Determination of priority peri-urban areas to prevent flood risk in the municipalities of Iztapalapa, Tlalpan, Xochimilco and Coyoacán at Mexico

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INTRODUCTION

The risk of flooding in urban areas is a growing challenge due to the increasing effects of climate change. There is an urgent need to develop strategies that reduce cities vulnerability, including the flood protection that natural ecosystems to urban areas. Often people, government and other relevant actors fail to consider nature base options. This report argues that peri-urban natural ecosystems have the potential to reduce or increase flood risks in urban areas. Therefore, ecosystem conservation or restoration act as insurance to flood damage reduction caused by extreme precipitation events, thus provisioning flood regulation to downstream at-risk urban areas.

This study builds on a partnership with Zurich, through the Z Zurich Foundation- under the climate resilience program- and the Metropolitan Autonomous University, which aims to help people to understand the risks associated with climate change. Likewise, the study is aligned with the Flood Resilience Program developed by Zurich in co-ordination with the International Federation of Red Cross and Red Crescent Societies, and the Mexican Red Cross. The study seeks to contribute towards solving the public problem of floods.

The objective of this study is to provide information on strategic intervention to restore ecosystem systems through target conservation and restoration actions that reduce the magnitude of flood effects in the urban soil of Iztapalapa, Tlalpan, Xochimilco and Coyoacán at Mexico City. This involves the generation of information at multiple geographic scales on both peri-urban and urban soil, which can be used to improve decision-making of different actors on the areas that offer the best potential to receive interventions, such as reforestation or afforestation. The approach used is the development of indicators about both regulating ecosystem service providing areas and vulnerability of at-risk urban areas.

THEORETICAL-CONCEPTUAL FRAMEWORK

Extreme hydrometeorological phenomena have produced human losses and increasing economic costs in Mexico and the world (EM-DAT, 2018). The most important global risks, according to the latest Global Risk Report, relate to environmental issues, particularly extreme weather events and failure policy to solve climate change (World Economic Forum-Zurich, 2019). Climate change poses a great risk to existing flood defences in different places, and it is also eroding flood regulation services provided by natural ecosystems. The result is that more households, businesses, infrastructure, and farmland are at risk of flooding. The way cities currently manage their water resources and environmental policies will impact their resilience to the effects of climate change that will occur in the future. Therefore, it is important that decision makers implement adaptation policies that reduce the vulnerability of cities.

Flood risks in urban areas can be reduced through the use of goods and services provided by natural ecosystems in peri-urban areas (Soto et al., 2020). These spaces, which serve as an interface between urban and rural territories, are key for the provision of ecosystem services, particularly flood regulation (McGregor et al., 2006). Peri-urban areas are under pressure from population growth, urban expansion, road construction, and economic development that combined erode provision of ecosystem services (Pisanti et al., 2009). Recent discussions identify peri-urban spaces, with their combination of urban infrastructure, agriculture, and natural ecosystems, as priority areas for improving multifunctional landscape management. Furthermore, under climate change, improving the resilience of peri-urban communities can reduce regional vulnerability (Morton et al., 2014).

The concept of ecosystem insurance value highlights the importance of the relationship between flood-prone urban areas that benefit and those that provide the regulation or protection service. In the case of flood regulation, upstream peri-urban areas are important. The concept of insurance value refers to the ability of natural ecosystems to mitigate risk of natural disasters and its ability to continue providing ecosystem services even when disturbed by extreme events. The implicit value of certain regulatory ecosystem services could be estimated through the cost paid if the existing ecosystem service were somehow eroded (Baumgärtner, 2008). The protective value of the ecosystems like a forested space which mitigates risks downstream is now frequently recognised (Quaas and Baugmgärtner, 2008; Kellet and Way, 2018).

As regulation ecosystem services are regularly considered public goods, they are often under-provisioned due to free-ridings, policy neglect, and lack of information (Kaul, 2012); thus interventions are needed to maintain or restore the insurance value of the ecosystem services already diminished.

Where an ecosystem is found to provide a regulating ecosystem service it is important to understand what aspects of the ecosystem are relevant. In the case of forests and natural spaces in peri-urban areas, regulating ecosystem services associated with controlling water flows are positively related to biomass and forest quality (Mueller et al., 2013). Fragmentation of forest habitat is a threat to the provision of associated ecosystem services. The insurance aspect of biodiversity is that the diversity of species within functional groups acts to increase response diversity, which reduces the negative impacts of external disturbances in terrestrial and aquatic ecosystems (Elmqvist et al., 2003).

Recommendations exist for the inclusion of ecosystem service flows by indicating supply side areas and demand side areas, through maps that denote the interdependence between ecosystem service providing and benefiting areas. Mapping the directional flows of ecosystem services is the first step to a new approach in which natural landscapes are managed for ecosystem services, replacing current practice whereby ecosystems which provide unspecified are protected (Johnson et al. 2010). An integrative approach mapping spatial relationships can reveal valuable visualization of information and its communication (Bagstad et. Al 2013).

In Mexico, climate-related declaratory disasters have increased. Between 1999 and 2017, for every geological disaster there were 13 climate-related disasters and costs related to these were 10 times higher than for geological disasters (INECC, 2018). Around 10.1 million people, roughly 8.5% of Mexico's population, live in peri-urban areas (Soto and Alfie, 2019). These areas share characteristics of urban and rural spaces, whether in contiguous or fragmented units. Households in these sites might still develop traditional activities in the primary sector and, sometimes they pursue a wider of range of economic activities in nearby city given their proximity. The problem is that peri-urban areas are mostly of low environmental quality, indicating the need to promote interventions to improve their capacity to reduce water runoff to downstream urban areas.

In Mexico City, the most frequent precipitation events register an intensity of 30 mm in 24 hours, while events with intensities greater than 70 mm in 24 hours were rarely in historical records (period 1959- 1988). However, some climate change scenarios show that events above 60 mm in 24 hours would increase by 150% and those above 70 mm in 24 hours would increase by 200% (Soto and Herrera, 2016). These scenarios indicate that there is a need to be prepared of the critical impacts due to increasing flood damage for different sectors of society.

Considering this conceptual framework on the insurance value of ecosystems and the evidence on the increase in costly hydrometeorological events in Mexico, this study seeks to apply a multi-criteria approach that integrates information from various sources, the objective of which is to restore ecosystems in peri-urban areas that have greater potential to reduce the magnitude of the floods in some urban areas of Mexico City.

METHODOLOGY

To determine peri-urban areas with the greatest potential to retain water runoff that can receive intervention to reduce urban floods, two-phase methodology was used (Soto et al., 2020). In the first phase, the Rational Method (Musa, et al., 2013; Gökbulak, et al., 2015) was used to evaluate the annual runoff coefficient and the potential volume of natural runoff. This method, generated at the end of the last century, determine the maximum flow rate of runoff in an area assuming that it occurs when there is a maximum constant and uniform rainfall intensity, is still widely used internationally.

This relationship is described by the equation:

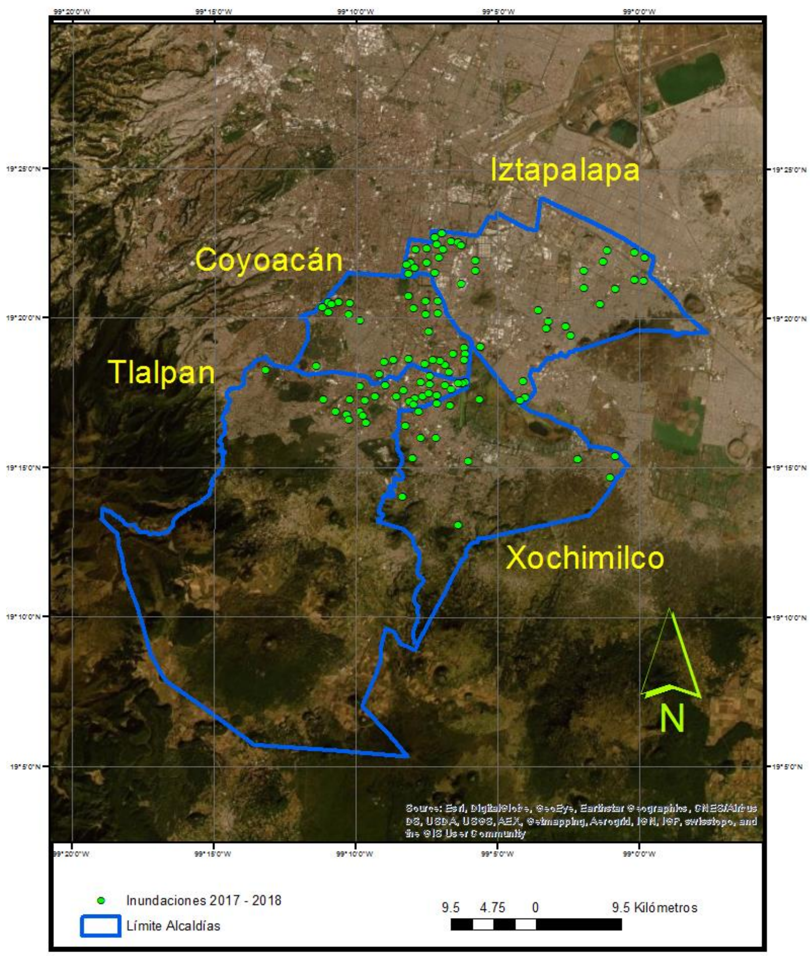
$Q = CiA$

Where

Q is the maximum runoff flow (ft3 / s); i the intensity of the rain (in / h); *A* area (acres) and *C* the runoff coefficient.

The runoff coefficient is the fraction of the rain that drains directly. Its value is a function of land use, the hydrological characteristics of the soil (hydrological group) and the slope of the terrain (Aparicio, 1992; Mc Cuen, 1998), see Table 1.

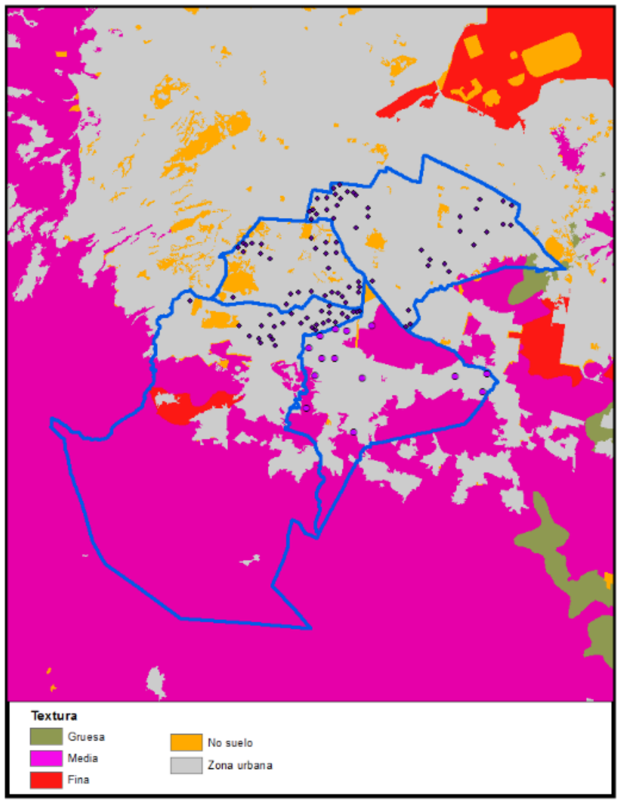
The Official Mexican Norm NOM-011-CONAGUA-2015 "Conservation of water resources" establishes it as an indirect method for calculating the average annual volume of natural runoff in basins without hydrometric records. The table described in this NOM was enhanced with the one presented in Mc Cuen (1998) to consider the terrain slope and modified to the data available for the study area. For the calculation of the runoff coefficient, we considered an area of 15 km around the studied municipalities, Iztapalapa, Tlalpan, Xochimilco and Coyoacán.



Study area.

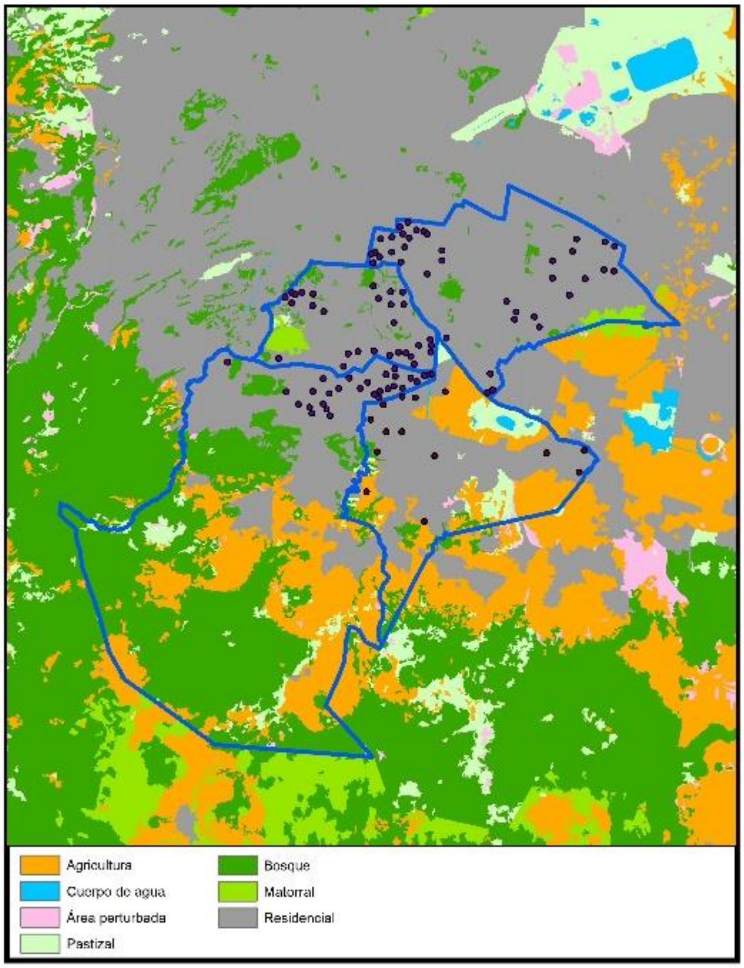
The generation of the spatial layers necessary for its calculation was carried out considering diverse elements. First, the terrain slope (%) was derived from the INEGI Digital Elevation Model (National Elevation Continuum) scale 1: 50,000, downloaded directly from the website of this institute (INEGI, 2013). This layer was reclassified according to the percentage categories described in Table 1: 1) less than 2%; 2) 2% to 6% and 3) greater than 6%.

Second, the soil layer was also downloaded from the official INEGI website, in this case the available working scale was 1: 250,000 (INEGI, 2004). From this layer, we used the soil texture that was classified as: 1) coarse, 2) medium and 3) fine. Although this layer also contains bodies of water, this category was not considered in our analysis.



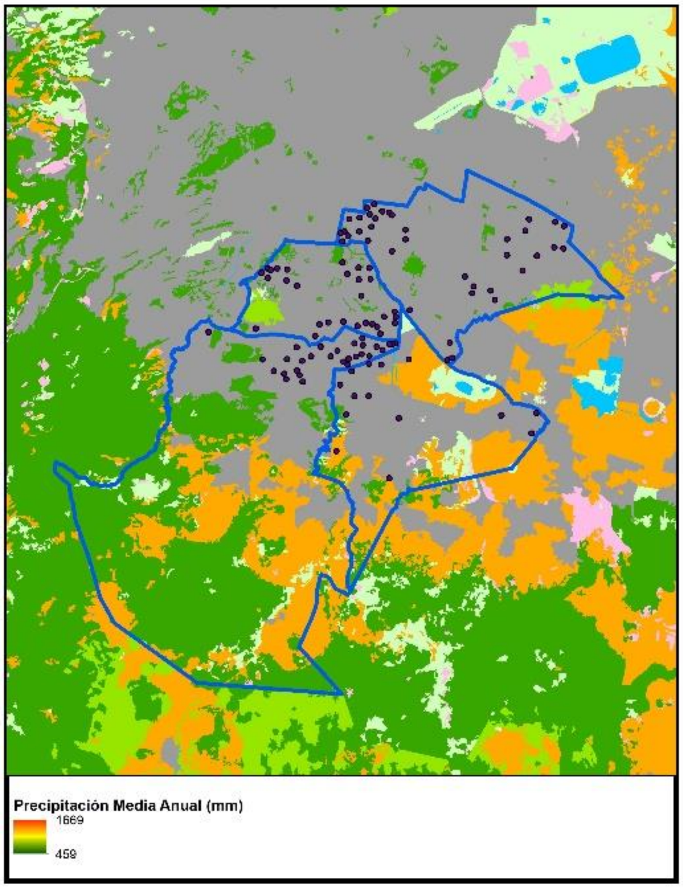
Soil texture

Third, the 1: 50,000 Land Use and Vegetation layer was obtained from the National Forestry Commission (CONAFOR, 2015). This layer contains the spatial distribution of different land uses and vegetation types. All of them were reclassified to seven types considered within Table 1: 1) Forest, 2) Scrub, 4) Agriculture, 5) Residential, 6) Disturbed area and 7) Others.



Land use and vegetation

Fourth, the average annual precipitation layer was obtained from the Digital Climate Atlas of Mexico generated by the Atmospheric Science Center of the National Autonomous University of Mexico, the National Meteorological Service and the National Water Commission. This layer was derived from the monthly average of daily data for the period 1902 - 2011 from the climatological base of the National Meteorological System (SMN) (UNAM, 2019). In its elaboration, a quality control was applied, eliminating the stations with values above and below the mean plus minus two standard deviations. For our analysis, the layers of the monthly averages were added to obtain the annual average.



Average annual rainfall

All the layers were cut to the extension of the study area and geo-referenced to the UTM Zone 14 North coordinate system, Datum WGS 1984. The spatial analyzes were developed in raster format with a pixel size of 15 m in the ArcGis software. Finally, to calculate the runoff coefficient, the categories of the three input layers (land use and vegetation, terrain slope, soils) were combined using map algebra. The different runoff coefficient values were assigned to the different combinations of the three layers according to Table 1.

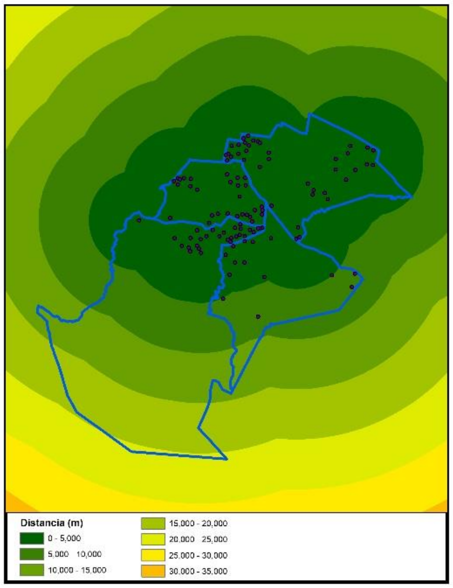
Table 1. RUNN OFF COFFICIENT				
LAND USE AND VEGETATION	**SOIL TEXTURE**	**PENDIENTE**		
		< 2%	**2 - 6 %**	**> 6%**
FOREST	GRUESA	0.1	0.14	0.18
	MEDIA	0.12	0.16	0.2
	FINA	0.15	0.2	0.25
	NA	**0.41**	**0.45**	**0.54**
MATORRAL	GRUESA	0.2	0.28	0.37
	MEDIA	0.26	0.35	0.44
	FINA	0.3	0.4	0.5
	NA	**0.41**	**0.45**	**0.54**
PASTIZAL	GRUESA	0.23	0.34	0.45
	MEDIA	0.3	0.42	0.52
	FINA	0.37	0.5	0.62
	NA	**0.41**	**0.45**	**0.54**
AGRICULTURA	GRUESA	0.16	0.21	0.28
	MEDIA	0.2	0.25	0.34
	FINA	0.24	0.29	0.41
	NA	**0.41**	**0.45**	**0.54**
RESIDENCIAL	GRUESA	0.35	0.39	0.44
	MEDIA	0.38	0.42	0.49
	FINA	0.41	0.45	0.54
	NA	**0.41**	**0.45**	**0.54**
AREA PERTURBADA	GRUESA	0.66	0.68	0.7
	MEDIA	0.68	0.7	0.72
	FINA	0.69	0.72	0.75
	NA	**0.41**	**0.45**	**0.54**
OTROS (AGUA)	GRUESA	0	0	0
	MEDIA	0	0	0
	FINA	0	0	0
	NA	0	0	0

Once the runoff coefficient was calculated, the annual runoff coefficient was calculated according to the conditions described in NOM-011-CONAGUA-2015:

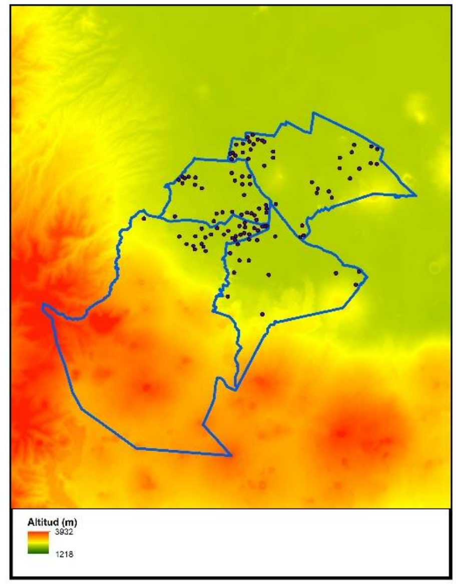
K: PARÁMETRO QUE DEPENDE DEL TIPO Y USO DE SUELO	COEFICIENTE DE ESCURRIMIENTO ANUAL (Ce)
Si K resulta menor o igual que 0,15	Ce = K (P-250) / 2000
Si K es mayor que 0,15	Ce = K (P-250) / 2000 + (K-0,15) / 1.5

In the second phase of this study, the areas that had floods in 2017 and 2018 were considered. This information was obtained from the Water System of Mexico City, the Secretariat of Administration and Finance of Mexico City and the Secretariat of Integral Management of Risks and Civil Protection of Mexico City. The data of flood events with costs covered through the insurance provided by the City Government, administered by the Secretariat of Administration and Finance, were captured, thus confirming the cases with considerable material damage. The information was processed at the neighborhood level and / or at a place or road location, using geographical coordinates in the GIS. The number of flood events experienced by the neighborhoods, place or road was counted. In most cases only one event occurred, but there was a place where six floods were reported (See excel file Colonias_inundadas).

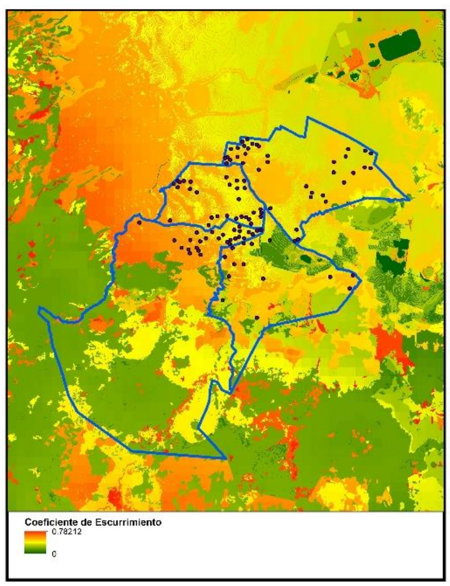
Finally, to assign the priority of areas to intervene through reforestation in peri-urban areas, a multi-criteria spatial analysis was used considering three attributes: distance to the flood areas, terrain altitude, and runoff coefficient.



Distance to floods



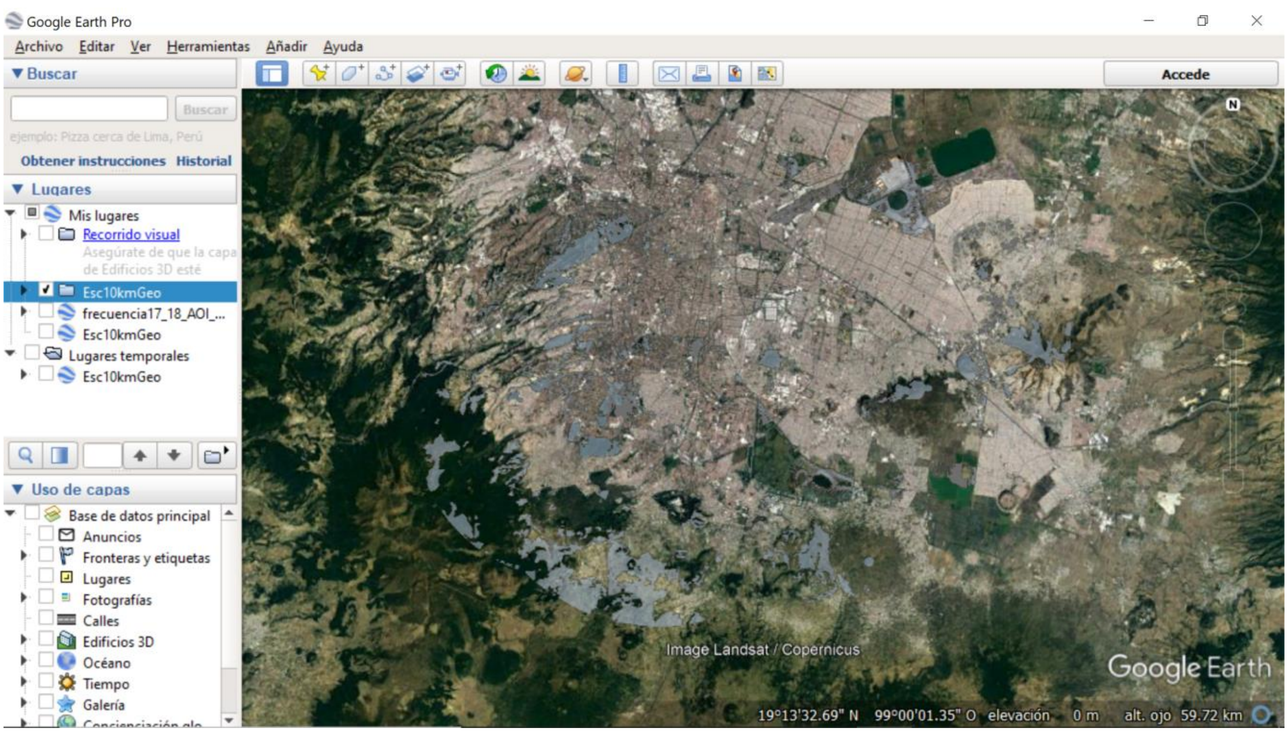
Altitude of the terrain



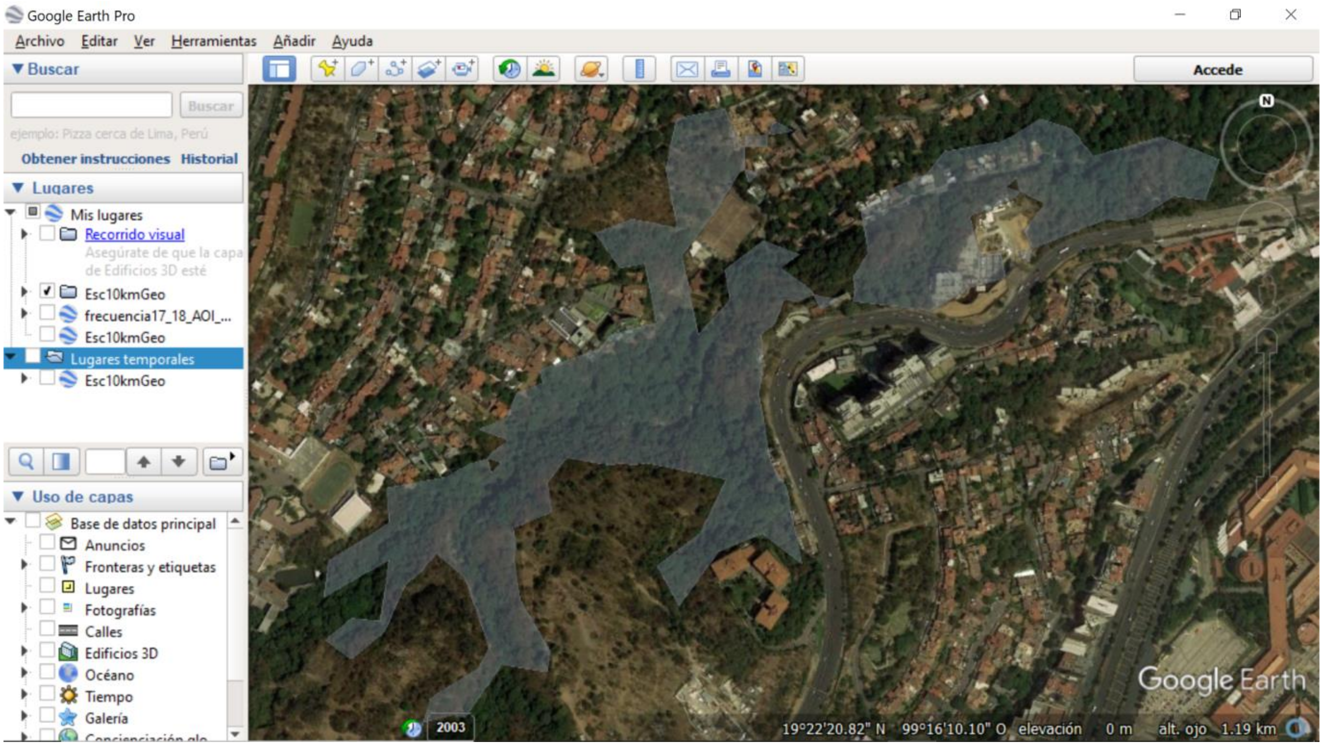
Annual runoff coefficient

A linear relationship between these variables and the priority for reforestation was considered. In the case of terrain altitude and runoff coefficient, a directly proportional relationship was considered (the higher the value of the variable, the higher the priority), while for the distance to the flood areas an inversely proportional relationship was used (the lower the variable value the higher the priority). The weight or contribution of each variable to the final prioritization for reforestation was distributed as follows: 50% for the runoff coefficient, 35% for terrain altitude and 15% for the distance to the flood areas.

The methodology generated a continuous layer of priority for reforestation. This layer was reclassified to five classes: Very Low, Low, Moderate, High, and Very High. The areas with high and very high categories were extracted.



The resulting layer was verified using high resolution satellite images in the Google Earth system. From this analysis it was found that in some cases the priority areas were located on golf courses or other sports facilities. All these areas were manually removed from the final layer of priority zones.


Google Earth Pro
Archivo Editar Ver Herramientas Añadir Ayuda
Buscar
Accede
Obtener instrucciones Historial
Lugares
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Lugares temporales
Esc10kmGeo
Uso de capas
Base de datos principal
Anuncios
Fronteras y etiquetas
Lugares
Fotografías
Calles
Edificios 3D
Océano
Tiempo
Galería
2003
19°22'20.82" N 99°16'10.10" O elevación 0 m alt. ojo 1.19 km
Google Earth

RESULTS

The runoff coefficient was processed for the peri-urban areas with influence of at-risk urban areas in the four selected municipalities - Iztapalapa, Tlalpan, Xochimilco and Coyoacán. Peri-urban areas had runoff coefficient values that ranged from 0.06 to 0.78; which means that it drains between 6 and 78% of the rainfall that precipitates, with higher runoff levels in the southern zone, in Tlalpan and Xochimilco municipalities (see Figure 1). The eastern zone also presents peri-urban zones with high runoff volumes, with a maximum runoff of 54%.

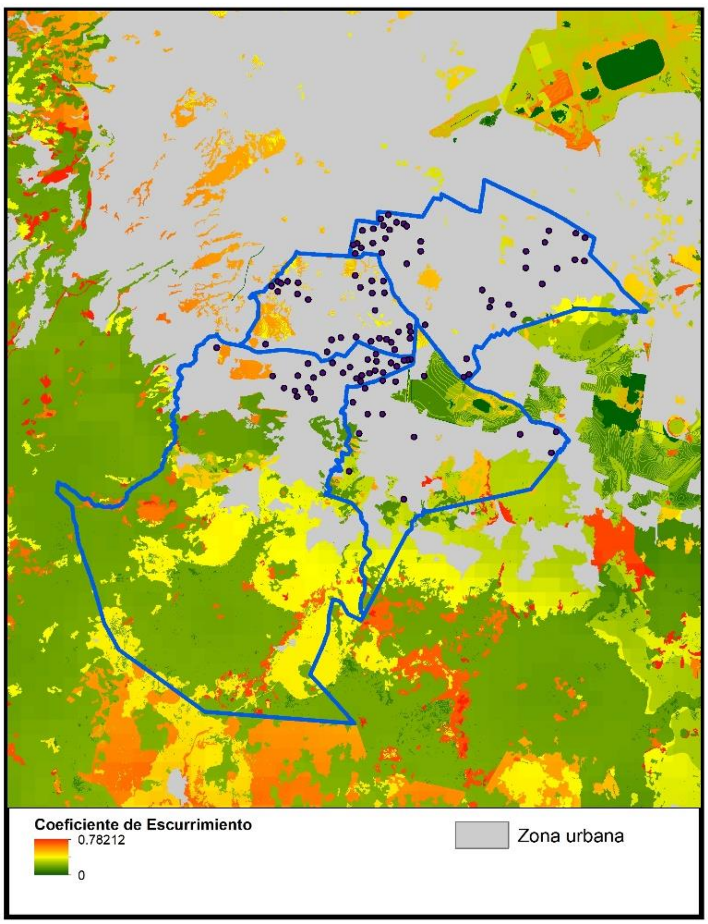

Figure 1: Annual runoff coefficient

Results of the spatial analysis show the polygons of the peri-urban areas that have the greatest potential to reduce floods in the urban areas of Iztapalapa, Tlalpan, Xochimilco and Coyoacán. Figure 2 shows the high and very high priority for reforestation in peri-urban areas. In total 1,982 polygons were identified with a total area of 9,810 hectares identified as peri-urban land. The size of the polygons ranged between 0.14 ha and 1,440 ha, with an average of 5 hectares (See Figure 2).

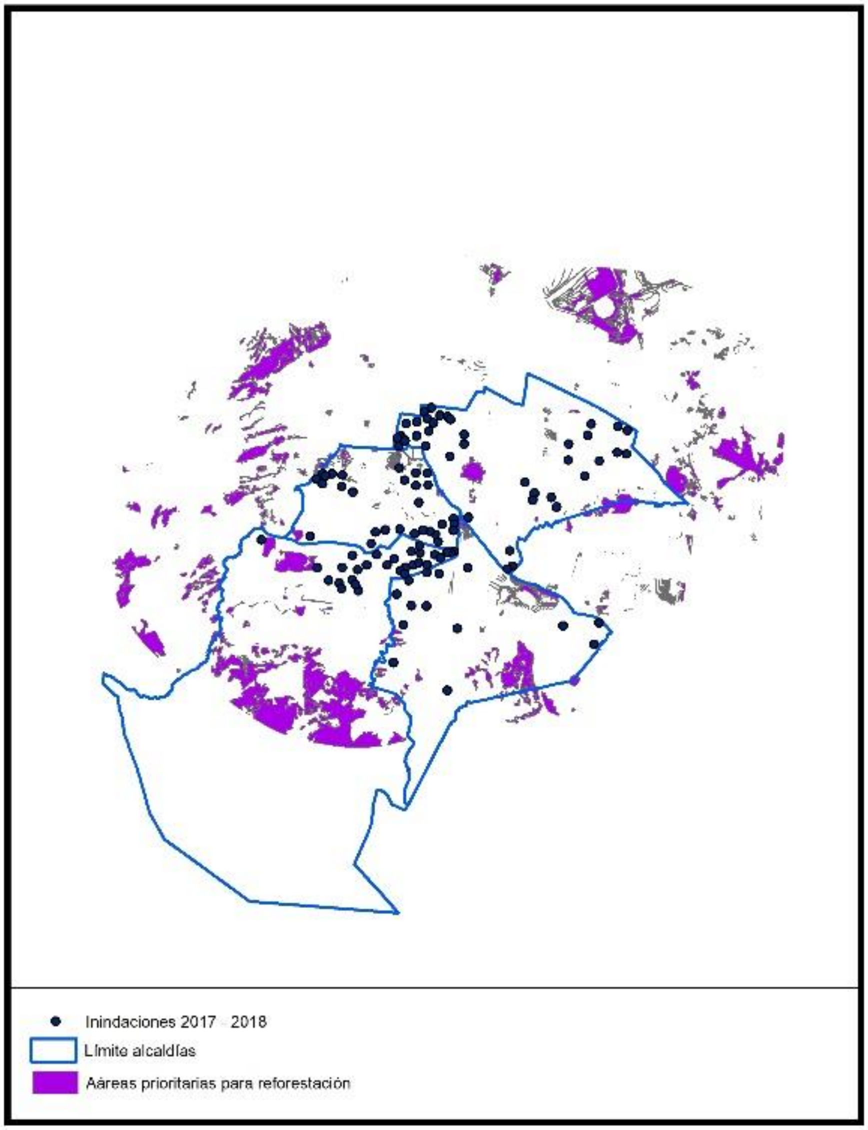

Figure 2. Priority areas for reforestation.

Annex 1 presents 64 maps with the spatial location and communication routes to reach the priority areas. Additionally, the polygons can be observed in the Google Earth system using the file Priority.kmz included in the USB memory, Annex 2. In this file, there are the polygons images, such as the one shown in Figure 3.

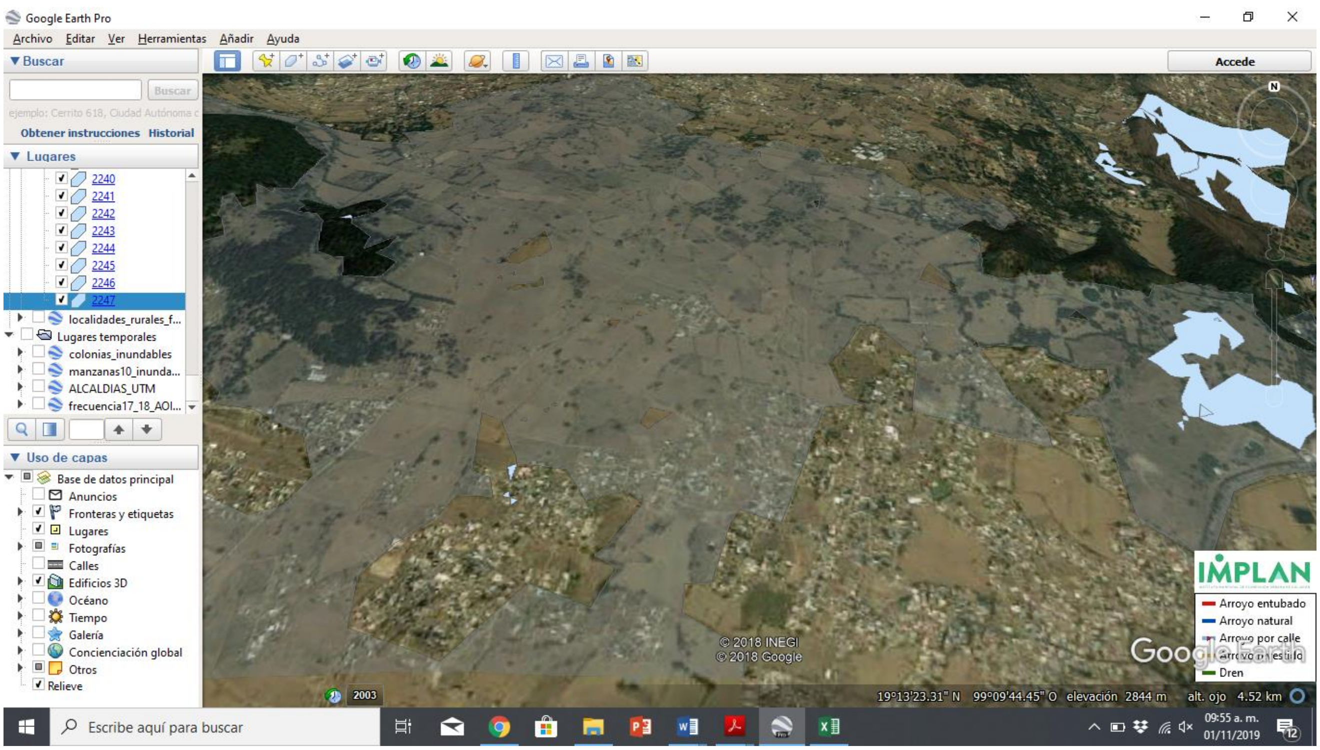

Figure 3. View of a priority peri-urban zone for reforestation -system in Gloogle Earth.

The Google Earth system has the alternative to display specific places in the Google Maps system (icon in the upper right), and verify access routes to different sites, as shown in Figure 4.

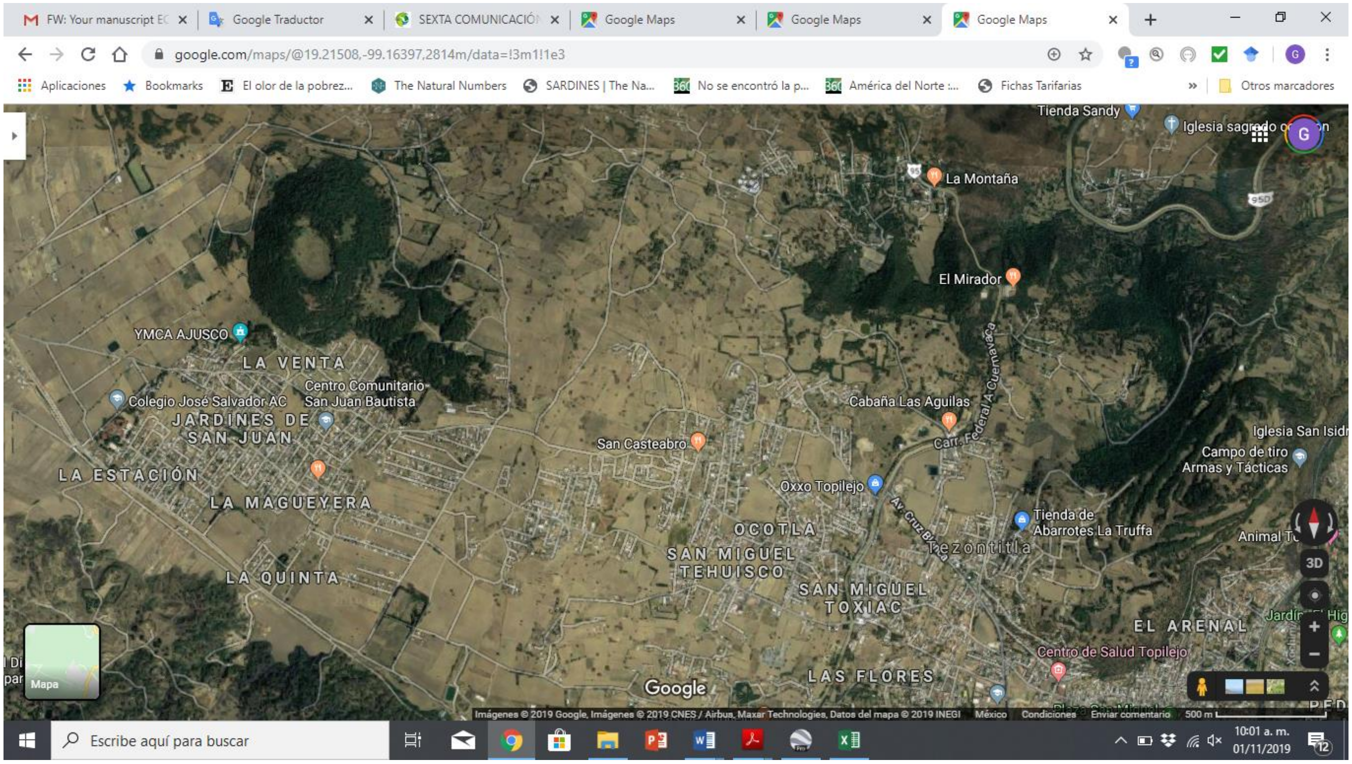

Figure 4. Image of a priority peri-urban zone for reforestation-system

Gloogle Maps

Considering a scenario where the priority areas were reforested, an average reduction in runoff sheet of 139 mm per year was estimated, meaning that for each hectare reforested there would be on average a runoff reduction of 1,390 m^3 per year (one million three hundred and ninety thousand liters). The estimation of the volume reduction of runoff water will depend on the area that is actually reforested, as well as the specific characteristics of those areas.

The priority polygons contain 101 rural towns, located in six municipalities of Mexico City and one in the State of Mexico. The largest number of towns is located in Tlalpan (71), followed by Milpa Alta (11), Magdalena Contreras (8), Xochimilco (7), Tláhuac (2) and Cuajimalpa, and La Paz (Edomex) (1).

Table 1 presents sociodemographic characteristics of the periurban rural towns, with 6,933 inhabitants and 1,668 households registered, most of these households are located in Tlalpan and Milpa Alta. A small proportion of inhabitants speak an indigenous language, 329 people, which is equivalent to 4.7% of the total population of these rural towns.

Table 1. Sociodemographic information of rural localities in peri-urban areas.

	No. Rural localities	Total population	Population speaking an indigenous	School average level	Population without health service affiliation	Inhabited households	Households without electricity	Households without water supply service	Households without sewage service
Cuajimalpa de Morelos	1	518	23	7.36	222	115	4	108	5
Magdalena Contreras	8	615	16	7.61	265	141	5	114	5
La Paz	1	429	39	7.16	214	107	9	102	3
Milpa Alta	11	1589	78	8.06	589	382	2	206	1
Tláhuac	2	47	3	7.53	33	11	0	4	1
Tlalpan	71	3232	139	8.68	1648	797	40	660	73
Xochimilco	7	503	31	7.34	231	115	6	110	20
Total	101	6933	329	7.68	3202	1668	66	1304	108

Several indicators show social marginality, since less than a half of the inhabitants have health service, while 1,304 households do not have piped water and 108 do not have sewage service. Specific data for each of the rural localities appears in the database (indicadores loc rurales-- Annex 3) and, by using the file (localidades rurales_final.kmz - Annex 4), it is the geographical location of each one is available.

Table 2 presents descriptive statistics of urban neighborhoods, which according to information provided by the Water System and the Mexico City Finance Secretariat, registed severe flood events in 2017 and 2018. Socio-demographic indicators can be observed (Indicadores zonas inundables file - Annex 5). There is a record of 110 flooded neighborhoods, mostly in Iztapalapa (38), followed by Tlalpan and Coyoacán (29 each) and Xochimilco (14). There are 172,305 households located in the affected neighborhoods, mostly in Iztapalapa and Tlalpan.

Table 2. Sociodemographic information of flooded neighborhoods during 2017 and 2018.

Municipality	No. of flooded neighbourhoods	Total population	Average population density	Total households	Averagae flood events	Marginality degree mode	Affected inhabitants with high marginality degree
IZTAPALAPA	38	266,018	341	76,737	1.3	Medio	45,547
TLALPAN	29	84,222	151	28,058	1.6	Muy bajo	0
XOCHIMILCO	14	94,568	113	26,701	1.9	Medio	22,230
COYOACAN	29	128,810	193	40,809	2.0	Muy bajo	0
Total	110	573,618	223	172,305	1.7		67,777

The number of flood events registered in these neighborhoods during these two years varies, most of them were flooded once or two times, although in one case six events occurred. Frequency of floods is on average between 1.3 and 2 times. These neighborhoods have 573,618 inhabitants, the majority are concentrated in Iztapalapa with 266,018 people, and in Coyoacán with 128,810 people. In addition, these municipalities have the highest average population density, registering 341 people per km^2 in Iztapalapa and 193 people per km^2 in Coyoacán.

Descriptive statistics highlights that social marginality was higher in the neighborhoods located in Iztapalapa and Xochimilco which may increase the vulnerability of urban inhabitants to hazards and raises the role of in situ natural insurance of the peri-urban ecosystems in the eastern zone and those in Xochimilco (see Annex 1). In the file colonias_inundables.kmz (Annex 6), the neighborhoods that presented flood events can be spatially located.

CONCLUSIONS AND RECOMMENDATIONS

The analysis of urban floods in the four municipalities studied - Iztapalapa, Tlalpan, Xochimilco and Coyoacán - showed that some peri-urban areas register high runoff values, which indicates a deterioration in the water control regulation. Rainfall runoff to urban areas contribute to the occurrence of different flood events in these municipalities, some with high costs.

The conceptual framework developed here is based on insurance or protection value provided by the natural resources of peri-urban areas, and it is based on studies that recommend evaluating the spatial relationship between areas that provision regulating ecosystem services and the areas that benefit. The mapping of the water flow control ecosystem service shows 1,982 polygons with a total area of 9,810 hectares that in principle could be targeted for interventions; for instance, reforestation.

A fundamental step for reforestation and restoration is to contact people or communities living in these spaces. As shown in the maps, some people live within urban spaces and others in semi-rural areas. Satellite images show that in some of these polygons there are agricultural lands with low productivity (Muñoz et al., 2008). Having 101 rural towns located close to the polygons that require interventions makes it easier to find the relevant actors. Rural communities that manage these areas might highlight the importance of these natural spaces. Many of these peri-urban areas are ejidos that have received little policy attention in public policy, might become recognized centers of ecosystem services, even with monetary value (Lamarque et al. 2011).

Community management in areas targeted for investment in regulating ecosystem services through restoration and conservation could also improve local well-being. At this local level, traditional ecological knowledge is important; policy interventions are more likely to succeed when there is a good understanding of stakeholders' perceptions of their traditional practices, as well as of the benefits they want to obtain. Current incentives for local communities to manage their lands focus on the provision of ecosystem services important to them and not on services important to other communities. The interest in restoring the ecosystem service for regulating runoff in certain areas may result in public-private partnerships, where different sectors might be willing to collaborate. The role of multi-sectoral alliances to strengthen the resilience of communities to floods can lead to new policy instruments around the provision of ecosystem services (IPBES, 2018). Different actors may now have information to proceed, through investments to restore natural ecosystems that increase natural protection and avoid social costs. The nature-based options provide new information to environmental authorities, as well as water, and risk management authorities. Habitats loss, fragmentation or degradation in certain peri-urban areas threat to the provision of ecosystem services mitigating urban flooding.

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LIST OF ELECTRONIC ANNEXES

Annex 1: A word document containing 64 maps with spatial location and communication routes of the priority areas

Annex 2: File Prioridad.kmz containing the priority reforestation polygons via Google Earth

Annex 3: Excel database with indicators of rural towns near the priority polygons

Annex 4. File Localidades rurales_final.kmz with the location of rural towns near the priority polygons.

Annex 5. Excel database with indicators of urban neighbourhoods that suffered severe flood events during 2017-2018

Annex 6. Colonias_inundables.kmz file with the spatial location of the neighbourhoods that suffered severe flood events.