International Journal of Combinatorial Optimization Problems and Informatics, 14(2), May-Aug 2023, 77-87. ISSN: 2007-1558.

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Analysis of the material unavailability of ICT in the State of Hidalgo.

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Abstract. The objective of this research work is to analyze the unavailability of the population of the State of Hidalgo for access to information technologies through the generation of the index of material unavailability of ICT, which allowed the classification of the municipalities in five dimensions analyzed statistically and using georeferencing techniques. The variables selected for this purpose were Internet connectivity, use of fixed telephone, mobile telephone, and computer. The information used was taken from the 2020 Population and Housing Census, as it was the only source of information that met the required Municipal coverage. Among the most significant findings, we found a clear tendency to use cell phones for connectivity instead of using the Internet on computer equipment; however, this brings with it the difficulty for efficient use in activities such as school homework.

Keywords: Digital divide, digital inclusion, access to technology, georeferencing.

Article Info
Received Dec 26, 2022
Accepted May 11, 2023

1 Introduction

The need for Internet access began to expand in 1995, a decade later, a large number of developed countries were connected to the network. Currently, the average number of individuals using the web is more than 80%, on the contrary, in developing countries, it only reaches 41% [1].

The study starts from the context that digital information and communication media (ICT) are basically defined by the attributes provided by connectivity, communication, and information exchange media [2]. In this regard, four variables were used to construct an indicator that would measure the digital divide conditions in the State: Internet connectivity, use of fixed telephone, mobile telephone, and computer. The application of the principal components algorithm to data resulted in the *ICT material unavailability index*, which is a classification measure with different magnitudes, which combined with georeferencing techniques allowed a precise analysis of the conditions in which the municipalities of the State of Hidalgo find themselves [3].

The main results indicate that the municipalities located in the north of the State are the most affected, presenting classifications ranging from medium, high and very high unavailability; on the other hand, in the south, the majority of the population with the highest use of ICTs is located (Figure 1). In the same way, the use of computers, landline telephones and the Internet for ICT access fell by approximately 40% in the zone in question, in contrast, we can observe that the low and very low classifications show more favorable indicators of the variables with differences of approximately 10%. The increase in the use of cellular phones is evident, which positions it as the main means of access to ICTs, mainly among the population in the high and very high strata. The analysis derived from the study suggests the adoption of policies and strategies by the different state government agencies to promote the acquisition and use of appropriate devices that allow access to and good use of ICT to reduce the digital divide and generate opportunities for economic and social development of the population, since it is not enough to provide coverage and access to ICT, equipment must also be considered for a better use of ICT.

2 State of the art and problem description

It is well known the importance of internet access for human development in these times, without connectivity, humanity faces barriers to participate in economic and social networks. Nowadays, communication services on the web are considered essential for citizen welfare and ICT inclusion is an extremely important element to face social inequalities [4].

The Federal Government, through the E-Mexico project in 2001, proposed to bring Internet initially to the municipal capitals and later to marginalized localities where there was no market for private initiative [5]. This same initiative was taken with the creation of the company "CFE Telecomunicaciones e Internet para todos" in 2019, a subsidiary of the Federal Electricity Commission (CFE) whose objective is to bring internet to marginalized communities [6].

It is undeniable that access to ICTs improves living conditions, the concept of a society free of geographical, age or race barriers is openly circulating on the Internet [1]. However, the restrictions of use and access in society were announced at the same time as their benefits, the concept of digital divide expresses the conditions that make the difference between the social groups that have access and use ICTs efficiently and those that do not, and is expressed in three cumulative levels: access to connectivity and devices, digital skills for their effective use, and digital community participation to share content and knowledge[7].

La brecha digital, es consecuencia de otras carencias, que contribuyen a su persistencia, es una relación recursiva en la que las desigualdades se retroalimentan, la exclusión digital, también contribuye a que otras brechas se fortalezcan. Es ineludible implementar políticas y estrategias por parte de los Gobiernos para reducir las desigualdades en forma paralela [8].

It is not relevant to know how many people are connected to the Internet, but why and what they use it for. In this context, digital inequality has several dimensions such as technological access, user autonomy, social support, individual skills, and types of use [9]. Therefore, it is necessary to know if a significant use of ICT is made according to certain individual objectives, among which are: the creation of contents, access to information and the critical capacity to analyze it [10].

Mexican households in localities with more than 2,500 inhabitants had an important evolution on the unavailability of ICT access elements from 2010 to 2020: Internet service went from 78.11% to 62.31%, computer from 69.30% to 73.91%, mobile telephony availability grew 17%, while fixed telephony dropped 21%. This positions mobile telephony as the main means of connectivity to ICT [11].

3 Methodology and data

A Principal component analysis.

Principal component analysis has this objective: given *n* observations of *p* variables, we analyze whether it is possible to adequately represent this information with a smaller number of variables constructed as linear combinations of the original ones. For example, with highly dependent variables, it is common that a small number of new variables explain most of them [12]. The principal component technique has its origins in orthogonal least-squares fitting [13]. Its usefulness is twofold:

1. It allows to represent optimally in a small dimension space, observations of a general space *p-dimensional*. In this sense, principal components are the first step to identify the possible latent, or unobserved, variables that generate the data.
2. It allows transforming the original variables, generally correlated, into new uncorrelated variables, facilitating the interpretation of the data.

Mathematical formulation of the principal components problem

In any principal component analysis problem, it is usual to work with the original variables typed to avoid problems of scale. *Y* is the matrix of original typed variables. Recall that we are trying to obtain a new set of variables that are a linear combination of the original variables [14], let us also note that the variance will be a measure of the information contained in each variable, with these assumptions the principal components analysis problem can be described as follows:

Any linear combination *c* of the original variables can be expressed as follows:

$$c = Yv$$

Where v is the vector that allows to obtain the linear combination.

The first principal component is the linear combination of the original variables of maximum variance. Therefore, we search for v_1 such that the variance of the first principal component c_1 is maximum.

As the variance of the principal components c is written as:

$$S_c^2 = v^t V_y v$$

The problem statement can be summarized as follows:

Search v such that $v^t V_y v$ is maximum

Subject to $\|v\| = 1$

In other words, it is a question of solving the following problem:

$$Max\ v^t V_y v$$

Subject to $v^t v = 1.$

For this purpose, the following Lagrangian is written:

$$L = v^t V_y v - \lambda(v^t v - 1).$$

Now it is enough to derive with respect to v and equalize to zero:

$$\frac{\partial L}{\partial v} = 2V_y v - 2\lambda v = 0 \Rightarrow V_y v = \lambda v \ \Rightarrow \ \left(V_y - \lambda I\right)v = 0$$

From which we conclude that v is the eigenvector of the variance-covariance matrix of the original typed data. Since we have imposed the condition that the variance be maximum, we will choose the eigenvector with the largest associated eigenvalue. The first main component c_1 is obtained by making: $c_1=Yv_1$ where v_1 is the eigenvector of the variance-covariance matrix with the largest associated eigenvalue. Once the first principal component has been obtained, we can see how the rest of the principal components are obtained. The second principal component would be that linear combination of original variables with maximum variance and orthogonal to c_1. to obtain this and the following principal components, it is not necessary to take up the maximization problem again from the beginning. Every variance-covariance matrix is symmetric and positive semidefinite, and has, therefore, p two-by-two orthogonal eigenvectors and their associated eigenvalues are all positive or null.

The eigenvectors of the matrix V_y associated to the eigenvalues written in decreasing form are, therefore, the searched vectors. These vectors allow us to calculate the principal components by means of the expression $c = Yv$. The variance of each principal component is given by the eigenvalues.

The number of non-zero eigenvalues give the dimension of the principal component space.

Since the variance is a measure of the information, let's see what the variance of the principal components is, it is defined as follows:

$$S_c^2 = v^t V_y v.$$

Thus, the variance of the *h-th* will be:

$$S_{ch}^2 = v_h^t V_y v_h = \lambda_h.$$

Therefore, it would make sense to define the measure of the information collected by each component as the quotient between the component variability and the total variance, i.e.:

$$\frac{S_{ch}^2}{Total\ variance} = \frac{S_{ch}^2}{Trace\ V_y}$$

But since the trace

$$V_y = \sum_{h=1}^{p} \lambda_h ,$$

Thus, the proportion of the variability explained by the *h-th* component can be defined as:

$$\frac{\lambda_h}{\sum_1^p \lambda_h}$$

In addition, as the variables are typed, we have:

Trace

$$(V_y) = p,$$

and thus, the above ratio would be as follows:

$$\frac{\lambda_p}{p}$$

Principal component results and their interpretation.

The first question is how many components to take into account. On the one hand, it seems logical to take those components whose associated eigenvalue is greater than one, i.e., those components that provide more information than any of the original typed variables. However, some other considerations must be taken into account, such as the fact that the components grouping a large number of original variables are of great importance. Experience and a good knowledge of the context in which the study is framed are almost always decisive in the interpretation of the axes [13]. The eigenvalues show that the sum of the eigenvalues is equal to the total number of initial variables p. This is because the sum of the eigenvalues is only the trace of the variance matrix of the principal components, i.e., it is the total inertia I expressed in terms of principal components. Now, since the initial variables were typed, we have that total inertia I as a function of the original variables is $I = p$

In summary:

$$I = \sum_{I=1}^{p} \lambda_1 = p.$$

The final coordinates of the individuals in the principal components are obtained by making

$$c_1 = Y v_1 \; i = 1, \dots, p,$$

where v_1 are the eigenvectors of the variance matrix of the original typed variables with associated eigenvalues written in decreasing order. Finally, the interpretation of the principal components is one of the most complex phases of the analysis in. In general, the interpretation of the factorial axes is done through the study of the correlations between the principal components and the original variables.

It is shown that these correlation coefficients are obtained by means of the following expression:

$$r_{k_j}^{*} = c_{kj}\sqrt{\lambda_k}$$

Where:

r_{kj}^{*} is the linear correlation coefficient between
$k-th$ main component (c_k)
j-th initial typed variable (Y^j),
and c_{kj} is the j-th coordinate of the $k-th$ main component.

In fact, taking M = D it has to:

$$Cov(Y^J, c_k) = \langle Y^J, c_k \rangle_D = Y_J^t D c_k.$$

If $Y_j^t = \delta_j^t Y_t$, where $\delta_j^t = (0, \dots, 0.1_j, 0, \dots, 0)$. We can then write:

$$Cov(Y^J, c_k) = Y_J^t D c_k = \delta_J^t Y^t D c_k = \delta_J^t Y^t D Y v_k = \delta_J^t V_y v_k = \delta_J^t \lambda_k v_k = \lambda_k \delta_J^t v_k = \lambda_k c_{kJ}.$$

And consequently:

$$r_{kJ}^* = \frac{Cov(Y^J, c_k)}{\sqrt{Var(Y^J) Var(c_k)}} = \frac{c_{kJ} \lambda_k}{\sqrt{\lambda_k}} = c_{kJ} \sqrt{\lambda_k}$$

It is therefore a question of observing the circle of correlations. Those original variables whose correlation with a given principal component is very close to 1 in absolute value, will be those that contribute most to the explanation of this principal component.

Once the coefficients have been calculated c_{kJ}, factor scores can be obtained, i.e., the component values corresponding to each observation:

$$C_{hl} = C_{h1} X_{1l} + c_{h2} X_{2l} + \cdots + c_{hp} X_{pl} \quad h = 1, 2, \dots, p \quad i = 1, 2, \dots, n.$$

If a component is divided by the standard deviation, a typified component is obtained. Thus, the typified factor scores of the h-th component will be:

$$\frac{c_{hl}}{\sqrt{\lambda_h}}$$

For the calculation of the principal components, the covariance matrix or the correlation matrix can be used, the first one when the original variables have approximately the same variance, so that the calculation of the components is made in terms of the original variables. The second is used when the measurement scales of the variables differ or their variances are significantly different, in this case, the principal components are obtained from the original standardized variables [15]. The second option was used to obtain the ICT physical unavailability index.

For the standardization of the indicators, the following identity was used:

$$Z_{ij} = \left[\frac{I_{ij} - I_j}{ds_j} \right]$$

Where:
Z_{ij}: It is the standardized indicator,
I_{ij} : It is the indicator j of the unit of analysis i,
I_j: It is the arithmetic average of the indicator values j, y
ds_j: It is the unbiased standard deviation of the indicator j.

The principal components technique transforms the space of standardized variables into a new one, i.e., finding $Y_{k'}$ (k=1, 2,....,m) such that they are linear combinations of the standardized variables.

In matrix terms, this can be expressed as:

$Y=ZA$

In this identity, $\boldsymbol{Z}$ is the standardized data matrix, $\boldsymbol{A}$ is the matrix of coefficients that transforms the space defined by the values $\boldsymbol{Z}$ in an orthonormal one. $\boldsymbol{Y}$ represents the new transformed variables, which are known as principal components.

4 Analysis of the results

Considering the consultation of the appropriate literature for the analysis, it is relevant to make a diagnosis of the current condition of the municipalities of the State of Hidalgo with respect to the unavailability of the means and instruments for access to ICT. Therefore, the principal components method was used to generate an indicator that allowed segmentation into five levels for 2020, this was achieved thanks to data from the 2020 Population and Housing Census [16], as it is the only available source of information at the Municipal level. To generate the index, four continuous variables were used, related to the use of the Internet and the mechanisms for accessing ICT: Percentage of households without internet access, percentage of households without a computer, percentage of households without a fixed telephone and percentage of households without a mobile telephone, which once obtained, were segmented into five strata (very low, low, medium, high, very high) that allowed us to give magnitude to this condition.

The selection of the principal component was that which presented the greatest contribution to the total variance and an eigenvalue close to one (component one, since it explains 99.9% of the variance), see table 1.

Tabla 1. Principal components

Component	Eigenvalue	Difference	Proportion	Cumulative
Comp1	3.99591	3.99225	0.999	0.999
Comp2	0.00366135	0.00332987	0.0009	0.9999
Comp3	0.00033149	0.00023245	0.0001	1
Comp4	9.9043E-05	.	0	1

Source: Own elaboration with data from the 2020 Population and Housing Census.

Once the component was chosen, it was stratified into 5 levels [17]. As a result, 37 municipalities are in the very low to low unavailability index stratum, representing 44.05%, 27 in the medium level (32.14%) and 20 in the high to very high stratum, representing 23.81%, see Table 2 (summary of municipalities by stratum).

Table 2. Summary of municipalities

Stratum	Frec.	Percent	Cum.
Very Low	17	20.24	20.24
Low	20	23.81	44.05
Medium	27	32.14	76.19
High	16	19.05	95.24
Very High	4	4.76	100
Total	84	100	

Source: Own elaboration with data from the 2020 Population and Housing Census.

The table 3 shows in detail the 84 municipalities of the State of Hidalgo with their corresponding stratifications for a more detailed analysis.

Table 3. Stratification of the index of unavailability of infrastructure for ICT access.

Key	Municipality	Stratum	Key	Municipality	Stratum
1	Acatlán	Low	43	Nicolás Flores	Very high
2	Acaxochitlán	Low	44	Nopala de Villagrán	Medium
3	Actopan	Very low	45	Omitlán de Juárez	High
4	Agua Blanca de Iturbide	High	46	San Felipe Orizatlán	Low
5	Ajacuba	Medium	47	Pacula	Very high
6	Alfajayucan	Low	48	Pachuca de Soto	Very low
7	Almoloya	High	49	Pisaflores	Medium
8	Apan	Very low	50	Progreso de Obregón	Medium
9	El Arenal	Low	51	Mineral de la Reforma	Very low
10	Atitalaquia	Low	52	San Agustín Tlaxiaca	Low
11	Atlapexco	Medium	53	San Bartolo Tutotepec	Medium
12	Atotonilco el Grande	Low	54	San Salvador	Medium
13	Atotonilco de Tula	Very low	55	Santiago de Anaya	Medium
14	Calnali	Medium	56	Santiago Tulantepec de L. G.	Low
15	Cardonal	Medium	57	Singuilucan	Medium
16	Cuautepec de Hinojosa	Very low	58	Tasquillo	Medium
17	Chapantongo	Medium	59	Tecozautla	Very low
18	Chapulhuacán	Low	60	Tenango de Doria	Medium
19	Chilcuautla	Low	61	Tepeapulco	Very low
20	Eloxochitlán	Very high	62	Tepehuacán de Guerrero	Medium
21	Emiliano Zapata	Medium	63	Tepeji del Río de Ocampo	Very low
22	Epazoyucan	Medium	64	Tepetitlán	High
23	Francisco I. Madero	Low	65	Tetepango	Medium
24	Huasca de Ocampo	Medium	66	Villa de Tezontepec	Medium
25	Huautla	Medium	67	Tezontepec de Aldama	Very low
26	Huazalingo	High	68	Tianguistengo	Medium
27	Huehuetla	Medium	69	Tizayuca	Very low
28	Huejutla de Reyes	Very low	70	Tlahuelilpan	Medium
29	Huichapan	Very low	71	Tlahuiltepa	High
30	Ixmiquilpan	Very low	72	Tlanalapa	High
31	Jacala de Ledezma	High	73	Tlanchinol	Low
32	Jaltocán	High	74	Tlaxcoapan	Low
33	Juárez Hidalgo	Very high	75	Tolcayuca	Low
34	Lolotla	High	76	Tula de Allende	Very low
35	Metepec	High	77	Tulancingo de Bravo	Very low
36	San Agustín Metzquititlán	Medium	78	Xochiatipan	Medium
37	Metztitlán	Medium	79	Xochicoatlán	High
38	Mineral del Chico	High	80	Yahualica	Low
39	Mineral del Monte	High	81	Zacualtipán de Angeles	Low
40	La Misión	High	82	Zapotlán de Juárez	Low
41	Mixquiahuala de Juárez	Low	83	Zempoala	Very low
42	Molango de Escamilla	High	84	Zimapán	Low

Source: Own elaboration with data from the 2020 Population and Housing Census.

Georeferencing of the ICT physical unavailability rate.

Among the many definitions of a Geographic Information System are the following (GIS), describe it as an information system designed to work with data referenced by spatial or geographic coordinates, in other words, a GIS is both a database system with specific capabilities for spatially referenced data, and a set of operations for working with the data itself [18].

The importance of georeferencing lies in the fact that it is a technological tool that makes it possible to locate the sites studied and is used in a wide range of research in biological and human sciences thanks to the use of GPS, (Global Positioning System) maps with high accuracy are achieved [19]. Geographic information systems are also tools for visualizing patterns, relationships, or trends because they are capable of handling very advanced analysis functions [20].

Using geo-referencing tools, a digital map showed the affected municipalities according to the stratification of the index of unavailability of infrastructure for ICT access.

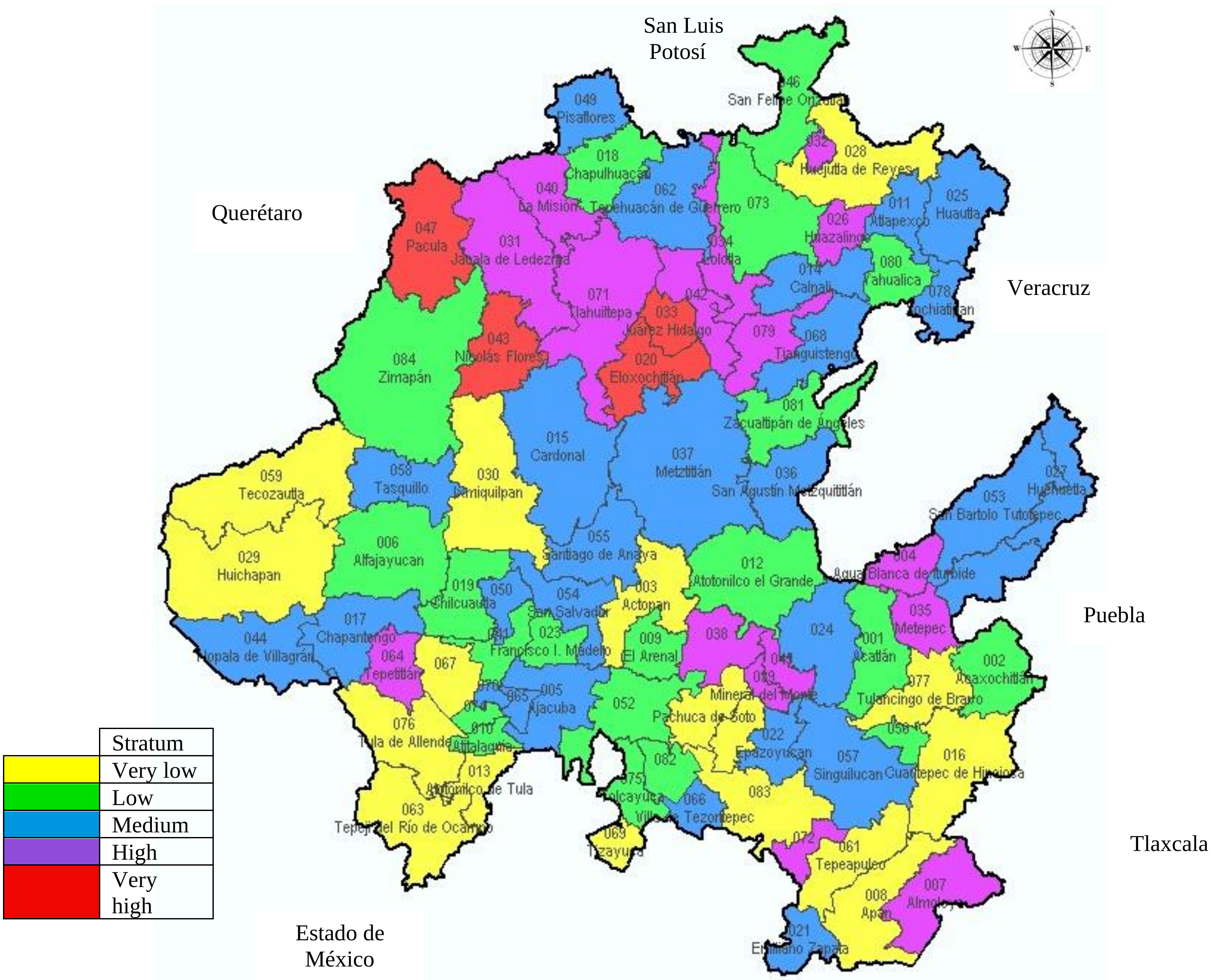
In Figure 1, we can see that the most affected municipalities are located in the northern part of the state: Pacula, Nicolas flores, Juarez Hidalgo and Eloxochitlan, with very high classification and Agua Blanca de Iturbide, Almoloya, Huazalingo, Jacala de Ledezma, Jaltocan, Lolotla, Metepec, Mineral del Chico, Mineral del Monte, La Misión, Molango de Escamilla, Omitlan de Juarez, Tepetitlan, Tlahuiltepa, Tlanalapa, Xochicoatlán, high, it is noteworthy that the majority of these municipalities have more unavailability in the use of ICT in the medium, high and very high strata, with the exception of Huejutla de Reyes, which has a low classification. On the other hand, the southernmost municipalities are less affected by the lack of access to ICT, which shows the great polarization among them.

In a medium ranking are: Ajacuba, Atlapexco, Calnali, Cardonal, Chapantongo, Emiliano Zapata, Epazoyucan, Huasca de Ocampo, Huautla, Huehuetla, San Agustín Metzquititlán, Metztitlán, Nopala de Villagrán, Pisaflores, Progreso de Obregón, San Bartolo Tutotepec, San Salvador, Santiago de Anaya, Singuilucan, Tasquillo, Tenango de Doria, Tepehuacán de Guerrero, Tetepango, Villa de Tezontepec, Tianguistengo, Tlahuelilpan and Xochiatipan, it is worth mentioning that most of these districts are adjacent to the high and very high strata.

The municipalities with low category are San Felipe Orizatlán, San Agustín Tlaxiaca, Santiago Tulantepec de L. G., Tlanchinol, Tlaxcoapan, Tolcayuca, Yahualica, Zacualtipán de Ángeles, Zapotlán de Juárez, Zimapán, Acatlán, Acaxochitlán, Alfajayucan, El Arenal, Atitalaquia, Atotonilco el Grande, Chapulhuacán, Chilcuautla, Francisco I. Madero and Mixquiahuala de Juárez, show a lack of material use of ICTs (computer use for internet access of approximately 20% and 4.5% of cell phone use, see graph 1).

The municipalities with the lowest ranking are: Actopan, Apan, Atotonilco de Tula, Cuautepec de Hinojosa, Huejutla de Reyes, Huichapan, Ixmiquilpan, Pachuca de Soto, Mineral de la Reforma, Tecozautla, Tepeapulco, Tepeji del Río de Ocampo, Tezontepec de Aldama, Tizayuca, Tula de Allende, Tulancingo de Bravo and Zempoala. Its main characteristic, in contrast to the zone classified as high, is its geographic location in the south of the state.

Figure 1. Georeferencing of the index of unavailability of infrastructure for ICT access by municipality in the State of Hidalgo.



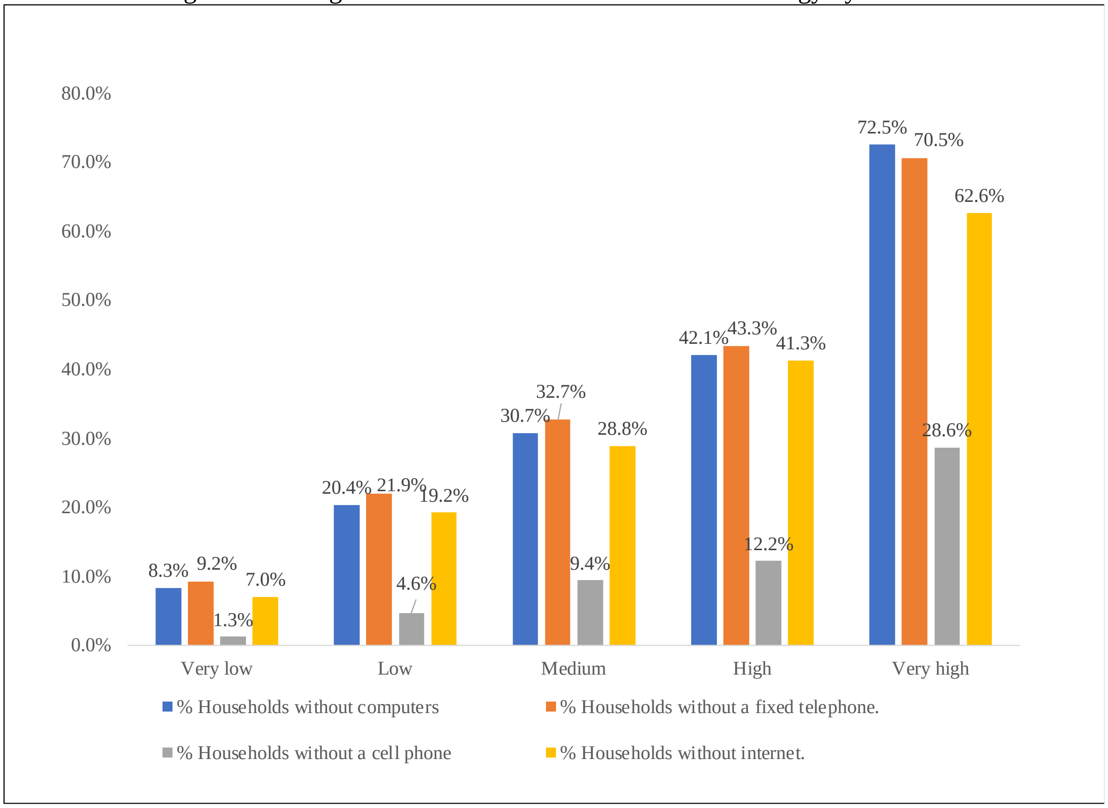
Source: Own elaboration with data from the 2020 Population and Housing Census.

5 Conclusions

One of the main conclusions about the availability of ICT in the municipalities of the State of Hidalgo is that the northern zone is the most prone to present a lack of access to technology, in addition to being historically one of the most disadvantaged areas in terms of economic growth and human development, which leads to a lower social penetration of ICT (see figure 1), in these municipalities show less access to fixed telephony and computing in 2020. (See graph 1). It can be observed that the relationship between Internet connectivity and computers had a significant drop in the classification from high to very high, which highlights the cell phone as a means of communication, due to the advantages of connectivity, but presents disadvantages in use and exploitation.

Currently, providing Internet service to society is not enough to counteract the results observed in this study, and private service providers do not seem to be very interested in entering an area where there is no market. There is a tendency to increase access to ICT through mobile telephony, which is not very favorable when it comes to its use in development focused on education or business development. In the case of municipalities in the higher strata, policies should be adopted to promote the availability of ICTs to cope with the new social and economic activities demanded by the digital era (see Fig. 2)

Fig. 2. Percentage of households without access to technology by stratum



Source: Own elaboration with data from the 2020 Population and Housing Census.

Participation among the different areas of the State Government is indispensable for the generation of an inclusive ecosystem oriented towards development objectives, which will imply the formulation of cross-cutting policies based on access to and good use of ICTs for the achievement of economic growth, human capital formation and the reduction of social inequality. Paradoxically, the effective use of ICT, which contributes to overcoming social barriers, eventually becomes a determining factor in exclusion.

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