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Spatial Analysis and Mapping Marginality Hotspots: A Vulnerability Factor of Rural Communities to Environmental Change

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Abstract: Marginality is an inter and transdisciplinary research concept, that is very useful where multiple causal linkages and relationships need to be investigated and understood to extract meaningful insights for scientific research about complex process. In Mexico, spatial, societal and ecological marginality persist around the less developed regions and communities, either as a single factor or in its different combinations; nevertheless, of these three dimensions of marginality, the social marginality have receive attention only.

Given that marginality is a complex and multifaceted phenomenon, thus, it is imperative and is the objective of this study assesses and mapping marginality in an integral way, including ecological, social-economic and spatial dimensions, what would help to decision managers to design politics and programs, what led to reduce vulnerability and increase resilience of communities and regions to environmental change impacts.

In this study spatial analysis and inference modelling were applied to analyze and mapping marginality at community and regional levels at Usumacinta watershed in Mexico; in this region most of people has a high to very high social marginality and depend on natural resources for their livelihood.

Although the study area is very homogeneous in terms of social marginality, other spatial patterns emerge when other dimensions of marginality, spatial and ecological, are considered. In terms of population affected the more critical area is located in the highland where the three dimensions of marginality overlap in a high grade. In the lowland area spite of the population affected is lesser; these communities are exposed to risk flooding, what is very high in this zone. The patterns of marginality visualized in maps can be a useful tool to help decision making to design politics and programs that led to the communities affected overcome the marginalization conditions.

Key words: marginality hotspots, mapping, spatial analysis, vulnerability, environmental change

1. Introduction

Marginality is an inter and transdisciplinary research concept, that is very useful where multiple causal linkages and relationships need to be investigated and understood to extract meaningful insights for scientific research about complex process[1]. In Mexico, spatial, societal and ecological marginality persist around the regions and communities less developed, either as a single factor or in its different combinations.

According with [2] “marginality is closely related to the vulnerability of both people and environment as it victimizes location and communities that are characterized by one or more factors of vulnerability”. This ill-treatis more evident and its role as factor of vulnerability is preponderant when spatial, societal and ecological marginality overlap, as is the case at many Mexican rural communities; nevertheless, of these three dimensions of marginality, the social marginality have receive attention only. Furthermore, the

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vulnerability of marginal regions and people is increasing with the growth of environmental change impacts.

In rural communities, causal complexes tie the marginalized people in systems from which they depend for their livelihood, therefore, in Usumacinta watershed, the rural and agricultural context is of particular relevance due to that large segments of the extreme poor live in rural areas. Given that marginality is a complex and multifaceted phenomenon, thus, it is imperative and is the objective of this study assesses and mapping marginality in an integral way, including ecological, social-economic and spatial dimensions, what would help to decision managers to design politics and programs, what led to reduce vulnerability and increase resilience of communities and regions to environmental change impacts.

On the other hand, one of the biggest changes to the nature of geographic knowledge during the last fifty years has been the development of relevant spatial theories about the location, arrangement, and distribution of geographical features and spatial interactions between physical and human components of these phenomena [3]. Today, one of the methodological challenges is to increase our ability to use data to solve problems; in this sense the space plays a fundamental role as integration and a conceptual approach to problem solving. The role of space as a means of integration appears to be unique [4]. According to the National Academy of Sciences (2009) [5] through integration and representation of the data in space, we can generate powerful procedures and spatial reasoning to address and solve problems. Therefore, include a geographic perspective in the analysis of a geographic phenomenon as marginality, would allow us: a) Increase our understanding of the relationships and marginality variations from place to place, b) get a complete basis for interpreting the human-nature — marginality relations at scales ranging from local to regional, and c) identify priority areas for attention and consider it and in research programs and the politics design to combat poverty and reduce vulnerability of rural communities

2. Assess and Mapping Marginality

The marginality concept calls for the integration of poverty concepts with those of social exclusion, geography, and ecology; the difficulties in reaching people at the margins of systems are explained by a set of distances, (physical distances such as being located in remote or harsh environments), social distances (being excluded, discriminated against, or not having rights or access to services or opportunities), but may also be related to technological and institutional infrastructure deficiencies [6].

Three main dimensions of marginality are reported in the literature: Social (socio-economic), spatial and ecological dimensions. Social marginality is concerned with “human dimensions such as demography, religion, culture, social structure, economics, and politics in connection with access to resources by individuals and groups” [1]. “Socio-economic marginality is a condition of socio-spatial structure and process in which components of society and space in a territorial unit are observed to lag behind an expected level of performance in economic, political and social wellbeing compared with average condition in the territory as a whole” [2].

Ecology marginality refers with phenomena that occur at biophysical limits, which may be geophysical boundaries, environmental thresholds, or habitats that are not well suited for particular species or populations [7]. Marginal areas may be environments that pose extreme challenges to the survival of certain species such as deserts, high altitude areas, ephemeral water bodies, or sites with heavy metal soils. According to these authors, “a translation of this relationship directly to social systems would describe social marginalization as a result of overexploitation of a system’s resources, often due to either high human population density or else decreased resource availability”.

The spatial marginality is usually linked to the geographical remoteness of an area from major economic centers (location), and refers to areas that are difficult to reach (access) in the absence of appropriate infrastructure and therefore isolated from mainstream development [8, 9].

"Spatial marginality tends to focus on the distance or connectivity of geographical areas in relation to centers of economic activity at different geographical scales" [10]; Leimgruber W. (2004) [11] denote this as macro-spatial marginality where its primarily manifests as a result of spatial disadvantages.

In the regions and communities less developed is common that these marginality dimension's overlap in different combinations; so many marginalized people often lack access to resources due to unfavorable (geographical) location or generally restrictive local biophysical conditions [12]; many social marginalized people live in marginal ecological Lands(of limited suitability and prone to degradation process), which exacerbate its marginalization.

There are few reports in the literature about mapping marginality; Graw Valerie and Husmann Christine, 2014 [13] used a set of variables covering ecological, social, and economic dimensions of marginality to identify "marginality hotspots" on Sub-Saharan Africa (SSA) and South Asia (SA).

In Mexico there is no reports about mapping marginality considering its three dimensions. The Mexican federal government has developed a social marginality index that ranks regions according to their performance in terms of education, housing, monetary income, and distribution of the population [14].

Although there is no report on mapping spatial marginality, the 2001-2006 National Population Program, recognizes that the territorial distribution of the population of Mexico has been characterized by a high concentration in a small number of cities and their dispersion in tens of thousands of small, isolated and scattered rural communities, which has been instrumental in the persistence of rural poverty and marginalization [15].

3. Methodology for Assessment and Mapping Marginality

In this study the definition of marginality provided by Gatzweiler et al. (2011) [12] is adopted: "Marginality as an involuntary position and condition of an individual or group at the edge of social, economic, and ecological systems, preventing the access to resources, assets, services, restraining freedom of choice, preventing the development of capabilities, and causing extreme poverty; the position of an actor describes their place and function within social and geographical spaces, and the condition of an actor refers to their decision-making and information processing capabilities, and the assets and resources they can make effective use of". In this study *marginality hotspots* are considered as locations where the three dimensions of marginality: social, spatial and ecological overlap in a high to very high grade (Fig. 1).

The study area (Fig. 2) is located in south of Mexico and corresponds to Usumacinta watershed, which includes 15, 5 and 2 municipalities of Chiapas, Tabasco and Campeche states respectively. In the area there are 1,000,000 of habitants, 4,950 localities, from which

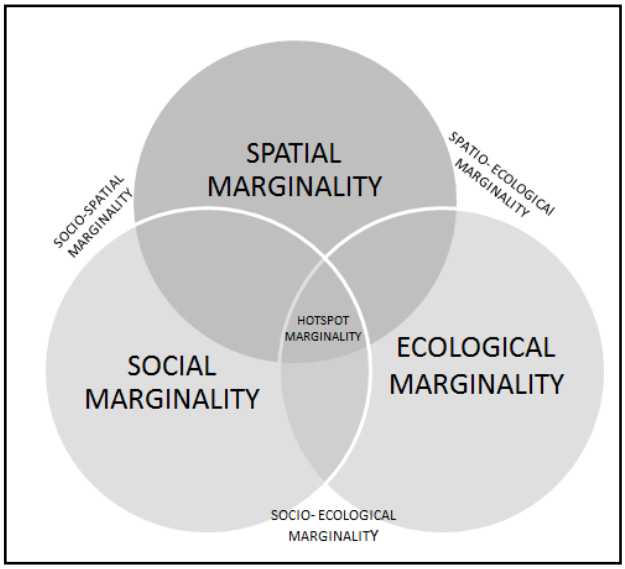

Fig. 1 Hotspot marginalities (own elaboration).

only seven have a population between 20,000 and 100,000 habitants; a great portion of population in the highland is native. The social marginalization is high to very high in the whole area. In the lowland the slope is less than 3%, the pasture and swamps are predominant; in the highland the slope range from 3 to 25% and higher, the subsistence agriculture and forest areas are predominant.

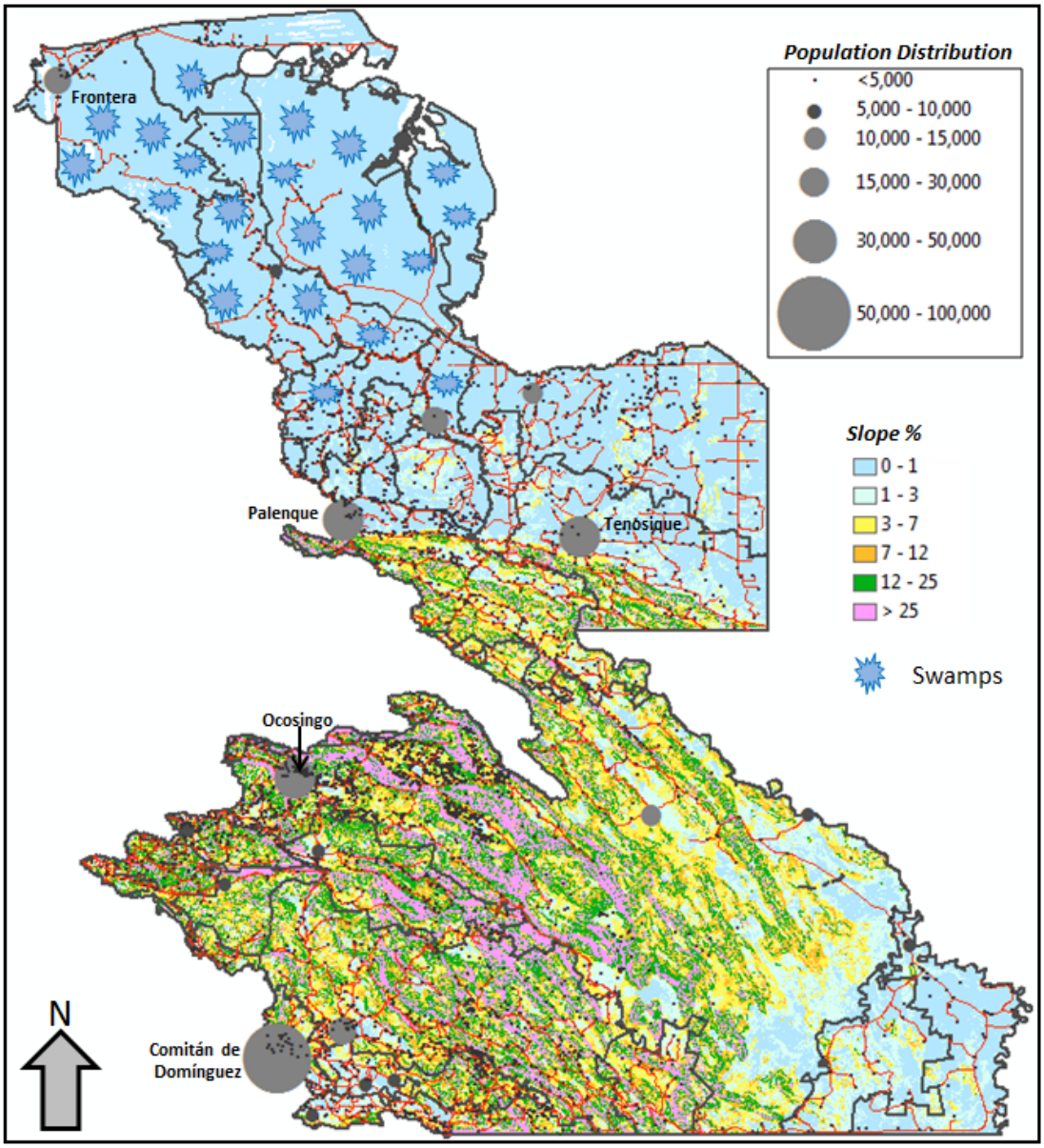

Fig. 2 The study area.

3.1 Methodology

In this study spatial analysis and modelling (inference modelling) were used to assess and map marginality Hotspot of rural communities in the Usumacinta watershed. Fig. 3 shows a diagram of the methodological approach used. The data used in this study include:

- A digital elevation model. Elevation data were obtained from the Shuttle Radar Topographic Mission/C-Band Synthetic Aperture Radar SRTM/C-SAR, with a spatial resolution of 90 meters. From this DEM the slope was calculated.

- Soil map, scale 1:250,000[16]
- Population census data [17]
- Social lag index [14]
- Susceptibility map to flooding [18]
- Data base of Health SECRETARY, Information General Direction [19]
- Land Tenure Spatial Database [20]

ERDAS Imagine, version 10 and ArcMap, 9.3 version were used for process and analyse the data.

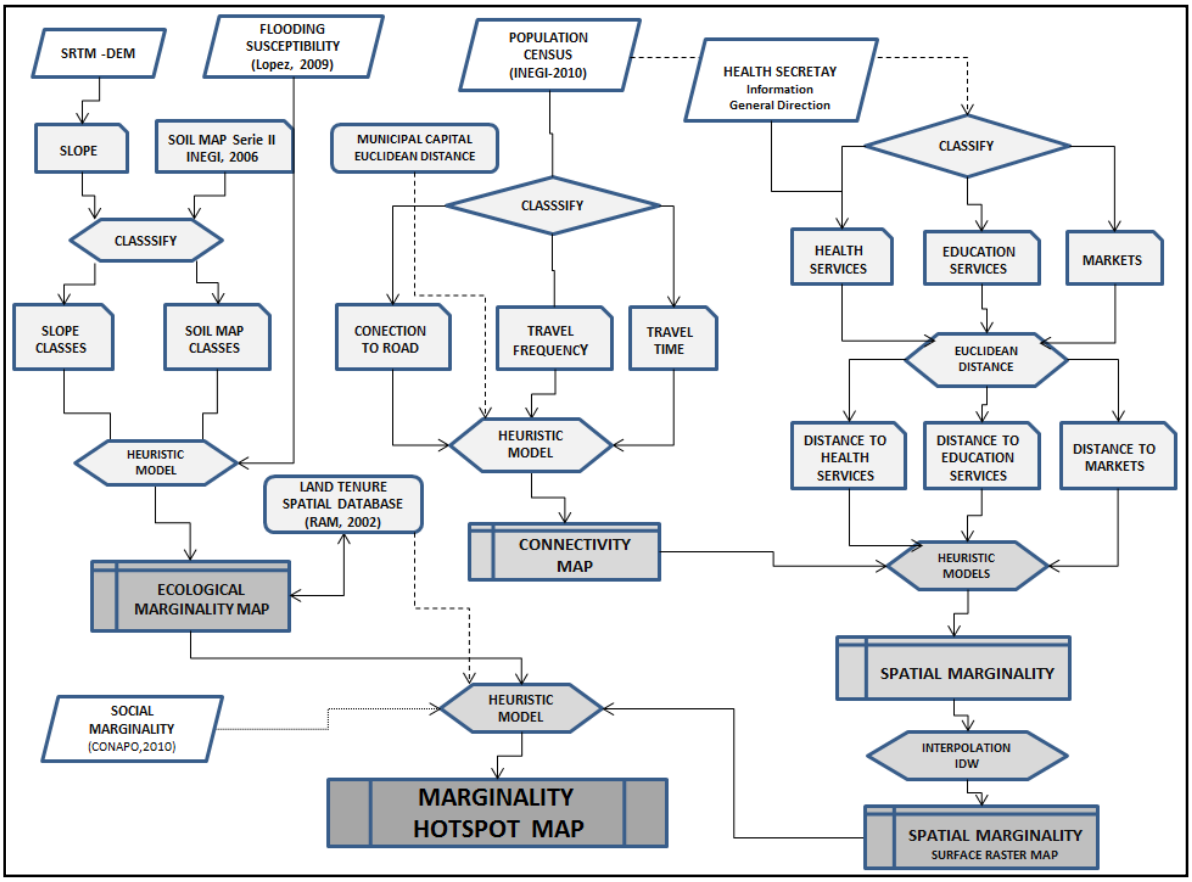

Fig. 3 Methodological approach for analysis and mapping marginality.

3.2 Ecological Marginality Mapping

The Ecological marginality assessment and mapping was based on three landscape characteristics: slope, soil restrictions and flooding susceptibility, according to classes defined in Table 1. These variables were combined in a decision model to produce an Ecological marginality map (Table A1, annex).

3.3 Spatial Marginality Mapping

The Spatial marginality was assessed and mapped based on the connectivity of rural communities and its distance to health, education and market services; for these services two levels were considered (Table 2). From location of each one of the services considered, distance maps were calculated using the Euclidean distance algorithm. The connectivity map was constructed base on the following criteria: a) If the community is or not connected to a road, b) the travel frequency, and c) the travel time; the ranking of these criteria are shown in Table 3. These criteria were combined in a decision model (Table A2, annex). to produce a connectivity map. This map was combined by decision models following the rules listed in tablesA3 and A4 (annex) to produce spatial marginality maps for each one of services considered.

Finally these spatial marginality maps were integrated throughout a decision model to produce an integral spatial marginality map (Table A5 annex).

3.4 Social Marginality

In this study the social marginality was analyzed based on the social lag index calculated by CONAPO (2010) using the principal components technique, which numerically synthesizes different dimensions, including education, health, quality of housing, and basic services. According to such index, in the study area, most of localities have a social marginality range from high to very high (Fig. 4).

Table 1 Ranking of variables for ecological marginality.

Classes	Slope %	Soil Marginality restrictions	Flooding susceptibility	Ecological Marginality
1	0-1	Sodic-Salic soils and Poor drainage	Very high	Very high
2	1-3	Poor Drainage	High	Light
3	3-7	Low Fertility	Moderate	Moderate
4	7 -12	Shallow soils*	Low	Low
5	12 - 25	Shallow soils+		Without restrictions
6	>25	Without restrictions		

*One component of cartographic unit has this characteristic;+two components of cartographic unit has this characteristic.

Table 2 Level of service for health, education and market.

Level/Services	Health	Education	Market
Level 1	Health center	High School	Detail market
Level 2	Hospital	University	Wholesale Market

Table 3 Ranking of variables for define connectivity.

Classes	Connection to road	Travel Frequency (travel/dia)	Travel Time (hours)	Euclidean Distance (Km)	Connectivity
1	Paved	> 10	<0.5	< 10	High
2	No paved	6-10	0.5-1	10-15	Moderate
3	Without connection	1-5	1-4 horas	15 - 30	Low
4		no hay	> 4 horas	30-50	Very Low
5				>50	No connected

3.5 Marginality Hotspot Map

The spatial marginality map (a points map) was interpolated, using IDW algorithm, to produce a surface marginality map. This map and the ecological marginality map were combined in a decision model to produce a Hotspot marginality map; in this case only the high and very high marginality areas where considered. Due to that social marginality is high to very high for the most of localities, it was not necessary included in the model, although conceptually it was taken account. Marginality Hotspot Map represents the areas where the three dimensions (Social, spatial and ecological) marginality overlaps.

4. Results and Discussion

4.1 Spatial Marginality

The connectivity and spatial marginality of rural communities are shown in Figs.5-7. Additionally to the elements considered in the connectivity decision model (connection to road, travel frequency and travel time) two factors determine the connectivity of rural communities in the study area: the steep topography in the high mountain and the presence of swamps in the lowlands, the connectivity is less in the most steep highlands and in the swamp lands. Considered the whole area, more rural communities located in the highland are affected by a low connectivity than in the lowland; one reason is the low population density in the swamp areas. In the highland area the communities affected by a low connectivity are located in the Margaritas and Ocosingo municipalities mainly, and a lesser proportion at Independencia, Altamirano and Oxchuc municipalities.

As was expected the connectivity (Fig. 5) is main determinant factor of spatial marginality, the pattern distribution of connectivity and spatial marginality are very similar. When comparing the spatial marginality of the two levels (Figs. 6 -7), the spatial marginality is more widespread in level 2, and in this case the

determinant factor is the distance to services considered.

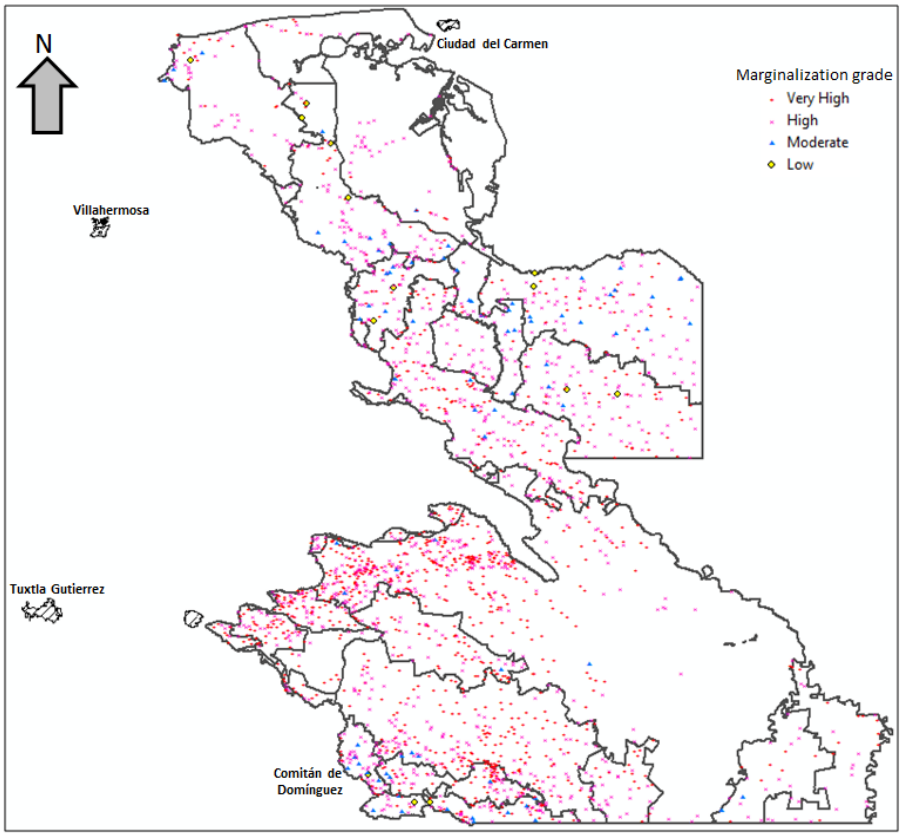

Fig. 4 Social marginality — Social lag index, CONAPO, 2010 [14].

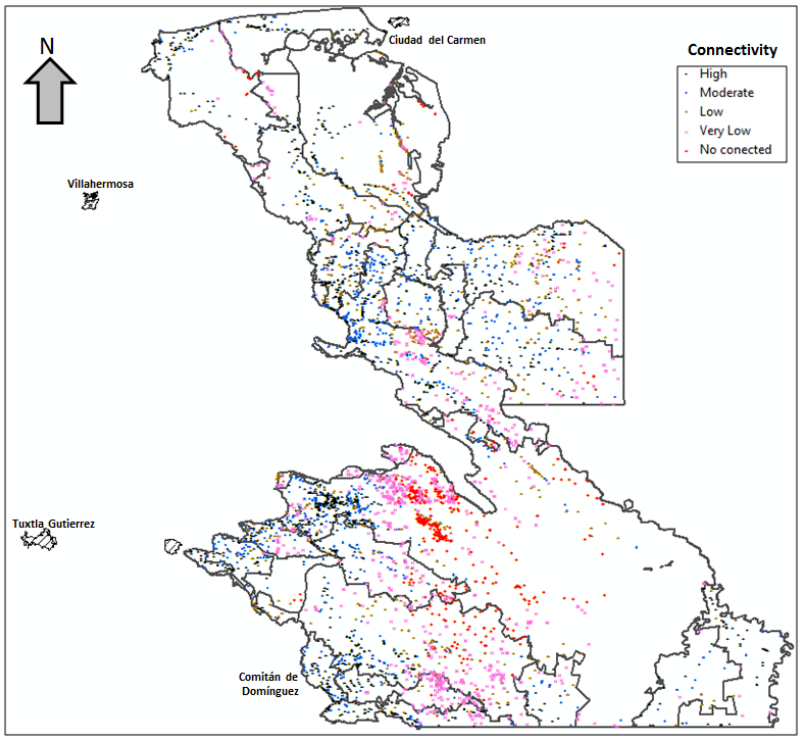

Fig. 5 Connectivity map of rural communities.

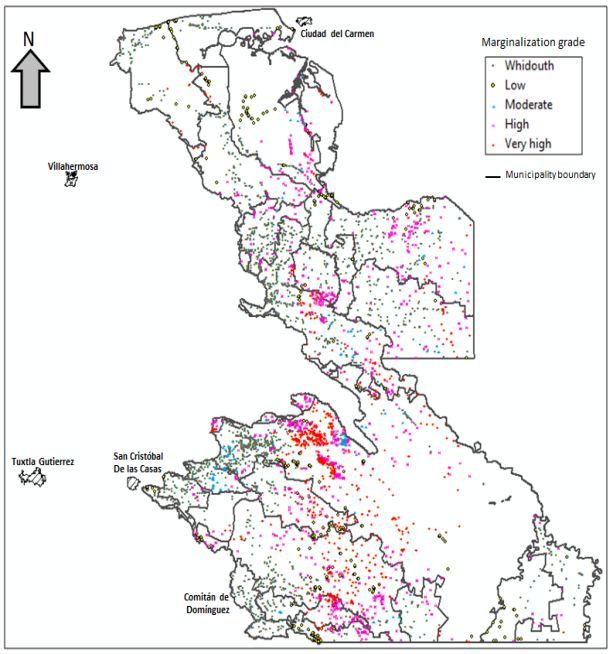

Fig. 6 Spatial marginality based on access health center, high school and Market (level 1).

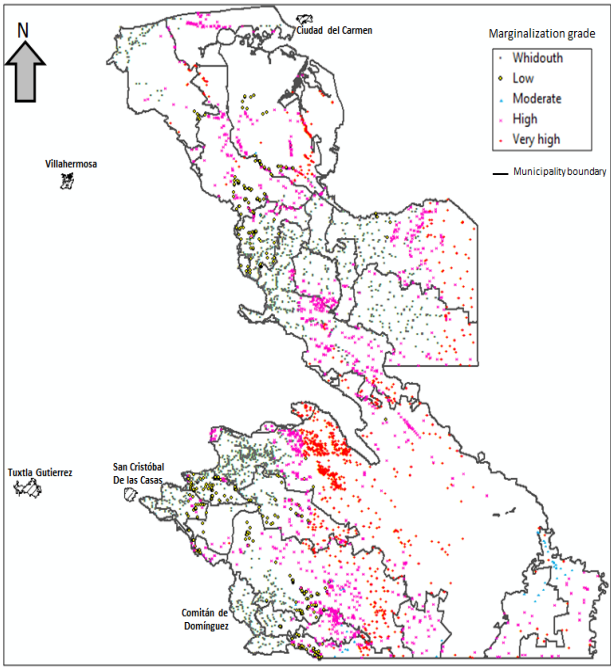

Fig. 7 Spatial marginality based on access to hospitalization, high education and wholesale market (level 2).

Having account that social marginality is high to very high for the whole area (Fig. 4), in the communities where the spatial marginality is high to very high an overlap between this two dimension of marginality exist. Additionally in these communities the access to technology and communication (telephone, internet) is limited or don't exist. It's clear that in these locations the spatial marginality exacerbates the social marginality of the communities involved, and for which a differential politics and programs must be design.

4.2 Ecological Marginality

The ecological marginality of the study area is show in Fig. 8. The high and very high marginality in the lowlands is due to the high susceptibility to flooding and the presence of salic and poor drainage soils. In the highland area the main factors of ecological marginality are the steep slopes and the presence of shallow soils.

Having account that the ability of the rural poor communities to sustain their livelihoods is generally constrained due to adverse environmental conditions: high ecological vulnerability, low productivity of natural resources, and limited access to land and other resources [21], the communities localized in the highland areas with a high ecological marginality would be more affected; on the one hand, the population density in theses area is higher, and second, these communities depend on natural resources (subsistence agriculture mainly) for their livelihoods. In the lowlands the areas with a high to very high ecological marginality, the population density is low and their livelihoods is based more on fish activities than subsistence agriculture. Nevertheless, the communities localized in this zone are exposed to suffer from extreme natural disasters, such as flooding risk which is very high in this area.

Considering the social marginality, as was point out before, in the areas where ecological marginality is high to very high, an overlap between these two dimensions of marginality exists. In this case, for communities localized in these areas, the ecological marginality exacerbates the social marginality of the

communities involved, and for which a differential politics and programs must be design too.

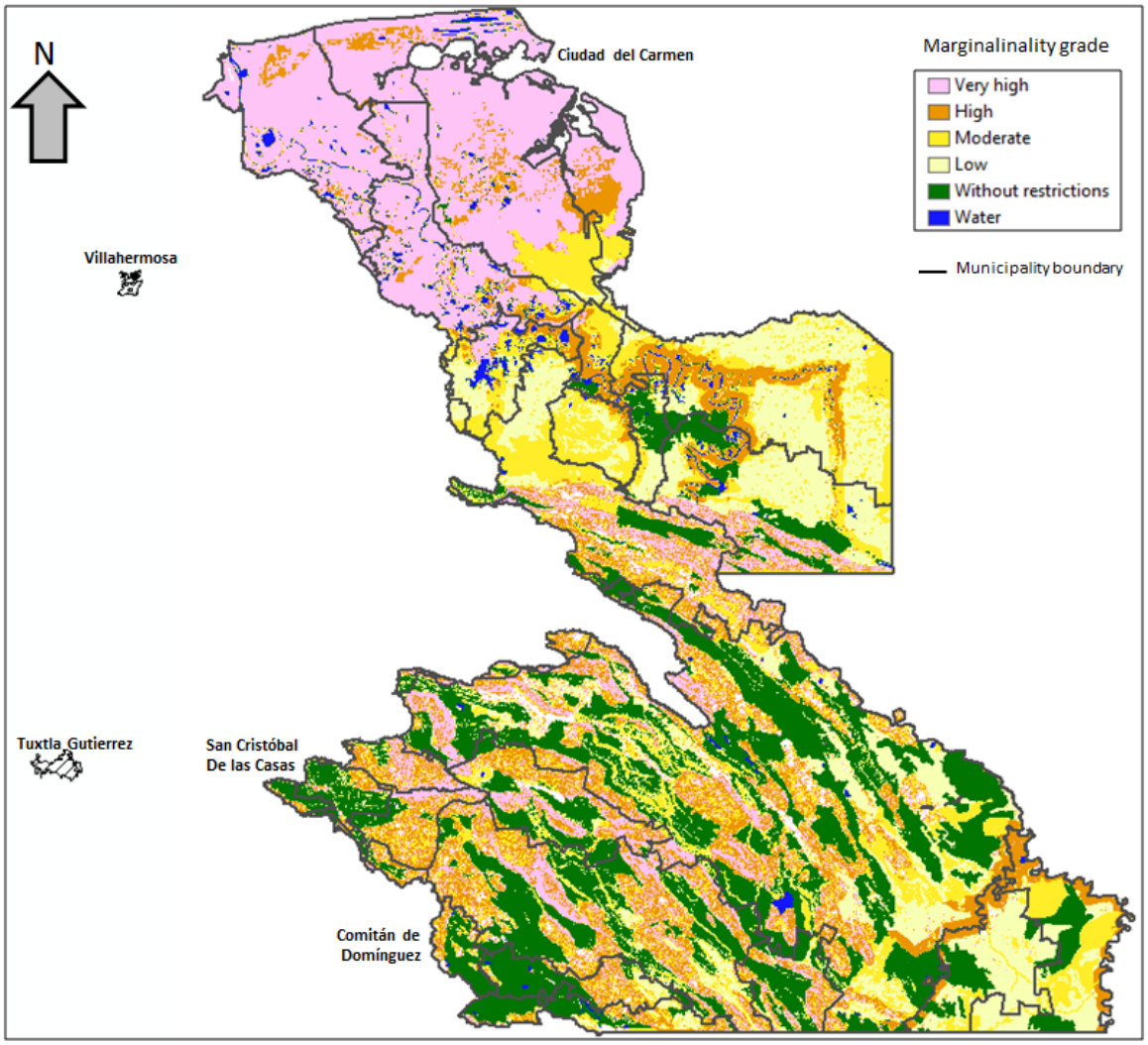

Fig. 8 Ecological marginality map.

4.3 Marginality Hotspot

The overlap of the three marginality dimensions (social, ecological and spatial) in a high and very high grade is shown is Fig. 9. The more critical areas — the Hotspot — are where the three marginality dimensions overlap (the pink area in the map). As was discussed before, in terms of population involved, the communities localized in the highland are more affected, but the communities in the lowland are exposed to flooding risk. For these zones, is a priority to design and focalize politics and programs that help these communities overcome the marginality conditions.The second priority would be for zones where two dimensions of marginality overlap must be attended too.

Finally an overlay between the hotspot areas and land tenure is shown in Fig. 10. The pink areas show the marginality hotspot zone for Ejidal and communal areas, and the orange ones show the marginality in other types of land tenure. In the case of the ejidal and communal land areas the marginality affect in a different way in terms of the extension affected, so some units are affect partially only, while others are affected totally, these last units compound the most critical marginality zones.

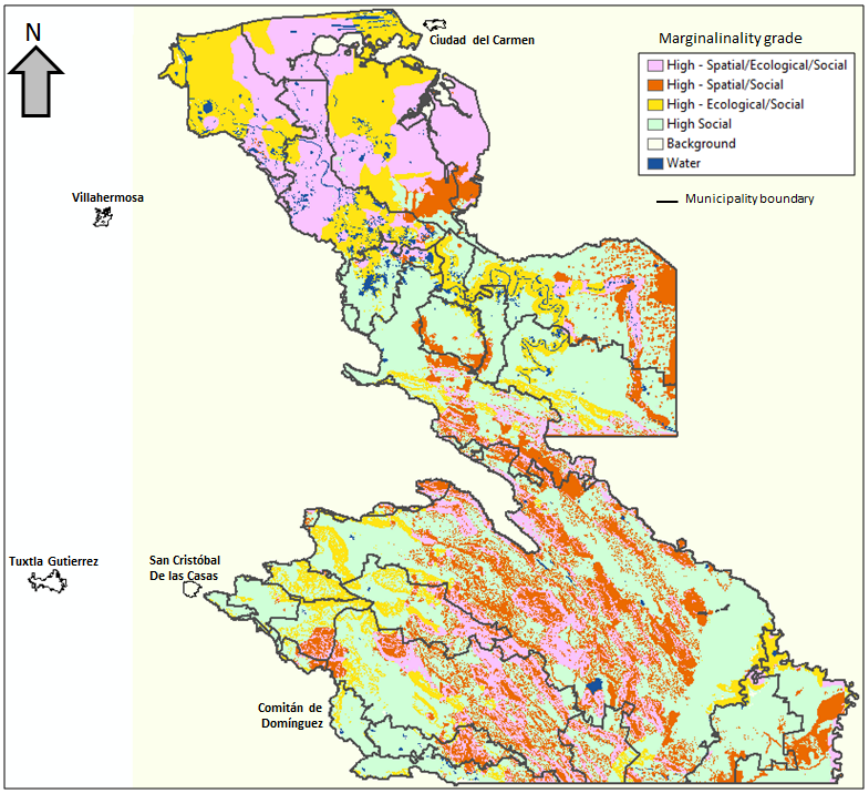

Fig. 9 Spatial, social and ecological marginality overlap map. Only the high and very high marginality grades were considered.

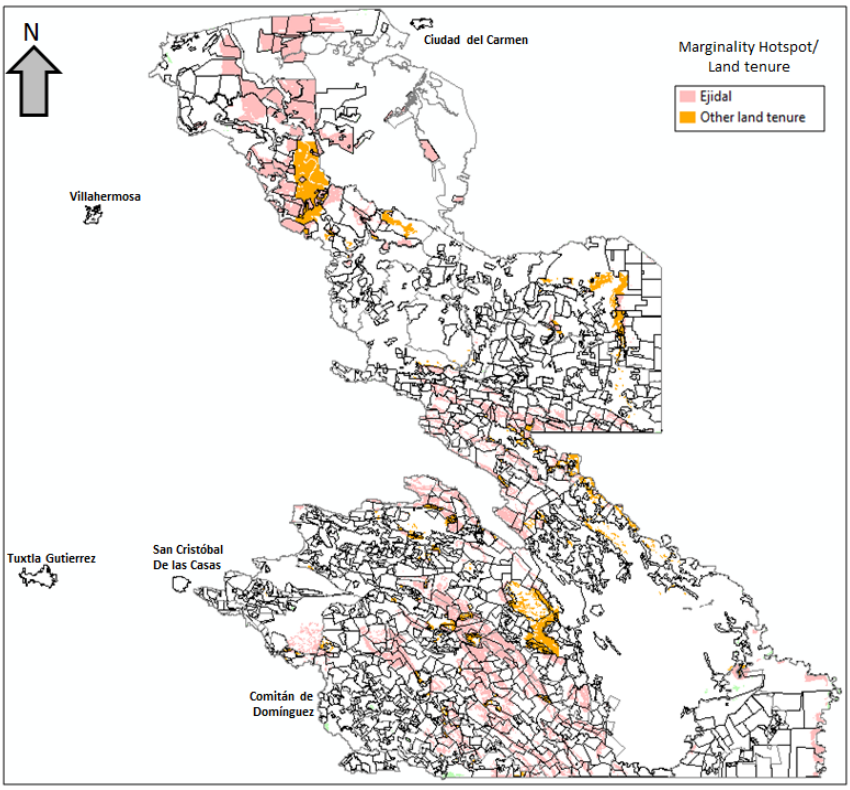

Fig. 10 Marginality hotspot map and land tenure.

5. Conclusions

From spatial analysis and mapping of different dimensions of marginality in the Usumacinta watershed some conclusions can be drawn:

- Although the study area is very homogeneous in terms of social marginality, other spatial patterns emerge when other dimensions of marginality, spatial and ecological, are considered.
- In terms of population affected the more critical area is located in the highland where three dimensions overlap.
- In the lowland area spite the population affected is lesser, these communities are exposed to risk of flooding, and that is very high in this zone.
- The patterns of marginality visualized in maps can be a useful tool to help decision making to design politics and programs that led to the communities affected overcome the marginalization conditions.

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Table A.1 Ecological marginality decision model.

Criteria.	Decision Rule	EcologicalMarginality
1 2 3 4	If clslope = 5 and soilmargi = 1* If clslope = 1 and soilmargi = 5 If clslope = 5 and susinund = 1 If clslope = 2 and soilmargi = 2	1-Very high
5 6 7	If clslope = 2 and soilmargi = 5 If clslope = 3 and soilmargi = 2 If clslope = 5 and andsusinund = 2	2 - High
8 9 10	If clslope = 5 and soilmargi = 3, If clslope = 5 and susinund = 3 Ifclslope = 3 and soilmargi = 2	3-Moderate
11 12 13	If clslope = 5 and soilmargi = 4 If clslope = 4 and soilmargi = 2, If clslope = 5 and andsusinund > 3	4-Low
14 15 16	If clslope = 5 and soilmargi = 5 If clslope < 3 and soilmargi = 5 If clslope < 3 and andsusinund > 4	5-Without

*clsope = slope class, soilmargi = soil marginality, susinund: flooding susceptibility

Table A.2 Decision model for connectivity.

Criteria	Decision Rule	Connectivity
1 2 3 4 5	If conectroad = 1 and travelfrec = 1 and traveltime = 1 or 2 or 3* If conectroad = 1 and travelfrec = 2 and traveltime = 1 or 2 If conectroad = 1 and travelfrec = 3 and traveltime = 1 or 2 If conectroad = 2 and travelfrec = 1or 2 and traveltime = 1 or 2 If conectroad = 2 and travelfrec = 3 and traveltime = 1	1-High
6 7 8 9	If conectroad = 1 and travelfrec = 1 and traveltime = 4 If conectroad = 1 and travelfrec = 2 or 3 and traveltime = 3 If conectroad = 2 and travelfrec = 1 and traveltime=3 If conectroad = 2 and travelfrec = 2 or 3 or 4and traveltime = 1 or 2	2-Moderate
10 11 12	If conectroad = 1 and travelfrec = 2 or 3 and traveltime = 4 If conectroad = 2 and travelfrec = 2 or 3 and traveltime = 3 If conectroad = 3 and euclideandistance = 1 or 2	3-Low
13 14	If conectroad = 2 and travelfrec = 2 or 3 and traveltime = 4 If conectroad = 2 and travelfrec = 4 and traveltime = 4	5-Very low
15	If conectroad = 2 and travelfrec = 4 and traveltime = 5	5-Extremelly low

*conectroad = connected to road, travelfrec = travel frequency

Table A.3 Decision model for spatial marginality based on the connectivity and distance to health centers and high school locations.

Criteria	Decision Rule	Spatial Marginality
1	If distance < 30 km and connectivity < 3	1-Without
2 3	If distance < 30 km and connectivity = 3 or 4 If distance 30-50 km and connectivity < 3	2-Low
4 5 6	If distance < 30 km and connectivity = 5 If distance 30-50 km and connectivity = 3 or 4 If distance 50-100 km and connectivity < 3	3-Moderate
7 8	If distance 30-50 km and connectivity = 5 If distance 50-100 km and connectivity = 3 or 4	4-High
9 10 11	If distance 15-30 km and connectivity = 5 If distance 30-50 km and connectivity = 5 If distance 50-100 km and connectivity = 5	5-Very High

Table A.4 Decision model for spatial marginality based on the connectivity and distance to retail market locations.

Criteria	Decision Rule	Spatial Marginality
1	If distance < 30 km and connectivity < 3	1-Without
2 3	If distance < 30 km and connectivity = 3 or 4 If distance 30-50 km and connectivity < 3	2-Low
4 5 6	If distance < 30 km and connectivity = 5 If distance 30-50 km and connectivity = 3 or 4 If distance 50-100 km and connectivity < 3	3-Moderate
7 8	If distance 30-50 km and connectivity = 5 If distance 50-100 km and connectivity = 3 or 4	4-High
9 10 11	If distance 15-30 km and connectivity = 5 If distance 30-50 km and connectivity = 5 If distance 50-100 km and connectivity = 5	5-Very High

Table A.5 Decision model of the spatial marginality based on health, education, and market services.

Criteria	Decision Rule	Spatial Marginality
1 2	If marespcs = 1or 2 and maresphighsch = 1or 2 and marespmarket = 1 or 2* If marespcs = 3 and maresphighsch = 1 or 2 and marespmarket = 1 or 2	1- Without
3 4 5 6	If marespcs = 1or 2 and maresphighsch = 1 or 2 and marespmarket = 3 or 4 If marespcs = 1or 2 and maresphighsch = 3 and marespmarket = 1 or 2 If marespcs = 3 and maresphighsch = 1 and marespmarket = 3 or 4 If marespcs = 4 or 5 and maresphighsch = 1 and marespmarket = 1 or 2	2-Low
7 8 9 10 11 12 13	If marespcs = 1 or 2 and maresphighsch = 1 or 2 and marespmarket = 5 If marespcs = 1 or 2 and maresphighsch = 3 and marespmarket = 3 or 4 If marespcs = 1 or 2 and maresphighsch = 4 and marespmarket = 1 or 2 If marespcs = 3 and maresphighsch = 1 or 2 and marespmarket = 3 or 4 or 5 If marespcs = 4 or 5 and maresphighsch = 1 and marespmarket = 3 or 4 If marespcs = 4 and maresphighsch = 2 and marespmarket = 1 or 2 If marespcs = 5 and maresphighsch = 2 or 3 and marespmarket = 1 or 2	3-Moderate
14 15 16 17 18 19	If marespcs = 1 or 2 and maresphighsch = 3 and marespmarket = 5 If marespcs = 1 or 2 and maresphighsch = 4 and marespmarket = 3 or 4 If marespcs = 1 or 2 or 3 and maresphighsch = 5 and marespmarket = 1 - 4 If marespcs = 4 and maresphighsch = 1 or 2 and marespmarket = 3 or 4 or 5 If marespcs = 5 and maresphighsch = 2 or 3 and marespmarket = 3 or 4 or 5 If marespcs = 1or 2 and maresphighsch = 4 or 5 and marespmarket = 5	4-High
20	If marespcs = 3 or 4 or 5 and maresphighsch = 3 or 4 or 5 and marespmarket = 5	5-Very High

*MarespCS = spatial marginality related to heath, MarespHighsch = spatial marginality related to education, and MarespMarket = spatial marginality related to markets