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Article

Socioeconomic determinants of foodborne disease prevalence in Ecuador: A principal component analysis study

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Abstract: Foodborne diseases are a global health problem. Every year, millions of people die worldwide from these diseases. It has been determined that the high prevalence of these diseases is related to unfavorable socioeconomic conditions of the population. In this study, the relationship between foodborne diseases and socioeconomic conditions of the population was determined using principal component analysis as a multivariate statistical analysis technique. In this study, the socioeconomic variables of each Ecuador province and the prevalence of foodborne diseases (hepatitis A, salmonella, shigellosis and typhoid fever) during the years 2018 and 2019 were considered. The results show the relationship between foodborne diseases and the socioeconomic conditions of the population, as well as identifying regions more vulnerable to present high levels of prevalence of foodborne diseases, thus facilitating the implementation of social investment programs to reduce the prevalence of these diseases.

Keywords: foodborne diseases; prevalence; socioeconomic conditions; principal component analysis

1. Introduction

Foodborne diseases are a public health problem in both developed and developing countries. The epidemiology of foodborne diseases is complex and is associated with the virulence factor of the organism and changing lifestyle, poor hygienic practices, international travel, migration, and poverty (Diriba et al., 2020). It is estimated that about one-third of the world's population is affected annually by foodborne diseases, resulting in millions of deaths yearly.

Some relevant aspects of the most common foodborne diseases are described below:

1.1. Typhoid fever

Typhoid, paratyphoid and enteric fever constitute a severe global public health problem, with 25 million new infections and more than 200,000 deaths per year (Dekker and Frank, 2015). Countries such as Pakistan have a high incidence of this disease, with 412.9 infections per 100,000 population (Siddiqui et al., 2015).

Among the symptoms generated by this disease are the gradual onset of sustained fever, chills, hepatosplenomegaly and abdominal pain. In some cases, patients experience rash, nausea, anorexia, diarrhoea or constipation, headache, relative bradycardia and decreased level of consciousness (Buckle et al., 2012). The population most at risk of contracting this disease is those living in overcrowded conditions, a common situation in poor populations with inadequate sanitation that are exposed to unsafe water and food (Crump, 2019). Prevention of these diseases is based on implementing socio-sanitary measures to achieve optimal management of wastewater and water supply systems and greater sanitary control in food handling (Jurado Jiménez et al., 2010).

1.2. Hepatitis A

The World Health Organization estimated that more than 90,000 people worldwide died from hepatitis A disease in 2010 and that at least 30,000 of these deaths could be directly attributed to the spread of the virus through consumption of contaminated food (Kirk et al., 2015). Factors contributing to the decline in hepatitis A prevalence include population access to clean drinking water sources and sanitation and hygiene facilities, such as toilets and hand-washing infrastructure (Jacobsen, 2018). Contact with improperly treated sewage, sewage-contaminated water, or infected food handlers represents the most common routes of hepatitis A contamination in food (Randazzo and Sanchez, 2020). From the analysis of global data, it has been confirmed that there is an inversely proportional relationship between access to safe drinking water sources and the incidence rate of hepatitis A virus (Jacobsen and Koopman, 2005; Nelson and Murphy, 2013). Likewise, there are aspects related to the socioeconomic development of the population that have been associated with a low probability of exposure to the hepatitis A virus, including individuals or households with higher income or higher levels of education, as well as smaller family groups and less overcrowding in the home (Jacobsen and Koopman, 2004). The epidemiology of hepatitis A varies considerably among different regions of the world, changing with the economic development of each region. Regions with better hygienic and sanitary conditions experience fewer outbreaks (Randazzo and Sanchez, 2020). In the case of indigenous populations, they may be disproportionately affected by these conditions (Murphy et al., 2016). The most common symptoms associated with acute hepatitis A infection are loss of appetite, fever, headache, nausea, diarrhoea, abdominal discomfort, anorexia, myalgia, dark-coloured urine, and jaundice (Randazzo and Sanchez, 2020; Wu and Guo, 2013).

1.3. Shigellosis

The worldwide incidence of shigellosis is approximately 165 million cases per year, although mortality has decreased substantially over the past three decades (Dekker and Frank, 2015). Most of these cases occur in developing countries (Lima et al., 2015; Ud-Din et al., 2013). Their high incidence is attributed to a lack of safe drinking water, poor hygiene, malnutrition and close personal contact. Ready-to-eat foods and beverages prepared by street vendors can also be a source of shigellosis. An example of a route of shigellosis transmission is food and beverages prepared by street vendors. In settings where human faeces disposal is inadequate, the typical house fly can also serve as a vector for shigellosis transmission (Taneja and Mewara, 2016).

Symptoms of Shigella infection include fever, malaise, diarrhoea, abdominal cramps, and myalgia (Dekker and Frank, 2015). Shigella dysentery can also lead to dangerous complications such as persistent diarrhoea, severe anorexia, weight loss and malnutrition, significant bowel dilatation, seizures, kidney damage, and hemolytic uremic syndrome. Public health measures such as safe water supply and adequate sanitation are of significant importance in reducing the burden of shigellosis (Taneja and Mewara, 2016).

1.4. Salmonella

Salmonella infection remains a significant public health problem worldwide, contributing to the economic burden of industrialised and underdeveloped countries through costs associated with disease surveillance, prevention, and treatment (Eng et al., 2015).

Salmonella is a foodborne pathogen. They are predominantly found in poultry, eggs, dairy products, and fresh fruits and vegetables (Eng et al., 2015). The most frequent clinical picture related to Salmonella is acute gastroenteritis, being also responsible for cases of bacteremia and focal extra digestive infections in some occasions, whose most frequent symptoms are endocarditis, arteritis, central nervous system involvement, pneumonia, osteoarticular, urinary tract and soft tissue infections. The transmission mechanism is consuming contaminated water or food (Jurado Jiménez et al., 2010).

Salmonella infection has been significantly decreased with proper food and water sanitation, pasteurising milk and other dairy products, and eliminating human faeces in food production (Eng et al., 2015).

In Ecuador, the Ministry of Health keeps a weekly record of the number of people attending the different health centres in the country infected by immuno-preventable diseases, respiratory diseases, zoonotic diseases and foodborne diseases. These records are published in the Weekly Epidemiological Gazette and are available on the web (Ministry of Public Health, n.d.). Regarding foodborne diseases, the Weekly Epidemiological Gazette records cases of typhoid and paratyphoid fever, hepatitis A, shigellosis, and salmonella.

Previous studies on the prevalence of foodborne diseases in Ecuador have shown that Ecuador has a high prevalence of these diseases compared to countries in the region (Pérez Parra et al., 2017). The consumption of contaminated food and water, and thus the prevalence of foodborne diseases, is, among other factors, associated with unfavourable socioeconomic conditions of the population such as, for example, lack of access to safe drinking water (Jacobsen, 2018), contact with sewage (Randazzo and Sanchez, 2020), improper disposal of human faeces (Taneja and Mewara, 2016) and overcrowding (Crump, 2019), among others. Governments need to know which socioeconomic conditions make the population more vulnerable to the prevalence of foodborne diseases to establish social investment policies to reduce the adverse effects of foodborne diseases.

Statistical methods are available to determine whether there is a relationship between variables. Studying the relationship between the prevalence of foodborne diseases and several variables associated with socioeconomic conditions involves, in total, a considerable number of variables, which makes it necessary to reduce the dimensionality of the variables. Statistical techniques exist to reduce the dimensionality of data. One of the most widely used is principal component analysis (PCA), which reduces the dimensionality of a data set while preserving as much variability as possible, i.e., statistical information (Jolliffe and Cadima, 2016).

This study aims to determine the relationship between the prevalence of foodborne diseases and the socioeconomic conditions of the population in each province of Ecuador through the implementation of PCA.

2. Materials and methods

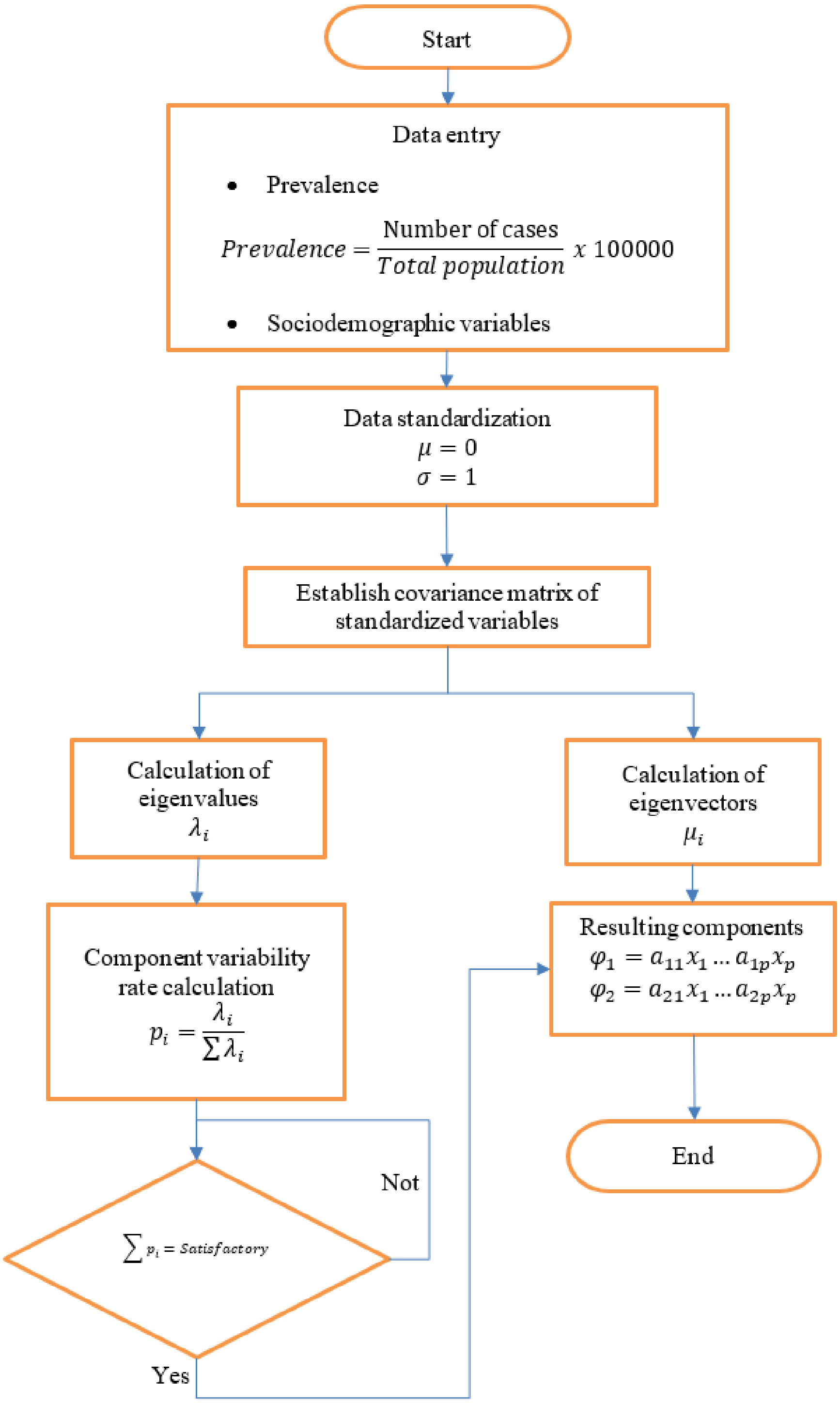

Figure 1. Complete process flow diagram implemented in this study.

The number of cases of people with foodborne diseases in Ecuador for 2018 and 2019 was obtained from the Weekly Epidemiological Gazette, which contains the cases registered weekly throughout the country, as well as the total number of cases registered in the year in each province (Ministry of Public Health, n.d.). The population by province was obtained from projections made by the National Institute of Statistics and Census (INEC, n.d.). The percentage coverage of sociodemographic variables for each province in Ecuador for the period under study was obtained from statistical information collected by the Ministry of Economic and Social Inclusion (MIES, n.d.). The prevalence of each foodborne disease was calculated from the ratio of the number of registered cases of the disease per 100,000 inhabitants in each province. Data cleaning was performed to address potential outliers, missing data, and standardization of variables, ensuring the information's quality and consistency.

PCA was applied to reduce the dimensionality of the dataset. Patterns of covariation were identified, and principal components that account for the most variance in the original variables were extracted to achieve this. For the PCA, ten variables were considered, four corresponding to the considered foodborne diseases (typhoid fever, hepatitis A, shigellosis and salmonella) and six corresponding to socioeconomic conditions of the population in each province of Ecuador (overcrowding, population without drinking water service, population without excreta sanitation, housing without garbage collection service, extreme poverty and poverty). PCA was carried out using RStudio software, specifically the 'FactoMineR' package for extracting principal components. Subsequently, the 'factoextra' package was used to calculate the quality of the representation of provinces and variables in the identified principal components. Finally, the 'ggbiplot' function was employed to represent provinces and variables on the principal components. **Figure 1** shows the complete process flow diagram implemented in this study. It starts with the data of reported disease cases, population projections, and socioeconomic conditions until the principal component models are reached.

3. Results and discussion

3.1. Year 2018

The two components or dimensions that explain the most significant variability in the data obtained from the PCA are shown in **Figure 2**. From this analysis, it was obtained that dimension 1 (Dim 1) explains almost half of the variability in the data (45.16%), so this dimension represents the most influential factor in the data set. As in principal component analysis, the dimensions best represent the variables with the highest loadings, the socioeconomic variables such as population without drinking water service (PWDWS), extreme poverty (EP), poverty (P), households without garbage collection (HWGC) and people without excreta sanitation (PWES) have the highest loadings in this component, this suggests that this dimension could be interpreted as a general indicator of adverse socioeconomic conditions, related to essential services and poverty and that it is these variables that have the most significant influence on the transmission of foodborne diseases.

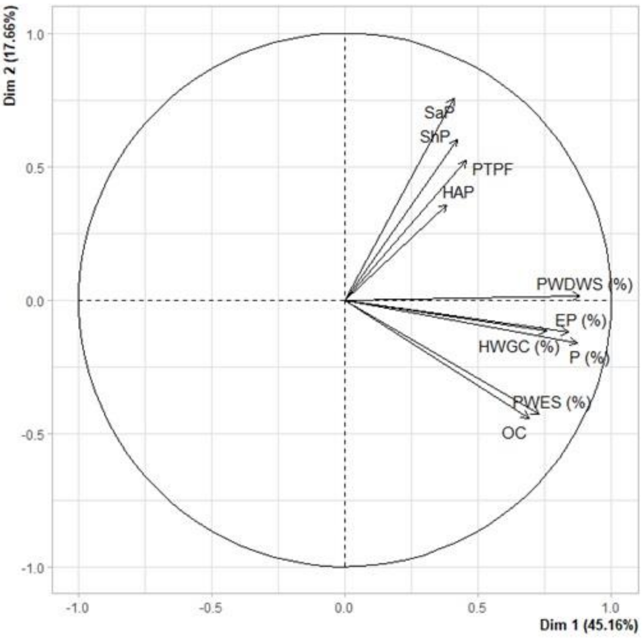

Figure 2. Biplot graph of the results of the principal component analysis of the prevalence of foodborne diseases and socioeconomic conditions of the different provinces of Ecuador during 2018.

On the other hand, diseases such as PTPF (Prevalence of typhoid and paratyphoid fever), ShP (Prevalence of shigellosis) and SaP (Prevalence of salmonellosis) have high loadings on dimension 2 (Dim 2), which could indicate that this dimension is more related to disease prevalence.

Although Dim 1 explains a higher variability than Dim 2, 45.16% versus 17.66%, the latter is still essential for the analysis. Diseases such as Salmonella and Shigellosis, which have high loadings in this dimension, may be influenced by factors other than those captured by Dim 1 and are possibly related to specific hygiene practices, access to safe food, or particular sanitary conditions. Understanding these differences is crucial for the design of public health policies and programs. If diseases are associated differently with socioeconomic variables, intervention strategies should also be different, i.e., specific and targeted. For example, measures to control typhoid and paratyphoid fever may need to focus more on improving sanitation and access to safe drinking water. In contrast, for hepatitis A, education campaigns on personal hygiene and safe food handling may be more effective.

When the first two dimensions are interpreted in combination, it can be inferred that socioeconomic variables and diseases have distinct patterns of variability in the data set. Access to essential services and living conditions, being in Dim 1, presents more significant variation between Ecuador's different provinces than the variation in foodborne disease prevalence between provinces. The high loading of variables such as OC, PWDWS and EP in the first dimensions suggests that factors such as living conditions and access to essential services are crucial in the prevalence of foodborne diseases. The finding of a relationship between unfavourable socioeconomic conditions and the high prevalence of foodborne diseases is consistent with previous studies by Crump (2019), Jacobsen (2018), Jacobsen and Koopman (2005), Jurado Jimenez et al. (2010), Nelson and Murphy (2013), Randazzo and Sanchez (2020), Taneja and Mewara (2016). These prior studies have also determined this association.

Significant variability between provinces in the two dimensions suggests notable differences in socioeconomic and health characteristics between them (**Figure 3**).

The province of Pichincha, belonging to the Sierra region and where the capital city of Quito is located, shows a very negative loading in Dim 1, indicating that this province has different socioeconomic and health characteristics, reflecting a different level of development and access to resources, which contrasts significantly with those provinces that have high positive loadings in this dimension, such as the province of Morona Santiago, located in the Amazonica region.

Some provinces, such as Napo and Zamora Chinchipe, show high values in Dim 2, which could indicate a unique pattern in the relationship between socioeconomic variables and the prevalence of diseases that are different from those of other provinces. The differing relationship between socioeconomics and disease prevalence across provinces could stem from variations in living conditions, hygiene practices, healthcare access, or cultural factors that impact disease prevalence.

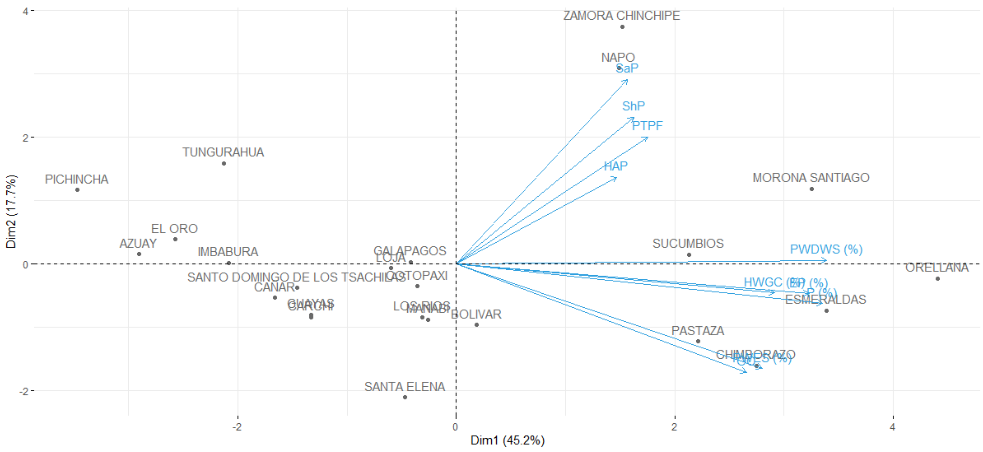

Figure 3. Biplot graph of the principal component analysis of the prevalence of foodborne diseases and socioeconomic conditions of the different provinces of Ecuador during 2018.

On the other hand, provinces such as Orellana and Morona Santiago have high positive values in Dim 1, indicating distinct particularities in these provinces compared to the rest.

Provinces such as Esmeraldas, Chimborazo and Pastaza have extreme values in Dim 1 and Dim 2, suggesting that these provinces could have very different characteristics regarding the leading health and socioeconomic variables.

Since the provinces of the same region have similar geographic, socioeconomic and cultural characteristics, the provinces were grouped based on the results obtained from the principal component analysis. The results obtained are presented in **Figure 4**. The grouping was carried out with three circles. The circle and provinces in purple belong to the Sierra region. The green circle and provinces belong to the Coastal region. The circle and the red provinces belong to the Amazonica region.

The following aspects can be appreciated from this grouping:

- The provinces of the Sierra and Costa regions are located in close positions in the biplot graph; this is evidenced by the overlapping of the two circles that group the provinces of these two regions, which indicates that the provinces of these regions present similarity between the variables considered in the study.

- The province of Galapagos, the only one in the Insular region, is located within both circles (Sierra region and Coastal region). However, its position is closer to provinces in the Sierra, such as Loja and Cotopaxi.
- The province of Esmeraldas, even though it is located in the Costa region, its position in the biplot graph is closer to the provinces of the Amazonica region. A similar situation occurs in the province of Chimborazo, which belongs to the Sierra region.

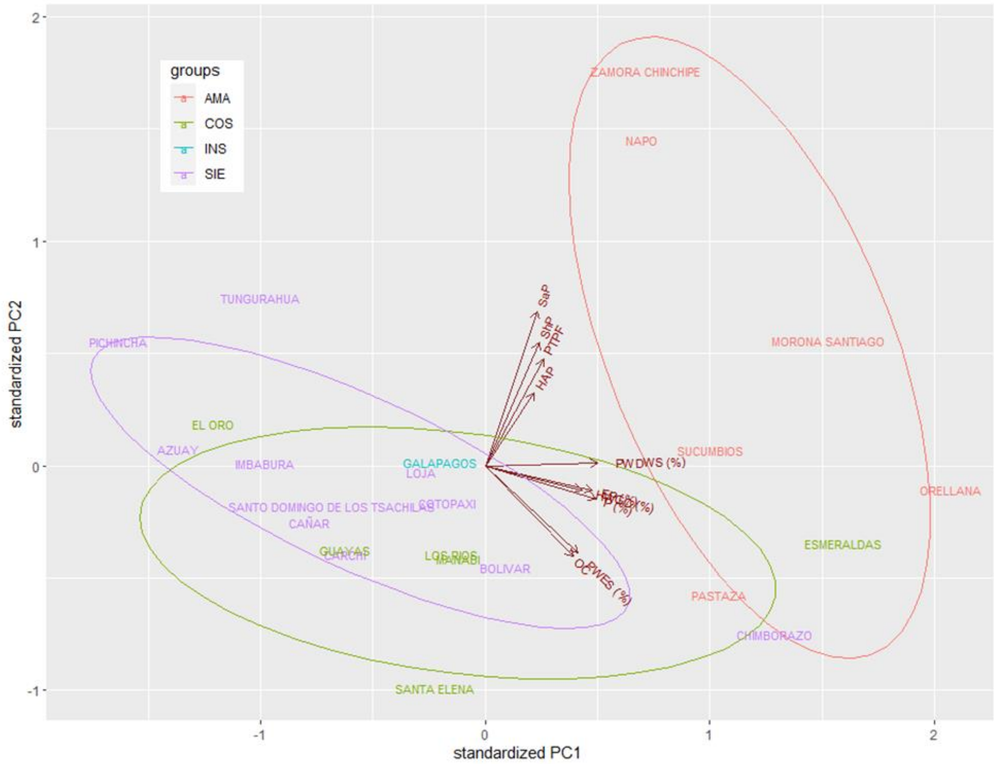

Figure 4. Biplot graph of the principal component analysis of prevalence of foodborne diseases and socioeconomic conditions of the different provinces of Ecuador, standardized, with grouping of provinces by region during 2018.

With this grouping, it is possible to identify the region with the provinces with the highest prevalence of foodborne diseases, and these are the provinces located in the Amazonica region. The ones that deserve more attention in this regard are Zamora Chinchipe and Napo, followed by Morona Santiago, Sucumbios and Orellana; it coincides with Murphy (2016), who states that indigenous populations are more susceptible to a high prevalence of foodborne diseases due to their socioeconomic conditions. Although Sucumbios and Orellana have unfavorable socioeconomic conditions, they do not have a high prevalence of foodborne diseases.

The provinces of the Sierra and Costa regions are those with better socioeconomic conditions and lower prevalence of foodborne diseases, except for the provinces of Esmeraldas (Costa) and Chimborazo (Sierra).

3.2. Year 2019

To verify how the results of this study vary from one year to another, the principal component analysis was repeated from the information generated on the variables considered during the year 2019. **Figure 5** shows the biplot graph with the PCA results for the 2019 data.

Similar to the results obtained for 2018, Dim 1 is strongly related to socioeconomic variables such as overcrowding, population without drinking water service, people without excreta sanitation and households without garbage collection. Dim 2 is strongly related to the prevalence variables of foodborne diseases: typhoid and paratyphoid fever, hepatitis A, shigellosis and salmonellosis.

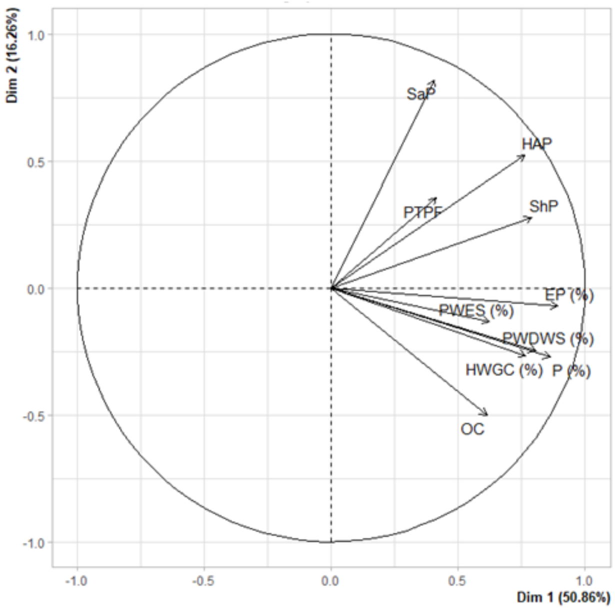

Figure 5. Biplot graph of the principal component analysis of foodborne disease prevalence and socioeconomic conditions of the provinces of Ecuador, as variables during 2019.

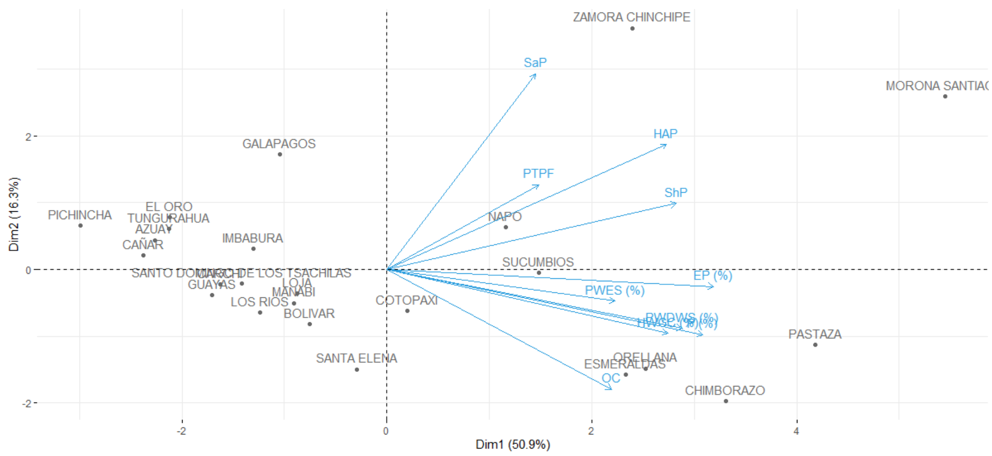

Figure 6. Biplot graph of the principal component analysis of foodborne disease prevalence and socioeconomic conditions of the provinces of Ecuador as variables during 2019.

The results obtained from the analysis of the provinces are presented in **Figure 6**. The aspects highlighted for the provinces of Pichincha, Napo, Zamora Chinchipe, Orellana, Morona Santiago, Esmeraldas, Chimborazo and Pastaza in terms of socioeconomic characteristics and prevalence of foodborne diseases for 2018 are repeated in 2019; it highlights the usefulness of PCA to determine patterns that allow associating socioeconomic variables with prevalence of foodborne diseases.

The graph corresponding to the grouping of the provinces by region for 2019 is shown in **Figure 7**. The overlap obtained for the Sierra and Costa regions from the analysis performed with the 2018 data is repeated for 2019. The Galapagos province presents a slight difference when comparing its location in the 2019 biplot graph with 2018. There is evidence of a higher burden in Dim 2, associated with a higher prevalence of foodborne diseases in 2019 compared to 2018.

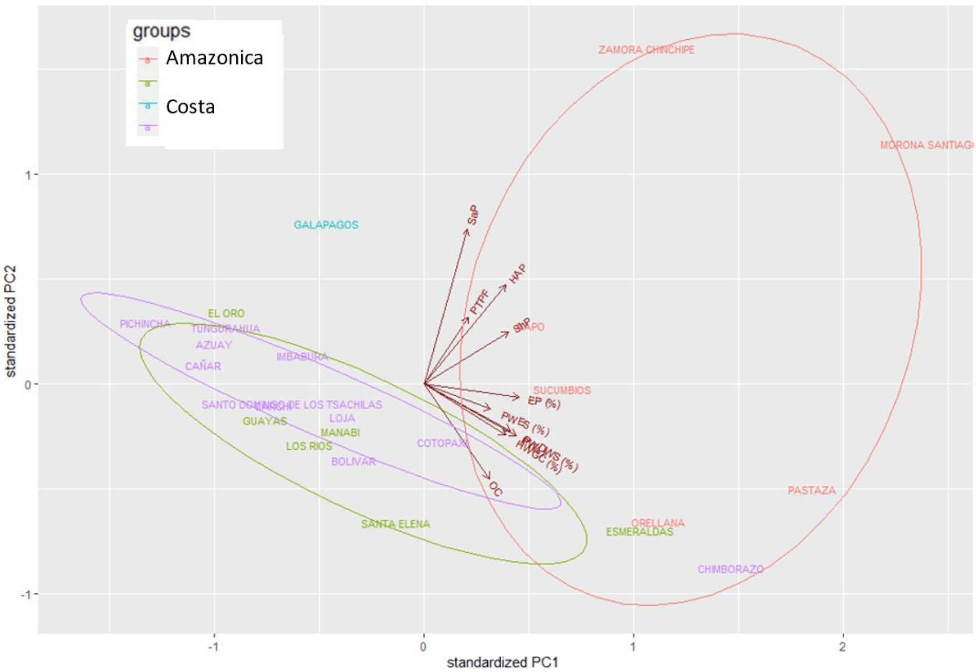

Figure 7. Biplot graph of the principal component analysis of foodborne disease prevalence and socioeconomic conditions of the different provinces of Ecuador, standardized, with a grouping of provinces.

4. Conclusion

The results obtained from this research highlight the usefulness of identifying patterns and the ability to reduce the dimensionality of PCA data; it can be beneficial in foodborne disease studies, as a large amount of data is often collected. PCA allows focus to be placed on the most critical aspects of the data, making it easier to analyze and understand.

The PCA has revealed that socioeconomic variables related to essential services and poverty are the most dominant factors in the first dimensions, which could have significant implications for the prevalence of foodborne diseases in the provinces of Ecuador. Diseases have different profiles in the dimensions, suggesting different patterns of association with socioeconomic variables.

The PCA can help researchers or policymakers to identify the provinces where interventions are most urgent, i.e., suggest priority areas for public health interventions: improving basic infrastructure and living conditions could have a significant impact on overall health, while measures focused on food security may be needed to address specific diseases. For example, if a province shows high values related to poverty and access to essential services, policies to improve these aspects may be more effective in reducing foodborne diseases.

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