1. Acidification potential (AP)

The AP environmental impact index deals with the regional level phenomenon, acid precipitation. The presence of CO2 makes the atmospheric pH 5.6. The other acidifying air pollutants lower the pH and cause acid rain. This further damages the vegetation, surface water, and aquatic life. Fig. 1(a) shows the variance of AP in that period. In this study, air pollutants such as NO, NO_x, SO_2, and NH_3 were considered for AP calculation, having SO_2 as the benchmark as given in Table S3. Among these, NO_x plays a crucial role in AP variation, as seen in Fig. S2 (a). The peak index value was around 290 $\mu g/m^3$ on March 8th and 21st, 2020, while the lowest was ~50 $\mu g/m^3$ after March 22. The resultant approximate reduction in AP is about 80.39% following the air quality due to the social lockdown.

3.1.2. Eutrophication potential (EP)

Eutrophication reflects an excess of nutrients, including vital nitrogen and phosphorous compounds, in soil and water ecosystems. Mainly, agricultural practices, industrial emissions, and traffic pollution from the burning of fossil fuels are the sources of air pollutants controlling EP. The EP causing pollutants are also generated from nitric acid mining, forging, usage of explosives, iron refining, and food production processes. Fig. 1(a) indicates the EP variation throughout the time frame. This study measures EP with the air pollutants NO_2, NO, NO_x, and NH_3 in the equivalent mass of PO_4^{2-} as given in Table S3. Multiple peak points with a value of 50 were observed in the EP plot (Fig. S2(b)) during the stipulated duration having the pollution concentration of 312 $\mu g/m^3$. After March 21, it was found to be reduced to 12. This observation informs that the social lockdown could cut down the EP to 1/5th within a week.

3.1.3. Photochemical ozone creation potential (POCP)

POCP is an indicator being used to calculate chemical species contribution to the production of tropospheric ozone, which is harmful to environmental and health aspects. Fig. 1(a) indicates the POCP variation over the duration. POCP in this study was calculated using benzene, ethylbenzene, xylene, O_3, and toluene, in O_3 equivalence, as mentioned in Table S3. Benzene is the significant contribution

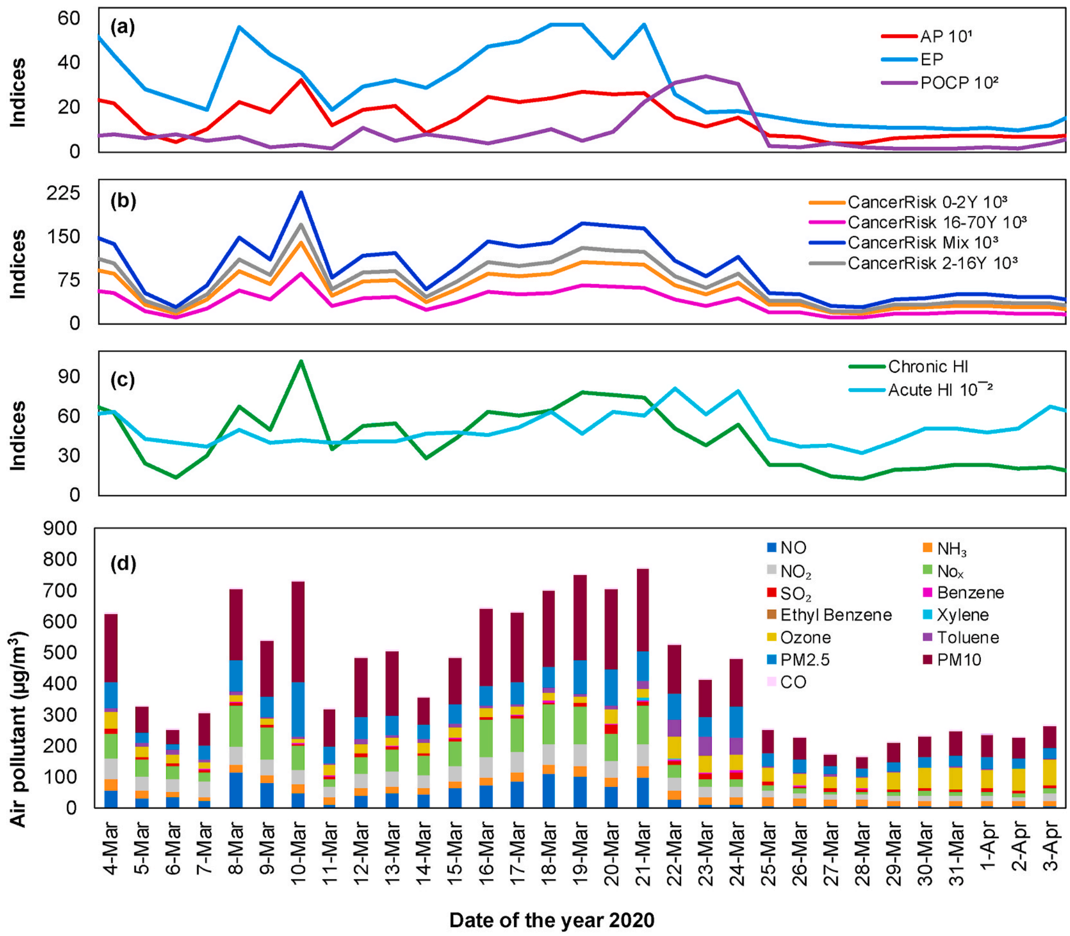

Fig. 1. Trend variation of indices with air pollutants.

commonly sourced from forest fires, volcanoes, burning of fuel and oil, and smoke from cigarettes. According to the study's scenario, the connection between POCP and air pollutants is limited to gas stations, engine exhaust, and industrial emissions.

POCP depends on pollutants including benzene, xylene, toluene, ethylbenzene, and O_3. Fig. S2(c), shows that except for O_3, the other POCP causing pollutants has fallen dramatically after the announcement of lockdown. Another interesting observation is the initial three days immediately after the lockdown announcement, during which the POCP reached a maximum of 3000 due to tripling of O_3 and toluene. This assumption may be attributed to the ambient organic chemistry that exists between nitrogen oxides and ozone. As shown in equations (1)–(3), NO_2 breaks down into oxygen atoms that form ozone in the NO and ground state (Suqin et al., 2011). Instead, NO combines with ozone again to create NO_2. It holds the ozone levels in a stable state.

$$NO_2 + h\nu \rightarrow NO + O \quad (1)$$

$$O + O_2 \rightarrow O_3 + M \; (\text{M is usually } N_2 \text{ or } O_2) \quad (2)$$

$$NO + O_3 \rightarrow NO_2 + O_2 \quad (3)$$

Seeing that the significant contributors to nitrogen oxides are vehicle emissions and vehicles' movement stopped in India during the lockout, the interactions between these substances ceased, increasing the amount of ozone present in the air. After March 24, a deep declination in the POCP curve was observed though the O_3 concentration remained the same or increased. The POCP potential of O_3 and toluene are 1 and 51, respectively. Although the air pollutants have increased by 16.89%, the POCP has decreased radically to 68.17% and impacted health and the environment due to the social lockdown.

3.1.4. Acute hazard index

The air pollutants such as NO_2, NH_3, SO_2, CO, O_3, benzene, toluene, and xylene are the key factors affecting the acute hazard index (HI) given in Table S5. This is the short-term impact that air toxins have on the wellbeing of a human being. Fig. 1(c) demonstrates the Acute HI variation in that time frame. BTEX vapors' acute health symptoms include inflammation of the ears, nose, and skin and effects on the central nervous system, such as vomiting, fatigue, drowsiness, dizziness, and even death. As shown in Fig. S2(i), while the total concentration of air pollutants decreased from 143.09 $\mu g/m^3$ to 120.5 $\mu g/m^3$, which is almost 15.78%, the frequency of acute HI also reduced about 0.54 $\mu g/m^3$ to 0.47 $\mu g/m^3$ which is around 12.96%. Like POCP, acute HI also found its peak value of 0.6–0.8 from 22nd to March 24 viz a viz after the beginning of social lockdown. The corresponding air pollution was measured to be 200–240 $\mu g/m^3$. The toluene concentration was the primary influencing compound, followed by xylene, which has the acute reference exposure level (REL) of 37000 and 22000. Though the change in acute HI is observable (~50–60%), the lockdown mediated change in the pattern was less than the other environmental and health indices since the decline was discontinued after March 28.

3.1.5. Chronic hazard index

The chronic HI is the health hazard index on an individual due to the long-term exposure to toxic air pollution. Chronic pollution presents a risk of infection, damage to the liver, kidneys, heart, lungs, nervous system, bone marrow, and blood supply, making a well-being's life and safety potentially harmful. BTEX molecules have an extreme propensity to bioaccumulation and are present in multiple types of human cancer and tumor. Chronic HI is measured with $PM_{2.5}$, PM_{10}, NH_3, benzene, toluene, and xylene in this study can be seen from Table S5. The primary determining factor of chronic HI is xylene, followed by toluene and NH_3. Fig. 1(c) indicates the variance of the Chronic HI over that period.

Contradictory to acute HI, a continuous decrement was observed in chronic HI during the social lockdown and air pollution as observed in Fig. S2(h). In this case, the total pollution decreased from 314.05 $\mu g/m^3$ to 120.5 $\mu g/m^3$, almost 61.63% during the social lockdown. The elimination of pollutants has reduced chronic HI from around 51.19 to 26, about 49.20%. Chronic HI was 100 on March 21, fell to 20 in a week, and hence the impact on health was expected to cut down to 1/5th of regular days.

3.1.6. Cancer risk

Cancer Risk is a function of body mass, and is age-dependent. The most affected classes are children and elderly people. In this study, cancer risk is measured for four age groups: 0–2, 2–16, 16–70, and mixed as detailed in supplementary information Table S6. $PM_{2.5}$, PM_{10}, benzene, ethylbenzene is considered compounds for estimating the incidence of cancer. Millions of people define this ratio as a risk incentive. The primary sources of particulate matter pollution are forest fires, vehicles, diesel engines, non-road cars, agricultural burning, industrial emissions, etc. The smaller the particles, the more damage they can inflict on human health. It triggers heart problems that are not severe, erratic heartbeat, exacerbated asthma, reduced lung capacity, etc.

The people most at risk for PM exposure damage include people with current lung or heart disease, older people, and children. The graph in Fig. S2(g), reveals that the maximum pollutant value is approximately 500 $\mu g/m^3$, which means that the probability of cancer risk is nearly 230000 chances per million. The mean pollutant concentration declines sharply from 260.31 $\mu g/m^3$ to 127 $\mu g/m^3$. It resulted in a decrease in cancer mortality for all age classes from 108,462 to 52,916 per million.

Although the value of cancer risk has reduced since the beginning of the lockdown as shown in the graphs Fig. S2(d-f), it can be noticed that PM_{10} and $PM_{2.5}$ increased for the initial days of the lockdown from March 22 to March 24. The main reason behind this was the rush of people and vehicles during this time to visit groceries to buy the stock of necessary items required daily in the lockdown as markets were announced to remain closed during the next 21 days. However, the total cancer risk during social lockdown was significantly lowered to 51.21% within a month.

3.2. Environmental and health risk indices for different cities

3.2.1. Delhi

As the COVID-19 pandemic spread in India, Delhi was one of the first states to report country's positive cases. The first positive case of Delhi was reported on March 1, 2020 (Ankita Bhandari, 2020). Along with the Nationwide social lockdown announcements, Delhi also began its first lockdown from March 24 up to April 14, followed by the next social lockdowns. Due to a nationwide social lockdown in India, significant activities contributing to air quality degradation had to stop all over the country and so also in Delhi. The significant factors that lead to the high amount of air pollution in Delhi are mainly motor vehicle emissions, wood-burning fires, fires done for agriculture purposes, exhaust from diesel generators, dust from construction work, burning waste and garbage in mass quantity, and also illegal industrial activities, with many more factors being a part of this. Curbing these activities showed a significant decrease in air pollution levels in major cities like Delhi. As per records of a study, Delhi has approximately 12.1 million registered vehicles. Among these, just a fraction was plucked during the social lockdown. During the social lockdown, the number of vehicles entering Delhi reduced by a significant number. Workplace visits reduced by 60%, while shopping and leisure activities decreased by 84%. Also, residential activity increased by 29%. Cycling and walking rose from 14% to 43% during social lockdown. The Indian capital, which is very frequently seen on the top of the world's most polluted city charts, recorded a 60% reduction in levels from March 23 to April 13 compared to the same time of 2019. The best air quality was experienced in Delhi in 2020, as per records. According to the Centre's System of Air Quality Weather Forecasting and Research (SAFAR) in Delhi, concentrations of $PM_{2.5}$ were found to be reduced by 36% during the social lockdown, PM_{10} by 43% and by 52% compared to the pre-social lockdown period (March 1 to 14). The resultant impacts are reflected in environmental and health risks as discussed below, specifically with monthly, one-week, and two-weeks averages.

3.2.1.1. Monthly average: 2019 vs 2020.

The year 2020 that came with a pandemic impacted humans and nature compared to the previous years. For a detailed comparison of the environmental changes, especially on the air pollution and thus on environmental impact and health risk indices in 2020 due to decreased human movements and human activities, we are using data of 2019. Fig. 2(a) & (e) represents the variations in various indices that affect the environment and people's health. The graphs have been separated based on these indices' annual effects on Delhi during 2019 and 2020. The graphs include representation of indices such as AP, EP, and POCP, which are majorly responsible for creating environmental impacts and plots of cancer risk, chronic HI, and acute HI, giving insight into health risks. As can be seen by comparing the line graphs of two consecutive years, sharp falls and rise can be seen in indices' values. For example, for the station Bawana of Delhi, the value of cancer risk for 2019 was around 170000 per million, which reduced to 90000 per million in 2020. The International Agency for Research on Cancer (IARC) had classified many outdoor air pollutants such as carcinogens, including diesel engine exhaust, solvents, and dust, along with other contaminants, as significant reasons for increasing cancer risk. During the social lockdown, the number of vehicles running on the road reduced by more than 50%, reducing air pollution. This has shown drastic changes in the values of health risk indices. Spatial plotting is shown in Fig. 5(a–e). Especially mentioning the station Punjabi Bagh, the values of all indices recorded at this station showed a considerable fall in 2020, shown in Fig. 3(a). Similar is the case of the Shadipur station of Delhi. Fig. 3(e) represents the six indices mentioned in this paper for Delhi to decrease the indices' average values. Also, Fig. 4 showcases the difference in the values of all the index considered very clearly. POCP values show a 70.79% decrease in the values, while AP values recorded show a 49.05% reduction in values in 2020 as compared to 2019 for Delhi. EP values show a fall of 52.86% in 2020 as compared to the previous year. The average value of cancer risk was reduced by 57.64% in 2020. At the same time, chronic HI recorded a fall of 58.22% in the average value. Also, there is a drop of 43.53% in the acute HI value due to the social lockdown.

3.2.1.2. One-week average before and during social lockdown.

Sudden changes in the daily activities of Delhiites due to the guidelines for lockdowns given by the Indian government showed a huge difference in the quality of air visible in the city. Delhi has been suffering from bad air quality for many years. Even in 2020, before the pandemic spread, Delhiites were seen as furious about this. However, as soon as the lockdown began, the story of Delhi changed. To understand the difference that the social lockdown had on Delhi's air quality, we consider comparing two consecutive weeks. The only difference is that of lockdown during one and the absence of it during another. Line graphs are shown in Fig. 2(i) & (m), for one-week variation. The values of all indices during social lockdown are much lesser than those before social lockdown. Out of the 38 stations in Delhi where the data was recorded, Punjabi Bagh was chosen to plot the bar graph (Fig. 3(e)), representing similar patterns in values at other stations. During the social lockdown, most indices show a more than 50% decrease in the values compared to the week before social lockdown. Spatial plotting is shown in Fig. 5(g–l).

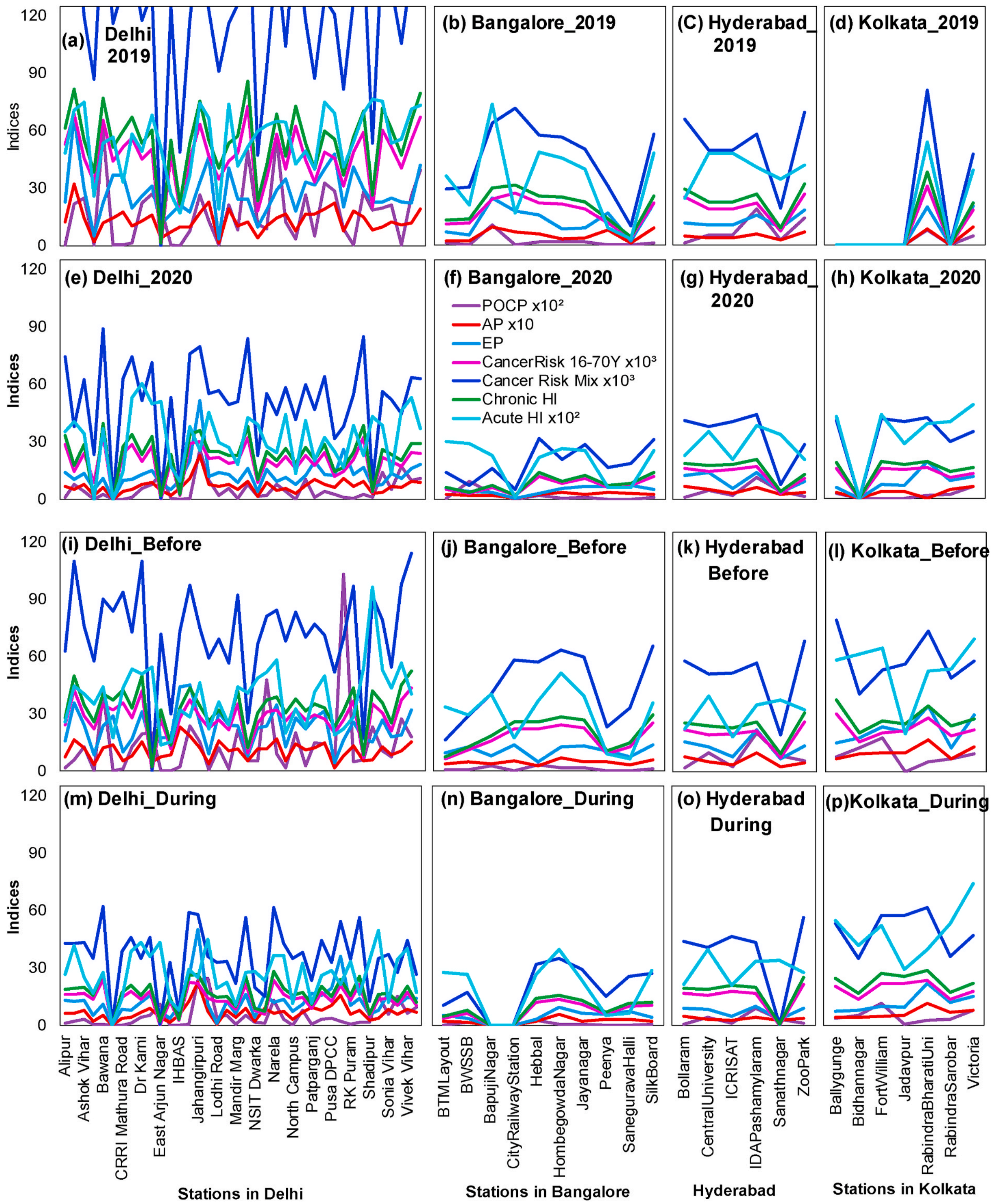

Fig. 2. Monthly Average (a–h) and One-week Average (i–p) of indices for different stations in 4 cities before and during the social lockdown.

A dramatic fall in the amount of $PM_{2.5}$, PM_{10}, and the atmosphere of Delhi was recorded once the nationwide social lockdown started in India from March 25, 2020. This directly affected the environmental indices such as POCP, AP, and EP and showed effects on indices of health risk values. There was a huge fall in the values of cancer risk (mix) during the social lockdown. The value of cancer recorded at Punjabi Bagh reduced from 77170 per million during the week before social lockdown to 44490 per million during the social lockdown.

3.2.1.3. Two-weeks average before and during the lockdown. For more detailed analysis and readings for a more extended period, the study was also done for two weeks each, before and during the social lockdown. From the mapping of ArcGIS shown in Fig. S3, the variability can be detected in various places for two weeks. The significant changes can be seen in cancer risk and chronic HI accompanied by AP and EP. The color change from red to green indicates an optimistic move towards a healthier fit for the environment. But as it is the data for 14 days in each condition, it only shows the very short-term effect of air pollution. Fig. 3 (m) distinguishes Punjabi Bagh's condition before and during the social lockdown phase. It can be observed that POCP, cancer risk, and acute HI

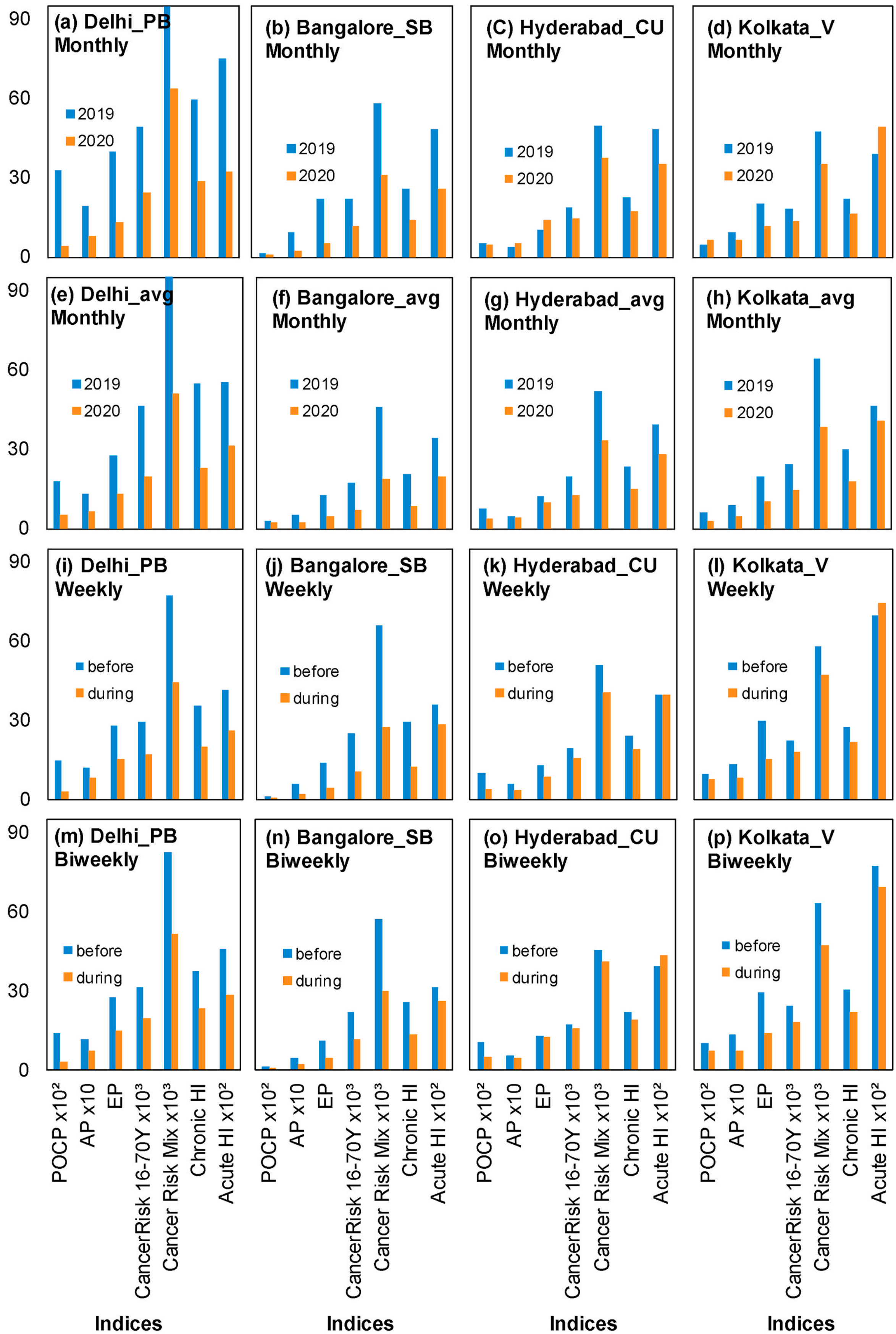

Fig. 3. Monthly (a–d), averaging of all stations monthly (e–h), one-week (i–l) and two-weeks (m–p) average of indices for different cities PB – Punjab Bagh, SB – Silk Board, CU – Central University and V – Victoria.

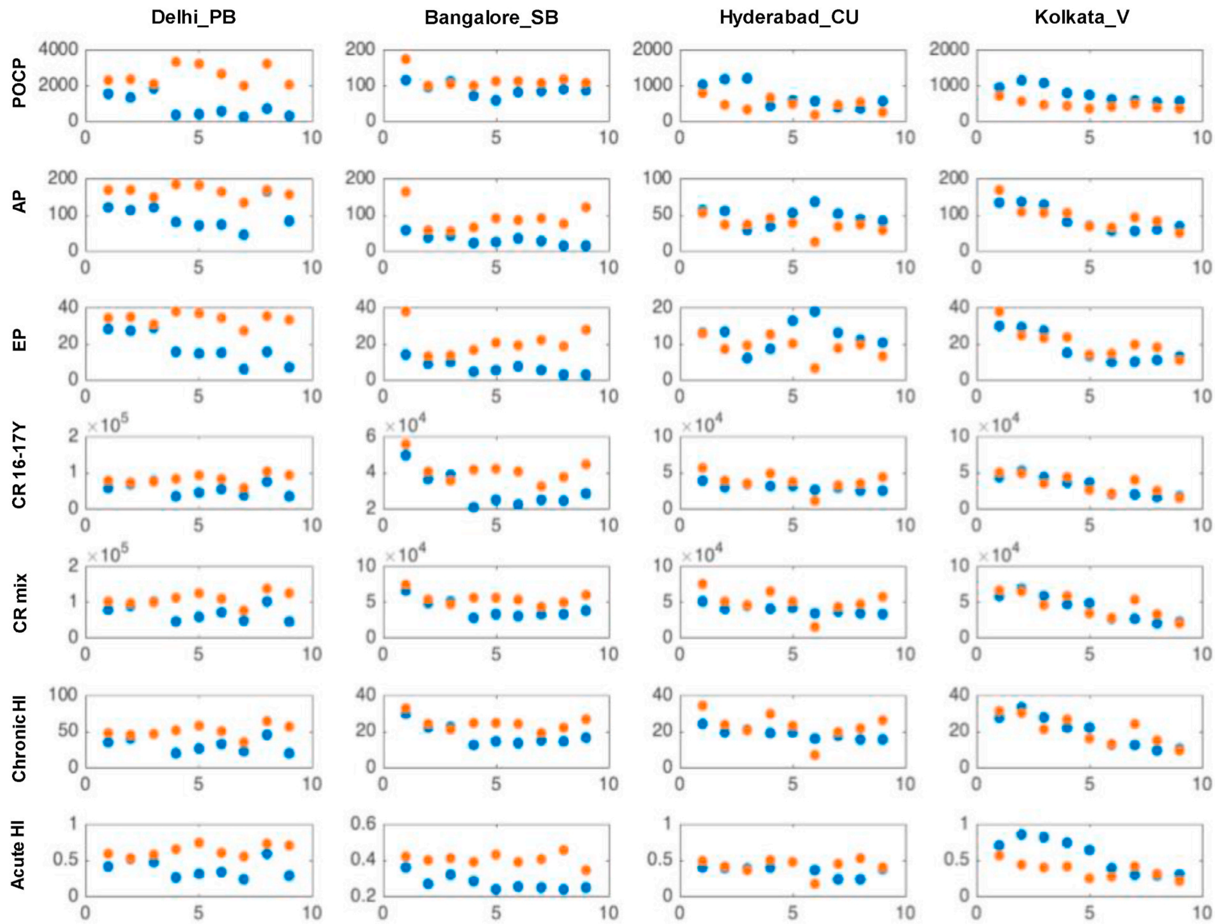

Fig. 4. One-week average (• 2019, • 2020) (9 points are average of March 4–10,11–17, 18–24, 25–31, April 1–7, 8–14, 15–21, 22-8, 29-May 5, respectively).

are experiencing a big decrease. All age group cancer risk decreased by 37.57%, POCP reduced by 76.25% in such a short period. Chronic HI and acute HI decreased by 37.96% and 38.47%, respectively. Subsequent variations can be seen at all other 37 stations in Delhi. The air efficiency of transport and manufacturing areas has increased by about 60%. Parts of central and eastern Delhi witnessed the maximum changes in air quality. The significant reduction in vehicle movement and the shutting down of industries, restaurants, hotels, markets, administrative centers, and many other public activity places have caused a dramatic improvement in air quality, mainly in the primary controlled ones such as $PM_{2.5}$, PM_{10}, and CO.

Delhi holds the record of being one of the most polluted cities globally. This is one of the primary reasons for selecting the capital for this study. According to the TIME publication of November 2019, air pollution in Delhi had hit an all-time high, creating breathing problems and even causing deaths. A public health emergency and a climate emergency had to be declared in Delhi (Sanya Mansoor, 2019). As shown in the observations recorded and plotted on a graph, health risk issues declined drastically after curbing the daily pollution-causing activities. Lung cancer, which is a significant issue in most polluted places, also decreased due to the same reasons. The number of hours rated as unhealthy in Delhi dropped from 68% in 2019 to 17% in 2020. From observations, it is found that cancer risk decreased by 61% in Anand Vihar during the first week of social lockdown compared with one week before social lockdown. Due to high levels of air pollutants always present in the air of Delhi, the city's residents have been facing many health issues that are influenced by the highly impure air. During the winter season, the atmosphere in the city becomes an even more significant threat due to the formation of smog all over the city. The decrease in pollution generating activities in the city during the lockdown has become a blessing for the city people, who are mostly worried about illnesses spread through contaminated air. Due to the changing scenario, decreasing health danger is a positive sign of the changing climate.

3.2.2. Bangalore

Bangalore is one of the most pleasant and enjoyable places to stay in. Construction and production are rising as the industry is advancing in the 'Garden City of India,' due to which its label is fading away. Establishment of factories, construction of warehouses, houses, and plants, thereby destroying the city's calm and peaceful climate. We can see massive structures and heavy traffic today. Increased traffic and urban congestion in the region have increased air pollution. In the last 15 years, traffic has risen exponentially. The movement of vehicles is too significant. The key source for contamination in Bangalore is vehicular traffic and waste emissions and burning, each adding up to 25% and the rest by construction dust. Sources say that automobiles in Bangalore produce 1200 tons of carbon per day, 4 tons of NO_x, and 0,5 tons of PM_{10} in 2018. Throughout heavy traffic hours, the particulate matter is $PM_{2.5}$ and PM_{10}. The index of air quality is rated as unhealthy, ranging from 118 to 159. But a drastic decrease is seen in Bangalore's air pollution level due to strict lockdown due to COVID-19, which is discussed in the section below.

3.2.2.1. Monthly average: 2019 vs 2020. Every year thousands of people shift to Bangalore for various purposes, mostly related to jobs and education. The increasing number of people in the city is leading to more harm to the assets of nature. In 2020, a drastic change was experienced by the rapidly growing city environment compared to previous years. The social lockdown in Bangalore led to hampering people's activities

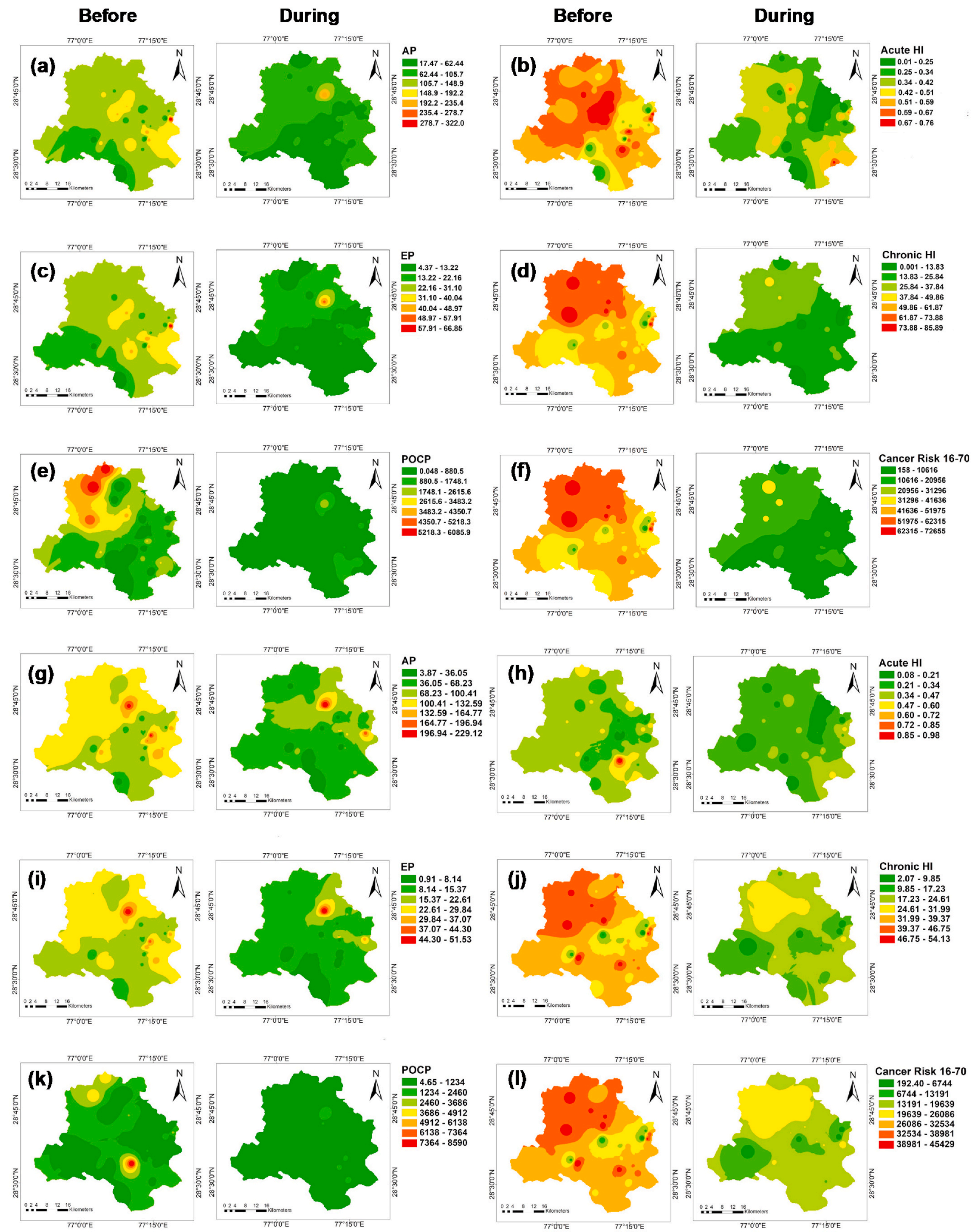

Fig. 5. (a–e) Monthly average 2019 vs 2020 in Delhi (f–l): Weekly average of before and during the lockdown in Delhi.

and traveling to a vast extent, but the atmosphere changed positively because of this. Fig. 6(a-f) can be referred to study the effect of nationwide social lockdown on Bangalore. It shows the difference in these indices' values in the two consecutive years, 2019 and 2020, and the indices' variance. The index showing health risk factors saw a significant plunge in their values in 2020 compared to the previous year. The cancer risk index saw a decrease of 58.62%, which shows improved air quality due to stopping certain industrial and transportation activities in Bangalore.

Similarly, chronic HI index and acute HI index values were reduced by 58.76% and 43.04%, respectively. Fig. 3(f) represents a dip in POCP, AP, and EP indices recorded in Bangalore. POCP average value fell by 36.89%, average AP value by 54.23%, and EP average value by 62.22%. These values were recorded at ten stations in Bangalore. There are also some of these stations where some index value rose in 2020 compared to 2019, despite the social lockdown. For example, the value of acute HI recorded at the BWSSB station is 0.29 $\mu g/m^3$ in 2020, whereas it was 0.20 $\mu g/m^3$ in 2019. There are exceptions like these, which indicate that social lockdown caused very little change in some places. For the Silk Board station, the contrasts can be seen in Fig. 3(b). The summed-up differences in the values of these indices have been very clearly plotted in Fig. 4.

3.2.2.2. One-week average before and during social lockdown. Like the monthly average for the years 2019 and 2020, weekly changes were also recorded before and during the lockdown. Fig. 2(j) & (n) illustrate Bangalore's variation for a one-week duration. Out of 6 stations, Silk Board station's data has been plotted in Fig. 3(j). Its spatial analysis can be seen in Fig. 6(g–l). At this station, the values of indices recorded during social lockdown are lower than the data of the week before social lockdown. Among the environmental impact indices recorded at Hebbal, POCP, AP and EP show a plunge in values by 38%, 60%, and 68%, respectively, once the social lockdown was followed. Health risk indices also followed the same trend by showing a plunge in cancer risk values (16–70), cancer risk(mix), chronic HI by 58%, and acute HI by 20%. Emissions from vehicles are the key contributors to air pollution in Bangalore. The substantial change in Bangalore air quality during the lockdown strongly shows the important exposure in traffic to air pollution. Air pollution during the shutdown duration of COVID-19, calculated as $PM_{2.5}$, decreased by an average of 28%.

3.2.2.3. Two-weeks average before and during the lockdown. Even after doing a weekly study, a two-weeks study became vital as it gave a comprehensive database for the analysis of the situation. Based on spatial data obtained shown in Fig. S4, it can be seen that there is a very rapid change in color from red to green, which shows that the hazardous effects of air pollution are significantly reduced. Fig. 3(n) indicates the seven indices listed in this paper for the Silk Board. Bangalore denotes a decrease in the average index. The decline in POCP and AP is much smaller, but there is a substantial drop in the EP value, which indicates a drop of 58.03%. Considering the health risk indices, the average risk of cancer decreased by 47.55%, while the average risk of chronic HI declined by 47.65%. In comparison, the acute HI rating has been reduced by 16.93%. A similar effect is seen in all other locations of Bangalore.

Bangalore, a city with panic in air quality, has seen air pollution as a big problem over the years as the city developed. As seen in Bangalore, economic growth has influenced emission sources' patterns, affecting the environment and public health. According to a paper of January 2019, vehicular emission contributes majorly to Bangalore's air pollution. According to data collected in 2019, 60–70% of Bangalore air pollution originates from vehicular emissions (Shashank Atreya, 2019). The use of diesel for the production of electricity also had an impact on air pollution.

In 2020, the social lockdown brought a drastic change in the number of air pollutants in Bangalore city. As the vehicular movement was stopped since the first day of social lockdown, there was a noticeable improvement in Bangalore's Air Quality Index in 2020 compared to 2019. Table S7 shows the impacts of different levels of AQI, which further explain the need for a better Air Quality Index. The harmful pollutants also showed a sharp dip in 2020, after the social lockdown. From the observations done for Hebbal station, we see that all EI indices reduced by 21–31%and the HR indices showed a decrease of up to 44% during the first week of social lockdown, which offers a satisfactory improvement in the environment and health of people. According to CPCB, there is almost a 60–65% reduction in Bangalore air pollutants since the social lockdown started.

Because of the minimal movement of people and vehicles in the city during the social lockdown, sulfur dioxide (SO_2) and nitrogen dioxide (NO_2) were the lowest in the social lockdown time. In certain places, a PM rise has been observed because of waste incineration, manufacturing, etc. For all environmental contaminants except ozone, a significant percentage shift was detected. Total reductions were found to be (~77.11%), accompanied by (~50.64%), and $PM_{2.5}$ (~40.50%) dropped by 21.41%, by 14.84%, and CO by 39.70%, including a rise of 28.73% in the ozone level.

With the improvement in air quality, health risks faced by people living in Bangalore also reduced drastically. Air pollution leads to not only lung diseases but also diabetes, according to the state of the global air 2019 report. Exposure to $PM_{2.5}$ is one of the primary reasons for causing type 2 diabetes. (Sunitha Rao, 2019). The social lockdown and the reduction in vehicular movement and other air pollution driving activities that followed caused a dip in $PM_{2.5}$ in Bangalore. The air quality of the city is lying between good and acceptable range.

3.2.3. Hyderabad

Hyderabad is the fourth most populated city in India to generate high-toxic particulate matter and the electricity used by public transport as a whole. Transportation is the main source of carbon pollution. Transportation is the main source of carbon pollution. Rapid urbanization development and the establishment of industries and populations have several adverse impacts in the region and pollution. The total urban commuting load of Hyderabad's particulate pollution is around 900 kg every day, which is highly worrying. The area is also a pioneer in the usage of electricity per trip and high environmental pollution. Between December 2018 and May 2019, Hyderabad reported exceptionally high rates of air pollution. In October the level of $PM_{2.5}$ increased and persisted until December. AQI varied from 150 to 230 in the region in the summer of 2019 (Arya Sharan, 2019). Nonetheless, the degree of air pollution in Hyderabad has considerably lowered due to the strict lockdown, addressed in the following segment.

3.2.3.1. Monthly average: 2019 vs 2020. Just like Bangalore, even Hyderabad is a rapidly developing city in Southern India. Everyday movement of people in the city all day long in large numbers makes it an important city to be studied in this scenario. To study about air pollution changes in Hyderabad due to COVID-19 spread, the data of indices for Hyderabad was recorded at 6 stations in the city. The variation of environmental indices such as AP, EP, and POCP and health risk indices such as cancer risk, chronic HI, and acute HI have been shown in Fig. 2 (c) & (g), comparing the data of 2019 and 2020. The plots are shown in Fig. 4 also represent index wise variations in values for 2019 vs 2020. As seen very clearly in the bar diagram for Bangalore city Fig. 3(g) and Central University, Hyderabad Fig. 3(c), the year 2020 recorded lower values of all the environmental impact and health risk indices as compared to the year 2019. This reduction in values is very drastic. Air pollution in Hyderabad reduced, causing effluents in the atmosphere that led to a reduction of 49.82%, 12.95%, and 21.52% in the values of POCP, AP, and EP respectively. Similarly, among the indices representing health risk, cancer risk reduced by 36.37%, chronic HI average

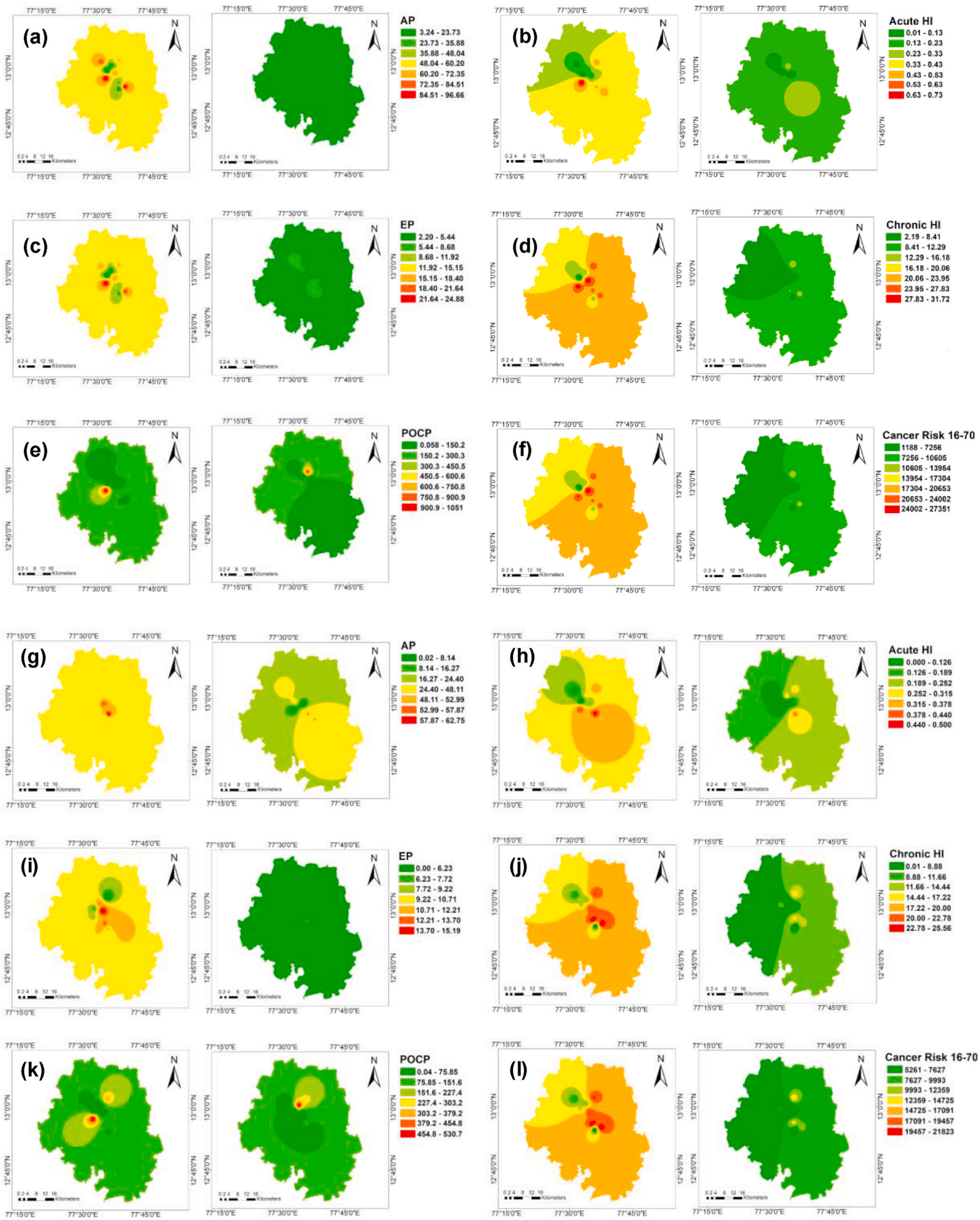

Fig. 6. (a–f) Monthly average 2019 vs 2020 in Bangalore Fig. 6(g–l): Weekly average of before and during the lockdown in Bangalore.

value dipped by 36.02%, and acute HI average value for the city plunged by 28.36% in 2020 as compared to 2019. The spatial variation is represented in Fig. 7(a–f). Just after the social lockdown began on March 25, ambient air quality standards have improved dramatically, with most of the vehicles staying off the route. With most of the vehicles staying off lane, factories shutting down, and building operations coming to a standstill, as a part of the social lockdown, Hyderabad city's emission rates have fallen.

3.2.3.2. One-week average before and during social lockdown. Change in the air quality index of Hyderabad was seen not only in comparison with the previous year but could also be seen significantly over consecutive weeks, with the arrival of coronavirus in the country. Fig. 2(k) & (o) shows the weekly collective variation of all the indices in the city. The Central University station, as shown in Fig. 3(k), is taken into consideration in this study to understand the pattern of changes in the values of indices and the drastic change in one week. As the bar diagram shows, similar to the graphs for Delhi and Bangalore, the social lockdown week from March 25 to 31st march 2020 shows a high improvement in the quality of air and atmosphere and also the health conditions of people by showing drastic fall in values of the indices considered for the study. Fig. 7(g-l) shows the spatial representation. At the Idapashamylaram station, POCP decreased from 1012 μg/m^3 to 415 μg/m^3, AP saw a fall from 56.02 μg/m^3 to 34.11 μg/m^3, EP reduced from 12.95 μg/m^3 to 8.53 μg/m^3. The health risk indices, cancer risk, and chronic HI plunged by 20.22% and 22.25 whereas acute HI value increased by 0.09% respectively over the social lockdown. This simultaneous fall in indices can even be noticed in such a small period of one week. A small-time span of a week showed sudden changes, but what showed a long-time change continuation was the study done for 2 weeks before and during the lockdown. This further is explained below.

3.2.3.3. Two-weeks average before and during the lockdown. Fig. S5 indicates the change in air quality. Of the city. Comparing the values of indices before and after the social lockdown of Central University, as seen in Fig. 3(o), the EI indices show a lower decrease relative to the HR indices, except for acute HI which indicates a rise of 9.89%. Analyzing spatial information, the minimal shift in acute HI may be detected or it can be assumed that there is a rise in acute HI, which is a concerning sigh. The health risk was reduced by 9.86%. Air quality has fallen throughout the district, even in heavily polluted areas such as Hyderabad University, Sanathnagar, and zoo park. Nitrogen dioxide (NO_2) levels also declined by 36%, mainly from cars and power plants. In the meanwhile, $PM_{2.5}$, which is known to be especially risky, also suffered a decline of about 24%. The fall is similar to a one-week observation.

Hyderabad records traffic emissions as the main reason for causing air pollution in the city. With around 49% of the harmful air pollutants being released by vehicles, the remaining 50% is contributed by construction, demolition, and deforestation. (Sarjeel, 2018). There is a continuous increase in pollution parameters, mainly nitrogen oxides, carbon monoxide, and ozone.

As seen in the observations and graphs, the values of environmental impact indices, POCP, EP, AP, plunged during 2020 in comparison with 2019. The reduction in major pollutants mentioned above leads to a drop in the values of these indices. $PM_{2.5}$ which is directly linked to automobile and factory emissions is lowered by 13.5%. In the same period, PM_{10} is down by 30%, which is another air quality metric. The oxides of nitrogen are down by 31% and the ammonia is down by 13%, owing to the burning of automobile engines or chemical boilers in the atmosphere. Nevertheless, ambient ozone, another metric, has risen 21% which attributed the temperatures rising.

When it comes to improvement in conditions, health conditions can't be ignored in the case of Hyderabad along with other major cities. Air pollution leads to lung and breast cancer. Less exposure of people to $PM_{2.5}$ due to continuous social lockdowns in the city, reducing the health risks caused because of air pollutants. Hyderabad's average air quality is satisfactory.

3.2.4. Kolkata

Kolkata is a metropolitan city and has been rated as the second polluted city in the country according to sources, and its air quality index decreases rapidly compared to that of Delhi. It is less known that in terms of air pollution, Kolkata has exceeded Delhi. Since vehicles have risen in numbers, construction works, industrialization has resulted in emissions in the region which are several identified explanations for the exponential increase in pollution. Several old cars release smoke, which is not tainted by emissions controls. In Kolkata, the Air Quality Index (AQI) was seen, as in November 2018, at 409, and in Dec'2018, as "bad." The city's citizens breathe 5 times poor air and about 71% of the population are suffering from respiratory problems. $PM_{2.5}$ is not available during all the seasons, but still, the Air Quality Level rises at the beginning of winter beyond 300/400 in December. Pollution and poor air quality worsen at night and early in the morning. The effects are expressed, according to the monthly, one-week, and two-weeks averages, in environmental and health risks listed below.

3.2.4.1. Monthly average: 2019 vs 2020. Kolkata, known as one of the leading cities of India in terms of economic and cultural growth, was considered for this study due to its involvement in multi-dimensional human activities. Just like the other cities mentioned above, even Kolkata had its share of good air quality since March 2020, i.e. since the beginning of the lockdown. To study the changed environmental and health conditions in 2020 as compared to 2019, the distribution all around the city is shown in Fig. 8(a-f). Fig. 3(h). The drop in the values of the indices in 2020 as can be seen in Fig. 4 is apparently because of the drop in the values of air pollutants. Drop-in $PM_{2.5}$, PM_{10} quantities in the atmosphere led to a reduction in the values of various indices, showing the overall effect on the environment and people's health. In Kolkata, POCP, AP, and EP average values in 2020 dropped by 62.82%, 57.23%, and 49.06% respectively, in comparison with 2019. Health risk indices also showed a dip in their values of 2020 as compared to the previous year as indicated in Fig. 2(d) & (h). According to the recorded data, cancer risk values in Kolkata reduced by 40.13% on an average, chronic HI values plunged by 40.86% and acute HI saw a dip of 12.11%.

3.2.4.2. One-week average before and during social lockdown. Along with the monthly average of 2019 vs 2020, weekly averages were also taken for all the indices. The collective result for the one-week average is plotted in Fig. 2(l) and (p) and the spatial distribution is shown in Fig. 8 (g-l). Even in Kolkata, we get to observe a decline in values of indices representing both environmental effects and health effects. But here we have an exception of acute HI values which show a rise in values during the social lockdown as compared to before social lockdown weekly data. Out of these, Fig. 3(l) shown, is plotted for data of station Victoria. For the Victoria station, among the environmental impact indices, POCP decreased by 17.84%, AP value fell by 40.21% and EP showed a decrease of 48.86%. For the same station, as can be seen in the bar graph, cancer risk (16–70 yrs) and cancer risk (mix) reduced by 18.522% and 18.523% respectively. While chronic HI values followed the same plunging pattern and showed a decrease of 20.69%, acute HI showed a rise in its values at the Victoria station by increasing by 6.48%. Thus, just over a week's difference, a large change was witnessed in Kolkata's air quality and people's health, as shown very clearly by the indices.

3.2.4.3. Two-weeks average before and during the lockdown. The effects of the lockdown for two consecutive weeks before and during lockdown are similar to the one-week observation. Taking the context of Victoria indicated in Fig. 3(p), there is a substantial drop of 10.63% in acute HI, although there is a relatively slight decrease in the risk of cancer. Indices

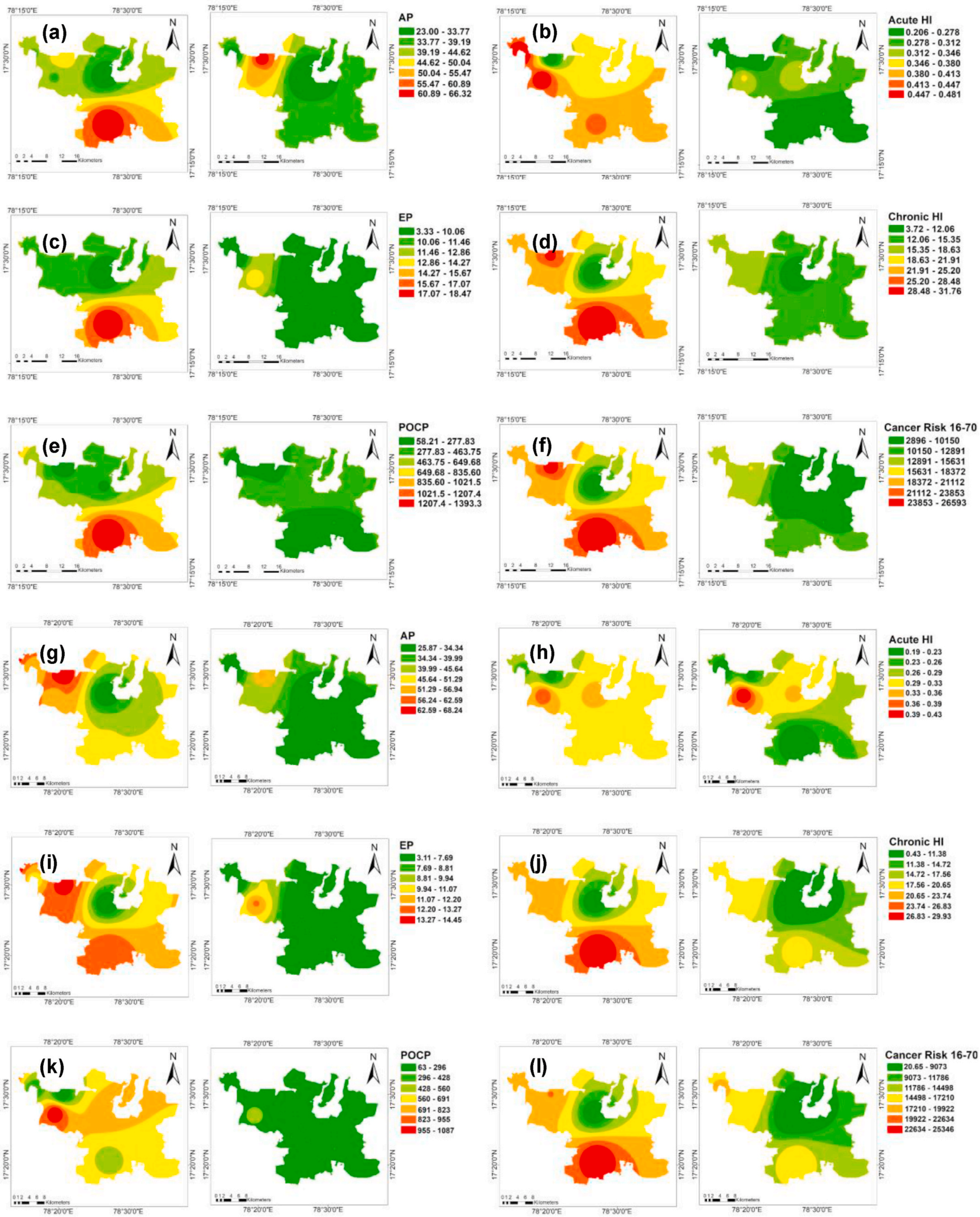

Fig. 7. (a–f) Monthly average 2019 vs 2020 in Hyderabad Fig. 7(g–l): Weekly average of before and during the lockdown in Hyderabad.

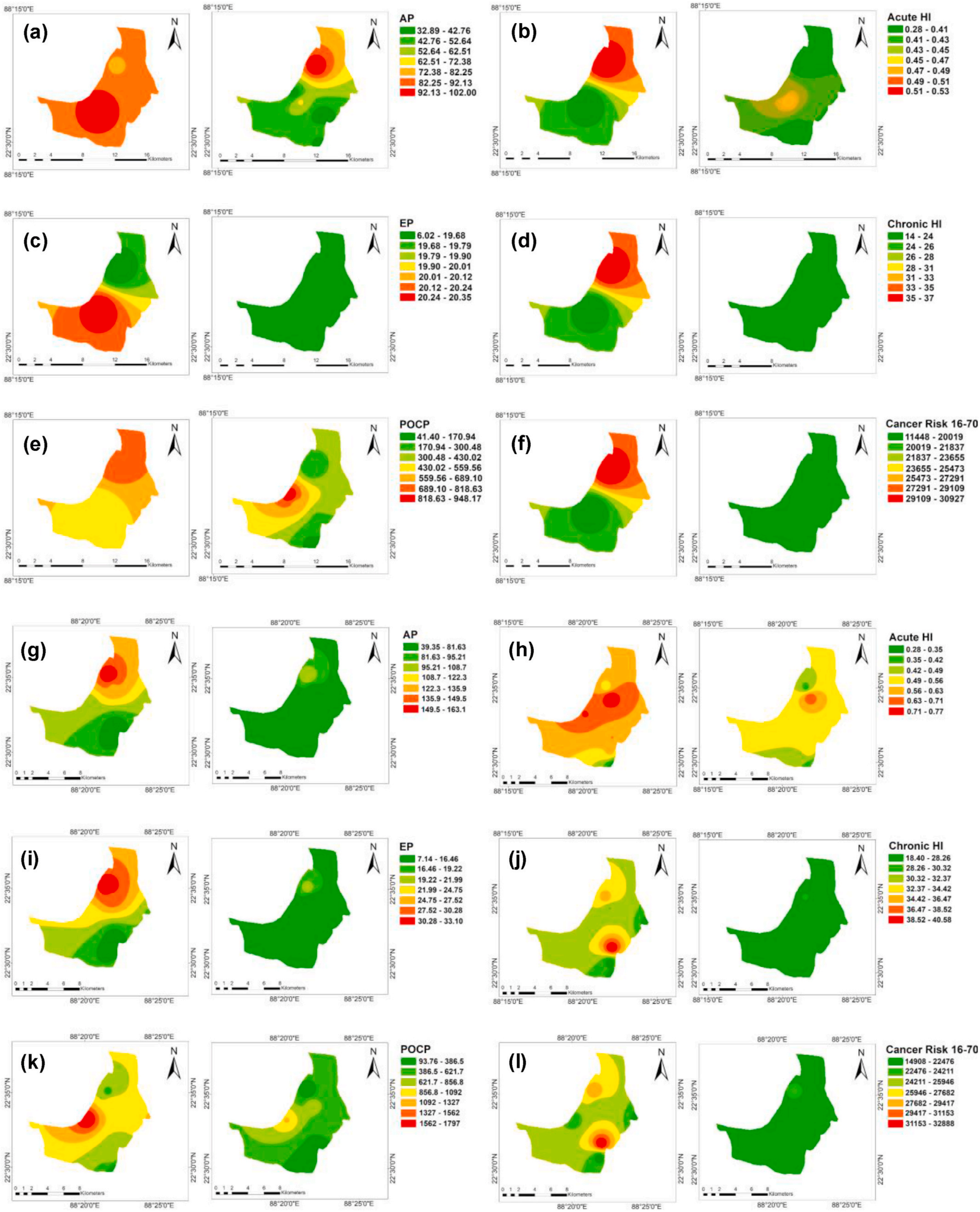

Fig. 8. (a–f) Monthly average 2019 vs 2020 in Kolkata Fig. 8(g–l): Weekly average of before and during the lockdown in Kolkata.

of the EI have declined substantially such as AP and EP decreased by 44% and 52% respectively. Similar results can be seen from other Kolkata stations. Spatial data as plotted in Fig. S6 also shows a subsequent shift in the indices which indicates an improvement in the air quality at various locations in Kolkata due to a reduction in emissions of pollutants from vehicles, factories, etc.

The air quality of Kolkata reported a big improvement with most residents staying indoors owing to the epidemic of coronavirus. With the reduction in the number of cars on the roads, halting manufacturing operations are some of the factors which reduced emissions in the region. A decrease in the average amount of environmental pollution can be observed except for $PM_{2.5}$and ozone. Over the same time, PM_{10} decreased by 15.21%. Social lockdown has a much stronger effect on NO_2. The concentration of nitrogen oxides is decreased by 62% and the concentration of ammonia by 38%. SO_2 decreased by 5.71% and CO by 21.97%. There is a sharp increase in the levels of $PM_{2.5}$ and O_3, which may have an effect on industrial emissions in the region.

The EI, including POCP and EP, decreased by 45% while the AP decreased by 39%. Kolkata's Bane is the vehicular emission that has decreased during the lock-off time, especially from diesel vehicles. Lung cancer is considered very categorical. The air quality in the city is regulated by ultra-fine particulates. The most affected are school-going and college-going students who fell victim to asthma. Cancer risk in the region is decreased by 20% and chronic HI and acute HI by 22% and 141% respectively. Kolkata records for the largest number of cases of lung cancer. Which has its origin in polluted air. But the purification of air in ways followed during the social lockdown can create a major positive impact on the air quality and thus on the number of people getting affected by it.

3.3. Comparison between cities

The 4 cities considered in this paper are fast-growing, highly populated cities of India. Even though this feature is common between these cities, they all are known for and represent different aspects of the country's growth and development. Delhi being the capital of India, has been a highly populated city and a hub of opportunities for many years. Due to the long exposure of the city's air to pollution and harmful effluents, the air of this place has become saturated with dust and pollutants. Many measures are now being taken by the government and citizens of Delhi to fight against this problem of air pollution.

But nothing had created a change in Delhi's air quality as much as done by the nationwide lockdown that followed the coronavirus pandemic. This is evident not only by the numbers and graphs mentioned in this paper but was also noticed by Delhiites over the course of the lockdown. On the other hand, Bangalore and Hyderabad are seen as emerging IT hubs and educational cities in India. The increasing population of people, accompanied by a rise in industries, vehicles, construction work, and development activities in these cities is leading to the deterioration of the environment's quality since the last few years in these places. These 2 cities of the Southern part of India notice movements and chaos of people throughout day and night. The environment of these cities had never seen a break of activities until the announcement of the nationwide lockdown. As can be seen in Fig. 6(a-f) and Fig. 7(a–f), the improvement at various stations of the cities can be seen concerning the quality of air. Not only the health of air but also the health of people in Bangalore and Hyderabad showed improvement over the course of the lockdown. Social lockdowns stopped movement of people across country boundaries as well as across states and even cities. This hampered the tourism industry, and thus Kolkata, which is one of the most visited places in India by tourists and travel enthusiasts started getting affected. But even though this caused economic hampering for the city, the atmosphere surrounding Kolkata showed signs of improvement since the beginning of the social lockdown. Fig. 8(a-f) is a representation of the improvement in the indices of environmental impact and health risk of Kolkata.

Even though each city witnessed improvements to a large extent, like never before in the recent past, there can be variations seen in the improvement rates. Delhi saw a large extent of positive change in the air quality, but yet, as compared to the other major cities of India, Delhi still has a long way to go on this path of air quality improvement. Whereas, Bangalore still has to see a lot of efforts being put in to save its citizens, especially small children from getting badly affected by the poor air quality. It is evident from the observations through all the tables, charts, and graphs included in this paper that the social lockdown has brought different changes at different places and also to different extents. But it can be surely said that the lockdown has shown everyone the right way of taking care of our natural resources.

4. Conclusion

During the spread of the coronavirus in India, human activities reduced to a great extent, causing drastic and substantial changes in the environment. The paper focuses on the impacts on environmental indices associated with air pollution, namely POCP, AP, EP, which change with changing environmental conditions. This article often includes information linked to air pollution-induced safety threats. Such indications address the risk of cancer, acute HI, and chronic HI.

The paper indicates that decreased human movements in the metropolitan areas listed for study, due to COVID-19 and the social lockdown in India, lowered the values of the above-mentioned indices The improvement in the values of the Environmental Impact (EI) and Health Risk (HR) indices recorded in the cities Delhi, Bangalore, Hyderabad, and Kolkata reflects the implications of cleaner air quality and increased human health conditions. The changes have been recorded by comparing the values of these indices in 2019 and 2020. The second comparison done is for data of a week before lockdown from March 1 to March 17 2020 and of a week during lockdown from March 25 to April 7 2020. All the observations, as seen in the graphs, suggest that the social lockdown created a big positive difference in the air quality of the cities of India with a high population and human activities.

For certain regions, $PM_{2.5}$ was decreased sufficiently among all pollutants. In contrast, an increase was observed for O_3 which could be attributed to a decrease in PM as well as a decrease in NO_x. It also proposed that in addition to the monitoring of primary PM, priority would be paid to rising precursor pollution of secondary pollutants. Moreover, strict pollution reduction steps as a consequence of science care and recycling of the industrial waste in the cities to provide a safe and breathable atmosphere in the future are the most important solutions recommended by specialists, i.e., from fossil-fuel to renewable energy and safer technology substitutes.

CRediT author statement

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Declaration of competing interest

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

Appendix A. Supplementary data

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