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Demographic pressure on water: a regional analysis for Ecuador

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Abstract: The analysis of demographic pressure on hydrologic resources is fundamental for a sustainable water management. In this work, the Water Demographic Pressure Index (IPDA) was determined for the 55 most populated cantons of Ecuador, combining five variables: distribution of the population, population in arid zones, estimated domestic water consumption, population growth and water stress. The results obtained indicated that the greatest demographic pressure on water resources is concentrated at the Coast, while the lowest pressure occurs in the Amazon region. These results are mainly due to the relative population concentration and the hydrological and climatic conditions, affecting the amount of available water.

Key words: water resource; population pressure; water stress; IPDA

1 Introduction

Nearly 75% of the earth's surface is covered with water, which is an essential and important element for all living things (Altieri, 2016). However, less than 1% of such resources are suitable for human consumption or use [World Wildlife Fund WWF, 2012]. As human activities have polluted water bodies, this small part is now in danger because of the industrial processes and the reduction of stratification of available water. In addition, in many countries of the world, poor management of this resource has led to imbalance between water supply and demand (Montfort-García and Cantú-Martínez, 2009). This problem is growing due to the inequalities in access and the continuous growth of the world population, which also leads to an increase in the demand for water resources. In 2011, the global population reached 7 billion, which is expected to increase by 1 billion by 2024. At this rate, the world population will approach 9 billion by 2045 (United Nations Population Fund, 2011).

With the expected growth in the next few years, the negative impact of human on natural resources will also increase, especially in terms of providing water to human beings (Altieri, 2016; Arévalo et al., 2011). In 2013, an estimated 780 million people had no access to drinking water and about 2 billion people did not have adequate sanitation (World Health Organization, 2015). According to the data of World Water Resources Development Organization (WWDR3; WWAP, 2009) on the development of world water resources , by 2030, nearly half of the world's population (47%) will live in the Mediterranean region. This prediction is worrying because in 2000, nearly 508 million people (8%) live in water shortage or water shortage areas (WWAP, 2009). This growth lies in the different factors which affect the global water supply, such as population growth, water pollution, land use change, climate change and social progress (Davis and Simonovic, 2011).

The largest fresh water in the world (65%) is located in Latin America (Fernández, 2009), and among them the Andean country Ecuador is one of the countries with the most concentrated water networks per unit area (Trombone, 2011). Ecuador enjoys a privilege in terms of water availability on its territory, because each resident in the coastal area can obtain 4.863,41 m^3 per year, and each resident in the Amazon area can obtain 172.786,36 m^3 per year (Campos et al., 2014). These values are much higher than the 1.700 m^3/resident/year threshold set by Falkenmark to determine global water stress (McCarthy et al., 2001). However, not only in the same area, but also in a year when there is a significant difference between the rainy and dry seasons, the available water will also change (Calles, 2016).

In general, Ecuador's water balance is positive for all regions; However, water resources are under pressure due to the demand of different sectors to meet their multiple needs [Galarraga, 2000; National Water Secretariat, 2011]. The water consumption of the country is distributed in human consumption (~10%), industrial use (~10%) and irrigation (~80%); (Senagua, 2013). However, not all places have direct access to the public drinking water network because of the severe inequality of water supply between urban and rural areas and between different parts of the country (Bell, 2015). The water consumption of the country is distributed in human consumption (~10%), industrial use (~10%) and irrigation (~80%); (Senagawa, 2013). However, not all places have direct access to the public drinking water network because of the severe inequality of water supply between urban and rural areas and between different parts of the country (Bell, 2015). In 2012, the coverage of drinking water networks in urban areas was 94%, but only 36% in rural areas (Ministry of National Planning and Development, 2013).

This difference between regions requires a study on water pressure in Ecuador. Therefore, the most vulnerable and priority areas can be identified to implement and improve the allocation of this resource, including the construction and optimization of infrastructure.

In order to assess the pressure on water resources, the work carried out a multi standard analysis at the regional and local levels, including multiple variables of territorial population distribution, population in arid areas, estimated household water use, population growth and water pressure. As a territorial analysis unit, the state division of each province in the country has been established, and the population water pressure index has been determined. The study analyzed the two most populous states in Ecuador, which have at least 10 years of climate and hydrological information. Based on the results achieved, a tool was developed to support decision-making on water management at the Ecuadorian government level.

2 Study area

Ecuador is located in the northwest of South America. It borders Colombia in the north and northeast, Peru in the south and southeast, and the Pacific Ocean in the west. Its geographic coordinates are between 1°28' N and 5°01' N and 75° 11' E and 81°00' E [Food and Agriculture Organization of the United Nations (FAO), 2015]. The Andes Mountains pass through the country from north to south, forming a climate watershed, which has led to the formation of three different natural regions: Coast or Coastline in the West, Andes Mountains or Mountains in the Central areas, and Amazon in the East (Fig. 1). In addition to the three continental regions, the fourth region, the so-called island, is also defined, including the Columbus Islands of Galapagos Province, located 1,000 kilometers west of the equator of the Pacific Ocean (Galarraga, 2000).

Each region has its own climate characteristics. The coastal climate is affected by the East Pacific Ocean Current, especially the Humboldt Cold Current and the El Nino Warm Current, which largely determines the rainfall regime. The area has rainy season from December to April; the rest of the year is usually dry. On the contrary, the mountain area shows a bimodal state, with the largest rainfall in April and October, and the sun perpendicular to the equator. However, there was a relatively dry period (June to September) when rainfall was low. In addition, the terrain in the Andes region is very irregular, especially in the upper part. The terrain forms a separate physical space, and the climate changes in a short distance. The Amazon region has a humid tropical climate with abundant rainfall throughout the year [National Institute of Meteorology and Hydrology, 2006]. In general, the annual rainfall in all regions of Ecuador is 2274mm, equivalent to 583 km^3/year.

Ecuador has 31 hydrological systems, of which 24 correspond to the Pacific coast, with a super land area of 124.644 square kilometers (49%), and 7 correspond to the Amazon coast, with a super land area of 131.726 square kilometers (51%). The hydrological system is divided into 79 watersheds, 72 of which belong to the Pacific lagoon along the Amazon River (FAO, 2016).

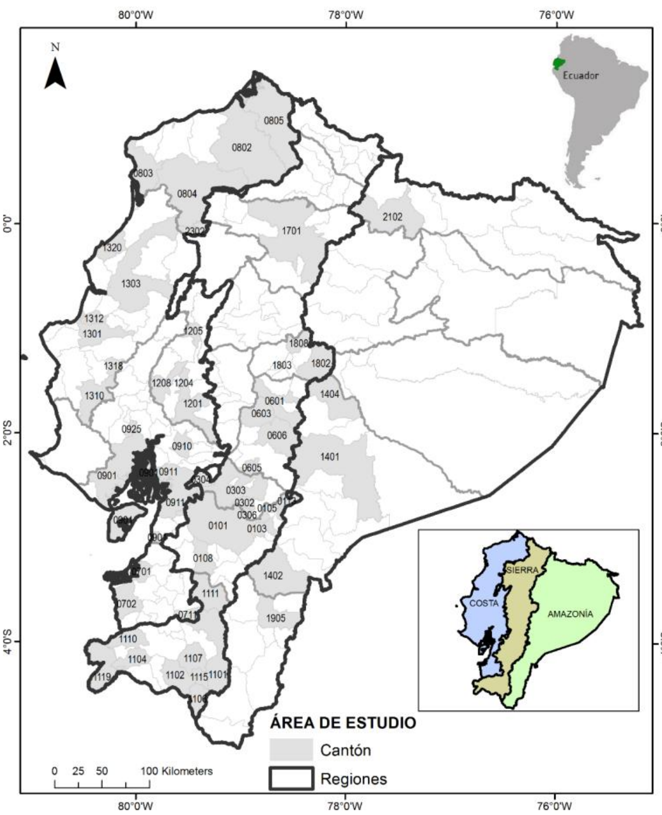

Fig. 1. Regional and political administrative map of Ecuador's most populous state

However, the country's largest water potential (88 per cent) lies in the latter. According to the data of the National Institute of Statistics and Census (INEC, 2017), Ecuador has a population of 16.776,977 million, mainly concentrated in coastal areas, totaling 8,303,168 people, followed by mountainous areas, totaling 7,504,942 people. The third is the Amazon region, with 898,547 residents, and the last is the island region, with 30890 residents. Due to this spatial distribution of the population, there are obvious water shortage areas in the country, especially in the coastal, southern and northern desert transitional regions of Peru [Economic Commission for Latin America and the Caribbean, 2013]. The country's Department of Politics and Administration is composed of 24 provinces, which are divided into 221 states, including 1500 dioceses.

According to the results of the 2010 census of the National Bureau of Statistics, Ecuador's population growth shows that the population in urban areas has increased, while the population in rural areas has decreased, which is related to the people's lack of access to basic services to some extent. The fastest growing provinces are: Guayas (code 09), Pichincha (code 17), Manabi (code 13), Los Rios (code 12), Azui (code 01) and Ernes Oden (INEC, 2014). The States known as territorial analysis units (UTA's) are coded according to statistical geographic classifiers (INEC, 2016).

3 Methodology

3.1 Data

This study is based on the existing population data of Ecuador's 55 most populous states (UTA's; Fig. 1). The data were provided and collected by INEC in the 2001 and 2010 censuses. The climate data were obtained from the meteorological yearbook of the National Institute of Meteorology and Hydrology of Ecuador (INAMHI, 2013) from 1990 to 2010. The meteorological yearbook includes monthly and annual information of all operational meteorological stations in the country, especially precipitation and temperature data. The average annual water consumption per capita in Ecuador is calculated based on the International Comparison Network of Water and Sanitation Companies (IBNET, 2016) and use ArcGIS 10 software (ESRI, 2012) to analyze data and plot results.

3.2 Index calculation

3.2.1 The index of demographic water pressure (IPDA)

IPDA is the result of comprehensive analysis of five variables: 1) the index of population spatial distribution (IDP); 2) the indicators of the population in arid areas (IPZA); 3) indicators of estimated domestic water use (ICDEA); 4) indicators of population growth; (ICP) 5) the index of water stress, (Chias et al., 2007; Quentin et al., 2007).

3.2.2 The indicator of population spatial distribution

The relative population of each Utah state is determined by the ratio between the subgroup (state) and the total population of the study area, which corresponds to the total population of the 55 study states (Eller, 2001). The IDP can be calculated by applying the following expression (equation 1).

$$IDP_i = \frac{p_i}{P} \qquad [1]$$

P_i is the total population of UTA analysis, and P is the total population of 55 states (7,980,253 residents).

3.2.3 The indicators of the Population in arid areas

IPZA determines the relative population (%) of each state living in arid climate zones. These areas were determined by the Martonne drought index (Wang and Takahashi, 1999), using the annual temperature (T) and precipitation (P) data of each existing meteorological station in the state (Maliva and Missimer, 2012). The drought index (A_m) of each station is estimated by equation 2:

$$A_m = \frac{P}{(T + 10)} \qquad [2]$$

The A_m value is explained as follows (Table 1)

Table 1. Classification of drought index

A_m Value	Region
0 – 5	Desert (super drought)

5 – 10	Semi desert (arid)
10 – 20	Semiarid
20 – 30	Subhumid
30 – 60	Humid
> 60	Hygroscopic

Spatial maps and continuous A_m values were generated for each state using ordinary *Kriging* interpolation geostatistical methods (FAO, 2001). These results were validated by data from the state's meteorological stations, which provided a series of data less than 10 years that were not included in the analysis (Garrado, 2006).

The IPZA is determined by expression [3].

$$IPZA_i = 100 \times \frac{A_m}{p_i} \qquad [3]$$

3.2.4 Estimated domestic water use indicators (ICDEA)

The ICDEA estimates the rate of water use by the population for household purposes. It is expressed by equation [4] (Manzano et al., 2007), the unit is liter/day (L/day)..

$$ICDEA_i = p_i \times x_i \qquad [4]$$

Wherein, x_i is the average water consumption per person (L/day).

The average annual water consumption per capita of Ecuador reported by IBNET (2016) is applicable to determine x_i.

The results are adjusted with the average temperature data of UTA, then, as suggested by Balling et al., there is a direct correlation between ambient temperature and water consumption (2008).

3.2.5 Population growth indicators

ICP can determine the population growth rate of each UTA through arithmetic, geometric or exponential models, which will affect household water consumption (Vörösmarty et al., 2000). In this work, an exponential model is used, assuming that the growth is continuous rather than every time unit (Ecuación 5; Torres-Degró, 2011).

$$ICP_i = 100 \times \frac{1}{h} \times ln \frac{p_{ic+1}}{p_{ic}} \qquad [5]$$

h is the time between two census activities (INEC, 2001; 2010), and P_{ic} is the total population of 55 states during the census period (*c*).

3.2.6 Index of water stress (IEH)

IEH estimates the distribution of a unit volume of water (1 million cubic meters) in Utah's population, indicating that the state's water resources are available. The estimation of available water is established by establishing a primary mass balance between precipitation and transpiration by applying the Thornwait method (Ruíz et al., 2012). The IEH of each UTA is calculated by the following formula [6] (Massa-Sánchez et al., 2018):

$$IEH_i = 0.01 \times \frac{k}{u_{4i}} \qquad [6]$$

k is the renewable water volume, and u_{4i} is the per capita available water volume in state.

3.3 Combined variable analysis

The expression for calculating IPDA using five indexes or indicators is as follows (Ecuación 7; Mas-sa-Sánchez et al., 2018):

$$IPDA_i = \sum_{j=1}^{j} f_j g_{ji} \qquad [7]$$

Where f is the specific weight factor assigned to each indicator (j), i represents the spatial unit of analysis, and g is the standardized population index calculated by the following expression (Chías et al., 2007).

$$g_j = \frac{d_j - d_{jm}}{d_{jM} - d_{jm}} \qquad [8]$$

Where d_j is the index of population pressure to be evaluated, and m and M are the minimum and maximum values of this index. The specific weight assigned to each variable has a significant impact on the final result. IPZA and IDP are generally considered to be the most important variables, because they represent the concentration of people living in arid areas, followed by IEH, which indicates the available water in the area (Manzano et al., 2007). The index with the lowest weight is ICDEA and ICP, because domestic water use depends on the water supply and population growth in the region. The weight of this study is from Massa-Sánchez et al. (2018), **(**Table 2**)**

Table 2. Weight factors assigned to each variable of the calculated IPDA

Index indicator	Specific weight factor (f)*
IDP	0.25
IPZA	0.40
ICDEA	0.10
ICP	0.05
IEH	0.05
Total	1.00

*These values represent the impact of each variable on water resource pressure

Finally, in order to better interpret the data, the IPDA values of each UTA are divided into three categories. In general, the IPDA value is between 0 and 1, and the value close to 1 indicates that the pressure on water resources is greater. The classification is based on the histogram generated by the "*Space Analyst"* tool of *Software* ArcGIS 10 (ESRI, 2012), which allows setting the range of the same interval. Since Ecuador's water balance is positive for all regions (Senagawa, 2011), the following categories have been established: 0-0.21 (low); 0.22-0.43 (medium); and > 0.43 (high).

4 Results and discussion

Fig. 2 to 7 respectively show the value range of each of the five indexes calculated.The IDP (Fig. 2) shows the relative population of each UTA and the total population of the 55 states under study. It is clear that more than half of the population (57.5%) is concentrated in two Utans [Guayaquil (0901): 29.46% and Quito (1701): 28.06%]. Guayaquil is the most populous city in Ecuador, followed by the capital Quito. Other highly populated states are usually provincial capitals (INEC, 2017).

Fig. 3 shows the location of the population living in arid areas according to the drought index. Senagua (2011) said that the water balance in all regions of Ecuador is positive; however, some deficit basins are concentrated in coastal areas, especially in Manabí (13), Guayas (09) and El Oro (07) provinces. The driest states have deficit basins, particularly in the desert transition zone in northern Peru. The high IPZA in these states shows that people are prone to water supply problems because the water supply is limited at least seasonally (INAMHI, 2006). The most sensitive UTA is Machala (0701), not only because it is located in the transition zone of the desert in northern Peru, but also because of the lack of a large-scale hydrological system.

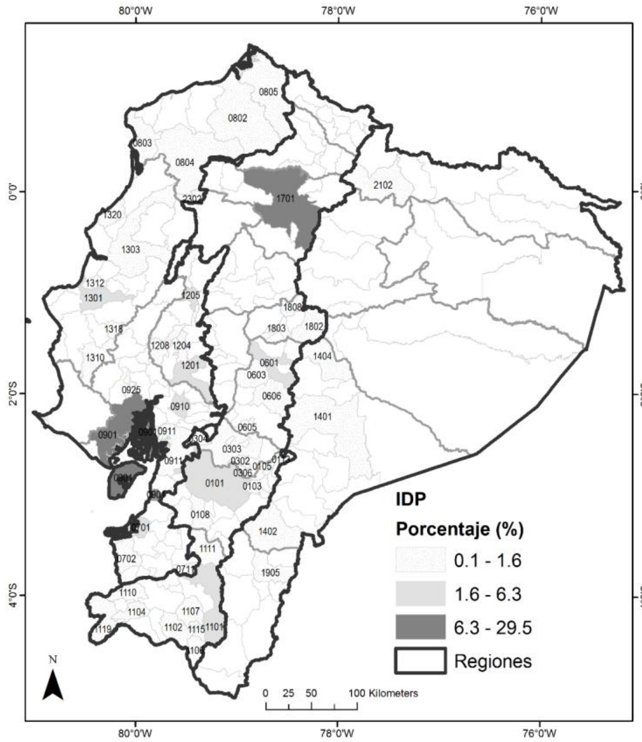

Fig. 2. Population spatial distribution indicators (GDP [%])

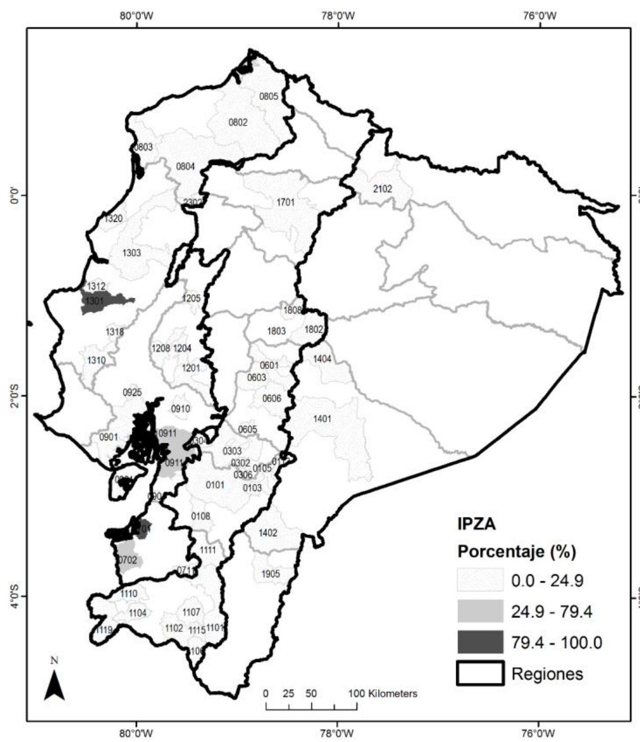

Fig. 3. Population indicators in arid areas (IPZA [%])

The ICDEA map (Fig. 4) is directly related to internally displaced persons. Obviously, in the most populous areas, the daily water consumption is the highest. It is estimated that the water consumption of UTA'S (0901 and 1701) in Guayaquil and Quito is the highest, including 533.081.730,825 L/d and 407.723.093,235 L/d respectively. The high concentration of population means that water resources face greater pressure, because the demand of the most populous cities is particularly increasing. The situation has worsened due to the outflow of rural population observed in Ecuador [United Nations Organization, 2014]. The most seriously affected cities are provincial capital cities and national capitals, as well as the largest ports where the population of the country is particularly concentrated, resulting in a large demand for water (Chías et al., 2007).

The ICP (Fig. 5) clearly shows the rural population outflow observed in Ecuador (United Nations, 2014). In 2001, 39% of Ecuador's residents lived in rural areas (INEC, 2001), and by 2015, this proportion had dropped to 32% (Latin American Centre for Rural Development, 2017). Urban population grows particularly due to the rural youth (15-24 years old), who seek new opportunities or want to continue their studies in cities. In general, most rural migrants are mobilized to provincial capital cities (93%), and only 7% go abroad (Villacis and Carrillo, 2012). Due to low production, the incidence rate of rural population outflow is high in Loha Province (11) in southern Ecuador Agriculture (transition to the desert in northern Peru) and jobs seats (Villacis and Carrillo, 2012). The three states with the largest population reduction in the country are Loha Province: Gonzanamá (1107; -1.64%), Espíndola (1106; -0.62%) and Quillanga (1115; -0.55%).

On the other hand, it must also include foreigners who migrate to Ecuador, especially from Colombia and Peru; however, due to better conditions for obtaining jobs, these immigrants mainly stay in cities or places with important ports (Cortez and Medina, 2011). This is particularly true in San Lorenzo (0805; population growth: 4.11%) and Quinindé (0.804; population growth: 3.28%), which are close to the border with Colombia and the third largest port of Ecuador in Esmeraldas (08).

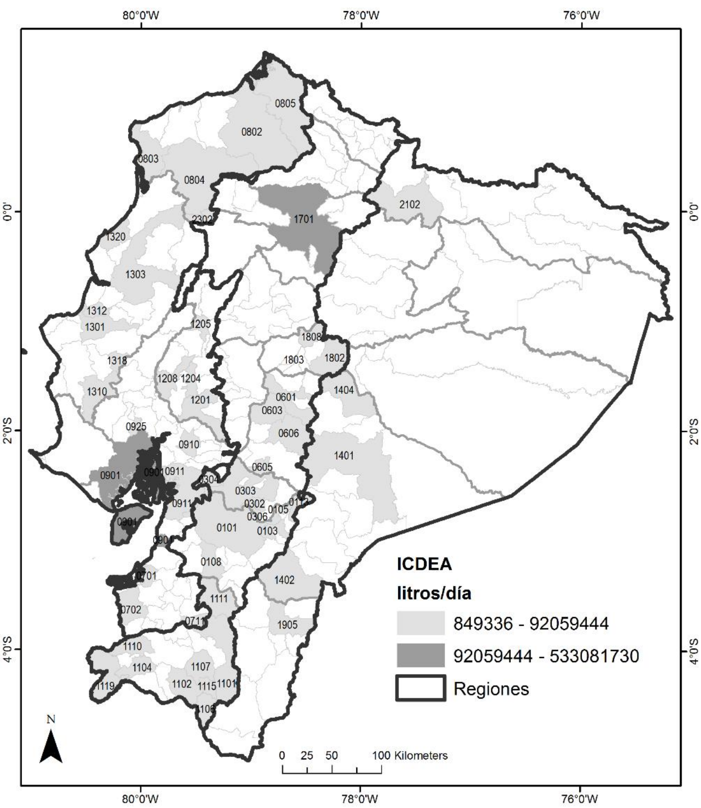

Fig. 4. Estimated household water use indicators (ICDEA [L/day])

Due to the oil and mining industry subsidized by the state (Ochoa et al., 2015), the population growth in the Amazon region, especially in Morona (1401) and Yanzatza (1905), is also obvious. In short, the fastest growing population is in the provincial capital, close to the main ports (Guayaquil, Manta and Esmeraldas) and mining areas.

The water stress index (IEH) is directly related to the amount of water available to Utah's population, and indicates the regulatory capacity of water resources in that year (Galarraga, 2000). Debido a esto, 2000). Therefore, IEH is closely related to IDPs and IPZA, because the highest CO value corresponds to the most populous states with insufficient water supply, which are mostly located in coastal areas (Fig. 6). The worst affected are Machala (0701; value: 16.15), Potoviejo (1301; value: 7.03) and Guayaquil (0901; value: 5.92). Compared with other regions in the country, the rainfall in coastal areas is usually low, concentrated from December to April (INMAHI, 2006), because this region is most seriously affected, especially in the deficit and transition area of the desert in northern Peru. As the annual water balance of the whole Ecuador territory is positive (SENAGAWA, 2011), the IEH of the rest of Utah analyzed is generally low.

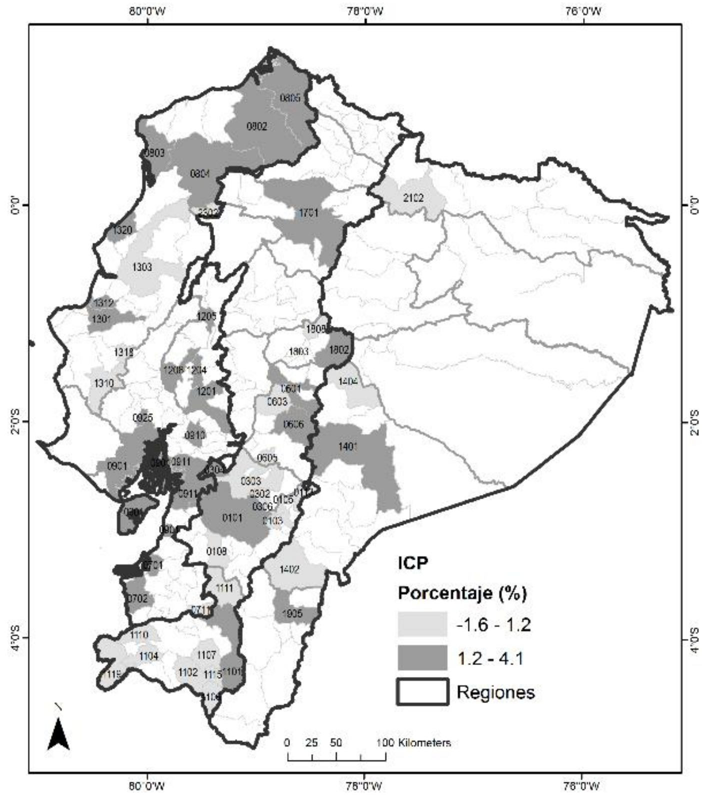

Fig. 5. Population growth indicators (ICP [%])

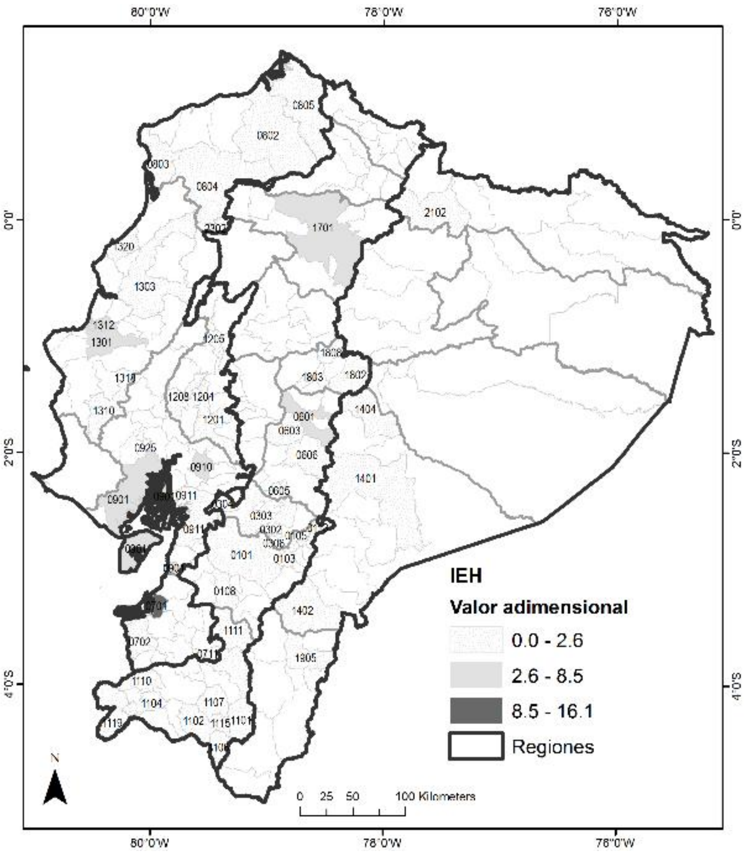

Fig. 6. Hydro extract index (IEH)

The water resource pressure of Ecuador's 55 most populous cities is determined by combining the unit index (equation 7) (Fig. 7). As mentioned above, the potential of water resources in the country is unbalanced; Coastal area accounts for 12%, Amazon area accounts for 88%. In addition, the population is concentrated near cities or important ports, so it is expected that runoff basins with high population density will face high pressure. For this reason, the highest specific weight of the individual index (Table 2) is assigned to IPZA (0.40) and IDP (0.25), which indicates the concentration of population in arid areas.

Among the 55 states analyzed, only 6 states have medium to high IPDA, and 5 of them are in the water shortage basin in the coastal area (Galarraga, 2000; SENAGUA, 2013), and only one is in the mountains [Quito (1701)]. Three states with high IPDA are located in coastal areas (Machala (0701): 0.66; Portoviejo (1301): 0.51; Guayaquil (0901): 0.46; Fig. 7), where there are deficit basins and highly concentrated populations. The high IPDA leads to domestic water supply problems because the surrounding basin cannot provide enough water to meet the demand (SENAGUA, 2011). Due to the expected population growth in these states, the future problems will be more serious.

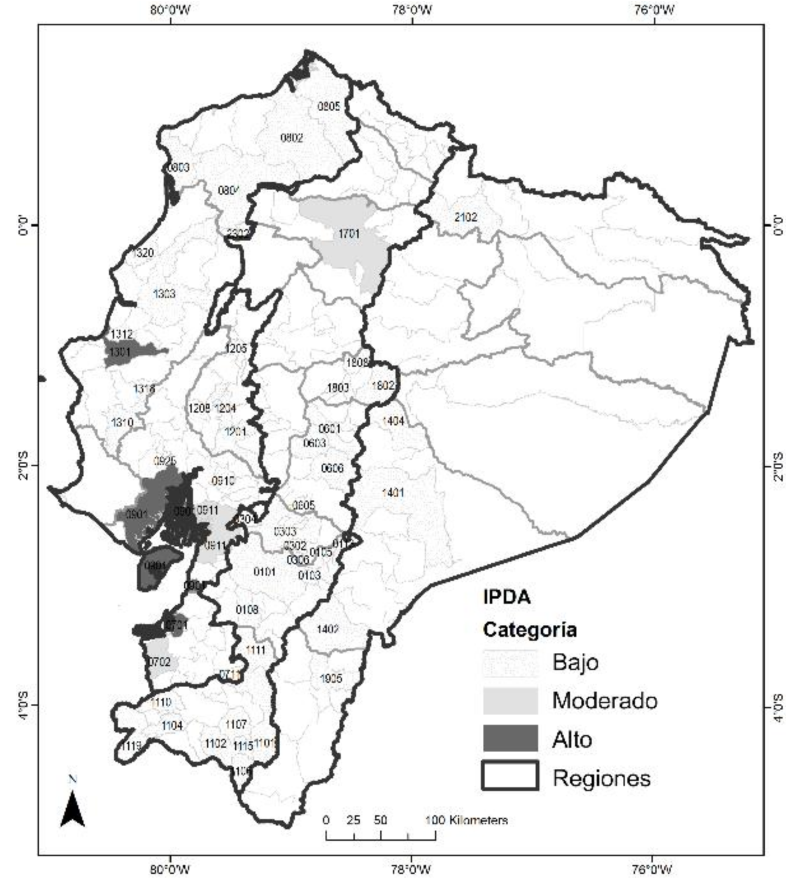

Fig. 7. Population pressure index of water resources (IPDA)

Quito is the only state with medium IPDA in the Andes region, the capital of Ecuador and the second largest population city in the country. Therefore, the pressure or demand for water resources is usually high (FAO, 2013). So, different water optimization schemes have been implemented in recent years, including the protection of water supply basin [Quito Public Drinking Water and Sanitation Company, 2017]. However, in urban areas, due to the increase of population, the continuous expansion of sewers and the consequent increase of wastewater, rainwater runoff has caused additional pressure on water resources and existing treatment facilities (Quentin et al., 2007).

Due to the low population density and high availability of resources (172.786,36m^3/inhabitant/year); Campos et al, 2014; CEPAL, 2013). there are no states under great pressure in the Amazon region. However, in many rural areas, there is not enough water infrastructure.

5 Conclusion

This work outlines the water demand and population growth in Ecuador's 55 most populous states. IPDA is obtained based on five indexes: population distribution (IDP), population in arid areas (IPZA), estimated domestic water use (ICDEA), population growth (ICP) and water pressure (IEH), which makes it possible to identify the most vulnerable areas. The results obtained correspond to the pressure of population on water resources, which depends on household supply and consumption demand. However, due to poor data availability, other water uses such as agriculture and industry are not taken into account. The most seriously affected UTA is located in the coastal areas (Machala, Potoviejo and Guayaquil), where there are water shortage caves, water supply problems and a large number of residents. These states include the capital cities and major ports of the country (Guayaquil, Manta and Esmeraldas). Therefore, they are the main destinations for foreign immigrants and rural population outflows. Due to the low population density and high availability of water resources, the lowest value corresponds to the Amazon region. The population density of the most vulnerable UTA in the territory is very high, and the per capita water availability is also very low. This is because the current climate conditions show obvious seasonal changes (rainy season and dry season), which directly affect the water supply and water quality in different seasons of the year. The spatial distribution of the most vulnerable areas related to water pressure can be used as a basis for implementing water management actions and as a reference for future research work to assess the population's impact on the evolution of water pressure.

Conflicts of interest

The author declares no conflicts of interest regarding the publication of this paper.

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