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One Health Index (OHI) applied to Curitiba, the ninth-largest metropolitan area of Brazil, with concomitant assessment of animal, environmental, and human health indicators

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ABSTRACT

One Health has been defined as a comprehensive approach to human, animal, and environmental health, but unsuccessful in providing a specific index for city, state, or country assessment. Accordingly, the present study aimed to calculate the One Health Index (OHI) in 29 cities of the Curitiba metropolitan area, the ninth largest in Brazil. Animal and Environmental health indicators were obtained from the city secretary of environment. The social vulnerability index (SVI) was used as the overall human health indicator. The indicators were parameterized following a binary logic Principal component analysis (PCA) was applied in association with city population, per capita income, and distance from the capital Curitiba. Permutational multivariate analysis of variance (PERMANOVA) was applied using the three first coefficients of the principal components obtained from Principal Component Analysis Plot (PCA) and exploring a pairwise comparison between the scenario ranges. A value of p less than 0.05 was considered significant. Overall, a higher OHI was associated with a higher city population and income, and shorter distance from the capital, and tendency of low-income cities to present lower OHI compared to higher-income cities. In conclusion, the OHI proposed herein portrays a holistic representation of a city's overall health. Moreover, animal issues should be considered part of local to global sustainability, considering OHI to calculate sustainability indexes.

1. Introduction

Advanced information technology and data analysis have been increasingly used by decision-makers as a tool for measuring environmental progress and policies towards sustainability. Despite its importance for global environmental protection, few indexes have been indicated to assess and compare environmental status and policies [1].

The Environmental Performance Index (EPI) of 2002, has been indicated as a quantification method arithmetically assessing the environmental performance of a state's policies and comprises 25 aggregated contributing indicators. Although such index has aimed to reduce environmental impact on human health and promote ecosystem balance and natural resource clearness, the fauna has been underrepresented. As water is crucial for life, another suggested index has been the pursuit for equilibrium among the economy, society, and environment using water resources as a solely indicator to assess sustainability [2]. Different from previous aggregated indicators, sustainability may be measured by the province distance to the ideal point of water supply development in such three dimensions, as shown in China, one of the most water-strained countries worldwide [2]. Overall, sustainability indexes have failed to account for animal health as part of assessing holistic health and prosperity. The One Health concept was developed to encourage sustainable

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collaborative partnerships [3,4]. Research groups in Brazil have been applying One Health as a practical tool to solve problems such as zoonoses in different populations [3].

Although One Health has been defined as a comprehensive approach to human, animal, and environmental health, no specific index has been proposed to date for the city, state, or country comparisons. In addition, institutional programs for animal protection and environmental initiatives in large metropolitan areas remain to be fully identified and evaluated. Accordingly, the present study aimed to concomitantly assess human, animal, and environmental health as the One Health Index (OHI) of the 29 cities belonging to the Curitiba metropolitan area, the ninth largest in Brazil.

Fig. 1. Illustrative map of the Metropolitan Area of Curitiba. Source: COMEC - Coordination of the Metropolitan Region of Curitiba.

2. Material and methods

2.1. Study area

The present study was conducted in the Curitiba metropolitan area (25°25′47" S, 49°16′19" W), the ninth most populated in Brazil, with estimated population of 3,693,817 habitants, and Human Development Index (HDI) of 0.783 [5], as presented (Fig. 1). The Curitiba metropolitan area comprised a total of 29 cities at the time (Fig. 1).

2.2. Data collection

Animal health indicators were obtained from the city secretary of the environment and included animal (information from the) protection plan and program, contact of individuals with hoarding behavior, mapping and service, animal microchip use, neutering program, responsible ownership program, animal cruelty. Environmental health indicators were also obtained directly from the city secretaries of the environment and included city waste management plan, residential waste, recycle waste, individuals with object hoarding behavior, and an ecological biodiversity index. The social vulnerability index (SVI) [6], which already includes 16 social indicators into three domains [7], was used as an overall human health indicator (Supplementary Tables 1, 2, and 3). Non-included human and animal indicators have been presented in Supplemental Material 1, 2 and 3.

The SVI is composed of 16 variables grouped into the following three categories: a) Urban infrastructure (three variables): 1) percentage of people in households with inadequate water supply and sewage, 2) percentage of the population living in urban households without garbage collection service, and 3) percentage of people who live in households with per capita income less than half the minimum wage and who spend more than 1 h to reach their place of work out of the total number of employed, vulnerable people who return from work daily; b) Human Capital (eight variables): 1) mortality up to 1 year of age, 2) percentage of children from 0 to 5 years of age who do not attend school; 3) percentage of people aged six to 14 years who do not attend school; 4) percentage of women aged 10 to 17 years who have children; 5) percentage of mothers who are heads of household, without complete elementary school and with at least one child under the age of 15, out of the total number of mothers who are heads of household; 6) illiteracy rate of the population aged 15 years or over; 7) percentage of children living in households where none of the residents have completed elementary school; 8) percentage of people aged 15 to 24 years who do not study, do not work, and have a per capita household income equal to or less than half minimum wage at the time, out of the total population of this age group; and c) Income and Work (five variables): 1) proportion of people with per capita household income equal to or less than half minimum wage at the time; 2) unemployment rate of the population aged 18 or over; 3) percentage of people aged 18 or over without complete elementary education and holding informal occupation; 4) percentage of people in households with per capita income below half minimum wage at the time and dependent on the elderly; and 5) activity rate of people aged 10 to 14 years [7].

2.3. Statistical analysis

2.3.1. Data analyses

The indicators were parameterized following a binary logic, in which "yes" responses are one and "no" responses are zero. The variable "Animal Health" is the sum of nine animal health indicators (Supplementary Table 4). The variable "Environmental Health" is double the sum of four environmental indicators. The variable "Human Health" is the value of the Social Vulnerability Index (SVI) adjusted by the following:

$$HH = \frac{A}{x} \times 10$$

where HH is the municipality's Human Health score; A is the lowest SVI value among the evaluated municipalities; x is the value of the municipality's SVI.

The municipalities were fit according to ranges of the three major factors, including city population, per capita income, and distance from the capital (Supplementary Table 5). Principal component analysis (PCA) was applied using the three health variables of each municipality. Permutational multivariate analysis of variance (PERMANOVA) [8] was applied using the three firsts coefficients of the principal components obtained from PCA and exploring a pairwise comparison between the scenario ranges [9]. A value of p less than 0.05 was considered significant. All statistical analyses were performed in the R statistical environment [10].

2.4. Ethics statement

The study was approved by the Ethics Research Committee of Health Sciences from the Universidade Federal do Paraná (protocol number 1,105,785/15), and the Coordination of the State Secretary of Curitiba Metropolitan Area.

3. Results

Data has been gathered and presented (Supplementary Tables 6, 7, and 8). Principal component analysis (PCA) was applied in association with three major factors, including city population, per capita income, and distance from the state capital, and presented (Figs. 2, 3, and 4). Overall, higher OHI was associated with higher city population, higher city income, and lower distance to the capital, according to PCA analysis and PERMANOVA [8] (Supplementary Tables 6, 7, and 8).

Analyses of spatial figures on axes x and y at the PCA analysis have shown the overview of 29 cities and variables, while the PERMANOVA presented the statistical significances of comparative analysis (Figs. 2, 3, and 4). Figures have shown that cities located more to the right and near axis x (as Piraquara, Curitiba and São José dos Pinhais) had higher One Health Index (OHI) than cities placed on the left (as Tunas do Paraná and Adrianópolis), with lower OHI. Such differences may be associated to scores given to indexes of human, environmental and animal health. Municipalities with higher population (over 50 thousand habitants) have presented higher scores for human (7.54 average and 1.07 SD), environmental (6.89 average and 1.05 SD) and animal (7.22 average and 1.71 SD) health indexes, when compared to municipalities with lower population (below 10 thousand habitants), which presented lower human (6.29 average and 1.58 SD), environmental (3.6 average and 1.67 SD) and animal (1.00 average and 0.7 SD) health indexes.

Municipalities closer to the state capital (0–25 km) have presented higher scores for human (7.83 average and 0.99 SD), environmental (7.25 average and 1.04 SD) and animal (7.63 average and 1.51 SD) when compared to more distant municipalities (over 76 km) in human (6.96 average and 2.02 SD), environmental (4.86 average and 2.27 SD) and animal (1.29 average and 0.95 SD) health indexes. Likewise, municipalities with higher income per capita (over R$700) have presented higher scores for human (8.51 average and 0.82 SD), environmental (6.57 average and 1.51 SD) and animal (4.86 average and 3.76 SD) health indexes, when compared to municipalities with lower income per capita (0-R$500), with lower scores of human (6.04 average and 1.00 SD), environmental (4.86 average and 2.27 SD) and animal (2.00 average and 1.53 SD) health indexes.

Considering a p-value lower than 0.05, the null hypothesis should be rejected. Thus, significant differences were found in municipalities with higher population (PERMANOVA; $F = 16.44$; $p = 0.012$), closer to the state capital Curitiba (PERMANOVA; $F = 10.01$; $p = 0.010$) and with

Fig. 2. Principal Component Analysis Plot (PCA) showing the influence of the health variables (Human, Environmental, and Animal) over the 29 cities included in the Metropolitan area of Curitiba, Parana State, Brazil, according to population. Ellipses around the groups expresses confidence ellipses [25].

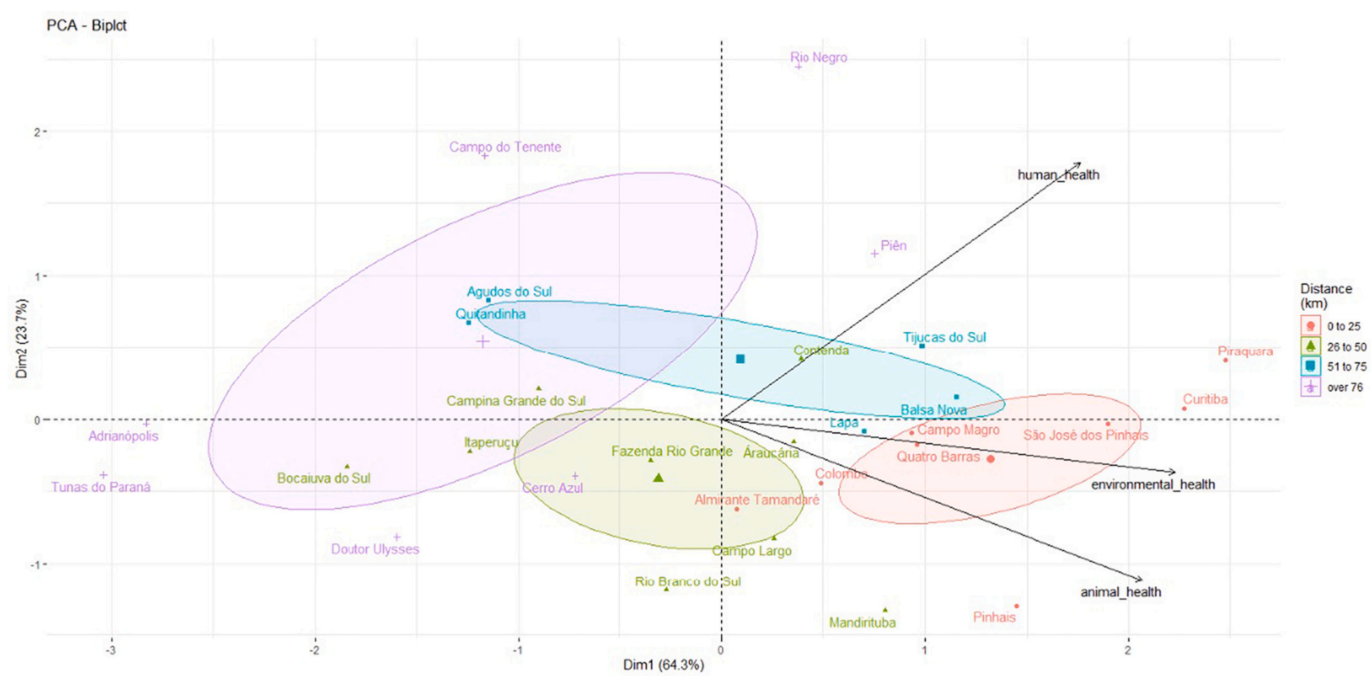

Fig. 3. Principal Component Analysis Plot (PCA) showing the influence of the health variables (Human, Environmental, and Animal) over the 29 cities included in the Metropolitan area of Curitiba, Parana State, Brazil, according distance from the capital. Ellipses around the groups expresses confidence ellipses [25].

higher income per capita (PERMANOVA; $F = 7.26$; $p = 0.04$), which have shown statistically higher OHI to municipalities with lower population, more distant from the capital and with lower income per capita, respectively (Supplementary Table 1, 2 and 3).

4. Discussion

To the authors' knowledge, this is the first simultaneous approach applied on human, animal, and environmental health indicators as an overall One Health Index, resulting in calculated maps for spatial axis for each health indexes and association to distance, population, and income (Figs. 2, 3 and 4).

A recent study has proposed a set of attributes and indexes to evaluate multisectoral collaborations in One Health surveillance, considering 23 organizational and 9 functional attributes of three organizational indexes and 75 criteria, resulting in correspondent scale of criteria fulfillment, which has not been tested in-field [11]. Although such matrix has been the first to provide a deeper evaluation of

Fig. 4. Principal Component Analysis Plot (PCA) showing the influence of the health variables (Human, Environmental, and Animal) over the 29 cities included in the Metropolitan area of Curitiba, Parana State, Brazil, according income per capita. Ellipses around the groups expresses confidence ellipses [25].

collaboration inside a multisectoral surveillance system, analysis has been focused on interface among different organizations by questionnaires rather than actual assessment of indexes of human, animal, and environmental health [11]. Thus, instead scoring interaction effectiveness, the study herein has proposed a practical measurement of One Health itself, with comparative composites for each health that may be assessed in different municipalities, states and countries worldwide.

Another recent study has also evaluated One Health initiative in given systems, focusing on effectiveness of "sharing, exchanging, collaborating and learning" in an inter-disciplinary setting [12]. Despite the outcome from the six assessment tools with 17 questions each have been presented as OH-index (OHI) and OH-ratio (OHR), indexes represent the surface and the top left section of a calculated hexagon in spider diagrams [12]. In addition, the Theory of Change (TOC) has also been proposed as indicator for measurement of desired or expected results, which application was described in eight case studies comparing One Health initiatives with conventional health initiatives [12]. As already mentioned, the OHI herein is an actual holistic index, which aggregates several other indexes within each of the three One Health components [12]. Thus, human health for example can be evaluated and compared along animal and environmental health within and among municipalities, showing strengths and weakness in each of them (Tables 1, 2 and 3). In addition, spatial analysis can demonstrate disparities and similarities among municipalities, providing basis for priority tasks and administrative decision. Besides as starting point, OHI can be used for future evaluations and goals, particularly in a comparative manner.

Municipalities have presented spatial distribution and clusters on respective biplots when sorted in population intervals, with a location trend of less populated cites to the left and more populated to the right of the x axis (Fig. 2). Such population trend was confirmed by the paired comparison of different extracts, with significant differences observed between municipalities of 0–10 and 10–20 ($p = 0.02$), 0–10 and 20–50 ($p = 0.01$), 0–10 and over 50 ($p = 0.002$), and 10–20 and over 50 ($p = 0.05$) thousand habitant strata, while no differences between 10 and 20 and over 50 ($p = 0.92$) and 20–50 and over 50 ($p = 0.10$) thousand habitants were observed (Supplementary Table 6). Thus, comparing population strata, municipalities with fewer inhabitants (0–10 thousand) have presented a signif cantly lower difference for One Health when compared to those higher than 20 (20–50 and over 50). Such findings have indicated that less populated municipalities may present lower OHI when compared to more populated cities in the present study. Whether this pattern may be extrapolated to other metropolitan areas of Brazil or worldwide should in-fiel.

In addition, municipalities strata based on per capita income have shown that low-income of 0–500 presented the worst OHI, when compared to higher income cities (Fig. 3). Thus, the lowest income (0–500) stratum has presented statistically significant differences when compared to all other groups, including 500–600 ($p = 0.03$), 600–700 ($p = 0.01$) and over 700 (p = 0.01); but not between 500 and 600 and 600–700 ($p = 0.59$), 500–600 and over 700 ($p = 0.12$), and 600–700 and over 700 ($p = 0.11$).

Low-income cities tended to be located on the left and higher-income cities to the right of the axis x, confirmed at the paired comparison in different extracts (Supplementary Table 7). Such findings have evidenced a tendency of low-income cities to present lower OHI compared to higher-income cities. The Principal Component Analysis Plot (PCA) presented three vectors, one for each health index (human, animal and environmental), according to population (Fig. 2), distance from state capital (Fig. 3) and income per capita (Fig. 4). Municipalities located to the right of the PCA Plot, at the same direction of these vectors, have shown better results for one or more health indexes when compared to municipalities located opposed to these vectors, at the left of the PCA Plot.

Despite a solely indicator for human quality of life, the human development index - municipality (HDI-M) represents a composite index calculated from three dimensions including long and healthy life, knowledge, and decent standard of living. The HDI-M for the 29 municipalities has been obtained and presented (Supplementary Material 4) [13]. Although the Curitiba metropolitan region is considered of very high HDI-M (0.809), the third highest in Brazil, the state capital pushes the index up, since only Curitiba has a very high index (0.823) out of metropolitan cities, followed by 12/29 high, 14/29 medium and 2/29 low HDI-M indexes [13].

When HDI-M was compared to OHI, differences among the 29 municipalities were related to differences in the calculated indicators obtained herein . The PCA has shown higher HDI-M cities as Curitiba

(0.809) among the highest OHI municipalities, despite differences in population, distance to the capital and income per capita, along with São José dos Pinhais (0.758), Araucária (0.740), Pinhais (0.751), Campo Magro (0.745), and Lapa (0.706). Likewise, the lowest HDI-M municipalities such as Cerro Azul (0.573), Doutor Ulysses (0.546), Tunas do Paraná (0.611), Itaperuçu (0,637) and Bocaiuva do Sul (0.640) were located at far left on the PCA Plot.

However, three municipalities with low HDI-M as Tijucas do Sul (0.636), Contenda (0.681) and Balsa Nova (0.696) were plotted as relatively higher OHI. In common, these three cities have 10–20,000 habitants, are located around 50 km from the state capital and present medium to high income per capita. Interestingly, along with São José dos Pinhais (0.758), Piraquara (0.700) and Colombo (0.733), these six municipalities are known as green cities, with green leave and vegetable production, lakes used for consumption water supply, ecotourism and preserved natural areas, as shown on the recent state map of green coverage in Paraná state and Curitiba metropolitan area [14,15](Supplementary Figs. 1 and 2). Although such green coverage ratio is available for Curitiba, which has around 5% of green areas with 70% vegetal coverage [16], no data is available for other municipalities for comparison. Another strong indicator for environmental health is the "ecological compensation", a tax-based reimbursement for municipalities according to their environmental initiatives such as garbage disposal, environmental education, prevention programs of deforestation and wildfire, biodiversity conservation, environmental education and legislation, identification of pollution sources, as presented [17] (Supplementary Material 5). Although still under development, with missing and incipient data among municipalities, such comprehensive indicator may become the standalone index for environmental health, as the SVI for human health.

Despite green coverage ratio could be used as part of environmental health, such data was not available at the time of survey and become a limitation for future improvement. Nonetheless, the OHI has shown itself as a relevant indicator, proven to be a sensitive, specific, and more important, supported by the reality that produced it.

Although livestock census is mandatory by the Brazilian Ministry of Livestock and Agriculture and yearly performed per municipality by the Brazilian Statistics Institute [18], companion animals have not been included in the animal census and only estimated once by the Brazilian Government in 2013 [19]. Since animal health and welfare statuses have not been accessed, livestock population has not been included herein as indicator for One Health Index composite. The major agricultural activity at the time in the surrounding municipalities were green leafy and vegetable production, annually consumed by approximately 3,7 million individuals [20,21]. All 29 municipalities have primary care and Family Health Strategy programs, composed by multidisciplinary professional teams such as physicians, nurses, dentists, veterinarians, and community health agents, according to the Brazilian National Unified Heath System [22].

Major zoonoses (diseases among human beings and animals) are of mandatory notification nationwide by the Brazilian Ministry of Health and were also accessed in 2020 [23]. However, Curitiba metropolitan area has not been endemic for several zoonotic diseases as acute Chagas, Schistosomiasis, Yellow Fever, Hantavirus, Visceral Leishmaniasis and Rabies, with no cases at the time [23]. Single non-related cases of Brazilian Spotted Fever and Malaria were diagnosed in Curitiba [23]. A total of 36 cases of cutaneous leishmaniasis and 143 of leptospirosis were diagnosed and presented per municipality [23]. Out of arboviruses, 524 human cases of Dengue and 16 of Zika viruses were diagnosed; Chikungunya cases were unavailable [23]. Due to the non-discriminatory nature for comparison, zoonoses were not included in the index composite herein [23]. However, as some zoonoses may be favored by anthropization of preserved areas, discussion of whether natural areas may positively or negatively impact vector-borne disease occurrence should be further investigated . Regardless, presence of zoonotic pathogens should be always considered as health-threating for both human beings and animals.

Finally, municipalities strata closer in distance to state capital Curitiba, the highest populated and center of the metropolitan region, have shown better One Health Index when compared to more distance municipalities. Thus, near capital municipalities presented relatively better OHI and were more likely to be plotted to the right of axis x (Fig. 4). Comparing city groups arranged by distance from the capital, cities of 0–25 km were significantly different when compared to all other groups, including 26–50 ($p = 0.003$), 51–75 ($p = 0.04$), and over 76 ($p = 0.001$). No significant differences were found between 26 and 50 and 51–75 ($p = 0.17$), 26–50 and over 76 ($p = 0.08$), and 51–75 and over 76 ($p = 0.18$). Thus, cities closer to the capital (0–25) presented significant differences in One Health than more distant cities (26–50, 51–75, and over 76 km). There was a clear tendency of more distant cities from Curitiba to be placed on the left and near cities to the right of the axis x, confirmed at the paired comparison in different extracts (Supplementary Table 8). Such findings have evidenced a tendency of more distant cities to present lower OHI compared to closer cities to the capital.

Although the One Health Index (OHI) may be compared to Sustainability, which has been based on the environmental, economic, and social overlapping domains, no animal has been inserted in the formula. Few environmental indicators of Sustainability such as biodiversity, forest area, and threatened species may indicate animal health; the other indicators such as air, land, water, ecological condition, and human exposure and health are directly related to environmental and human health [24].

5. Conclusions

In conclusion, despite limitations on animal and environmental health indicators, the OHI proposed herein may more holistically represent the overall health of a city. Moreover, animal issues should always be considered part of sustainability, considering OHI as a significant part of the composite calculation of sustainability indexes.

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Declaration of interests

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

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