Original Article

An Investigation of Environmental Inequality in a Metropolitan Area

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Abstract

Introduction: Inequalities in urban environment are of significant concern, where socioeconomic status plays an important role. Inequality in environmental hazards is recognized as potential determinants of health disparities.

Materials and Methods: In this study, we used individual and cumulative environmental hazard inequality indices to compare inequalities among 379 neighborhoods in Tehran. Inequality indices were calculated based on unequal shares of environmental hazards for socioeconomic status (SES). The hazards include ambient concentrations of PM_{10} and NO_2 in 2011. We computed two individual inequality indices for NO_2 and PM_{10} and then the CEHII for the two criteria pollutants by the multiplicative and additive approaches.

Results: Results revealed that inequalities from cumulative hazards (additive and multiplicative) and individual PM_{10} in different education rates were significant ($P<0.001$). However, there was no significant relation between inequalities in distribution of the pollutants and the variable of unemployment rate ($P>0.05$).

Conclusion: These results confirm CEHII using multiplicative approach had higher value than the additive approach. Findings are useful for policymakers and city managers to investigate environmental inequities particularly in mega cities.

Keywords: Air Pollution, Urban Population, Socioeconomic Factors

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Introduction

Environmental injustice or inequality is broadly defined as the unequal exposure of socially or economically deprived individuals and/or groups to pollution and its associated effects on their health or their environment [1]. In spite of the fact that the field of environmental justice suffers from many conceptual and methodological shortcomings (e.g. 2, 3 and 4), research works have documented that (sub) populations and /or minorities with low socio-economic status (SES) are disproportionately affected by environmental hazards [5-16].

These disparities are increasingly identified as potential determinants of health inequalities [17-18] and additional research is needed to evaluate the cumulative impact of multiple environmental hazards and their toxic effects on these vulnerable communities.

The potential interactions of elevated environmental hazards and socioeconomic stressors have been explained as a form of "double jeopardy" [19]. As a result, environmental justice advocates have urged the regulatory and scientific communities to incorporate cumulative impacts in their decision-making and enforcement activities.

This paper uses a cumulative environmental hazard inequality index (CEHII) [19] to assess inequalities caused by socio-economic status in exposure to multiple air pollutants in Tehran County, Iran. The environmental hazards are nitrogen dioxide (NO_2) and particulate matter PM_{10} (aerodynamic diameter less than 10 µm). According to Su et al. [19], derivation and use of an index to characterize inequalities in cumulative environmental hazards have two major components: (1) a measure to qualify inequality, and (2) an estimate of cumulative environmental hazards.

In order to measure inequality related to socioeconomic measures, they developed "environmental concentration index". Since the term "concentration" has a different meaning in environmental health science, they refer to the extension of the concentration index as the "cumulative environmental hazard inequality index (CEHII)". Specifically, the CEHII measures socioeconomic and racial-ethnic inequalities in exposure to cumulative environmental hazard.

Concentration index is commonly used in the fields of social sciences and health planning [20]. The concentration index was developed to assess inequality of health distributions across socioeconomic groups, with the term "concentration" in this context meaning the concentration of health in a small group of people [21, 22].

The concentration index can also be used to assess inequalities from environmental hazards between different social groups. To our knowledge, concentration indices have only been utilized in one study to assess inequalities in exposure to individual environmental hazards [23], and the index introduced by Su et al [19] has been tried for the first time to characterize inequalities to cumulative environmental hazard.

In Iran, the current methodological approach is the first attempt for deriving individual environmental hazard and CEHII to characterize cumulative impact in a way that it integrates environmental hazard and social data.

In this paper, we have used the concentration index to summarize the inequality in the distribution of multiple pollutants across different socioeconomic neighborhoods. Therefore, the aim of this study was to investigate socioeconomic inequalities caused by distribution of air pollution.

Materials and Methods

Study area

The present study has been conducted in Tehran (Fig. 1), the capital and the largest urban area of Iran, having 379 neighborhoods with 8.7 m inhabitants [24]. The city is also categorized as one of the largest cities in Western Asia and the 19th city in the world. Like other large cities, Tehran is encountered with serious air quality problems.

In general, 20% of the total energy of the country is used in Tehran. Pollutants such as PM_{10}, SO_2, NO_2, HC, O_3 and CO are the major air pollutants in the city, about 80-85% of which is produced by mobile sources of pollution [25]. The city has a capacity for 700,000 registered cars while streets hold three millions on a daily basis. With the location of 35° 41' N - 51° 25' E and altitude of 1000–1800 meters above mean sea level, Tehran is placed in valleys and is surrounded by high to medium high (3800–1000 m) mountain ranges on the north, northwest, east and southeast [26].

As a consequence, the mountain range stops the flow of humid wind to the city and prevents the polluted air from being carried away from the city. Therefore, lack of wind and cold air in winter causes the polluted air to be trapped within the city. These concomitant situations make Tehran one of the worst areas in the world due to atmospheric pollution with many days exceeding air quality standards during each year [27].

Due to the air pollution in the Great Tehran area, morbidity, mortality and symptoms emerge. At the moment, the concentration of these pollutants most of the time exceeds the standard level, which leads to numerous impacts on the health of Tehran citizens [25-26].

Selecting and Modeling Environmental Hazards

Selection of the air pollutants used for this study was aimed at examining the potential cumulative and unequal impacts of important air pollutants in the region, as well as indicating how the CEHII metric can incorporate various pollution measures with different spatial, reactive and health risk characteristics. In this case, we related pollutants concentration to standards of the Supreme Council for the Environment Standard (SCES) (i.e., NO_2, nitrogen dioxide and PM_{10}, particles less than or equal to 10 μ min aerodynamic diameter) [19].

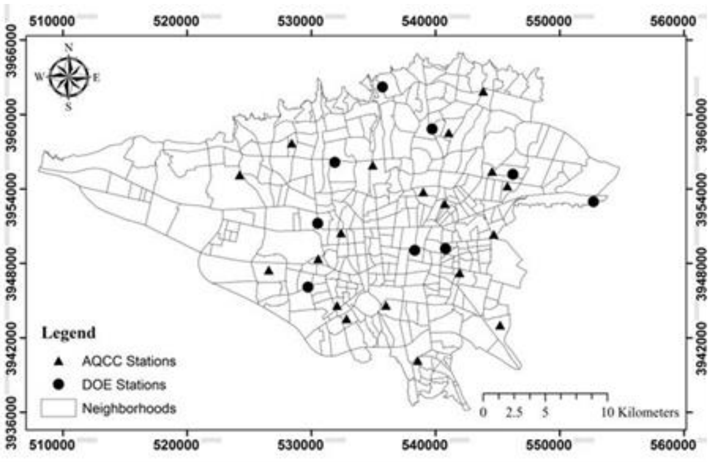

Figure 1: Study area and monitoring sites

The data of air pollutant concentrations for 2011 were extracted from two governmental air quality-monitoring agencies, which belong to Air Quality Control Company (AQCC) and Department of Environment (DOE). We used inverse distance weighting (IDW) method to estimate the concentration of pollutants [28].

Since there are a limited number of governments monitoring sites available [19] for pollutants of NO_2 and PM_{10}, respectively, 26 and 22 station data were imported into the IDW method. Neighborhood level mean concentrations of NO_2 and PM_{10} were elicited from corresponding modeled surfaces. We then measured ratios by dividing each neighborhood concentration estimated by the SCES of 21 ppb for NO_2 and of 20 μg m_3 for PM_{10} [29].

Individual Inequality Index

To figure out the unequal distribution of an environmental hazard, for each population group (neighborhoods), we plotted the cumulative proportion of the population group (neighborhoods), ordered by area-based percentage socioeconomic composition, starting from the most disadvantaged _against the cumulative share of the environmental hazard (See Fig. 2). If the population group has the same share of the cumulative impact of environmental hazards, the curve concurs with the equality (i.e., 45 degree or diagonal) line. If the curve lies above the equality line (inequality index is negative), then the most disadvantaged groups feel higher cumulative environmental hazard burdens. A curve below the equality line (inequality index is positive) indicates that the least disadvantaged groups carry a higher proportion of cumulative environmental hazard burdens. A summary measure of inequality is specified as twice the area between the curve and the equality line (Eq.1):

$$I = 1 - 2\int_{1}^{\pi} e(s)ds \quad (1)$$

This measure gives a quantitative summary of inequality among neighborhoods, in which 0 is the lowest level of inequality, where all neighborhoods are equally exposed to an environmental hazard and 1 is the highest level of inequality, where one group has the burden of all exposures [19].

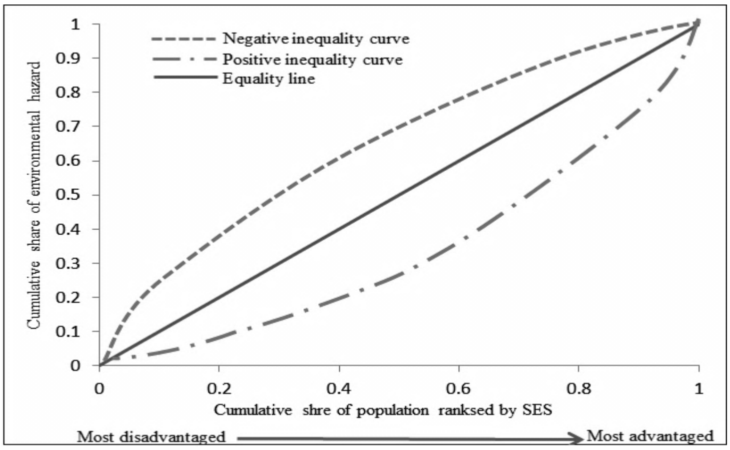

Figure 2: Positive and negative inequality curves (Su et al. 2009)

Characterizing Cumulative Environmental Impact

There are many aggregation methods, which can be used to construct cumulative environmental impact [30-34], including additive, multiplicative, and mixture approaches. The multiplicative approach, also known as the geometric mean method, is one of the most commonly used aggregating methods for building the cumulative environmental impact measure [33]. It can be presented as follows [19] (Eq. 2):

$$C_j = \prod_{i=1}^{N} w_i x_{i,j} \quad (2)$$

Where $x_{i,j}$ is environmental hazard of x_i at community/region j, and w_i is a weight connected to x_i. To make a multiplicative index of cumulative environmental impact, the variables are usually normalized to allow comparison without scale effect; however, this is not always the case. The individual variables do not have to be in the same scale and the CEHII remains unchanged if multiplied or divided by a constant. The additive approach, also known as the weighted-sum method, can also be utilized to derive an estimate of cumulative impact [33]. It is constructed as follows [19] (Eq. 3):

$$C_j = \sum_{i=1}^{N} w_i x_{i,j} \quad (3)$$

Where $x_{i,j}$ is a normalized variable at community/region j, and w_i is also a weight related to x_i, with $\sum_i^N = 1 w_i = 1$ and $0 \le w_i \le, i = 1, 2, \ldots, N$. w_i is weighted by experts or figured out through regression coefficients. The additive approach included a weighted linear aggregation rule applied to a set of variables. The main technical steps employed for its construction are (a) standardization of variables to allow comparison without scale effect, and (b) weighted summation of these variables [19 and 31].

Developing Cumulative Environmental Impact

An assumption indicated by the multiplicative and additive approaches is that environmental variables are preferentially independent. Due to the potential correlation or chemical reaction between individual environmental factors, the potentiality for double-counting or mixture/ interaction of cumulative hazards should be considered. For example, precursors to nitrogen oxides may contribute to formation of secondary PM_{10}. If the mixture consists of the interactions of chemical and physical agents, the primary and secondary hazards should be investigated at the same time. At present, there is no broadly accepted method of aggregating environmental hazards with potentially overlapping components.

The cumulative environmental impact of the multiplicative approach included multiplying the ratios of the two criteria air pollutants for each district. The cumulative environmental impact (r_j) to the criteria pollutants at district j was changed from Eq. 2 and estimated as follows [19]:

$$r_j = p_j \times \left(\prod_{l=1}^{k} r_{l,j} \right) \tag{4}$$

Where $r_{l,j}$ is the normalized (ratio or rate) environmental impact at district j of hazard l. p_j is the population at district j, and n represents the total number of environmental hazards being considered, which is $k=3$ in this research. We assumed that neighborhoods of greater population with the same cumulative effect would have higher environmental risk; thus Eq. 4 is population weighted.

For the cumulative impact through the multiplicative approach, although no normalization is needed to the environmental hazards after being adjusted by the benchmark standards, special attention should be given to areas with very low levels of environmental hazards or with a non-presented environmental hazard while other environmental hazard levels are high. The multiplicative approach may inadvertently indicate that cumulative impact in this area is lower, which in fact may not be the case [19].

The second illustration assumed an additive effect and included adding the ratios of each air pollutant at the district level. The additive approach requires each individual environmental hazard to be on the same scale (e.g., all values between 0 and 1 or with a mean of 1) [19]. Thus, the ratios were further normalized to have a mean of 1 using Eq. 5:

$$r_{l,j}^{norm} = \frac{r_{l,j}}{\left(\sum_{j=1}^{n} (r_{l,j} \times p_j) / \sum_{j=1}^{n} p_j \right)} \tag{5}$$

In this equation; n equals the total number of neighborhoods. The metric for cumulative environmental impact (r_j) to the criteria pollutants at district j in an additive scenario in

Eq. 3 was changed and estimated as:

$$r_j = p_j \times \left(\sum_{l=1}^{k} r_{l,j}^{norm} \right) \tag{6}$$

Like multiplicative scenario, the additive approach was also population weighted. The variables in Eq. 5 and 6 have the same definitions as in Eq. 4 [19]. The population data for each neighborhood were extracted from the Iran Census for year 2011.

Measuring Socioeconomic Variables

Based on the literature, available data and numerous ways to evaluate social disadvantage population from environmental hazards, we chose to use two metrics for illustrative purposes [35-41]. Metrics based on the 2011 Tehran Urban HEART Study, are higher education for over 17 years and unemployment rate for over 15 years. In addition, a population with lower education levels and higher unemployment is exposed to higher concentrations of pollutants and vulnerability to air pollution [15 and 1]. Though other metrics such as deprivation indicators and racial-ethnic composition could also be applied [19], in this study, we had access to the aforementioned SES.

Computing Environmental Inequality Indices

We computed individual inequality indices for NO_2 and PM_{10} and then the CEHII for the two criteria pollutants by the multiplicative and additive approaches expressed above. We extracted the following measures: (1) individual inequality indices according to the higher education for over 17 years for NO_2 and PM_{10} and (2) CEHII based on the higher education for over 17 years for NO_2 and PM_{10} combined by both multiplicative and additive methods. We also computed the same metrics for the individual pollutants and for the cumulative environmental impact using proportion of unemployment rate for over 15 years. The inequality index is sensitive to change in several factors. The index relies on distribution of the individual or cumulative environmental hazards, distribution of the socioeconomic metric used to explain the population, and their joint co-variation (for cumulative indices).

The index is also sensitive to the level of aggregation used to express the population and the number of population-based units, in this case neighborhoods, especially if there are not a large number of aggregation units [19].

Results

This section would explain neighborhood level characteristics of socioeconomic measures, followed by NO_2 and PM_{10} levels. The individual and cumulative environmental hazard inequalities by education were then summed up and followed by unemployment. Regarding the education of the population composition, the highest neighborhoods, 67% of the population was educated, whereas the lowest neighborhoods, 2.99% of the population was educated with a standard deviation of 3.33% (Table1). Figure 3a shows that neighborhoods with higher education are mainly focused in the northern area. The minimum, mean, maximum, and standard deviation for unemployment rate were 1.54, 9.21, 22.88, and 15.61, respectively. Based on Fig. 3b, we saw that unemployment among neighborhoods of Tehran does not have a clear spatial pattern.

Table 1: Descriptive statistics for neighborhood included in the analysis for the Tehran Area

Measures	Minimum	Maximum	Mean	SD
% of population education	2.99	67.44	31.71	3.33
% of population unemployment	1.54	22.88	9.21	15.61
NO_2 (ppb)	14.00	80.00	38.86	8.77
PM_{10} (μg/m^3)	25.12	140.68	86.67	15.31

(a) (b)

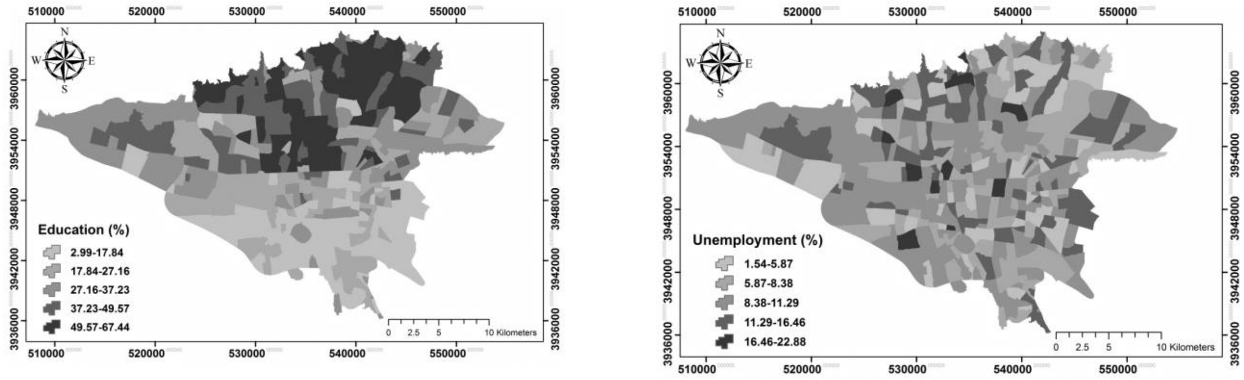

Figure 3: Neighborhood level percentage education (3a) and percentage unemployment (3b)

NO_2 and PM_{10} levels for Tehran are also demonstrated in Table 1. The annual average of NO_2 concentration for this area was 38.86 ppb, with neighborhood level annual concentrations varying from 14.38 (minimum) to 80.00 ppb (maximum) and a standard deviation of 8.77 ppb. The NO_2 concentrations were high in North and Northeast area (Fig. 4a). The minimum, mean, maximum, and standard deviation for PM_{10} were 25.12, 86.67, 140.68, and 15.31 μg/m^3, respectively. The spatial distribution of PM_{10} indicated a general pattern in the southwest area and this part of Tehran having the highest concentrations (Fig. 4b). If we consider the cumulative environmental hazard, additive and multiplicative approaches indicate that high cumulative hazards are focused in the north, southwest and southeast area (Fig. 5a-b).

(a) (b)

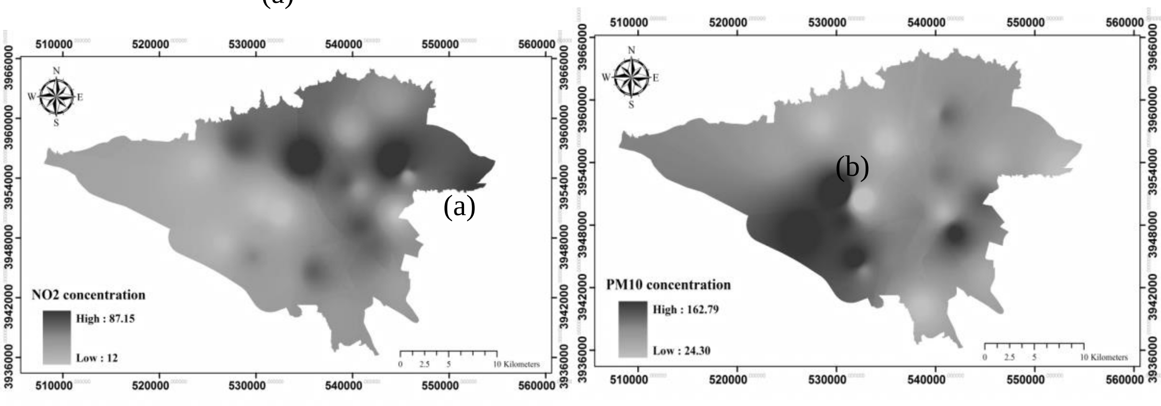

Figure 4: Distribution concentration of NO_2 (4a) and PM_{10} (4b) in metropolitan Tehran

(a) (b)

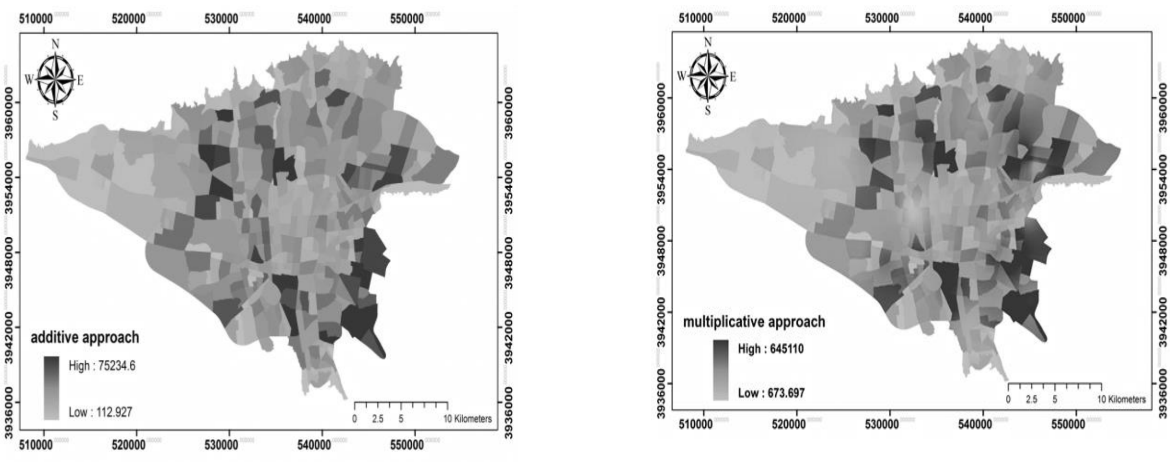

Figure 5: The cumulative environmental hazard using additive approach (5a) and multiplicative approach (5b)

Inequality curves for each of the two individual environmental hazards and the cumulative environmental hazards, by the multiplicative and additive approaches are displayed in Figures 6 and 7, showing the differences with regard to education and unemployment rate.

Table 2 shows their corresponding individual and cumulative environmental hazard inequality indices. Studying socioeconomic inequality in distribution of pollutants PM_{10} and NO_2 throughout the neighborhoods of Tehran related to different socioeconomic conditions revealed that when the index of SES in neighborhoods is the level of education, there is an inequality in distribution of PM_{10} throughout different neighborhoods of the city (concentration index= -0.070 and 95% CI = -0.105, -0.034). In addition, the negative sign of the concentration index indicates the higher concentrations of the pollutant PM_{10} in the neighborhoods with lower level of education. We observed the greatest environmental inequalities from PM_{10} in different education rates (C = -0.070).

Investigating environmental inequality due to NO_2 showed that different neighborhoods of the city with social and economic conditions under investigation are equally exposed to this pollutant with no inequality in distribution.

Moreover, the results showed that there is a significant relationship between environmental accumulation and education parameter (Table 2).

Therefore, neighborhoods with lower level of education are more exposed to the above-mentioned pollutants.

Also, Table 2 revealed no significant relationship between inequalities in distribution of the pollutants with parameter of unemployment. Also, in different education rates in neighborhoods of Tehran, the cumulative environmental hazard inequality index utilizing the multiplicative approach (CEHII-B_1= -0.055) had a higher value compared to the additive approach (CEHII-B_2= -0.048).

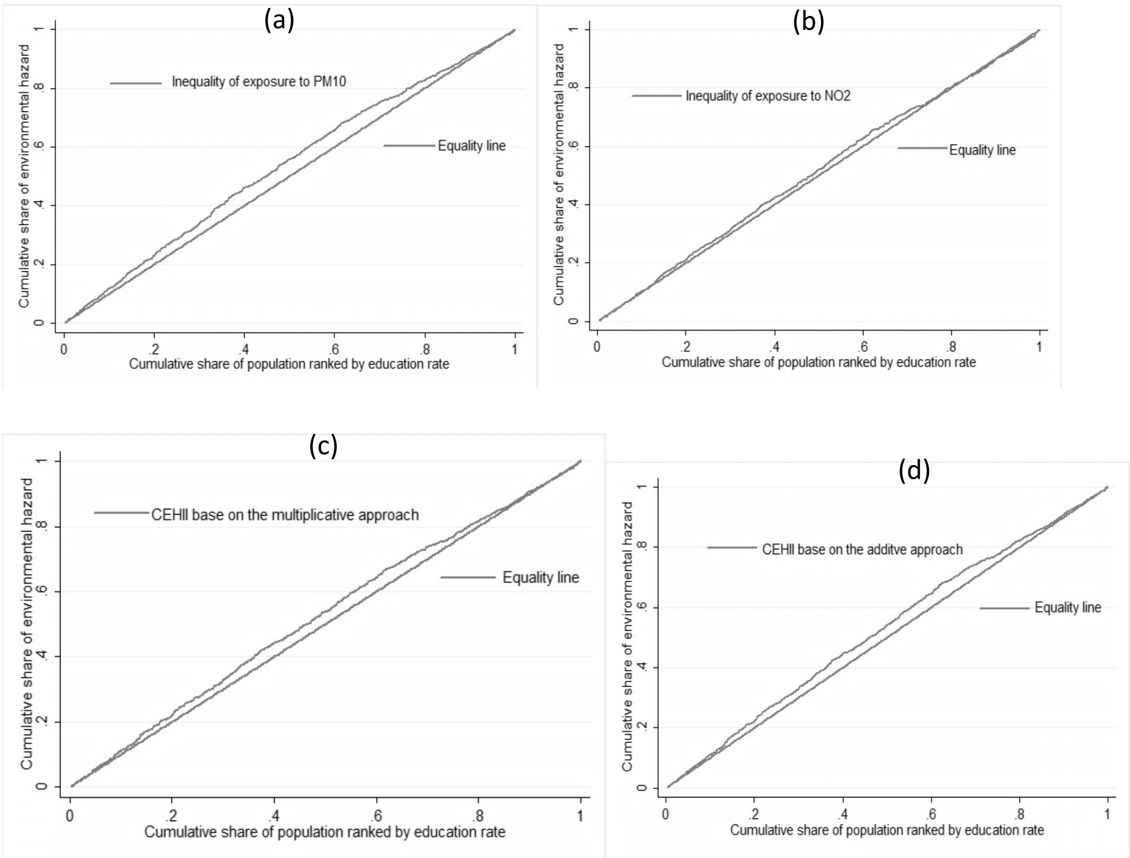

Figure 6: The environmental inequality of individual and cumulative impact to NO_2 and PM10 using the multiplicative and additive approach based on the education rate in neighborhoods

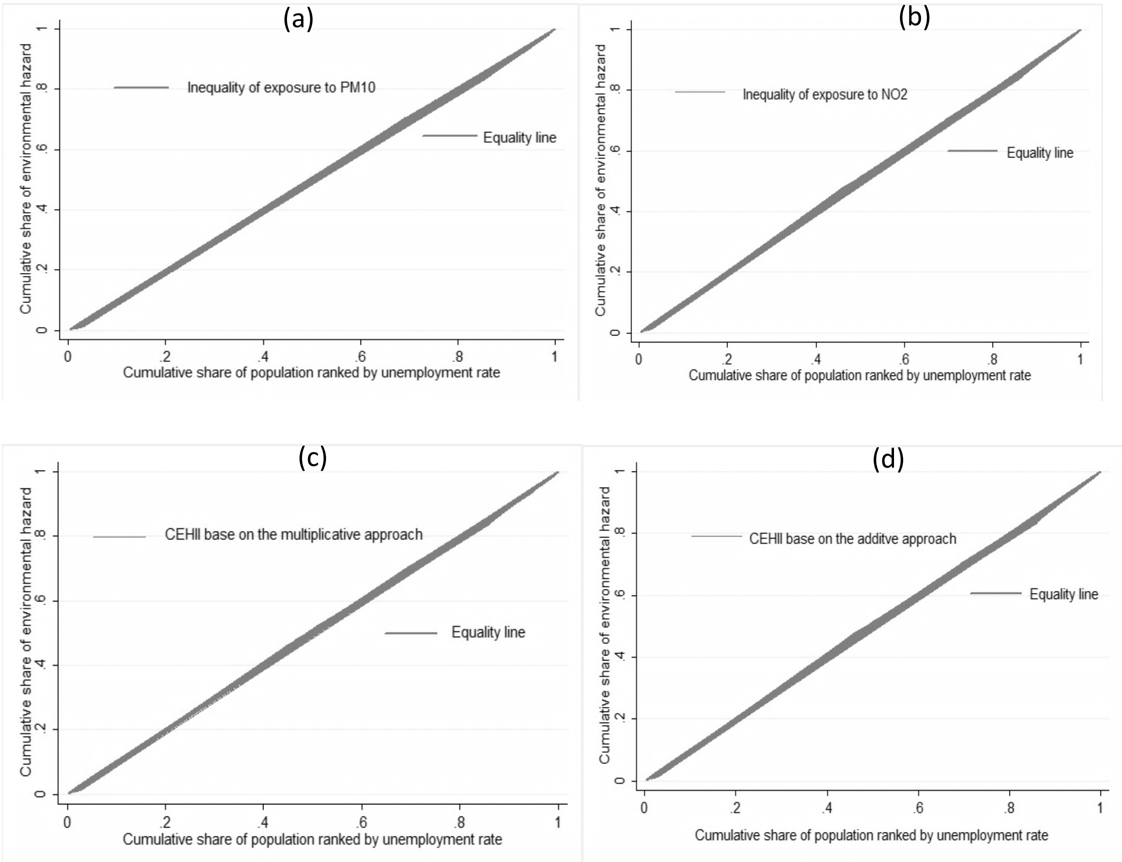

Figure 7: The environmental inequality of individual and cumulative impact to NO_2 and PM10 using the multiplicative and additive approach based on the unemployment rate in neighborhoods

Table 2: Significance tests of inequality in socioeconomic measures for both individual and cumulative environmental hazards.

Category of SES		**Environmental inequality index**	**95% CI** [c]
Proportion of education	NO_2	-0.022	(-0.061, +0.017)
	PM_{10}	-0.070	(-0.105, -0.034)
	CEHII-B_1[a]	-0.055	(-0.092, -0.017)
	CEHII-B_2[b]	-0.048	(-0.083, -0.012)
Proportion of unemployment	NO_2	0.002	(-.037, +0.041)
	PM_{10}	0.013	(-.023, + 0.049)
	CEHII-B_1	0.002	(-0.036, + 0.039)
	CEHII-B_2	0.002	(-0.037, +0.042)

[c] 95% CI= 95% confidence interval, [a] CEHII-B_1= Cumulative environmental hazard inequality using the multiplicative approach, [b] CEHII-B_2= Cumulative environmental hazard inequality using the additive approach.

Discussion

In this study, we evaluated the present environmental inequality in Tehran. This was carried out through applying the CEHII index to assess the socioeconomic disparities in individual and cumulative environmental hazards of the city. We investigated individual and cumulative environmental inequalities in exposure to NO_2 and PM_{10} while considering two main socioeconomic parameters, i.e. education and unemployment rate. Furthermore, we develop an integration of inequality and cumulative effects.

Our findings highlighted that environmental inequality indices for PM_{10} and cumulative environmental hazards in different education rate are significantly different from the equality line. Furthermore, the spatial source and distribution of pollutants appeared to be important. In the city, most factories and industries are located in the west and the southwest [42]. Consequently higher concentration of PM_{10} was observed in the southwest of study area although it had lower education rate. However, in this context, the results were reversed for the pollutant NO_2. In the studied area, NO_2 pollutant is mostly emitted by vehicles. In center and approximate to north of Tehran the traffic is heavy [43], while education rate in this area was high. So, neighborhoods of the area under study were equally exposed to this pollutant. In general, we displayed that environmental inequalities exist in Tehran neighborhoods at different education rates and more importantly, the CEHII may produce useful information for environmental justice debates. This is agrees to results of O'Neill et al. [15] and Branis and Linhartova [1] pointing out that low educational attainment of a community also seems to be a consistent indicator of its vulnerability to air pollution.

Though some studies found associations between unemployment rate and inequality environmental hazards [1, 9, 15], this was not the case in our study. This was due to having no clear spatial pattern for the SES. As a methodological point of view, it is totally expected that cumulative hazards in the multiplicative method results in higher differences compared to the additive approach [19].

Conclusion

The results obtained in this study revealed that CEHII using multiplicative approach had a highest value compared to the additive approach, which is similar to the results of Su et al [19].

This approach can estimate inequalities across regions and by different demographic groupings. This indicator has been useful for informing regulatory decision-making that seeks to assess geographic and demographic patterns of social inequities in exposure to multiple hazards. It is also recommended that in future studies, social and economic parameters, like poverty, age and gender should be considered. In addition, this method can be used in other cities to compare the results.

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