A probabilistic map to optimize human blood collection

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Abstract

In the present work it is found the geographical configuration of the set of potential blood donors (between 17 and 65 years old) in Ecuador, taking advantage of the information provided by the National Health and Nutrition Survey 2011 - 2013 and 2010 Population and Housing Census. We obtain a full classification of the population according to their capacity to donate blood (real, deferred and failed) discriminated by provinces and cantons. The final product, obtained by the application of mathematical modeling (mainly Markov chains), is a stochastic map which can help institutions involved in blood collection (e.g. the Ecuadorian branch of the Red Cross) to focus their activities to improve this social service.

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1. Introduction

The transfusion therapy (TT) is one of the regular services at health or medical centers since it helps to save lives, e.g. when a surgery causes a high amount of blood loss, or to improve the quality of life of people with conditions that require regular transfusions such as hemophilia or cancer, [4]. Therefore, as a social service, it's expected that TT is always safe, available to and affordable by the common people, [2]. However, there are millions of patients in developing countries and transitional economies that do not have access to TT with the mentioned characteristics, being failures in the blood collection approach one of the main reasons.

In Latin America, the blood collection index has grown in the last decade (14.5 units/ 1000 persons / year in 2005) but it's still much lower than that in the developed world (40 - 50 units/ 1000 persons / year), [2]. This is the case of Ecuador, where the

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Ecuadorian branch of the Red Cross provides 69% of the blood supply, despite years of one-to-one and media-based motivation campaigns.

"*Providing an uninterrupted supply of blood while ensuring the safety of donors and recipients is a Sisyphean undertaking in view of the continuous demand for blood*", [9], for the blood's shelf life is short. The sanitary restrictions that apply to potential donors are very strict and actually is not eligible as blood donor a person with at least one of a number of conditions: diabetes, cardiac disease, kidney condition, neurological condition (e.g. epilepsy), respiratory disease, venereal disease (e.g. AIDS and syphilis), etc.

Because of what has been exposed it is important to analyze the geographical configuration of the population of potential donors in a country so that the motivation or educative campaigns and the actual collection can be more efficient. In the present paper we take this task for the case of Ecuador having as primary source of information ENSANUT (National Health and Nutrition Survey 2011 - 2013), developed by INEC (National Institute of Statistics and Censuses). Our study applies Markov chains and was mathematically motivated by [1], where a model is built up to describe internal and external population mobility.

The paper is organized as follows. Section 2 is devoted to the methods applied in the study. In particular, the elements of the model for the population projection as well as the way it was constructed are presented in Section 2.1. The evolution of the factors that can provoke a change of the demography, i.e., mortality and fertility, is studied in Section 2.2. The projections of life expectancy and mobility are made in Sections 2.3 and 2.4, respectively. The projection of the blood donors population via the Verhulst differential equation is the subject of Section 2.5. The final product of the research, that is the stochastic map of blood donors, is briefly presented Section 3, for space limitations. Yet the maps presented in this section as well as some other interesting figures can be downloaded from

`https://drive.google.com/folderview?id=0B-Hv8c_pBEHaRm9md1NZSnI5eDQ&usp=sharing`

2. Methods

The present study analizes information obtained by INEC, the statistics public organism in Ecuador, mainly from ENSANUT and the 2010 Census (2010 Population and Housing Census), to build a probabilistic map to help optimize human blood collection in Ecuador.

ENSANUT was a national survey applied to 19949 homes grouped in 1645 census sectors, getting information on Child Health, Maternal Reproductive Health, CNCDs (Chronic Noncommunicable Conditions and Diseases), Nutritional Health, people's (between 0 - 59 years old) amount of expenses in health, etc., classified by geographic locations, ethnic origin, and some other social and economic factors.

By using an stochastic modeling, mainly based on Markov chains, we shall classify the Ecuadorian population (between 17 and 65 years old) according to their capacity to donate blood: real, deferred and failed donors. As a side effect of the geographic identification of these three groups, a map for the chronic diseases is obtained.

Next, we shall introduce the necessary general framework.

2.1. *Population projections*

Projections are the main element to estimate the demographic variations (for 2010 - 2020) of the Ecuadorian population. Actually they help to compute approximations of the fertility and mortality rates and then the interprovincial migration and immigration rates.

2.1.1. *Elements of the model*

The model is build up in several stages since there are many factors intervening. We start with some formulations and introduce notation which considers province, age and year.

i: The province index, e.g. $i = 1$ corresponds to the province of Azuay. If two province indexes intervene it should be assumed that i and j denote the origin province and the destiny province, respectively.

t: The year during the projection period, e.g. $t = 2010, 2011, \ldots, 2020$.

x: Age of the population.

$P_{i,x}(t)$: Size of the population of the province i with age x at the year t.

$D_{i,x}(t)$: Number of persons of the province i with age x that die at the year t.

$m_{i,x}(t)$: Mortality rate for the population of the province i with age x in the year t:

$$m_{i,x}(t) = \frac{D_{i,x}(t)}{P_{i,x}(t)} \tag{2.1}$$

$q_{i,x}(t)$: Probability of dying for the population of the province i with age x during the year t,

$$q_{i,x}(t) = 1 - \exp(-m_{i,x}(t)).$$

$l_{i,x}(t)$: Number of remaining persons of the province i with age x in the year t,

$$l_{i,x+1}(t) = l_{i,x}(t)(1 - q_{i,x}(t)).$$

$d_{i,x}(t)$: Estimated number of persons of the province i with age x that die during the year t,

$$d_{i,x}(t) = l_{i,x}(t) - l_{i,x+1}(t).$$

$L_{i,x}(t)$: Size of the stationary population between the ages x and $x+1$ of the province i in the year t.[1] Since we are dealing with simple ages, [7], we have $n = 1$ and

$$L_{i,x}(t) = l_{i,x+1}(t) + \frac{n}{2} d_{i,x}(t) = \frac{l_{i,x+1}(t) + l_{i,x}(t)}{2}.$$

[1] Number of years lived by the generation between the ages x and $x+1$.

$S_{i,x}(t)$**:** Probability of the population residing in the province i to achieve the age x, also known as the probability of surviving during the year t,

$$S_{i,x}(t) = \frac{L_{i,x+1}(t)}{L_{i,x}(t)} \tag{2.2}$$

$T_{i,x}(t)$**:** Number of years that a person lives since age x while residing in the province i.

$$T_{i,x}(t) = \sum_{k=0}^{99-x} L_{i,k}(t). \tag{2.3}$$

Even though the Ecuadorian life expectancy is 76.36, [6], in the sum (2.3) we take 99 as upper bound so to take account of lesser probability events.

$\mathrm{edv}_{i,x}(t)$**:** Life expectancy of the population of the province i, with age x at the year t,

$$\mathrm{edv}_{i,x}(t) = \frac{T_{i,x}(t)}{l_{i,x}(t)}.$$

$S_{i,j,x}(t)$**:** Number of province-i native persons, with age x, who reside in the province j at the year t.

$\widehat{S}_{i,j,x}(t)$**:** Probability that a person with age x moves from the province i to the province j, during the year t,

$$\widehat{S}_{i,j,x}(t) = \frac{S_{i,j,x}(t)}{\sum_{j=1}^{n} S_{i,j,x}(t)},$$

so that

$$\sum_{j=1}^{n} \widehat{S}_{i,j,x}(t) = 1 \qquad i = 1,2,\ldots,n. \tag{2.4}$$

Here $n = 25$, considering the 24 provinces of Ecuador plus an index for the non-delimited areas.

$N_{i,x}(t)$**:** Net migratory balance which is the difference between the yearly average number of immigrants and that of emigrants.

2.1.2. Construction of the projection model

If we consider the base population[2] $P_{i,x}$ and the probability to survive $S_{i,x}$, then the size of the population for the province i with age $x+1$ at the year $t+1$ will be given by

$$P_{i,x+1}(t+1) = P_{i,x}(t)S_{i,x}(t) \tag{2.5}$$

Now, by applying to (2.5) the mobility factor, i.e. the probability of moving from the province i to the province j, we get

$$P_{j,x+1}(t+1) = \sum_{i=1}^{25} P_{i,x}(t)S_{i,x}(t)\widehat{S}_{i,j,x}(t) \qquad j = 1,2,\ldots,25. \tag{2.6}$$

[2]The base population is taken from the 2010 Census.

To complete the model, it is necessary to include the international migration, with which the model becomes:

$$P_{j,x+1}(t+1) = \sum_{i=1}^{25} P_{i,x}(t) S_{i,x}(t) \widehat{S}_{i,j,x}(t) + N_{j,x}(t), \qquad j = 1,2,\ldots,25. \tag{2.7}$$

Remark 2.1. To handle a simpler but still good model we have considered a constant net migratory balance for every year of the projection instead of estimates of the international migration.

To guarantee that the model converges year after year, it is necessary to apply a closure property: the computed projected population shouldn't be bigger than the existing population. And, in virtue of this, to handle mutually exclusive groups we shall use only (2.5):

$$\widetilde{P}_{j,x+1}(t+1) = P_{j,x}(t) S_{j,x}(t). \tag{2.8}$$

By considering the native population, I, the non-native population, nI, and the total population, T, it should hold the closure property:

$$\widetilde{P}^{T}_{j,x}(t) S^{T}_{j,x}(t) = \widetilde{P}^{I}_{j,x}(t) S^{I}_{j,x}(t) + \widetilde{P}^{nI}_{j,x}(t) S^{nI}_{j,x}(t). \tag{2.9}$$

Remark 2.2. The symbol "$\widetilde{\ }$" which appears in (2.8) is used to indicate that it has been considered only the reducing factor corresponding to mortality.

By using (2.8), we can compute the migration that receives each province:

$$\widehat{P}_{j,x+1}(t+1) = \sum_{i=1}^{25} \widetilde{P}_{i,x+1}(t+1) \widehat{S}_{i,j,x}(t). \tag{2.10}$$

Remark 2.3. The symbol "$\widehat{\ }$" which appears in (2.10) is used to indicate that it hasn't been incorporated the international migration term.

Moreover, by (2.4) the number $\widehat{S}_{i,j,x}(t)$ is distributed only to the provinces without perturbing the national amount. With respect to the international migration, it is not possible to obtain an ethnic classification for lack of information. Because of this, we assume that the incidence of the international migration does not change among province populations. Under this consideration, the computation of each of the considered populations is established in the following way:

$$\begin{aligned} P^{I}_{j,x+1}(t+1) &= P^{T}_{j,x+1}(t+1) \frac{\widehat{P}^{I}_{j,x+1}(t+1)}{\widehat{P}^{I}_{j,x+1}(t+1) + \widehat{P}^{nI}_{j,x+1}(t+1)} \\ P^{nI}_{j,x+1}(t+1) &= P^{T}_{j,x+1}(t+1) - P^{I}_{j,x+1}(t+1). \end{aligned} \tag{2.11}$$

Once obtained the native and non-native populations for the year $t+1$, it's mandatory to obtain the new generations that will be arriving to the existing population.

2.2. *Evolution of the demographic change factors*

The current tendencies of the Ecuadorian fertility and mortality rates provoke the decreasing in the average yearly growth and an increasingly aging population. Moreover, the internal and external migration, whose subjects are mainly youngsters, can influence the aging of the population both at national and subnational level, [3]. In this context, the provincial mobility and demographic evolution shall be estimated.

2.2.1. *Fertility projection*

One of the most important demographic changes is the steady decreasing of fertility. The main reason for this decreasing is an ever increasing of the female EAP (economically active population), [8]. Considering this, the fertility projection is obtained at a general level, that is, without taking in consideration the mother age. So, the estimation of the Global Fertility Rate, TFG, for the years of the considered period, is given by

$$\mathrm{TFG}(t) = k_1 + \frac{k_2}{1 + \exp(\alpha + \beta t)}, \tag{2.12}$$

where k_1 and k_2 are a mother's minimum and maximum number of children, respectively. The constants α and β are computed using the values established in [8]:

$$\alpha = \ln\left(\frac{k_1 + \mathrm{TFG}(0)}{\mathrm{TFG}(0) - k_1}\right), \qquad \beta = \frac{1}{T}\left[\ln\left(\frac{k_1 + k_2 - \mathrm{TFG}(T)}{\mathrm{TFG}(T) - k_1}\right) - \alpha\right].$$

Now, to estimate the fertility rate $F_{i,x}$ is necessary to consider the following points:

$\overline{P}^f_{i,x}(t)$**:** Province-i female population with fertility age (between 15 and 49 years old) in the middle of the year t,

$$\overline{P}^f_{i,x}(t) = \frac{P^f_{i,x}(t) + P^f_{i,x}(t+1)}{2}.$$

$g_{i,x}(t)$**:** Weight per age of the mother, given by:

$$g_{i,x}(t) = \frac{\overline{P}^f_{i,x}(t)}{\sum_{x=15}^{49} \overline{P}^f_{i,x}(t)} \qquad \text{so that} \qquad \sum_{x=15}^{49} g_{i,x}(t) = 1.$$

Then, the provincial fertility rate is given by

$$F_{i,x}(t) = TFG(t) \cdot g_{i,x}(t).$$

To compute the number of persons that will be integrating to the population, it's necessary to estimate the yearly total amount of births:

$$B_i(t) = \sum_{x=15}^{49} \overline{P}^f_{i,x}(t) F_{i,x}(t). \tag{2.13}$$

It is possible to classify $B_i(t)$ in dependence of the ethnic self identification of the mother:

$$w_i(t) = \frac{B_i^I(t)}{B_i^I(t) + B_i^{nI}(t)} \qquad \text{and} \qquad 1 - w_i(t) = \frac{B_i^{nI}(t)}{B_i^I(t) + B_i^{nI}(t)}.$$

Then we have native and non-native components:

$$B_i^I(t) = B_i(t) w_i(t) \qquad \text{and} \qquad B_i^{nI}(t) = B_i(t)[1 - w_i(t)],$$

so that a closure property is verified in each province:

$$B_i(t) = B_i^I(t) + B_i^{nI}(t). \tag{2.14}$$

The births are separated by sex assuming, as a simplification, that at subnational level remains valid the 2010 Census national relation of 102 women to 100 men, [8]. Then we have:

$$\widehat{P}_{j,0}(t+1) = \sum_{i=1}^{25} B_i(t) S_{i,0}(t) \widehat{S}_{i,j,0}(t), \tag{2.15}$$

where

$S_{i,0}(t)$**:** Probability that a person of age $x = 0$ survives to the year $t+1$, similar to (2.2):

$$S_{i,0}(t) = \frac{L_{i,0}(t)}{l_{i,0}(t)},$$

where $l_{i,0}(t)$ is the province-i life table radix. Let's recall that $l_{i,x}$ is the number of survivors of age x residing in the province i, so that it's taken $l_{i,0} = 100000$, [7].

$\widehat{S}_{i,j,0}(t)$**:** Probability that a person of age $x = 0$ moves from the province i to the province j during the year t. For all the newborns it has been taken the mobility probability of the population with $x = 5$ years old.[3]

2.2.2. *Mortality projection*

Mortality is the main factor for the population aging. As it was done for the case of fertility, it is necessary to classify the native and non-native population considering age, province and year:

$$D_{i,x}^T(t) = D_{i,x}^I(t) + D_{i,x}^{nI}(t).$$

Let's recall that the mortality rate is given by

$$m_{i,x}(t) = \frac{D_{i,x}(t)}{P_{i,x}(t)},$$

whence we have

$$P_{i,x}^T(t) m_{i,x}^T(t) = P_{i,x}^I(t) m_{i,x}^I(t) + P_{i,x}^{nI}(t) m_{i,x}^{nI}(t),$$

[3]A baby can not answer the question, ¿where did you live 5 years ago?

as well as the total mortality rate:

$$m^T_{i,x}(t) = w_{i,x}(t) m^I_{i,x}(t) + (1 - w_{i,x}(t)) m^{nI}_{i,x}(t) \qquad \text{with} \qquad w_{i,x}(t) = \frac{P^I_{i,x}(t)}{P^T_{i,x}(t)}.$$

Now we obtain the relative mortality rate for each of the populations by province and age:

$$\begin{aligned} 1 &= w_{i,x}(t) \frac{m^I_{i,x}(t)}{m^T_{i,x}(t)} + (1 - w_{i,x}(t)) \frac{m^{nI}_{i,x}(t)}{m^T_{i,x}(t)} \\ &= w_{i,x}(t) \delta^I_{x,i}(t) + (1 - w_{i,x}(t)) \delta^{nI}_{i,x}(t), \end{aligned} \tag{2.16}$$

where δ denotes the relative mortality rate.

It's important to mention that the survival probabilities computed with (2.2) do not necessarily verify the closure property (2.9). Therefore, to keep valid the closure property for each province it was made a small correction, $k_x(t) \approx 1$, in every projected year, which does not depend of native or non-native but that changes with the age. The correction factor is estimated by

$$S_{i,x}(t) = k_x(t) S^{(0)}_{i,x}(t), \tag{2.17}$$

where (0) denotes the initial value. Replacing in (2.7) we get

$$P_{\bullet,x}(t) S_{\bullet,x}(t) = k_x(t) \sum_{i=1}^{25} P_{i,x}(t) S^{(0)}_{i,x}(t),$$

whence,

$$k_x(t) = \frac{P_{\bullet,x}(t) S_{\bullet,x}(t)}{\sum\limits_{i=1}^{25} P_{i,x}(t) S^{(0)}_{i,x}(t)}. \tag{2.18}$$

By putting (2.18) into (2.17) we obtain the probability that a person residing in the province i achieves age x; moreover, this replacement verifies the property mentioned in (2.9).

2.3. Life expectancy projection

To project the life expectancy we assume that it has a maximum value of 83.4 years for women and that of 77.53 years for men, [6], and that both genders it has a minimum value of 30.0 years. Considering the data of live expectancy at birth corresponding to previous years we can apply the following formula, [5]:

$$\text{Logit}(\text{edv}_{i,x}(t)) = \frac{\text{edv}_{i,x}(max) - \text{edv}_{i,x}(t)}{\text{edv}_{i,x}(t) - \text{edv}_{i,x}(min)},$$

where $\text{edv}_{i,x}(max)$ and $\text{edv}_{i,x}(min)$ are the values 83.4 and 30.0, respectively, for each considered province and population. Thereafter, a linear regression model is build up as:

$$\text{Logit}(t) = \beta_0 + \beta_1 t.$$

From this equation it's possible to estimate the life expectancy at birth for every year among the considered period:

$$\text{edv}_{i,x}(t) = \text{edv}_{i,x}(min) + \frac{\text{edv}_{i,x}(max) - \text{edv}_{i,x}(min)}{1 + \exp(\text{Logit}(t))}.$$

2.4. Mobility projection

The international migration complex factors and the scarcity of data are the main problems to work out a population projection, making difficult to detect the meaningful changes in the geographical mobility of native and non-native groups. Therefore we shall assume that the migration rates keep constant during the projection period, which implies that the net migration rate converges in each province.

The internal mobility projection considers origin and permanent-residence provinces. Then the probability of moving from one province to other, without considering mortality, is given by:

$$\widehat{S}_{i,j,x} = \frac{S_{i,j,x}}{S_{i,\bullet,x}} \qquad \text{with} \qquad S_{i,\bullet,x} = \sum_{j=1}^{25} S_{i,j,x}, \tag{2.19}$$

where the transition matrix for each age is written as:

$$\widehat{S}_x = \begin{bmatrix} \widehat{S}_{1,1,x} & \widehat{S}_{2,1,x} & \ldots \widehat{S}_{25,1,x} \\ \widehat{S}_{1,2,x} & \widehat{S}_{2,2,x} & \ldots \widehat{S}_{25,2,x} \\ \vdots & \vdots & \vdots \\ \widehat{S}_{1,25,x} & \widehat{S}_{2,25,x} & \ldots \widehat{S}_{25,25,x} \end{bmatrix}. \tag{2.20}$$

The problem lies in dealing with children of less than five years old and with the new population which gets into the projection. For the first group it is not possible to know both the origin and the permanent-residence provinces. For the second group the problem is even worse since it doesn't exists yet. Accordingly, it shall be assumed the same rate used in the first projection.

We compute the interprovincial migration rates by using the transition probabilities:

$$\widehat{S}_x = e^{\widehat{M}_x}, \tag{2.21}$$

where

$$\widehat{M}_x = \begin{bmatrix} -\sum_{j\neq 1} M_{1,j,x} & M_{2,1,x} & \ldots & M_{25,1,x} \\ M_{1,2,x} & -\sum_{j\neq 2} M_{2,1,x} & \ldots & M_{25,2,x} \\ \vdots & \vdots & \ldots & \vdots \\ M_{1,25,x} & M_{25,2,x} & \ldots & -\sum_{j\neq 25} M_{25,25,x} \end{bmatrix}. \tag{2.22}$$

$\widehat{M}_x$ is the mobility rates matrix and $M_{i,j,x}$ is the migration rate from the province i to the province j. Then, from (2.21), we get

$$\widehat{M}_x = \ln\left(\widehat{S}_x\right). \tag{2.23}$$

The total number of migrants from the province i to the province j is given by

$$S_{i,j}(t) = \sum_{x=0}^{99} \overline{P}_{i,x}(t) M_{i,j,x},$$

where, $\overline{P}_{i,x}(t)$ is the province-i resident population in the middle of the year t. The total numbers of migrants and immigrants are obtained by

$$I_j(t) = \sum_{i=1}^{25} S_{i,j}(t) \qquad \text{and} \qquad E_i(t) = \sum_{j=1}^{25} S_{i,j}(t). \tag{2.24}$$

Finally, if we divide (2.24) by the total average population, are obtained the crude interprovincial migration rates.

2.5. The Verhulst equation

The projection of the blood donors population is made by applying the logistic Verhulst equation, [7]:

$$\begin{cases} P_i'(t) = r_i P_i(t)\left(1 - \dfrac{1}{K_i} P_i(t)\right), \\ P_i(t_0) = P_i(0), \end{cases} \tag{2.25}$$

where

K_i: Carrying capacity. It represents the maximum number of persons that the population admits. In this case, the projection ceases at 2020 so that K is the size of the population at that year.

r_i: Growth rate. It describes the growth of the population compared with the average size of the population and it's given by

$$r_i(t, t+n) = \frac{\frac{P_i(t,t+n) - P_i(t)}{n}}{\frac{P_i(t,t+n) + P_i(t)}{2}},$$

where $n = 1$ since the growth rate is being computed year after year.

$P_i(t_0)$: Initial condition. The initial condition of the population that, by ENSANUT, corresponds to the year 2012. Here are considered real, deferred and failed donors, only between 17.0 and 65.0 years old.

Then the solution of (2.25) is

$$P_i(t) = \frac{P_i(t_0) K_i}{P_i(t_0) + (K_i - P_i(t_0)) e^{-r_i t}}.$$

Because of the lack of information of some cantons, the ENSANUT size of the population at 2012 differs in 3,75% with the model projection. By continuing with the projection, the difference increases up to 8,46% with respect to the official projections.

Therefore, to get a better estimation it was used the yearly growth rate instead of the intercensus one.[4]

With the previous considerations, the projection was made in the following way:

$$P(t_0) = P(0) = P(2012) \qquad \text{then} \qquad P(t_1) = P(1) = P(2013).$$

After this first projection, a new value is used as initial condition:

$$\begin{aligned} P(t_0) = P(0) = P(2013) &\qquad \text{then} \qquad P(t_1) = P(1) = P(2014) \\ &\qquad\qquad\vdots \\ P(t_0) = P(0) = P(2019) &\qquad \text{then} \qquad P(t_1) = P(1) = P(2020) \end{aligned}$$

that is, to take a growth rate r and a carrying capacity K that vary year after year is not possible to take a single initial condition. With our solution both r and K will change with the time.

3. Results

Here we show the results obtained by applying the model described in Section 2. It will be presented the concentration of the population classified by real, deferred and failed blood donors and by the administrative division of the country.

Once the set of potential blood donors has been classified, it's obtained an estimation which is described in Table 3.

Year	Real	Real (%)	Deferred	Deferred (%)	Failed	Failed (%)
2012	4.676.859	55,49	3.456.010	41,01	295.001	3,50
2015	4.758.543	55,33	3.534.912	41,10	306.415	3,56
2020	4.910.135	55,09	3.676.252	41,25	326.367	3,66

Table 1: Estimated population of blood donors for 2012, 2015 and 2020.

[4]It's called intercensus growth rate since the Ecuadorian Population and Housing Census is developed every 10 years, so that it's expected that the population projection will be similar to the value of the next census.

3.1. Provincial concentration for 2012

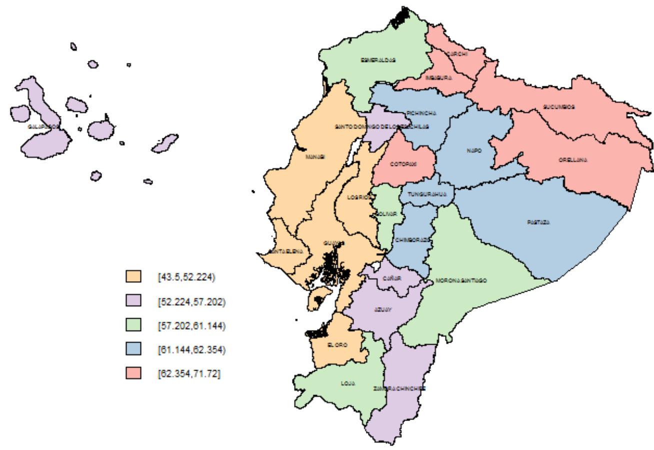

Figure 1: Ecuadorian real blood donors for the year 2012.

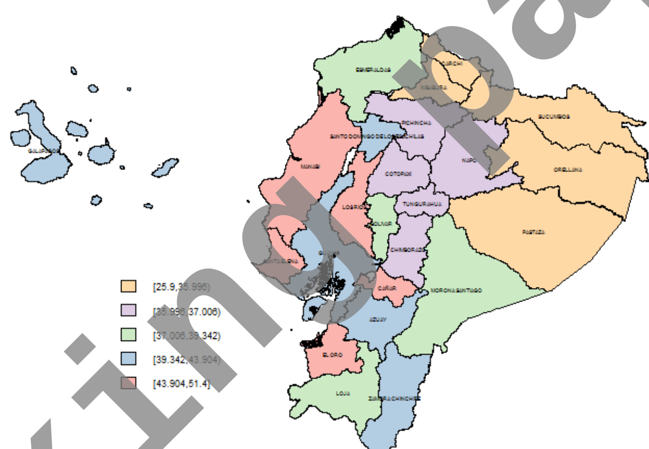

Figure 2: Ecuadorian deferred blood donors for the year 2012.

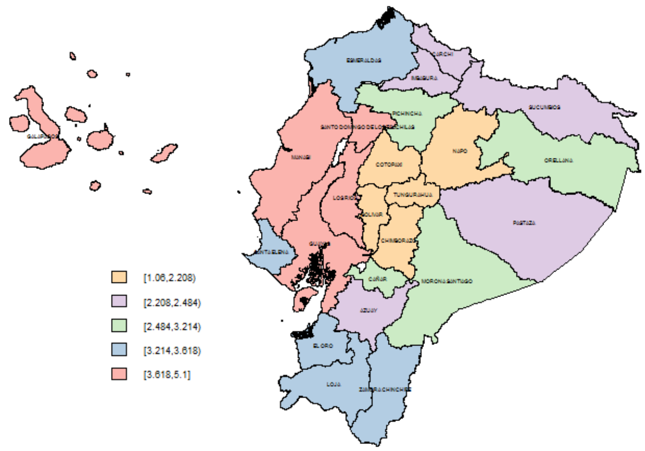

Figure 3: Ecuadorian failed blood donors for the year 2012.

3.2. *Provincial concentration for 2015*

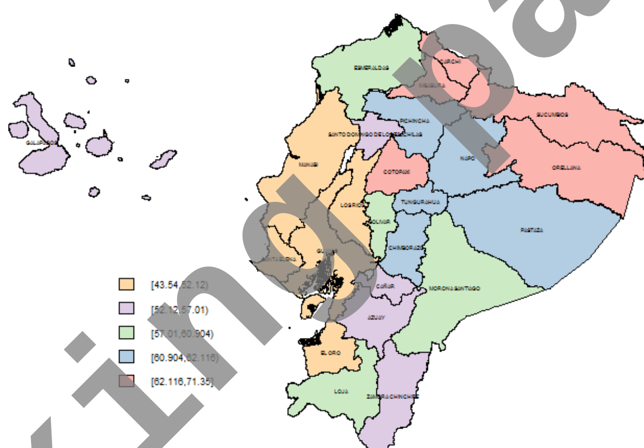

Figure 4: Ecuadorian real blood donors for the year 2015.

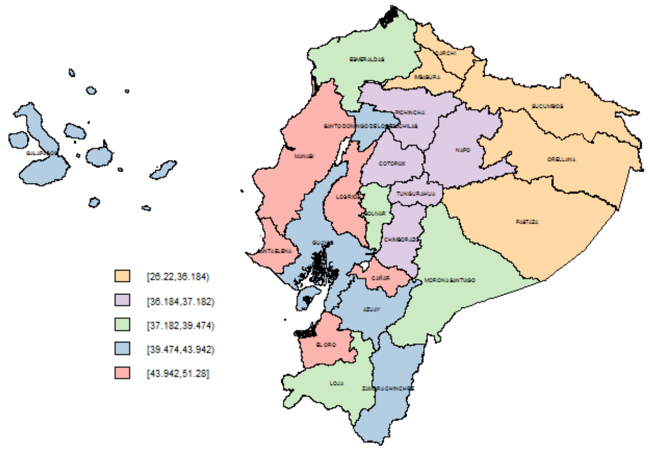

Figure 5: Ecuadorian deferred blood donors for the year 2015.

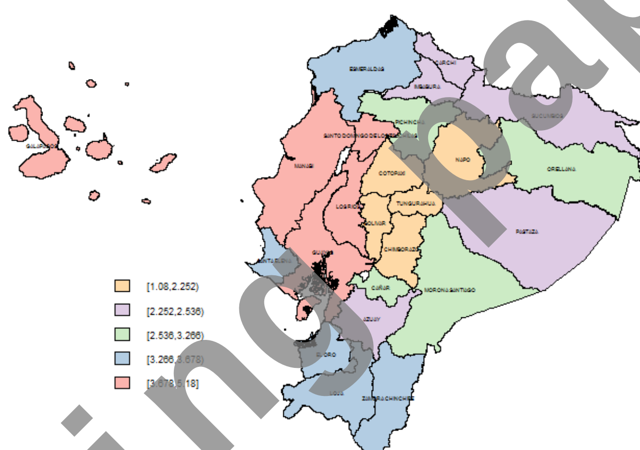

Figure 6: Ecuadorian failed blood donors for the year 2015.

3.3. Provincial concentration for 2020

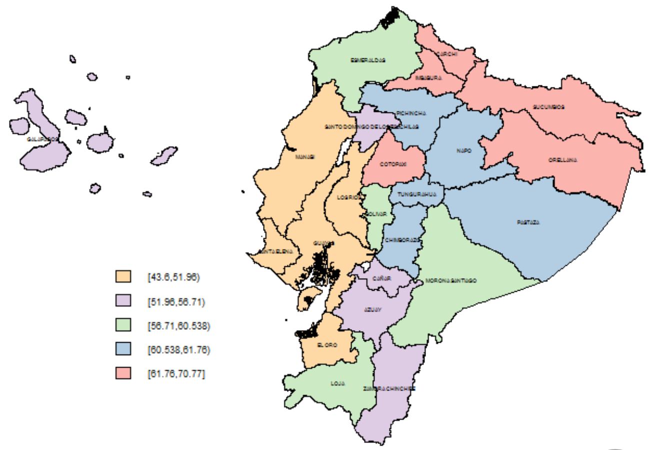

Figure 7: Ecuadorian real blood donors for the year 2020.

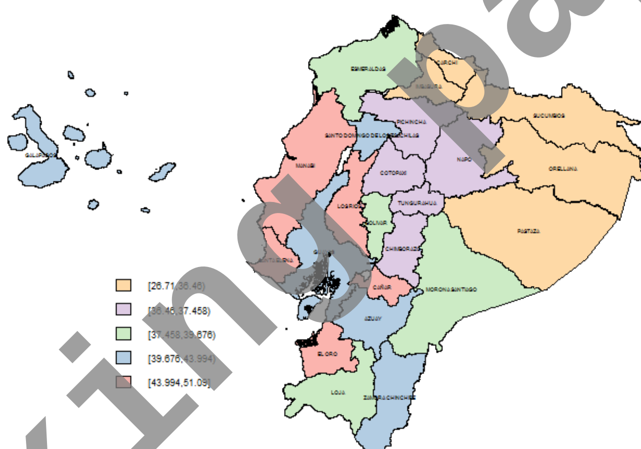

Figure 8: Ecuadorian deferred blood donors for the year 2020.

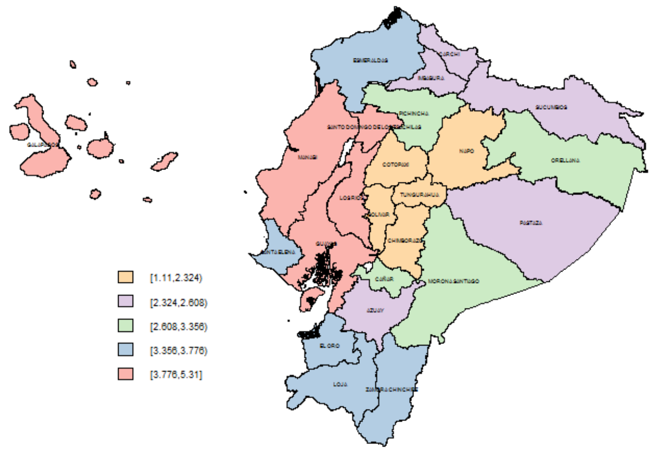

Figure 9: Ecuadorian failed blood donors for the year 2020.

3.4. *Cantonal concentration for the years 2015 and 2020*

The maps presented in this section are valid for 2015 and 2020 since the global variation is lesser than 1%.

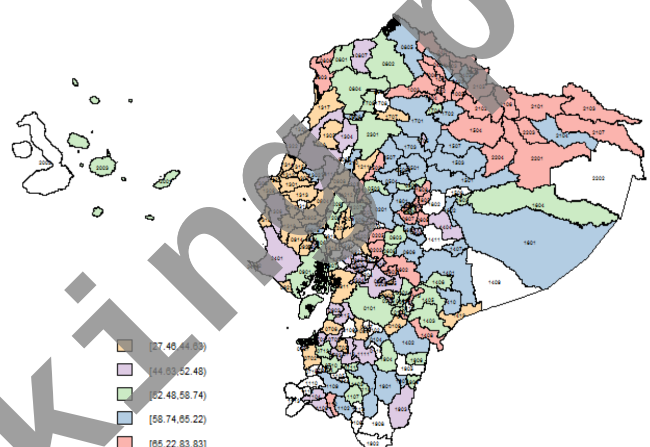

Figure 10: Ecuadorian real blood donors for the years 2015 and 2020 by canton.

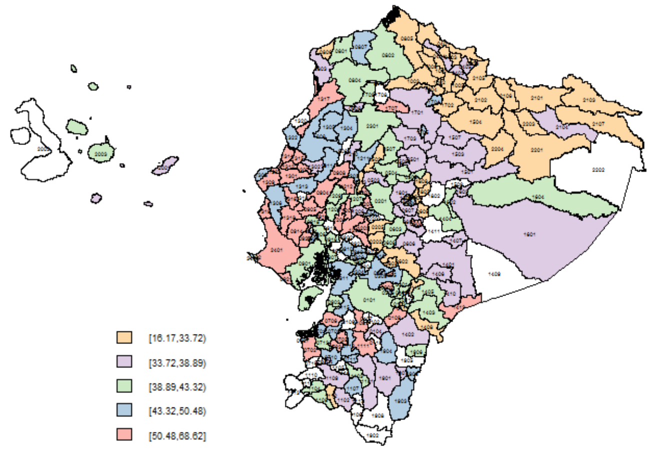

Figure 11: Ecuadorian deferred blood donors for the years 2015 and 2020 by canton.

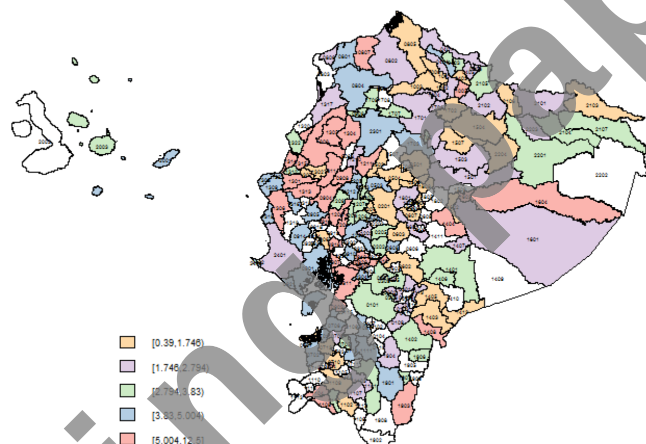

Figure 12: Ecuadorian failed blood donors for the years 2015 and 2020 by canton.

4. Conclusions

It was estimated the evolution and geographical configuration of the set of potential blood donors (between 17 and 65 years old) in Ecuador, taking advantage of the information provided by the National Health and Nutrition Survey 2011 - 2013 and 2010 Population and Housing Census.

The final product, obtained by the application of mathematical modeling (mainly Markov chains), is a stochastic map which will help the institutions involved in blood collection (e.g. the Ecuadorian branch of the Red Cross) to focus their activities and efforts so to improve the social service to persons who need it.

Because of the space limitations, the results presented in this paper are just a sample. Actually, we have a full classification of the population according to their capacity to donate blood (real, deferred and failed) and by provinces and cantons. In particular, we can mention that:

- The provinces where the real donors population is above 65% are Imbabura, Sucumbíos, Orellana, Carchi and Tungurahua.
- In the cantons Chunchi, Patate, Cotacachi, Penipe, Chordeleg, La Maná and Alausí the real donors segment is above 75%.
- In the cantons Samborondón, El Triunfo, Celica, San Juan Bosco, Palora, Flavio Alfaro, Rioverde, Santa Ana and Sucre the failed donors component is above 8%.

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Appendix A. Some points on ENSANUT

ENSANUT was a national survey applied to 19949 homes grouped in 1645 census sectors, getting information on Child Health, Maternal Reproductive Health, CNCDs (Chronic Noncommunicable Conditions and Diseases), Nutritional Health, etc., classified by geographic locations, ethnic origin, and some other social and economic factors.

ENSANUT does not provide information concerning cantons of a number Ecuadorian provinces:

Azuay (province): Girón, Pucará, San Fernando, Oña, El Pan, Guachapala.
Bolívar: San José de Chimbo.
El Oro: Marcabelí, Las Lajas.
Galápagos: Isabela.
Guayas: Alfredo Baquerizo Moreno, Urbina Jado, Yaguachi, Simón Bolívar, Lomas de Sargentillo, General Antonio Elizalde.
Loja: Chaguarpamba, Espíndola, Puyango, Zapotillo, Pindal, Quilanga, Olmedo.
Manabí: Olmedo, Jama.
Morona Santiago: Taisha, Pablo VI.
Orellana: Aguarico.
Napo: Carlos Julio Arosemena.
Pichincha: Pedro Vicente Maldonado.
Santa Elena: Libertad.
Tungurahua: Baños.
Zamora Chinchipe: Chinchipe, Yantzaza, Palanda.
Non-delimited areas (no province): Las Golondrinas, Manga del Cura, El Piedrero.

Social factors can affect the decision of donating blood; therefore the instrument applied before a potential collection of blood should help to discern if we are dealing with either a real, deterred or failed donor. In the following table are shown the main conditions that are taken account.

Donor status	Condition(s)
Real	Without health problems
Deferred	breathing problems
	vomiting or digestive problems
	skin problems
	eyes problems
	neuromuscular
	dental problems
	pregnancy problems
	psychological problems
	bone problems
	fractures, cuts and bruises
	women diseases
	men diseases
Failed	cardiovascular problems
	chronic diseases
	kidney diseases
	AIDS
	Hepatitis B, C and others

Table A.2: Information required from potential donors.

The factors have been found in the instruments used to obtain the information of ENSANUT. The questions are about but not restricted to:

- Personal data: civil status, gender, age, education.
- Frequency and predisposition to donate blood.
- Psychosomatic and somatic discomfort including diseases and medicine consumption.
- Drug consumption: alcohol, habit of smoking and other kinds of drugs.
- Sexual behavior: STD (sexually transmitted diseases) and practices with risk of acquire them.