THE STREET CONNECTIVITY INDEX (SCI)

OF SIX MUNICIPALITIES IN JALISCO STATE MEXICO

DOCUMENTOS TÉCNICOS

POR UN MEJOR FUTURO URBANO

ONU HABITAT


Zapotlan el Grande

The Street Connectivity Index (SCI) of six municipalities in Jalisco State, Mexico

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List of abbreviations

CPI	City prosperity index
GDP	Gross Domestic Product
ID	Intersection Density
MDG	Millennium Development Goal
LAS	Land allocated to streets
SCI	Street Connectivity Index
SD	Street Density
SGD	Sustainable Development Goal
UN- Habitat	United Nations Human Settlements Programme

Historical perspective

Urbanisation and mobility

Urbanisation remains a key global concern and a major contribution to many economies of this world; there are currently more people living in cities than in rural areas and it is estimated that 70% of the world's population will be living in cites by 2050. Even within more urbanised countries, urban re-organisation continues to shape living arrangement. Cities and urban areas continue to influence an increasing proportion of the social, cultural, political and economic aspects of modern societies and account for 70 per cent of world's gross domestic product (GDP). [1] As we plan for the future of our world, it is imperative that we consider the effects of urbanization and development on both the environment and human populations. A city is only truly sustainable if it uses natural resources and its spatial forms efficiently while still fully meeting the needs of its inhabitants and a decent standard of living. This requires meticulous planning and designs, and applying appropriate technology at all the various stages of the city development.

Urban spatial forms and mobility are key factors of a city's functionality as they underlay the social and economic development by allowing access to goods, services, facilities and experiences. Efficient, inclusive and sustainable mobility systems are a major characteristic of prosperous and developed cities while efficient city connectivity networks are associated with better accessibility, mobility, efficiency and ultimately a better quality of life. Furthermore, high street connectivity increases the overall productivity of a city by reducing commute time to work, school, parks, shopping areas, health facilities or other to amenities. Cities with infrastructure that promotes walking and cycling reduces burden of chronic health conditions such as obesity and hypertension. Encouraging larger proportion of the population to walk or cycle also serves to improve quality of air by reducing reliance on motorised transportation and pollution. Good connectivity is also essential in improving response times during emergencies. Improvement in street connectivity is influenced by the design of the streets, quality or size of the streets that are well maintained, paved and clearly marked to promote movement of vehicular and non-vehicular traffic more efficiently.[2,3]

Measuring different aspects of urban life has increasingly gained traction. Setting up systems for monitoring are important for benchmarking, accountability and tracking progress. The Sustainable Development Goals (SDGs) and the City Prosperity Index (CPI) provide the framework for measuring street connectivity a key measure of urban mobility and for gauging overall city performance.[4] UN-Habitat’s City Prosperity Index which is the measurement framework for the City Prosperity Initiative (CPI), translates the six dimensions of prosperity i.e. productivity, infrastructure development, quality of life, equity and social inclusion, environmental sustainability, good governance - into measurable indicators that are consistent with the principles of smart, sustainable and just city. Considering the need for housing, mobility /city connectivity demands, urban infrastructure, population growths in cities projected/expected over the coming decades, the current spatial forms and urban growth plans are critical to achieving long-term sustainability cities objectives.

Measuring connectivity: linkage to the Sustainable Development Goals (SDG)

The United Nations Sustainable Development Goals Summit adopted a framework for guiding development efforts between 2015 and 2030. The SDGs address, in an integrated manner, the social, economic and environmental dimensions of development, their interrelations, aspects related to peaceful societies and effective institutions, as well as means of implementation. SDGs were a follow up to the Millennium Development Goals (MDGs). The Sustainable Development Goal 11 focuses on “making cities and human settlements inclusive, safe, resilient and sustainable”. The following SDG targets under SDG goal 11 address issues related to urbanisation, mobility and street connectivity. [5]

- Target 11.2: By 2030, provide access to safe, affordable, accessible and sustainable transport systems for all, improving road safety, notably by expanding public transport, with special attention to the needs of those in vulnerable situations, women, children, persons with disabilities and older persons.
- Target 11.3: By 2030 enhance inclusive and sustainable urbanization and capacities for participatory, integrated and sustainable human settlement planning and management in all countries
- Target 11.7: By 2030; provide universal access to safe, inclusive and accessible, green and public spaces, particularly for women and children, older persons and persons with disabilities
- Target 11.7a: Support positive economic, social and environmental links between urban, peri-urban and rural areas by strengthening national and regional development planning

These SDGs targets and their associated indicators are part of the city prosperity initiative that applies the city prosperity index in the assessments of city performances and this approach is already being implemented in over 200 cities globally, including over 30 cities from Mexico.

City Prosperity Index (CPI)

The City Prosperity Index (CPI) was launched in 2012 by UN-Habitat to measure sustainability and prosperity at urban/city level.[6,7] The CPI is a composite index made of six interlinked dimensions which include infrastructure, productivity, quality of life, equity, environmental sustainability and governance. Of specific interest to this study are the CPIs spatial analysis tools that measure the spatial forms of the city (street connectivity) that support efficiency of the city connecters and mobility.

Despite predating SDGs, CPI integrates goal 11 of the SDGs and therefore has been used to monitor and report on targets under these goal in a structured manner. CPI is measured at a city level and not at the country or national level allowing greater focus into the variability and disparities that may occur in cities within the same country as has been a hallmark of many developing economies. Definitions of cities vary greatly and include towns, municipalities or metropolitan regions. A major sub-dimension within the City Prosperity index that focuses on the spatial forms is the street connectivity index (SCI). Figure 1 below shows how different SDG goals are integrated with the CPI. Furthermore, 23% of all SDGs targets that can be measured at the local level are covered by the CPI.

Figure 1: Linkage between SGD targets under goal 11 and the City Prosperity Index (CPI)

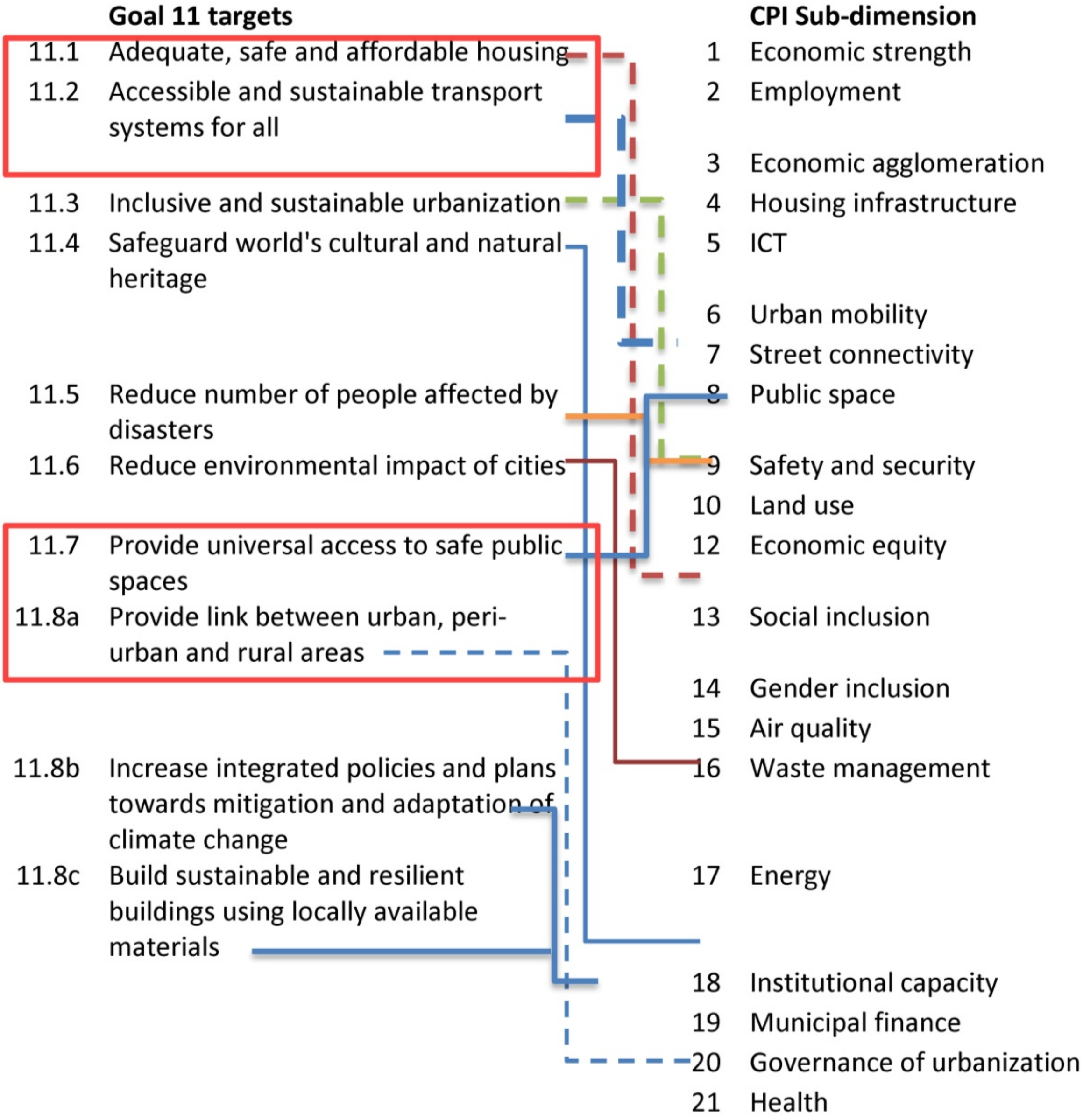


Figure 2: City Prosperity Initiative (CPI) and the street connectivity index

CPI DIMENSION	**CPI SUB-DIMENSION**	**INDICATORS**
PRODUCTIVITY INDEX	Economic Strength	City Product per Capita
	Economic Burden	Old Age Dependency
	Economic Agglomeration	Economic Density
	Employment	Unemployment Rate
		Employment to Population ratio
INFRASTRUCTURE DEVELOPMENT INDEX	Housing Infrastructure	Improved Shelter
		Access to Improved Water
		Sufficient Living Area
		Population Density
	Social Infrastructure	Physicians Density
	ICT	Internet Access
		Average Broadband Speed
	Urban Mobility	Length of Mass Transport Network
		Traffic Fatalities
		Per Capita Public Transport Vehicles
	Street Connectivity	Intersection Density
		Street Density
		Land Allocated to Streets
QUALITY OF LIFE INDEX	Health	Life Expectancy at Birth
		Under-Five Mortality Rate
	Education	Literacy Rate
		Mean Years of Schooling
	Safety and Security	Homicide rate
	Public Space	Accessibility to Open Public Area
		Green area per capita
EQUITY AND SOCIAL INCLUSION INDEX	Economic Equity	Gini Coefficient
		Poverty rate
	Social Inclusion	Slum Household
		Youth Unemployment
	Gender Inclusion	Equitable Secondary School Enrolment
ENVIRONMENTAL SUSTAINABILITY INDEX	Air Quality	Number of Monitoring stations
		PM2.5 Concentration
		CO2 Emissions
	Waste Management	Solid Waste Collection
		Waste water treatment
	Water and Energy	Share of renewable energy
GOVERNANCE AND LEGISTRATION INDEX	Participation and Accountability	Voter Turnout
	Municipal Finance	Local Expenditure Efficiency
		Own revenue collection
		Subnational Debt
	Governance of Urbanisation	Urban Sprawl

The spatial capital analysis of the six municipalities of Mexico utilizes indicators from the of CPI's street connectivity sub-dimension (3 indicators) and from public space sub-dimension (one indicator). Below formal definitions of each of these indicators are provided.

Street connectivity Index (SCI)

Street connectivity is a sub-dimension under the infrastructure dimension of the City Prosperity Index (CPI) and consists of three distinct and inter-related measures namely: *Street Intersection Density, Street Density and Land Allocated to Streets*.[8]. Street connectivity is part of the wider set of measures used to assess the spatial capital of cities. Other indicators within the CPI that are used for spatial capital analysis include: length of mass transport network, accessibility to open public areas, and green area per capita. The linkage between CPI and SCI has been illustrated in figure 2 above. Consequently, Street connectivity (SC) is computed using the formula below;

$$SC \quad = (1/3)\ [\text{Street Intersection Density} + \text{Street Density} + \text{Land allocated to streets}]$$

Operational definitions for Street Intersection Density, Street Density and Land allocated to streets are provided below.

Street intersection density (SID)

Street intersection density is a measure of the number of intersections (nodes) per square kilometre of land. More intersections within an urban area allow points where vehicles, cyclists and pedestrians can join streets moving in different directions across blocks of land therefore reducing connection distance. Intersections also provide areas where cars stop allowing pedestrians to cross busy streets; this however is influenced by the level of enforcement of traffic rules at the intersection. Urban areas with fewer intersections, experience journeys that are longer as people and vehicles are forced to circumnavigate before getting to their destination. Too many intersections also create a layer of congestions resulting from the need to turn at short distances ultimately slowing traffic flow.

Street density (SD)

Street density (SD) is the length of roads or streets in kilometres per square kilometre of urban land. Higher street density means that there are short and direct routes that promote vehicular movement, walking or cycling to destinations. A prosperous city seeks to achieve a tight network of paths and streets offering multiple routes to destinations. (ITDP, 2013)

Land allocated to streets

Land allocated to streets is a calculation of the total area allocated to streets based on sampling techniques as a proportion of the total surface of the built-up area. Transportation systems consume large amount of land for circulation and parking of vehicles and for complementary facilities related to transportation such as terminals and stations. UN-Habitat recommends that approximately 30 per cent of urban land is allocated to streets for efficient connectivity.

The land allocated to streets in most urban areas ranges from 6% to 36%. The following four categories are used to classify cities based on the percentage of land allocated to streets.

- Low land allocated to streets if less than 15% of land is allocated to streets
- Low to moderate land allocated to streets if between 15 and 20 % of land is allocated to streets
- Moderate to high land allocated to streets is where between 20 and 25% of land is allocated to streets
- High land allocated to streets when more than 25% of city land is allocated to streets.

Other measures of street connectivity, which are not part of the street connectivity index presented in this study include:[9]

Public space (PS) analysis

Target 11.7 of the SDG on cities is to "provide universal access to safe, inclusive and accessible, green and public spaces, particularly for women and children, older persons and persons with disabilities." The inclusion of this target in Goal 11 goes to show how important the measurement of public space is in achieving the global urban sustainable development agenda within the social, economic and environmental pillars. In order for cities or municipalities to be vibrant and safe places, we must visualize them as systems of interdependent parts that offer complex connections and interactive/social spaces. Reclaiming urban spaces for people is part of how we can humanize our cities and make our streets more communal. Public spaces are often more than anonymous places that can be replaced with one another: the meetings and exchanges that occur there affect our relationships with each other, giving meaning to our communities and urban landscapes.

Cities that improve and sustain the use of public space, including streets, are more likely to enhance community cohesion, civic identity, and quality of life. Having access to open public spaces does not only improve the quality of life: it is also a first step toward civic empowerment and greater access to institutional and political spaces.

Measuring accessibility to open public area

Public spaces are all places publicly owned or of public use, accessible and enjoyable by all for free and without profit motive. Public spaces and streets are multifunctional areas for social interaction, economic exchange and cultural expression. The methodology for measuring accessibility to open public areas applies these concepts in assessing the level of accessibility to open public areas.

According to CPI methodology guide, the following elements are considered as open public space in any city or urban areas:

- Park: open space inside a municipal territory. Its objective is to provide free air recreation and contact with nature. The principal characteristic is the significant proportion of green area in the zone.
- Civic parks: open space created as the result of building agglomeration around an open area, which later was transformed to a representative and civic area. It has a considerable proportion of nature, specifically gardens. Civic parks provide desirable space for cultural events and passive recreation.
- Square: open space created as a result of building agglomeration around an open area. Its main characteristics are the significant proportion of architectonic elements and the interaction between those buildings and the open area. Squares are usually public spaces that are relevant for the city due to their location, territorial development and/or cultural importance.
- Recreational green area: public green areas that contribute to environmental preservation. All recreational green areas have to guarantee accessibility and have to be linked to urban areas. Their main functions are ornament and passive recreation.
- Facility public area: open space meeting and recreational facilities that are part of the land for city's facilities (a facility is defined such as places which are elementary in all cities. Places that all cities have to have; e.g.: public libraries, stadium, public sports centres, etc.). This land complies with the following characteristics: public property, free transit and access, and active and passive recreation. (e.g.: public area outside a stadium).

Accessibility to open public area is estimated as the proportion of the city population that is less than 400meteres away from an open public area or estimated as the percentage of urban area that is located less than 400 meters away from an open public space. To calculate the indicator it is necessary to use a map of urban open public areas and to follow the below steps:

- Delineate a buffer of 400 meters from the open public spaces polygons.
- Merge and clip with urban perimeter.
- Calculate areas inside the 400 meters buffer.
- Calculate the proportion of urban area located inside the buffer.

Remote sensing imagery can be used to identify intra-urban open public areas when no other information is available.

Other city related spatial indicators that can be used to assess the spatial capital of cities but not applied for this study are provided in Box 1.

Box 1. Other Spatial Capital measures

Ratio of intersection density to street density (intersection frequency)

This translates to the number of nodes (intersections) per length of street in kilometres and is influenced by the design of the roads and the lengths of blocks in urban areas. Higher intersection frequency promotes connectivity and also determines how walkable a city is.

The number of intersections per kilometre of road/street length

This measure is related to the intersection density; however, it is measured as the number of intersections per kilometre of street length as opposed to number of intersections per square kilometre area. Increased number of intersections on a street length will increase interconnectivity with other streets until a maximum number of intersections after which the increased intersections limit movement of traffic within the street. There is usually higher intersection frequency in areas with grid pattern

Average street width

The average street width is reported in meters and has been indirectly estimated from the percentage of land allocated to streets and the street density. In many cities there is a hierarchical allocation in street width, with the streets within certain areas having larger width and narrower widths within residential areas. Wider streets provide space for dedicated lanes for pedestrians, buses, emergency vehicles or trams. Excessively wide roads may inhibit transverse movement of cyclists and pedestrians necessitating construction of specialised crossing zones.

Connected node ratio

The connected node ratio is the number of street intersections divided by the number of nodes plus cu-de-sacs. The maximum value for connected node ratio is 1. A higher number is preferred by planners and indicates that there are relatively fewer cul-de-sacs and therefore greater connectivity in theory.

Methodology for computing street connectivity - spatial analysis

Computation of the connectivity index is grounded on a spatial sampling technique which is based on the Halton sequence of coordinates that uses semi- random selection of 10 hectare locales which contain a set of city blocks surrounded by streets and bounded by the medians of all blocks within these areas. Sample density is determined by the size of the study area. In large urban areas more than 25 square kilometres, one sample per hectare is selected. In a smaller study area, two samples per hectare are selected. The dimensions of the street connectivity index are measured in each of the sampled areas. The average values are computed from all locales sampled in the urban area. Figure 1 below illustrates sampling for computation of land allocated to streets.

Figure 1: Halton sequence of coordinates used for sampling locales win an urban area

Definitions of urban typologies used

The study reports street connectivity disaggregated by land use and by built up density. The following are the definitions of typologies used for disaggregation.

Land use typology

1. Open space consists of unbuilt up areas and include parks, water bodies, forests and unbuilt up urban areas. Open public spaces on the other hand include parks, squares, recreational green areas, and facility public areas such as libraries, etc.
2. Non-residential areas are built up areas that are not used as living areas. These include land under industries, sports facilities, educational facilities, public buildings, hospitals etc.
3. Atomistic or organic developments– the hallmark of atomistic development are buildings that are unconnected and built independently.

4. Informal subdivision refers to areas where groups of housing units have been constructed on land that the occupants have no legal claim to, or occupy illegally or unplanned settlements and areas where housing is not in compliance with current planning and building regulations
5. Formal subdivision where building developments are in compliance with building regulations.
6. Housing project – planned housing development covering a large area usually intended for housing low or moderate income residents
7. Vacant – land available for development but containing no houses, offices or other permanent structures

Built-up density

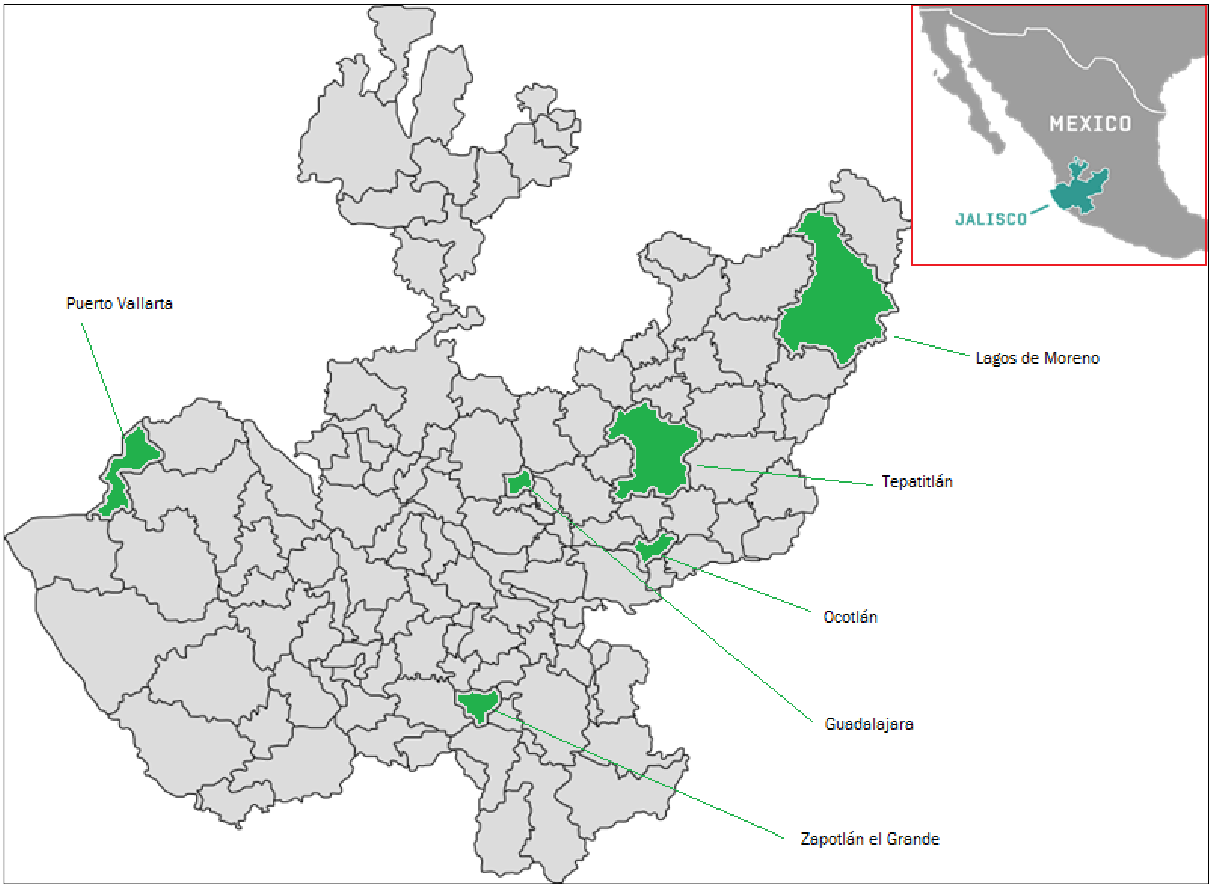
Built-up density also defined as the residential density is a measure of the intensity of dwelling within a given area. Built-up density is the ratio of the number of dwellings to the area of land they occupy including parks, reserves, educational institutions and land taken up by transport infrastructure. UN-Habitat has set a threshold of 15000 to 25000 residences as ideal population density. Areas with lower than 15000 are considered to have low residential density, while areas with more than 25000 are considered to have high residential density.

Measuring the street connectivity for Municipalities in Jalisco State, Mexico

Jalisco State, Mexico

Jalisco (*Estado Libre y Soberano de Jalisco*) is a western Mexico state that borders the Pacific Ocean and had an estimated population of 7.35 million residents by 2010. This street connectivity study covers 6 of the 125 municipalities of Jalisco i.e. Lagos de Moreno, Zapotlan el Grande, Tepatitlán, Puerto Vallarta, Ocotlan and Guadalajara. Five of these municipalities are also seats for the twelve administrative regions of Jalisco and play key economic and administrative roles in the state. Lagos de Moreno is the seat for the Altos Norte region, Tepatitlán de Morelos the seat for Altos Sur region, Zapotlán el Grande the seat for Sur region, Puerto Vallarta the seat for Costa Norte region and Guadalajara the seat for the Centro region and also the state capital.

Figure 2: Jalisco State showing the six municipalities in this study - . Lagos de Moreno, Zapotlan el Grande, Tepatitlán, Puerto Vallarta, Ocotlan and Guadalajara

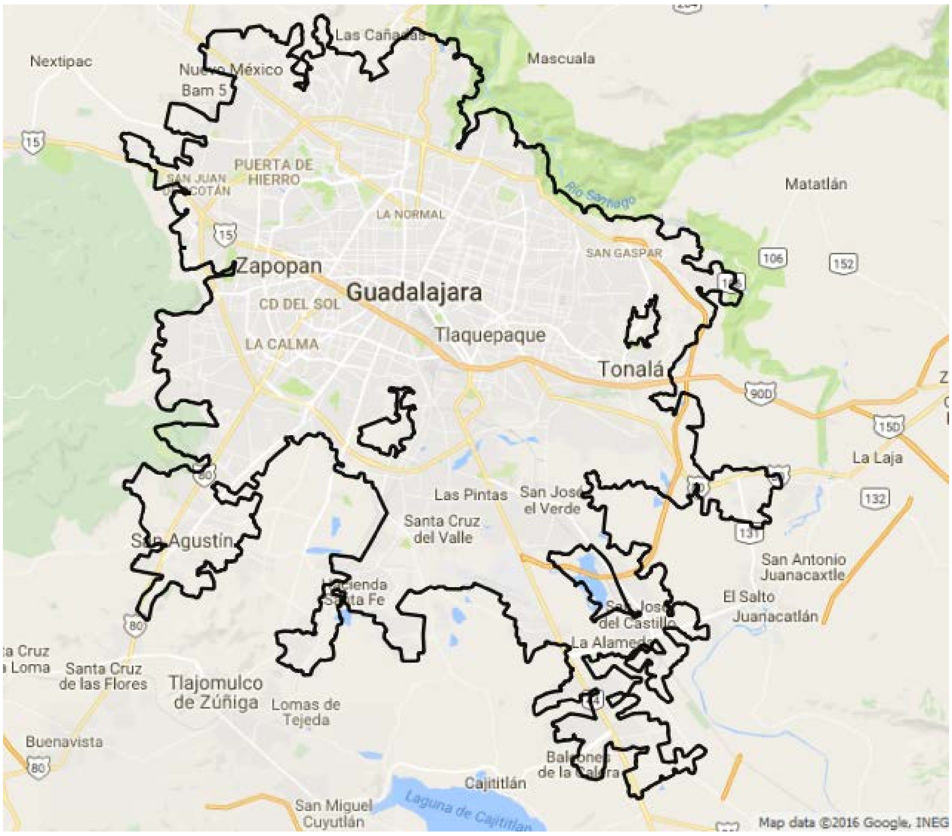


Defining the urban form in the six municipalities

Street connectivity has been measured in more than 100 cities and municipalities across the world. More recently municipalities are requesting for the support of UN-Habitat to compute their Street Connectivity Index independently or as part of the City Prosperity Index. More cities are expected to measure and report their street connectivity in the coming years especially since some of these measures form part of the SDG goal 11 targets and indicators. In Mexico, the street connectivity Index was computed for the built-up urban form comprising of the municipal centre and the suburbs. It is important that boundaries used for computation of indicators are maintained in subsequent computation to allow for comparison.

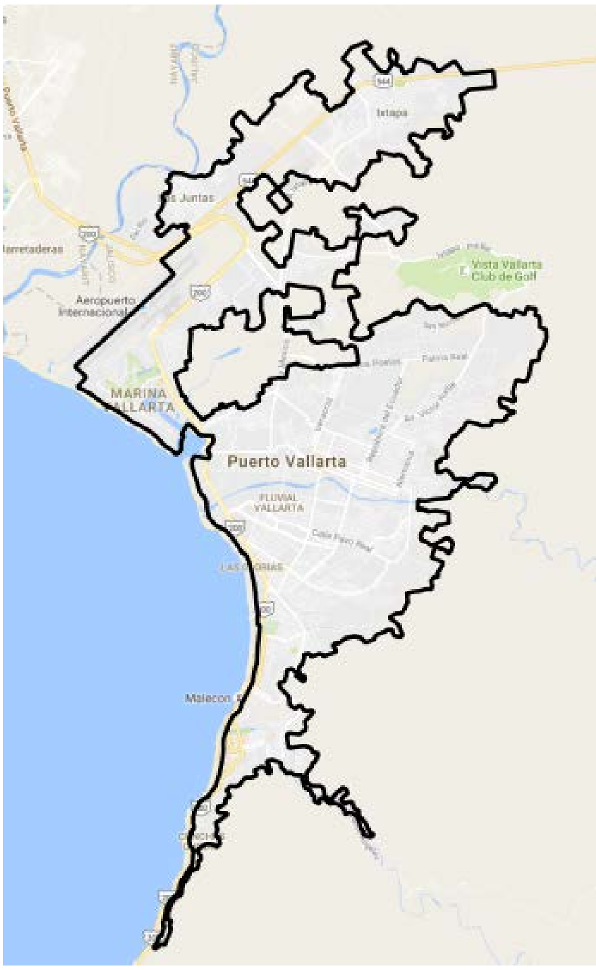
UN-Habitat has defined built-up area of a city as the contiguous area occupied by buildings and other impervious surfaces including the vacant areas in and around them but excluding rural areas beyond the urban fringe. The delimitation of the built-up areas distinguishes urban, suburban and rural areas based on the built-up densities. Boundaries of the urban form used in the six municipalities have been described in figure 3 to figure 8 below.

Figure 3: Guadalajara Municipality



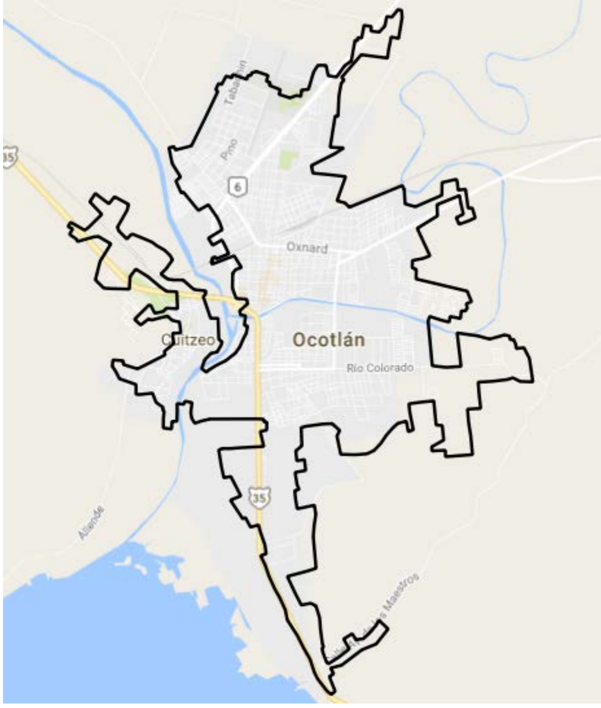
Municipality: Guadalajara
Area: 2,734 km^2
Population: 4.8 million
SCI: 88

Figure 4: Puerto Vallarta Municipality



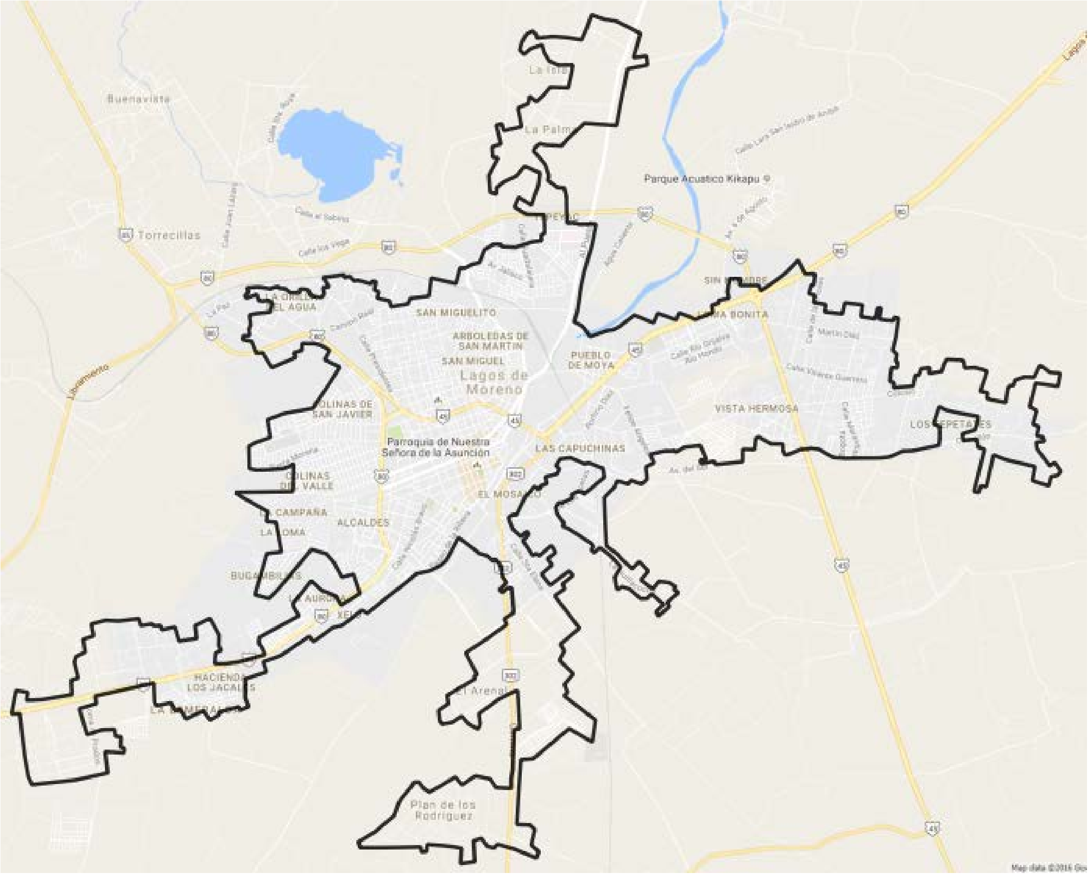
Municipality: Puerto Vallarta
Area: 1,300 km^2
Population: 440,000
SCI: 86

Figure 5: Octolán Municipality



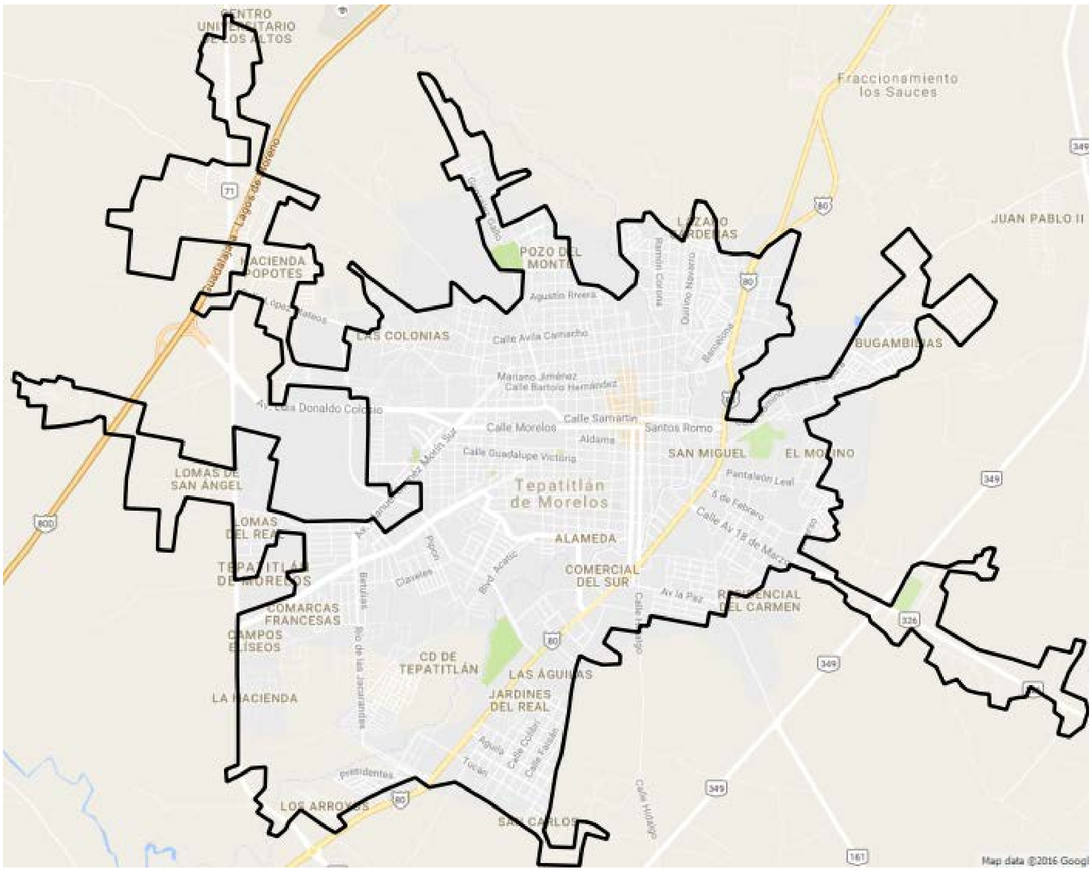
Municipality: Octolán
Area: 247 km^2
Population: 150,000
SCI: 84

Figure 6: Lagos de Moreno Municipality



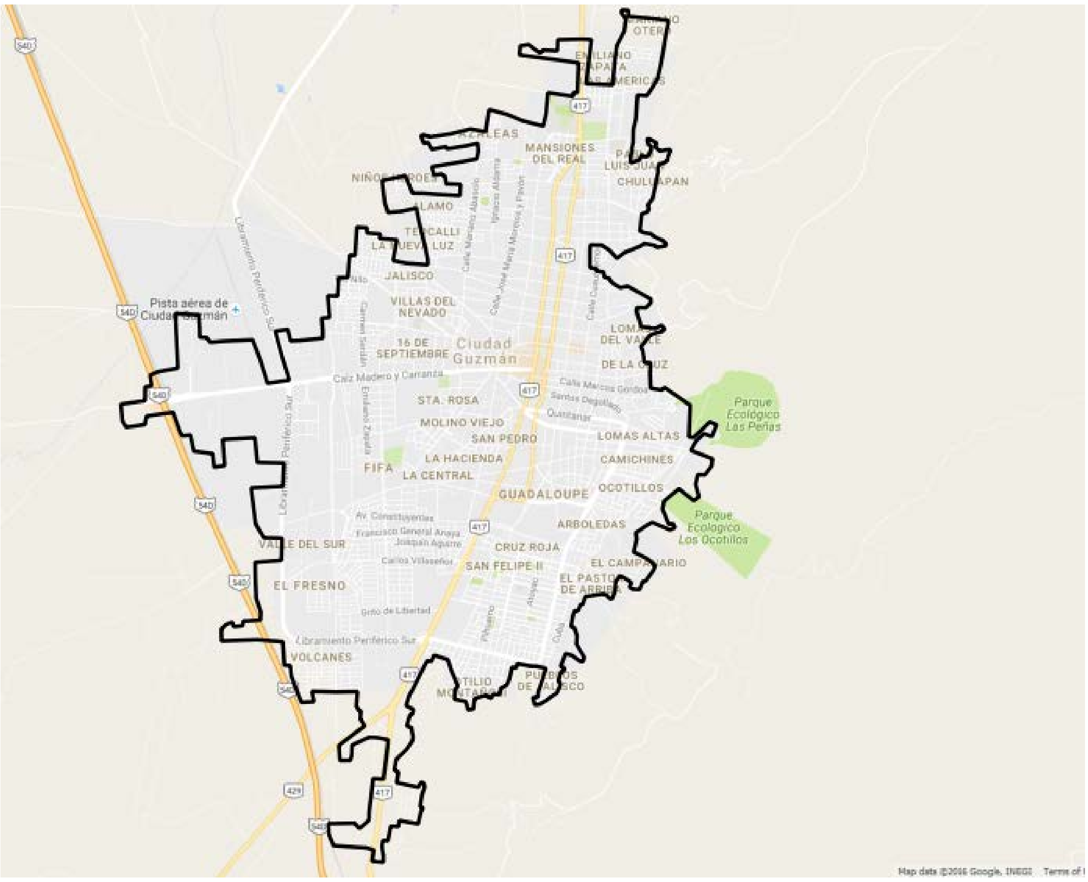
Municipality: Lagos de Moreno
Area: 2,648 km^2
Population: 166,000
SCI: 81

Figure 7: Tepatitlán de Morelos Municipality



Municipality: Tepatitlán de Morelos
Area: 1,532 km^2
Population: 136,000
SCI: 85

Figure 8: Zapotlan el Grande Municipality



Municipality: Zapotlan el Grande
Area: 295 km^2
Population: 107,000
SCI: 86

Results for the street connectivity index

This study presents findings from the street connectivity analysis for 6 municipalities in Jalisco State, Mexico. Findings from the street connectivity index analysis are meant to facilitate and enable officials of these municipalities to benchmark their municipalities with other cities/municipalities in Mexico and around the world and also serve as a catalyst to advocate for policy changes and increased investments to address gaps that may be identified by this study.

In this study, street connectivity has been presented in two broad disaggregation categories. The first major disaggregation category is by land use and the second category is by built up density.

Street connectivity in six municipalities in Jalisco

As noted earlier, Street connectivity is a composite index of land allocated to streets, intersection density and street density. This composite index measures the integrated form of the street density, street length and the number of intersections per square kilometre. High scores on the street connectivity indicator imply better accessibility, connections, penetration, mobility and coverage of the whole city. Derivation and computations of the SCI has been described earlier. SCI has been reported for urban areas excluding open space so as not to distort the index by providing spuriously lower values in municipalities with high proportion of vacant land. Standardised measures of intersection density, street density and the land allocated to streets have been used in computation of the street connectivity index. The standardisation process uses cut-offs for land allocated to streets and for intersection density. In the case of street density, the standardisation process is targeted at 20 kilometres of streets per square kilometre and penalises municipalities with values higher or lower than 20 kilometres street length. Details of the standardisation procedure are presented in the appendix.

Table 3: Results of street connectivity index for the six municipalities showing the crude and standardized land allocated to streets, street density and intersection density.

Municipality	Percentage of Land Allocated to Streets (%)	Street Density (Km/Km2)	Intersection Density (#int/Km^2)	LAS^s	SD^s	ID^s	SCI
Lagos de Moreno	22.6%	22.6	170.7	55	86.8	100	81
Zapotlán el Grande	25.7%	21.4	144.2	66	93	100	86
Tepatitlán	26.0%	22.1	132.7	67	90	100	85
Puerto Vallarta	25.5%	21.5	151.6	65	93	100	86
Ocotlan	24.7%	22.3	142.2	62	88	100	84
Guadalajara	26.9%	21.3	150.9	70	93	100	88

LAS^s, SD^s and ID^s are standardised measures for land allocated to streets, street density and intersection density.

#Int/Km^2 The number of intersections per square kilometre

Table 3 above presents findings of the street connectivity index for the six municipalities in Jalisco. The SCI scores ranges from 81 points in Lagos de Moreno to 88 in Guadalajara which is the state capital. All the cities have high SCI, high intersection density and high street density. Moderate proportion of land has been allocated to streets in all the municipalities. This may indicate use of traditional narrow street design or instances where land originally planned for streets is converted to other uses. The overall street density and the intersection densities are above UN-Habitat recommendations for all the municipalities. Guadalajara has the highest proportion of unstandardized land allocated to streets at 27% while the lowest figure is observed for Lagos de Moreno (23%). The SCI in this analysis is mainly driven by the variability in land allocated to streets and the street density since all the municipalities have very high standardised intersection density values. Figure 9 below illustrates the relationship between the three indicators and street connectivity index for the various municipalities.

Figure 9: Relationship between the street connectivity indexes, land allocated to streets, intersection density and street density.

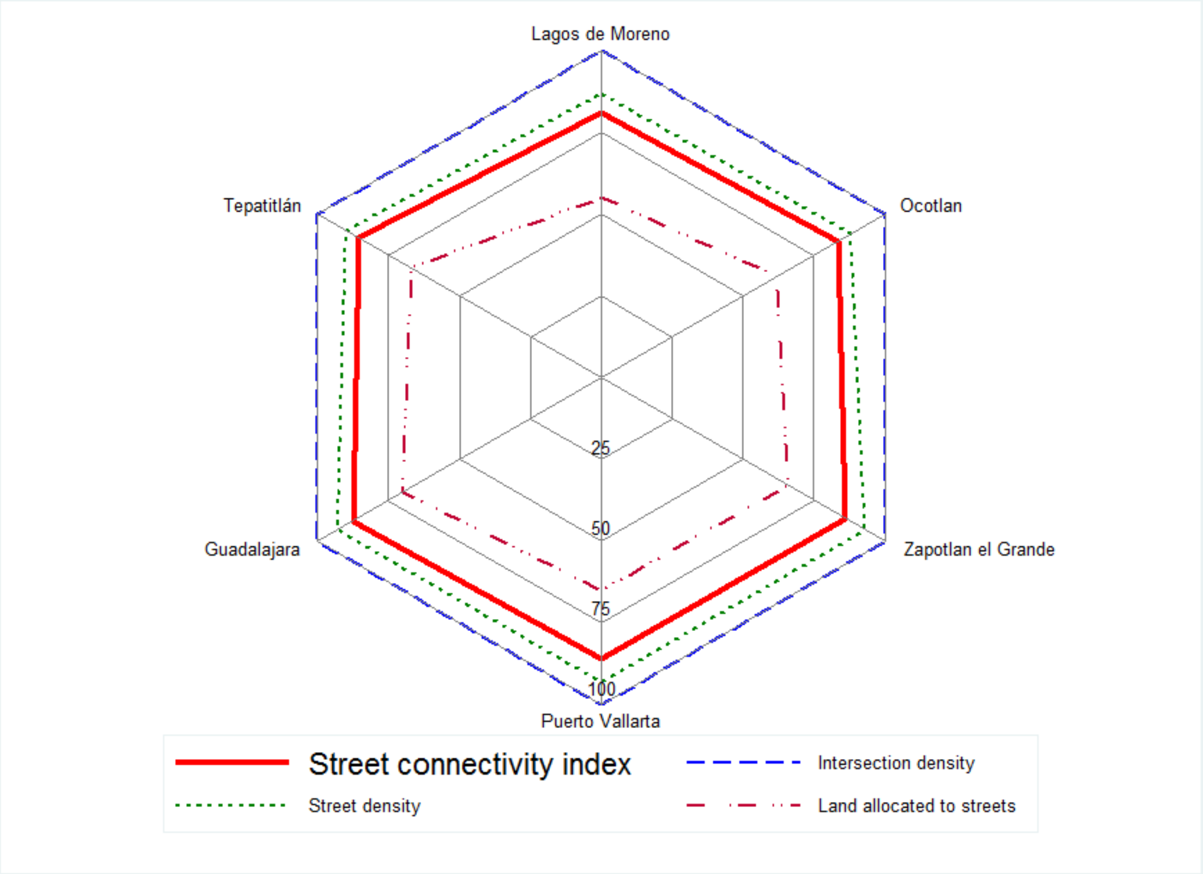


Figure 10: Street connectivity index across land use typologies and by built-up density in the six municipalities

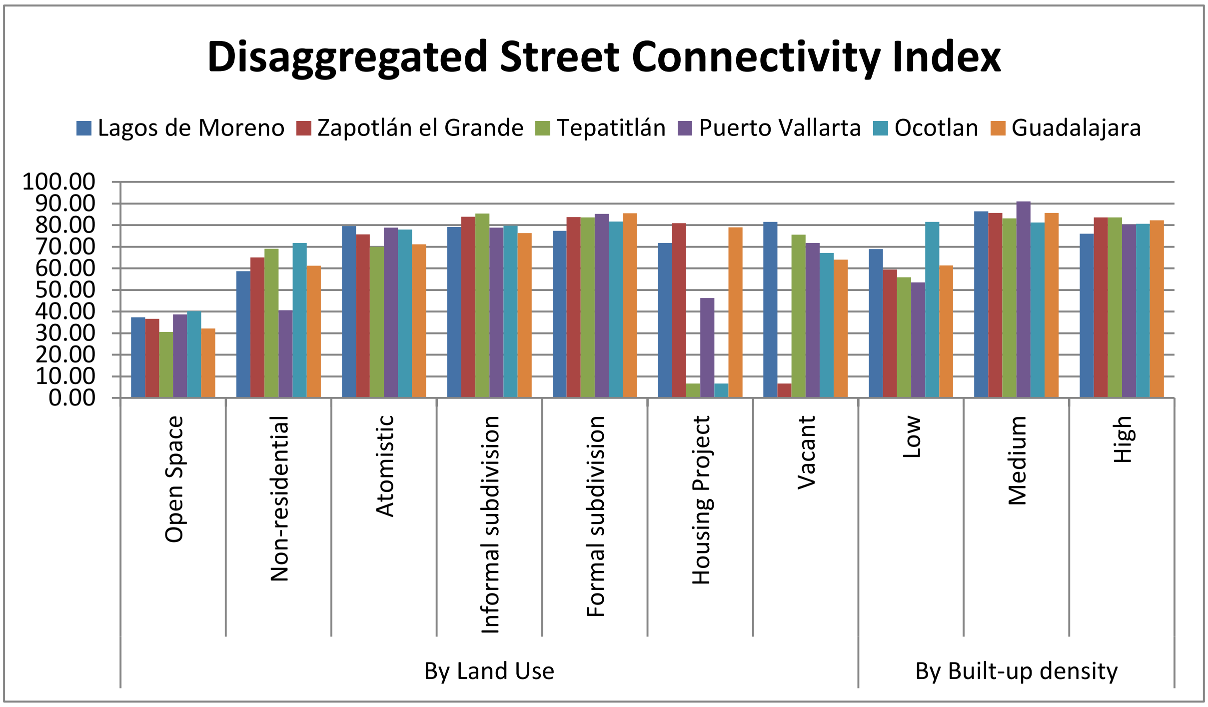
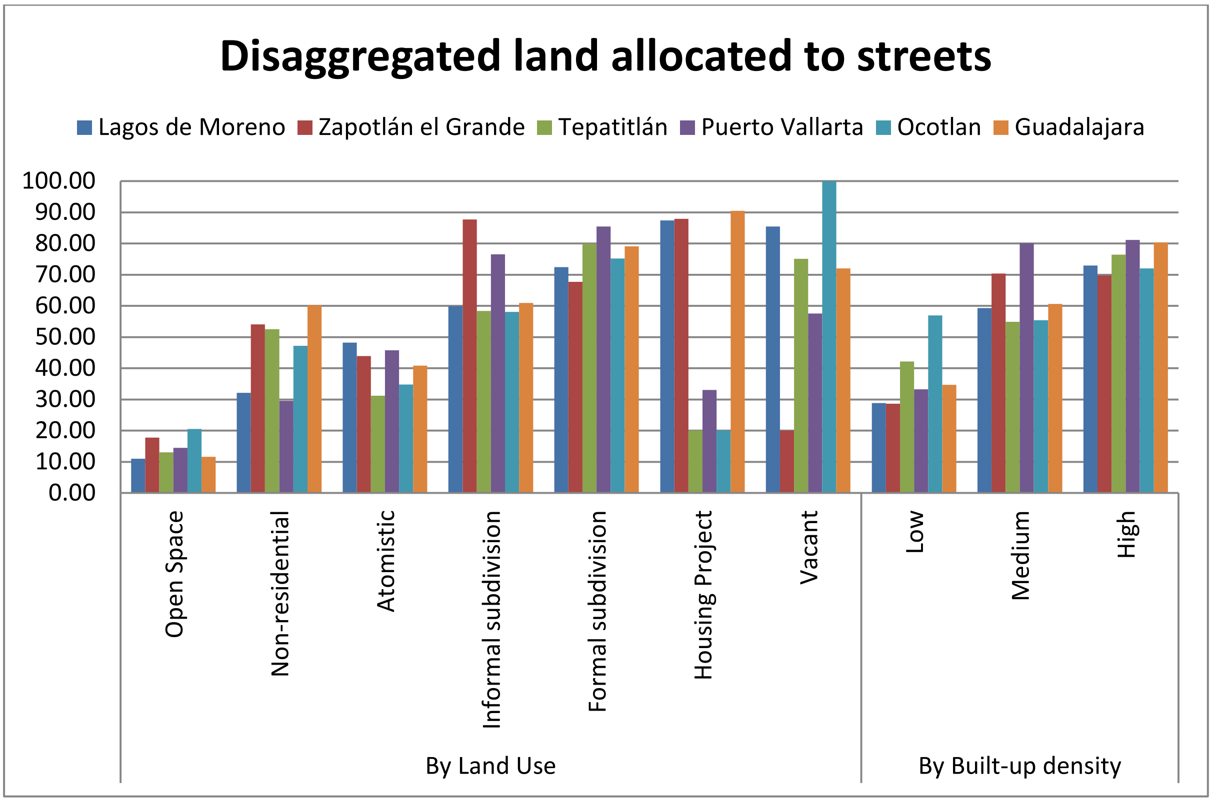


Figure 10 shows the SCI disaggregated by land use typologies and by built-up density. The SCI in non-residential typology ranges between 41 points in Puerto Vallarta to 72 points in Octolan. Non-residential typology includes facilities such as hospitals, schools and industrial parks which may be built over large portions of land without interconnecting streets. Majority of the residents in the six municipalities would be living in areas under atomistic, formal subdivision and informal typologies. These typologies have moderate to high SCI across all municipalities ranging from 72 points to 92 points. SCI within the housing project typology shows a mixed pattern with Lagos de Moreno, Zapoltlan el Grande and Guadalajara having high SCI of above 90 points while Puerto has a low SCI of 46.3 points. Tepitlan and Octolan did not have any of the sampled land under housing project typology. Housing projects are built to accommodate high population density with minimal per capita investment on infrastructure. When housing projects are built on land with existing streets or with street connectivity to match surrounding areas, the result is a typology with high SCI. Occasionally; housing projects are built on a large contiguous piece of land with few streets between individual blocks resulting in low SCI as seen in Puerto Vallarta. SCI in vacant land is high, above 85 points in all the municipalities apart from Zapoltlan el Grande which has SCI of 6.7 points under the vacant land category.

Land allocated to streets

As previously mentioned, the UN-Habitat recommendation for land allocated to streets is 30% of the urban area. In this study, land allocated to streets is the most important factor in distinguishing how the cities perform on the street connectivity index since it is the only indicator that contributes to significant variability of the index. The land allocated to streets (unstandardized) generally falls below the UN-Habitat recommendation and ranges between 23% in Lagos de Moreno to 26% in Guadalajara. The values of land allocated to streets is similar to land allocated to streets in many cities in the developed world of between 23 and 28 % LAS which can be classified as low to moderate LAS as per UN-Habitat proposed standards in the City Prosperity Initiative.

Figure 11: Land allocated to streets (LAS) – standardised- across the land use typologies and by built-up density in the six municipalities



Standardisation of LAS transforms crude LAS to point based system with values between 0 and 100. Areas with less than 6% of land allocated to streets are allocated 0 points while areas with more than 36% of land allocated to streets are allocated 100 points. Standardised land allocated to streets however varies greatly based on the residential disaggregation and built-up density. Figure 11 illustrates the land allocated to streets (LAS) by the land use typologies and by built-up density in the six municipalities. As expected, open spaces generally have less land allocated to streets than other urban typologies. The standardised land allocated to streets in open spaces is 11 points while the land allocated to streets in housing projects of Lagos de Moreno is 87 points. This pattern of low land allocated to streets in vacant lands and highest amount of land allocated to streets is repeated across all the six municipalities apart from Octolan and Tepatitlán which do not have land under housing projects. In Octolan and Tepatitlán the highest amount of land allocated to streets is under the formal subdivision typology category.

The results show that in all the six selected municipalities of Mexico, the land allocated to streets increases as the built- up density increases. When land allocated to streets is disaggregated by land use, land allocated to streets shows variations across the various categories of land use—i.e. land allocated to streets is lowest in the open spaces categories and increases for the non-residential, atomistic, informal subdivision and formal subdivision respectively. There is a mixed pattern of land allocated to streets in housing projects and vacant land, however, in these two typologies; land allocated to streets is higher than what is observed for the open spaces.

Figure 12: Land allocated to streets (LAS) – unstandardized- across the land use typologies and by built-up density in the six municipalities

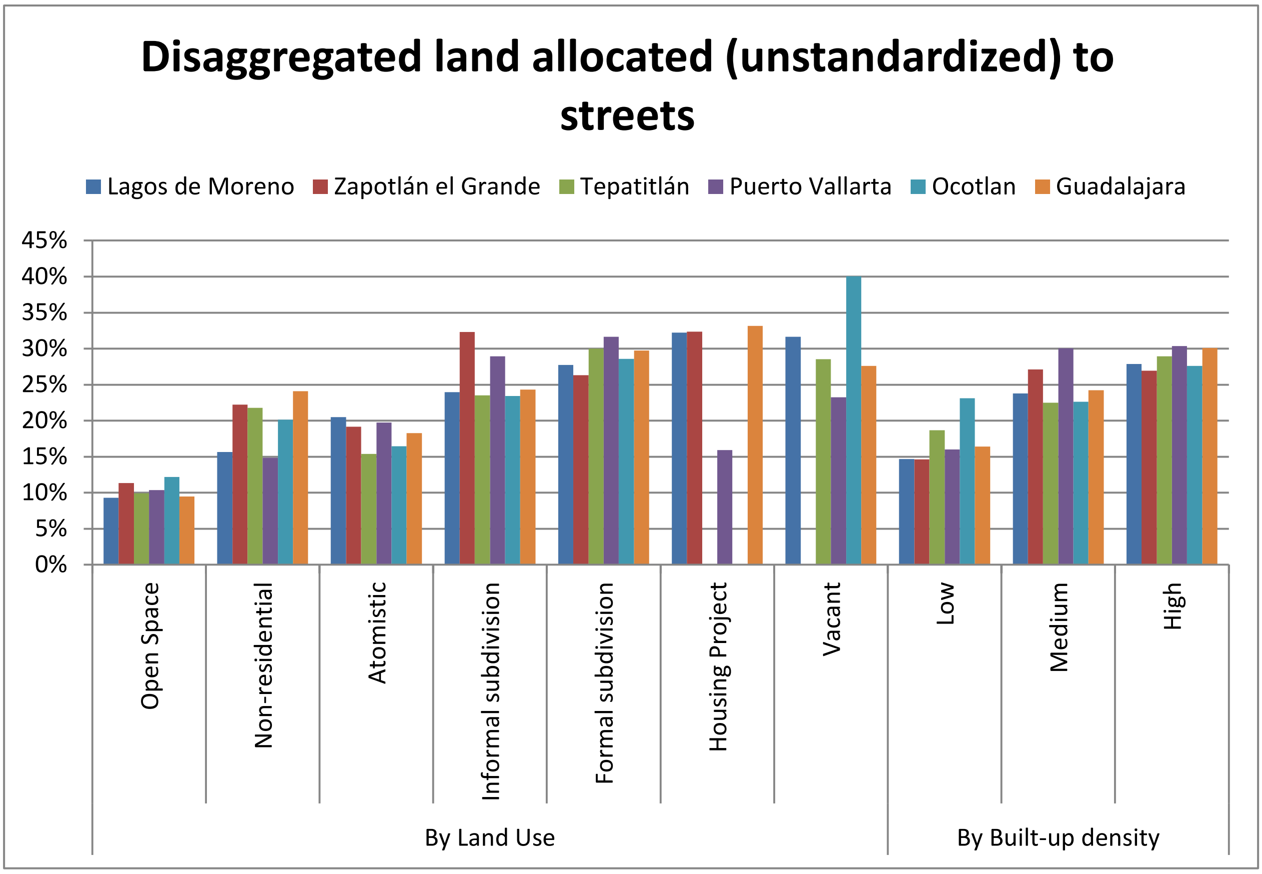


Figure 12 illustrates the unstandardized land allocated to streets (LAS) by the land use typologies and by built-up density in the six municipalities. The proportion of land allocated to streets varies through the different typologies in a similar pattern across all the municipalities. The lowest proportion of land allocated to streets is observed under the category of open spaces followed by non-residential typology, atomistic, informal and formal subdivisions respectively. Housing projects and vacant land also have higher proportion of land allocated to streets of between 20 and 35%, however housing projects do not appear in Tepatitlán and Octolan and there is no vacant land in Zapotlán el Grande and Octolan. When disaggregated by built up density, land allocated to streets increases with increasing built up density - with the land allocated to streets at approximately 15%, 20% and 25% in low, medium and high residential densities respectively. Formal subdivision typology meets the 30% LAS threshold in Tepatitlán, Puerto Vallarta and Guadalajara.

Street density

When standardising street density, a street density of 20 kilometres of street per square kilometre is used as the target for street density. Areas with street density of less than 20 kilometres per square kilometre are penalised during standardisation of street density since values higher or lower than 20 have been found to slow movement. Areas or typologies with a street density of more than 20 km/km^2 have perfect standardised street density of 100 points. In this analysis, open spaces have standardised street density of approximately between 40 and 50. Atomistic typologies have high standardised street density of between 81 and 90 points. Figure 14 below show the standardised street density (SD) across the land use typologies and by built-up density in the six municipalities.

Street widths

Street widths can be indirectly estimated from the LAS and street density. The average street width ranges from 10.0 metres in Lagos de Moreno to 12.6 metres in Guadalajara. Examining the average street width by different land use typologies, non-residential areas have wider streets ranging from 12.3 metres in Lagos de Moreno to 19.34 metres in Guadalajara compared with other residential typologies. Street width is an important factor in connectivity as it determines the number and type of transportation units can be accommodated within a single street such as walking paths, dedicated cycling and bus lanes.

Figure 13: Street density (SD) – standardized- across the land use typologies and by built-up density in the six municipalities

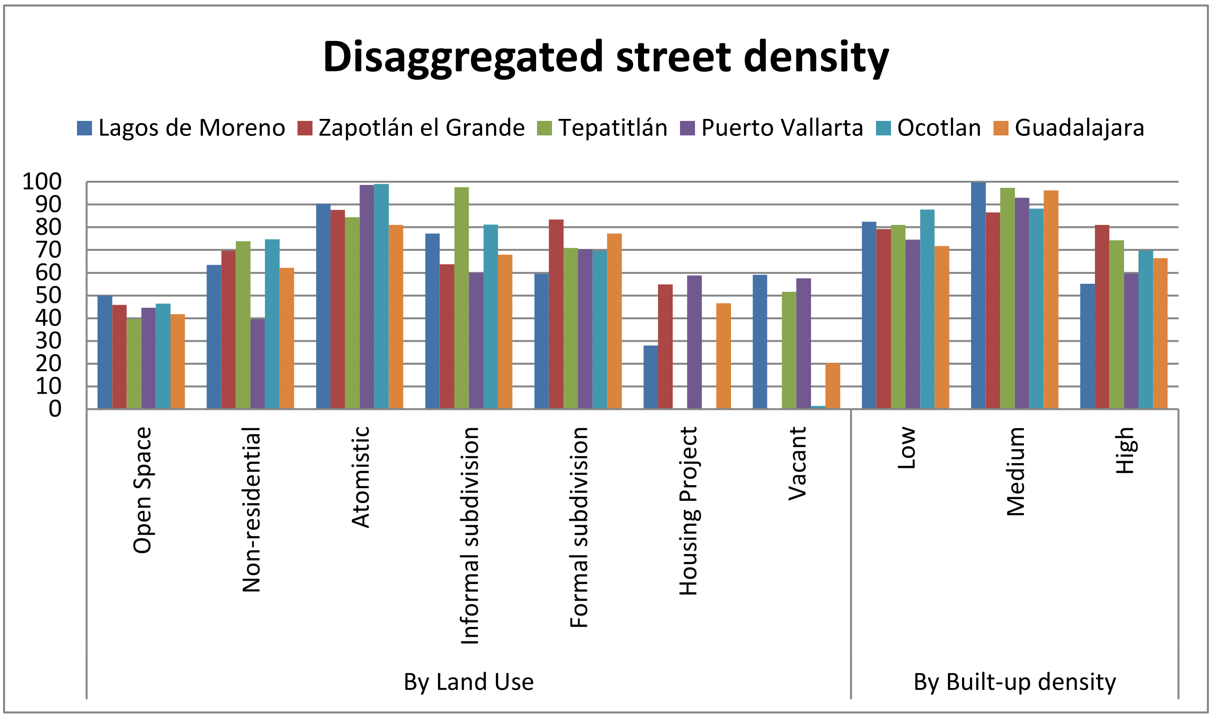
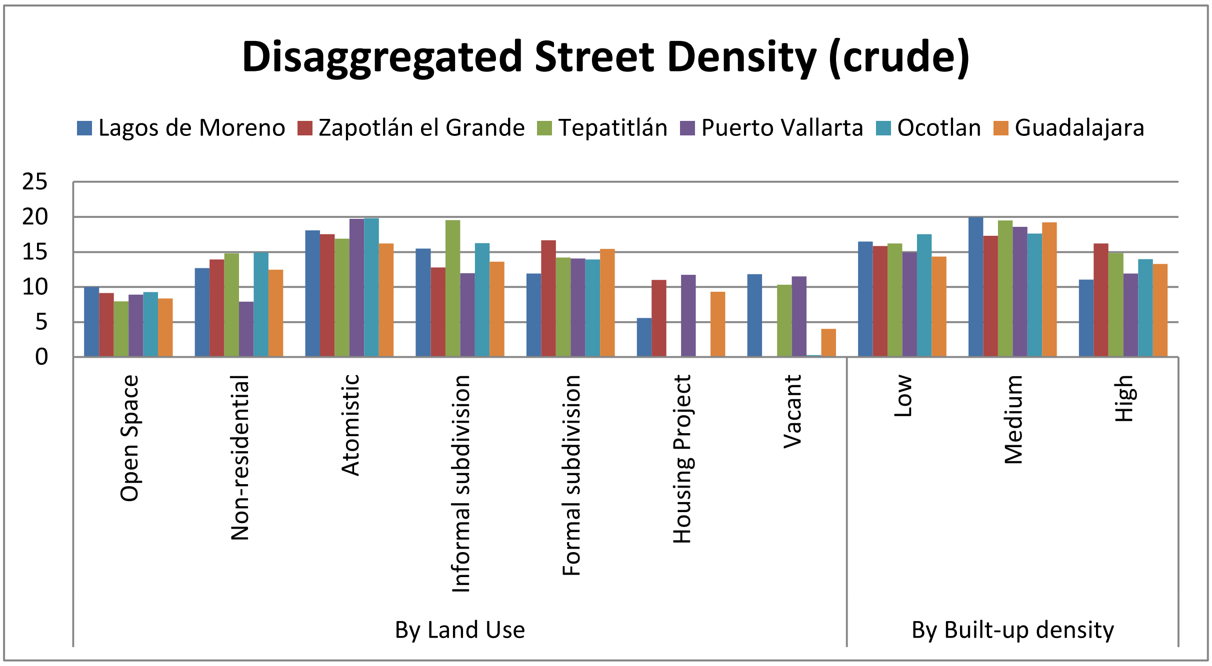


Figure 13 shows the unstandardized street density (SD) across the land use typologies and by built-up density in the six municipalities. The unstandardized street density for the six municipalities in Jalisco varies in a similar pattern as the other indicators through the typological disaggregation and built-up density. The unstandardized street density is lowest in typologies under open space and highest in typologies under formal and informal subdivisions. There is a gradual increase in the street density with increase in built up density. Lagos de Moreno municipality has the lowest street density while Guadalajara has the highest street density.

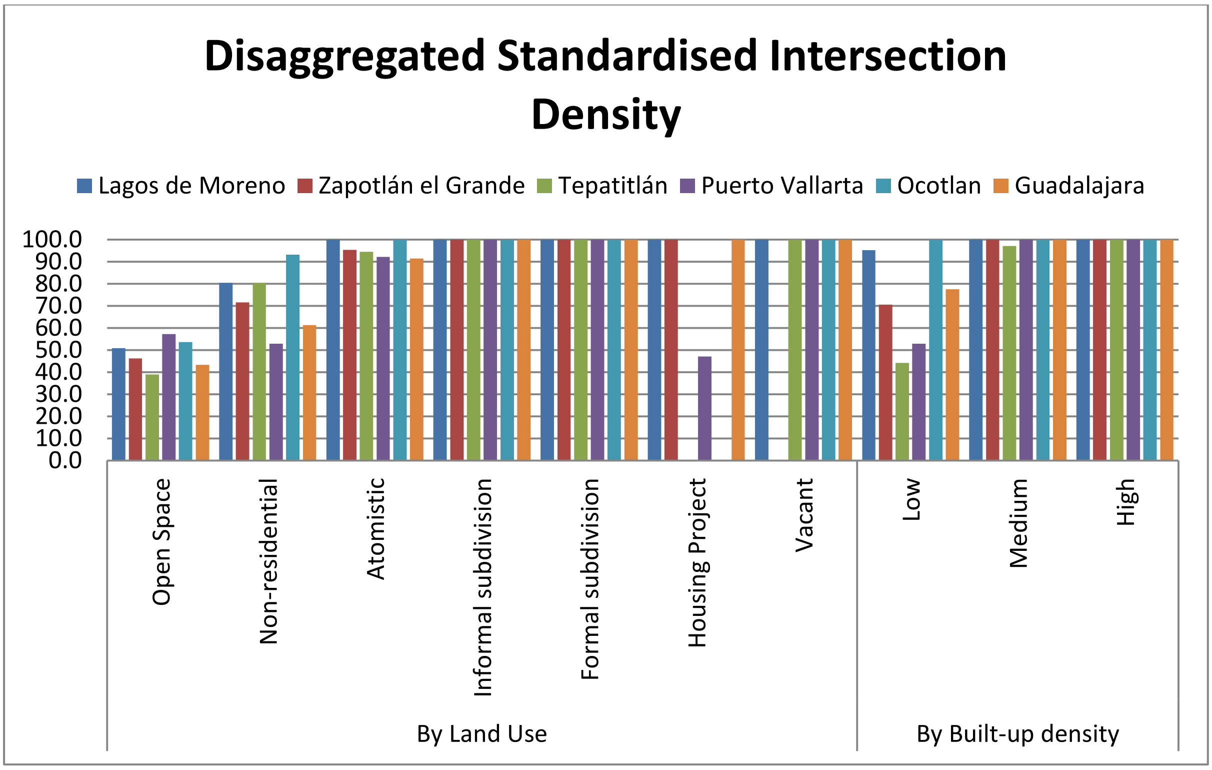
Figure 14: Street density (SD) – unstandardized- across the land use typologies and by built-up density in the six municipalities



Intersection density

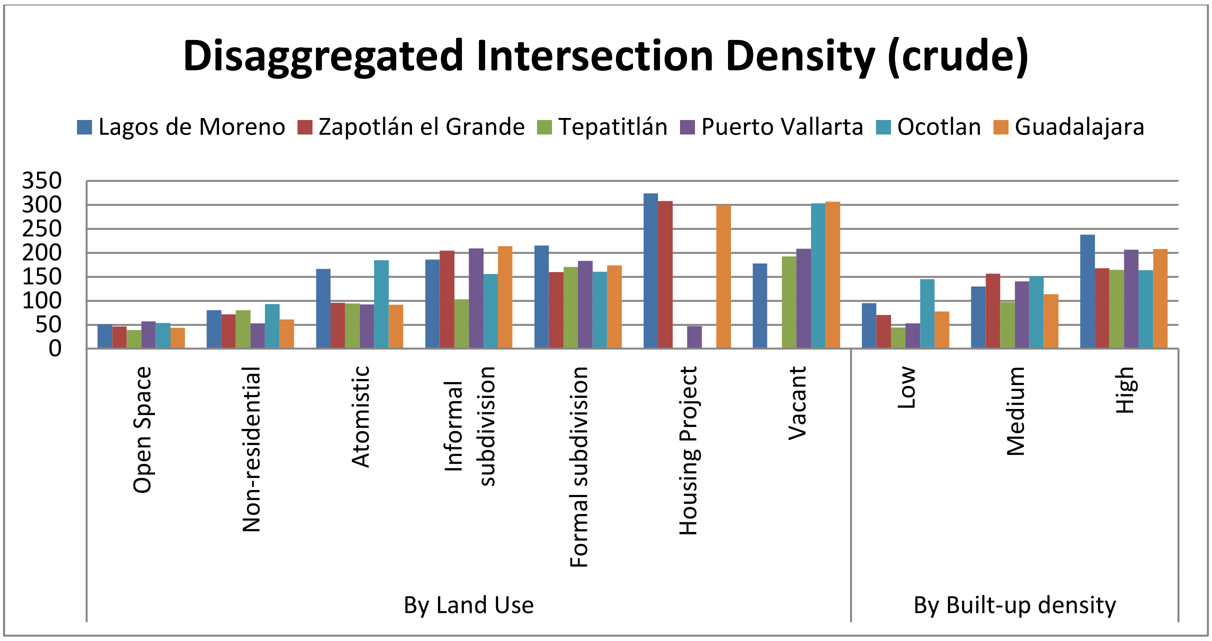
Intersection density is a key factor to street connectivity. UN-Habitat recommends about 100 intersections per square kilometre, and such a level makes the city to be more conducive to the use of non-motorized transport. During standardisation of intersection density, 100 intersections per square kilometre is the upper limit; typologies with intersection density equal or above 100 have their values defaulted to 100 points during standardisation. In all the six municipalities the average unstandardized intersection density is more than 100 intersections per square kilometre. However when disaggregated by typology and built up density open spaces and non-residential areas typologies and areas with low residential density have lower than 100 intersections per square kilometre. A city with a ‘perfect’ grid street pattern, with square blocks and a street every 100 m on each direction would have 100 intersections per km^2. Figure 15 below shows the standardised intersection density (ID) across the land use typologies and by built-up density in the six municipalities while figure 16 shows the unstandardized intersection across land use typologies and built-up density.

Figure 15: Intersection density (ID) – standardized- across the land use typologies and by built-up density in the six municipalities



The unstandardized intersection density shows higher variability than the standardised intersection density and ranges from 39 intersections per square kilometre in open space typology in Tepatitlán to 324 intersections per square kilometre in housing project typology of Lagos de Moreno. Generally intersection density varies in a similar pattern in all municipalities across the disaggregation by land use and by built up density. Open spaces have the least intersection density across all the municipalities while formal subdivisions and housing projects have highest intersection density. Similarly, intersection density increases with the residential density with areas with lower residential density having the lowest intersection density and areas with high residential density having the highest intersection density. Overall, residential typologies in the cities of Mexico have intersection densities that fall on average above UN-Habitat threshold, while non-residential typologies tend to have are below the minimum recommended UN-Habitat threshold.

Figure 16: Intersection density (ID) – unstandardized- across the land use typologies and by built-up density in the six municipalities



Results from the accessibility to open public area and green area per capita in five municipalities of Jalisco

We also analysed the data on accessibility to open public spaces and green area per capita for five of the six municipalities in Jalisco. The data was analysed for accessibility to open public areas, open public space per capita, and green area per capita (see table 6 below). About one third of residents in Zapotlan el Grande have accessibility to open public spaces, while in Ocotlan and Lagos de Moreno municipality results show that nearly one in four residents have access to some form of open public area. Guadalajara and Puerto Vallarta have relatively high number of residents that have access to open public spaces i.e. 47 and 42 per cent respectively. In Tepatitlan, nearly half of all residents have access to open public areas. With the exception of Lagoes de Moreno and Ocotlan municipalities, the other remaining municipalities with relatively high levels of access to open public space show signs of some level of deliberate housing and public space planning at the city design level which shows compliance with original municipal plans. However, even when open public space is widely available, the growing numbers of city populations can easily overwhelm the accessibility, usage and maintenance of such facilities. The measure of open public space per capita is a good measure of assessing whether there is equitable and sustainable accessibility to open public spaces.

Table 6: Accessibility to open public spaces, open public spaces per capita and the green area per capita

Indicator	Guadalajara	Lagos de Moreno	Ocotlan	Puerto Vallarta	Tepatitlan	Zapotlan el Grande
Accessibility to Open Public Area	46.9	25.7	24.1	41.8	51.6	33.9
Open public space per capita	7.2	0.4	1.8	1.8	1.6	2.7
Green area per capita	16.9	1.8	2.6	6.6	-	3.8

Open public space per capita is lowest in Lagos de Moreno at 0.4 square metres per person, and highest in Guadalajara municipality at 7.2 square metres per person. Given the low accessibility to public spaces in Lagos de Moreno and Ocotlan, the land allocated for public spaces for the population is also low at about 0.4 and 2 square metres per person, respectively. Surprisingly open public space per capita in Puerto Vallarta and Tepatitlan is also low at 1.8 and 1.6 square meters per person. On the other hand, Zapotlan had a relatively low score on accessibility to open public areas (34%), but has a better score at 2.7 in terms of open public space per capita than the four other municipalities of Lagos de Moreno, Ocotlan Tepatitlan and Puerto Vallarta. This finding has several implications in terms of planning for today and planning for future demands of open public spaces.

Green areas perform important environmental functions in urban areas. Primarily, they help improve the air quality, urban climate, capture atmospheric pollutants and provide recreation for urban inhabitants. In the selected municipalities of Jalisco state, the average green area per capita ranges from 1.8 square metres per person in Lagos de Moreno to 16.9 square metres per person in Guadalajara. Green area per capita follows similar pattern to the open space per capita with municipalities having larger green areas per capita having larger open space per capita. The high levels of access to open public spaces contrasted by low per capita open public space and per capita green area may be an indication of municipal areas whose population density has grown as the open public spaces and green areas have remained constant. This is a challenge that many rapidly urbanising municipalities face. From this analysis, it is evident that Mexico's municipalities and cities at large are becoming denser and they will need a variation of green space solutions to maintain the right ratios or combinations of green spaces to populations. Municipal officials need to explore creative solutions to ensure that in the background of rapid urbanisation and growing population, all residents are able to access open public spaces and green spaces incrementally. This can be achieved through urban extensions that accommodate increased shares of the open public spaces or reclaiming lands in urban areas to accommodate a fair ratio of these spaces that matches the population growths.

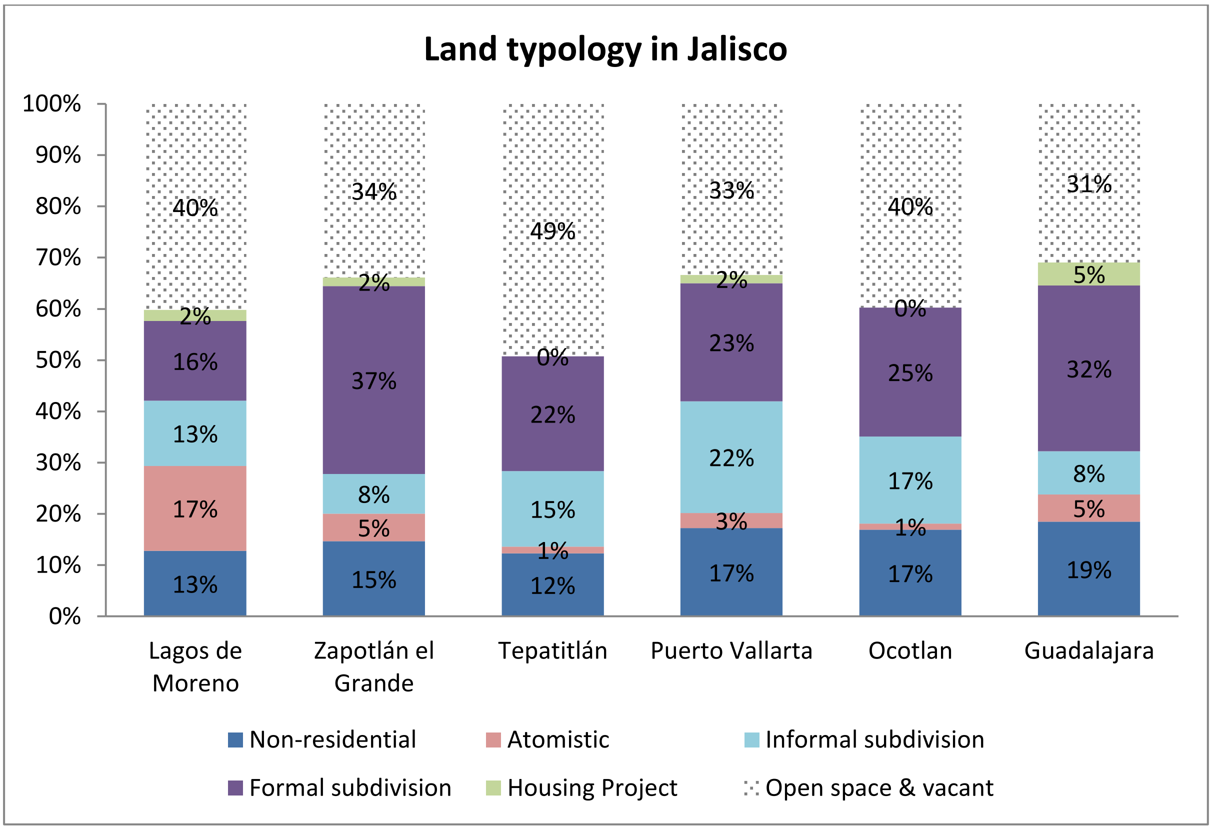
Intra-municipality street connectivity analysis

The intra-municipality model of street connectivity aims at assessing which urban forms have better connectivity and therefore better placed for prosperity. Different urban typologies are analysed in view of how they perform.

There are seven typologies under the land use category i.e. vacant land, non-residential, atomistic (organic), informal subdivision, formal subdivision, housing project and vacant land.

All typologies are dichotomised into two main functional areas; the residential type which includes atomistic, formal subdivisions, informal subdivisions and housing projects; and non-residential areas which includes urban amenities, open space and vacant land.

Figure 17: Land typologies for the six municipalities in Jalisco



Based on land typology disaggregation, majority of the urban land in the six municipalities falls under formal, informal subdivision and non-residential subdivision. Figure 17 above illustrates the proportion of land use typologies in the six municipalities.

Land under formal subdivision ranges from 16 % in Lagos de Moreno to 37% in Zapotlán el Grande. Land under formal subdivision represents areas of the municipalities where deliberate planning has taken place or where original plans have been enforced. Zapotlán el Grande and Guadalajara have the lowest proportion of the urban area under informal subdivision at 8% while Puerto Vallarta has the largest proportion of land under informal subdivision at 22 %. Land under non-residential use ranges from 12% in Tepatitlán to 19% in Guadalajara. Tepatitlán and Octolan municipalities have no land under housing projects while 2% of the land in Lagos de Moreno, Zapotlán el Grande and Puerto Vallarta and 5% of the municipal land in Guadalajara is under housing project. Land under atomistic subdivision ranges from 1% in Puerto Vallarta and Octolan to 17% in Lagos de Moreno.

Table 4: Proportion of land occupied by different residential typologies

Typology	Lagos de Moreno	Zapotlán el Grande	Tepatitlán	Puerto Vallarta	Ocotlan	Guadalajara
Non-residential	13%	15%	12%	17%	17%	19%
Atomistic	17%	5%	1%	3%	1%	5%
Informal subdivision	13%	8%	15%	22%	17%	8%
Formal subdivision	16%	37%	22%	23%	25%	32%
Housing Project	2%	2%	0%	2%	0%	5%
Open space & vacant	40%	34%	49%	33%	40%	31%

Table 5: Street connectivity index (SCI) for different municipalities by land category

Functional area	Typology	Lagos de Moreno	Zapotlán el Grande	Tepatitlán	Puerto Vallarta	Ocotlan	Guadalajara
Group 1 – residential	Atomistic	79.55	75.70	70.04	78.83	77.97	71.19
	Informal subdivision	79.09	83.86	85.36	78.80	79.80	76.33
	Formal subdivision	77.32	83.70	83.62	85.29	81.64	85.46
	Housing Project	71.81	80.95	-	46.33	-	79.00
Group 2 – non-residential	Open Space	37.33	36.63	30.60	38.79	40.22	32.25
	Vacant	81.55	-	75.60	71.71	67.13	64.08
	Non-residential	58.72	65.16	69.02	40.70	71.71	61.27
	Low	68.87	59.51	55.85	53.60	81.59	61.33
	Medium	86.36	85.65	83.17	91.05	81.19	85.64
	High	76.05	83.62	83.59	80.28	80.60	82.23

Residential-Atomistic typology

Atomistic development is irregular in layout and was not subdivided before residential development took place. As a category, it includes all residential development that is not a subdivision or a project and usually represents areas of the municipality that have grown organically rather as a result of systematic planning. The SCI in atomistic typology ranges from 70 points in Tepatitlán to 80 points in Lagos de Moreno. Despite having developed organically, areas under atomistic development have moderately high connectivity in the six municipalities. The SCI for different municipalities by atomistic typology are presented in table 5 above.

Atomistic development

Residential – Informal subdivision

Informal subdivisions are areas in which land has been subdivided for urban use, but lacking visible evidence of legal formality, such as paved streets, streetlights, or sidewalks. Plot sizes may be regular or semi-regular. Structures are laid out along linear or generally linear roads, with regular intersections. Informal subdivisions have a SCI of between 76 points in Guadalajara to 85 points in Tepatitlán. The informal subdivision has high street connectivity and meets the UN-Habitat recommendations for intersection density. The land allocated to streets and the street densities in this typology are also close to the recommendations in all the six municipalities.

Informal subdivision

Residential – Formal subdivision

Formal subdivisions are characterised by high level of infrastructural investments. The streets are usually linear and meet at right angles. On the street level, there is investment on walking paths and the qualities of the structures are usually higher than other subdivisions. In this study the street connectivity in the formal subdivision ranges from 77 points in Lagos de Moreno to 85 points in Guadalajara. The formal subdivision has met UN-Habitat recommendation for street connectivity.

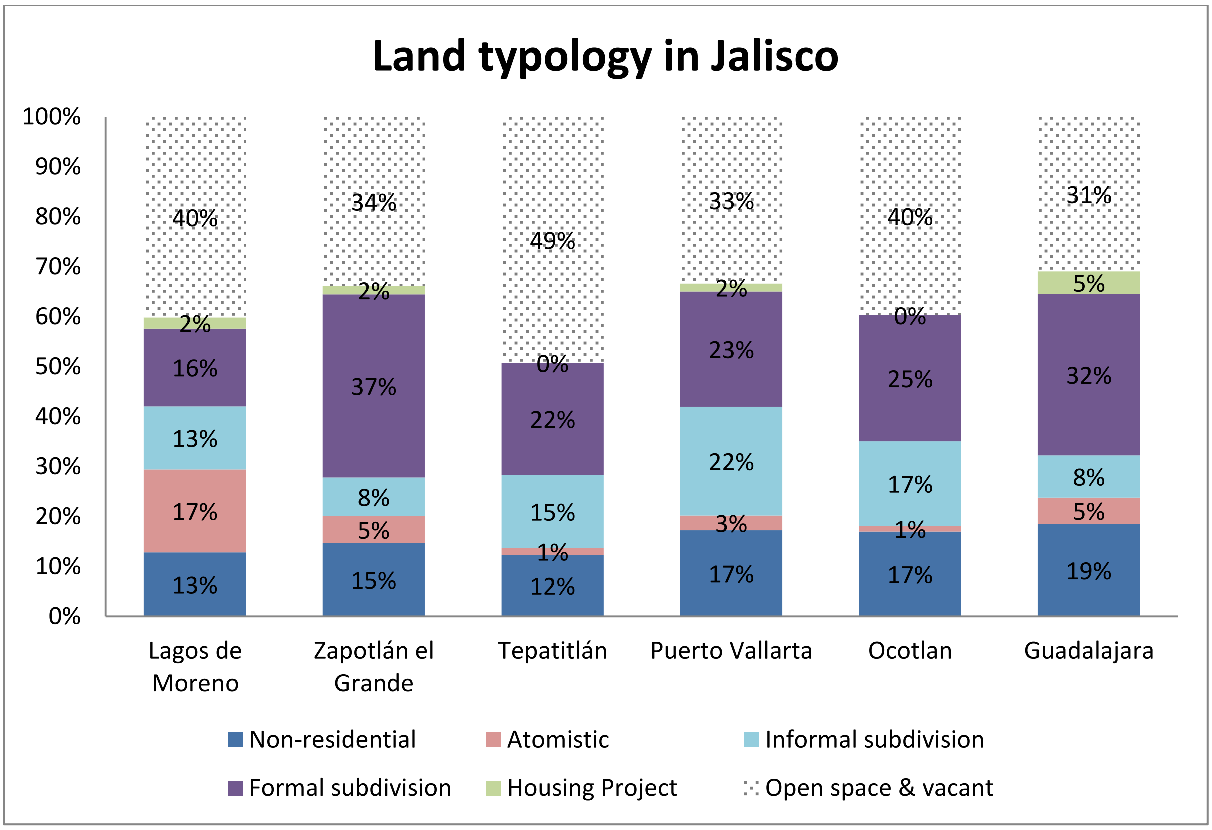
Formal subdivisions

Residential – Housing projects

Housing projects are usually homogenous built-up areas developed to house large populations. Traditionally, housing projects were used to house poorer segments of societies but increasingly high value apartments are modelled similarly but with provision of more facilities. Housing projects occupy very limited space in the ranging from 2% in Lagos de Moreno to 5% in Guadalajara. Tepatitlán and Octolan do not have any portions of under housing projects. The SCI is 71, 79 and 81 points in Lagos de Moreno, Guadalajara and Zapotlán el Grande respectively.

Housing projects

Figure 18: Proportion of land occupied by open spaces and vacant land in the six municipalities



Vacant and open spaces

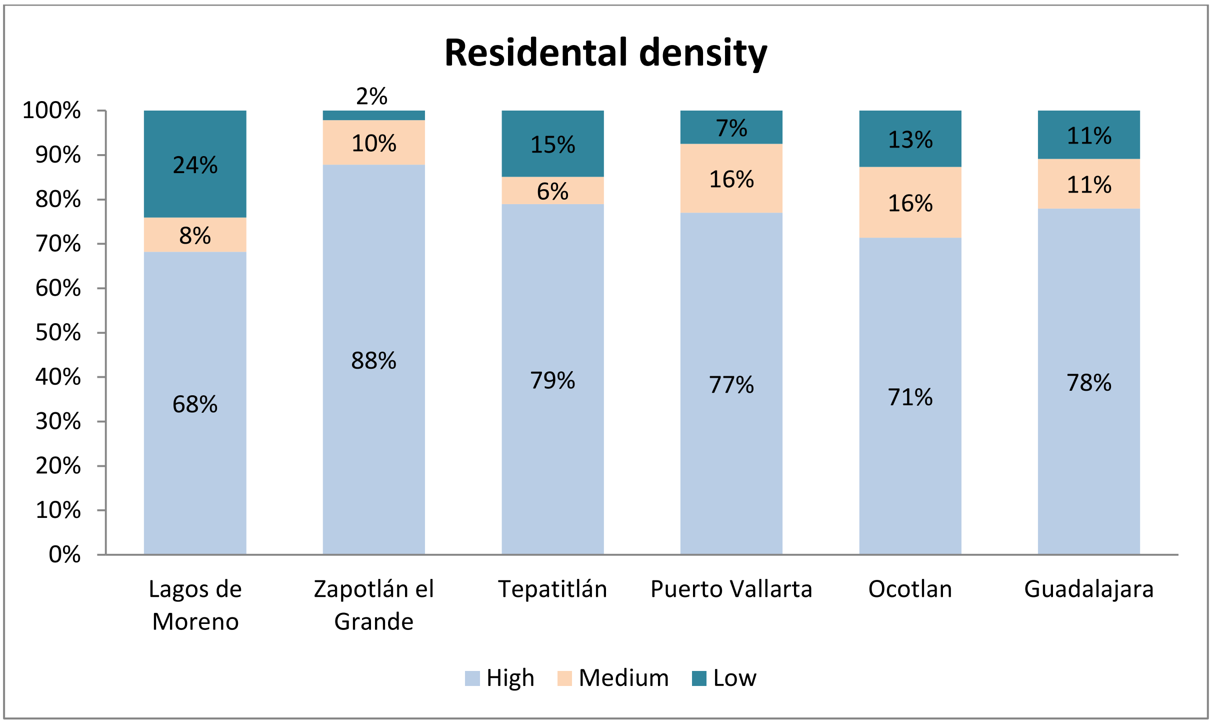
Typically, lower investments on infrastructure are made in open spaces and vacant land compared to infrastructural investments in other urban typologies. Cities with larger proportion of land under open spaces and vacant land have spuriously lower street connectivity index when compared with urban areas with lower land under vacant land and open spaces. In this analysis open spaces and vacant land have not been considered when computing the street connectivity index. Figure 18 above illustrates the proportion of land under open space or vacant land in the six municipalities.

In the six municipalities of Jalisco in this study, the amount of land classified as open space or vacant ranges from 31% in Guadalajara to 45% in Tepatitlán. Vacant land constitutes less than 5 % of all municipalities. Zapotlán el Grande, Ocotlan and Guadalajara have no vacant land within their municipal boundaries. Open spaces occupy slightly below a third to half of municipal land. Tepatitlán has 51% of the municipal land allocated to open spaces.

Disaggregation by residential density

Three built-up densities have been used in this study – low, medium and high. Area for computation of urban residential density includes residential areas, local roads and non-residential areas such as parks and schools. Assuming that buildings have similar occupancy rate, residence density is related to the population density with areas with higher residence density having higher population and vice versa and therefore increasing requirements for infrastructure for mobility. Areas with higher residential density are therefore expected to have higher connectivity to be able to handle increased demand on the transport infrastructure. Infrastructural demands may be higher to support movement of commuters to offices and business which are in high residential density areas. Figure 19 below illustrates the proportion of land under different residential densities in the six municipalities. Majority of the land in all the municipalities falls under high residential density and ranges from 68% in Lagos de Moreno to 88% in Zapotlán el Grande in keeping with highly urbanised cities. Land under medium residential density is only between 6 % in Tepitalan to 16% in Octolan and Puerto Vallarta while land under low residential density ranges from 2% in Zapotlán el Grande to 24% in Lagos de Moreno.

Figure 19: Land disaggregation by residential density in the six municipalities



Relationship between street density, intersection density and land allocated to streets.

Figures 20, 21 and 22 below explore the relationship between street density and land allocated to streets, street density and intersection density and intersection density and land allocated to streets across different land typologies. There is a linear relationship between street density and land allocated to streets and intersection density and land allocated to streets.

The ratio of intersection density to street density is a key pointer to interconnectivity in an urban area. There are about 5 intersections for every kilometre of street length. This distribution of intersections is uniform across all the typologies. Whereas open spaces have less street density than other typologies, the number of intersections per kilometre of street matches the number of intersections per kilometre of street in typologies with higher street densities.

Figure 20: Relationship between street density and land allocated to streets- across the land use typologies

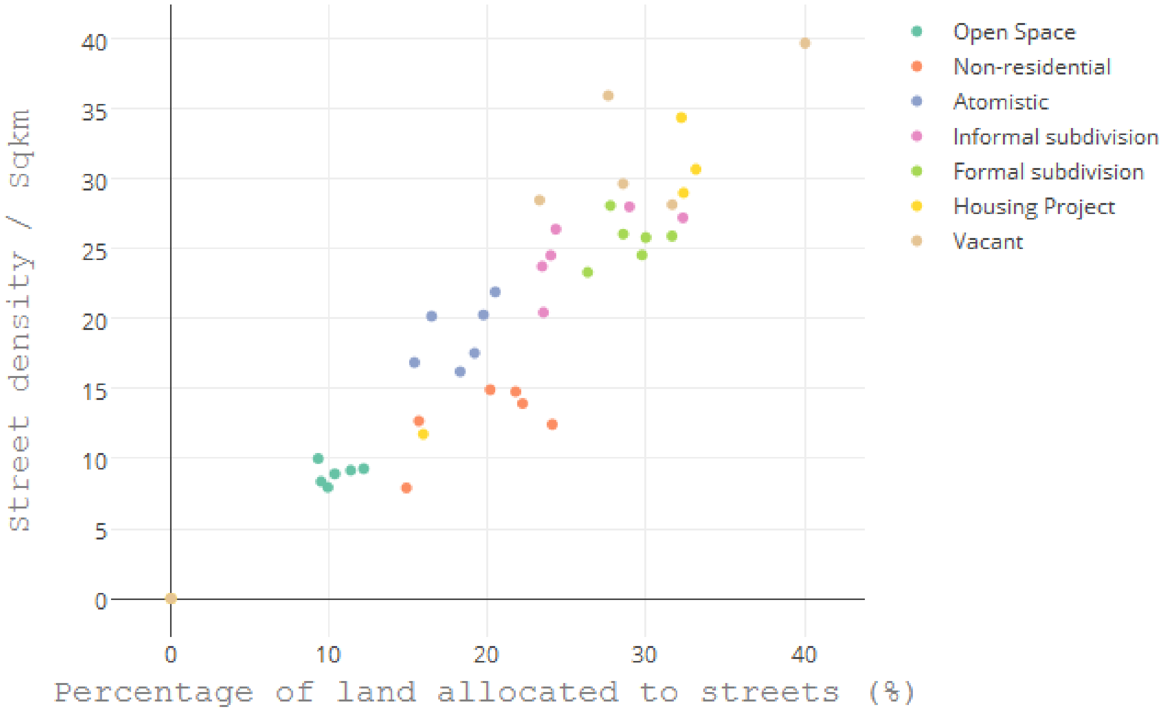


Figure 21: Relationship between intersection density and land allocated to streets- across the land use typologies

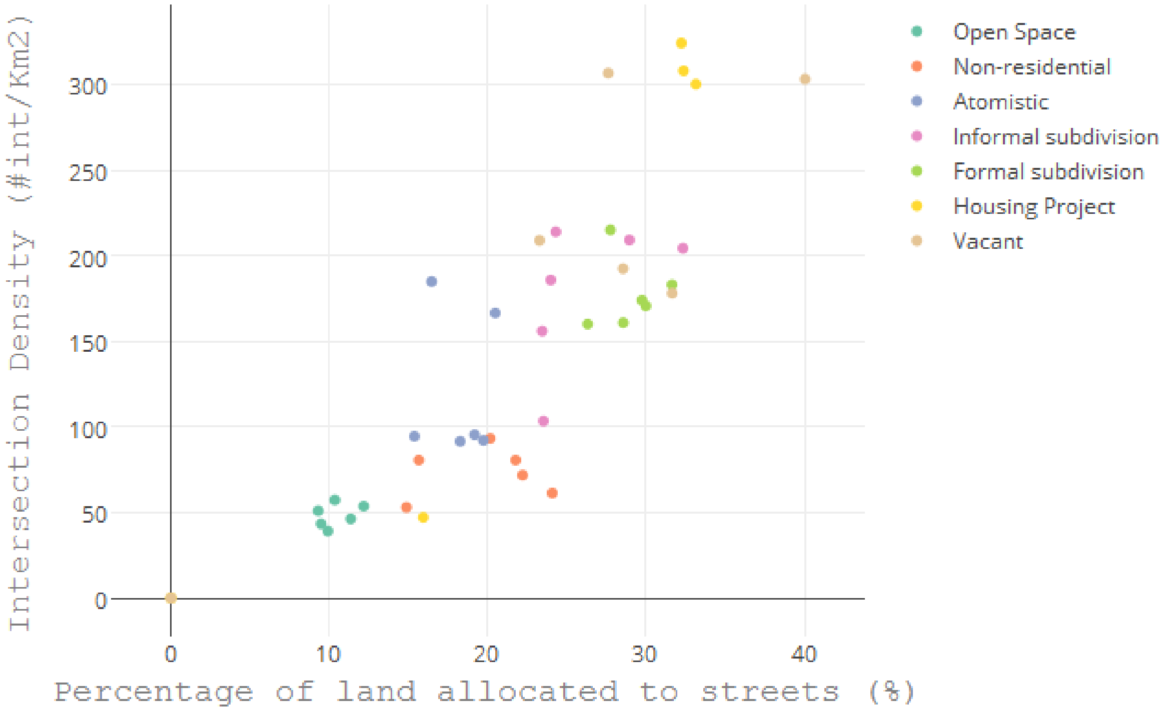
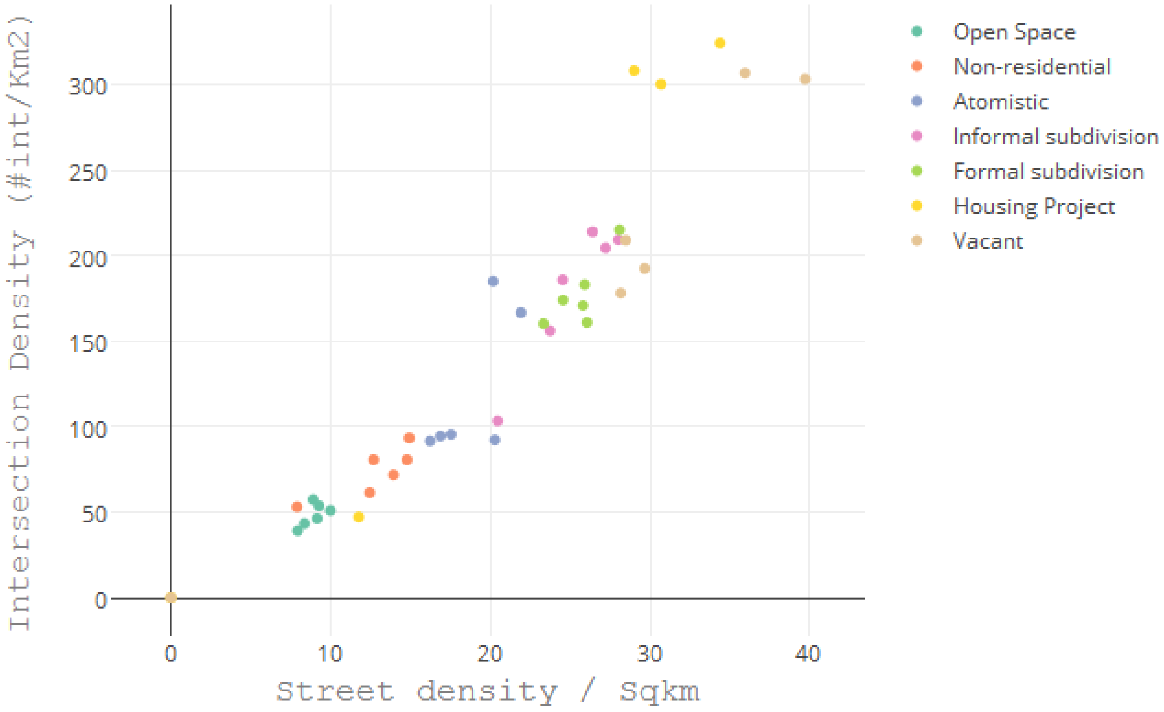


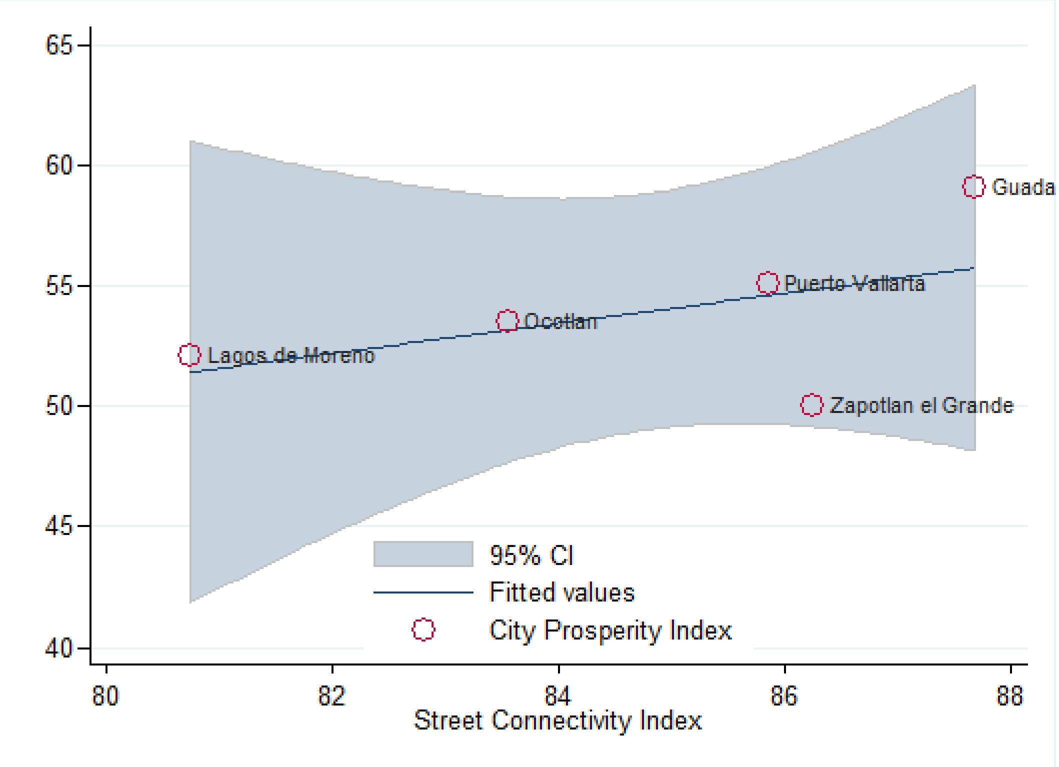
Figure 22: Relationship between intersection density and street density across the land use typologies



The spatial capital of cities – comparing street connectivity with other variables

In this study, we also explored the relationship between street connectivity index and the city prosperity index (CPI) and components of the CPI. This analysis is however limited by the few data point available – most of the data points were available for only five municipalities and the fact that values for most of the other indicators did not show variability across the municipalities. The lack of variability across municipalities is probably because the municipalities are from the same state and there is little variability within the state for these indicators due to proximity. The full list of available CPI indicators for the six municipalities is provided in appendix c.

Figure 23: Relationship between SCI and CPI



There is a positive linear relationship between SCI and CPI. Municipalities with higher street connectivity also posted higher values of the propsperity index in the six municipalities. This finding falls within expectation as connectivity underlies effeciency and ease of conducting business as we had previously discussed. Zapotlan el Grande is a lone outlier municipailty with relatively high connectivity but a much lower prosperiity index. Zapotlan el Grande however lies within the lower confidence limit for this linear relationship between CPI and SCI.

Figure 24: Relationship between street connectivity and poverty rate and street connectivity and unemployment rate

There is an unexpected finding of positive relationship between high connectivity and high poverty rate. Further exploration finds similar relationship between street connectivity and unemployment. This finding may be due to pressures of rural-urban migration where people move to prosperous, more connected cities in search for economic activities. As cities and municipalities develop, they attract more people. This is cirtical from a policy perspective to ensure that the growth and investments in these mmunicipalities is inclusive and responsive to poor urban populations.

Figure 25: Relationship between street connectivity and open public spaces per capita

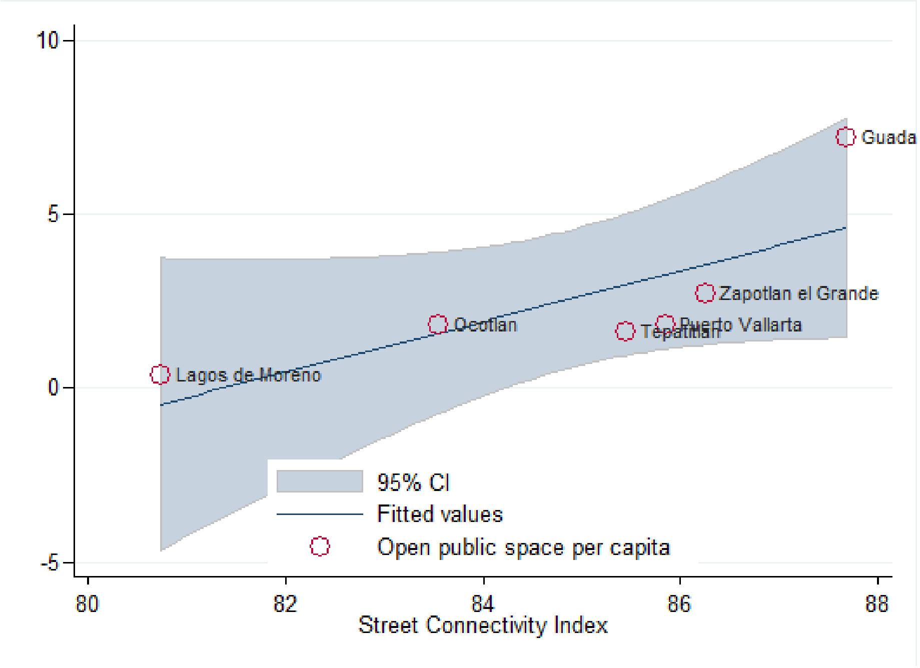


Figure 25 illustrates that municipalities with higher street connectivity also have higher open public spaces per capita. This may indicate deliberate and all rounded planning by municipal authorities whereby municipalities do not only address connectivity but also address access to parks and other open spaces. This oberrvation is also replicated when the relationship between connectivity and accessibility are examined as shown in figure 26 below. The relationship between connectivity and provision of municipal services was also explored. Figure 27 looks at one example of municipal service provision for collection of solid waste. Better connected municipalities also have higher levels of collection of solid waste. This may indicate overall better service performance of the municipality or may be that better access allows for garbage trucks to move within the municipality and hence a more fficient solid waste collection system.

Figure 26: Relationship between street connectivity and accesibility

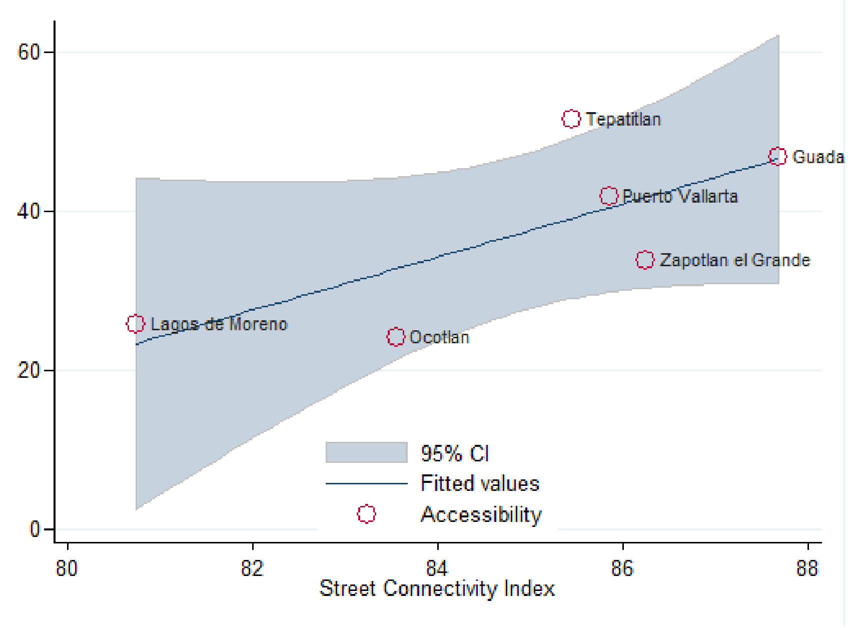
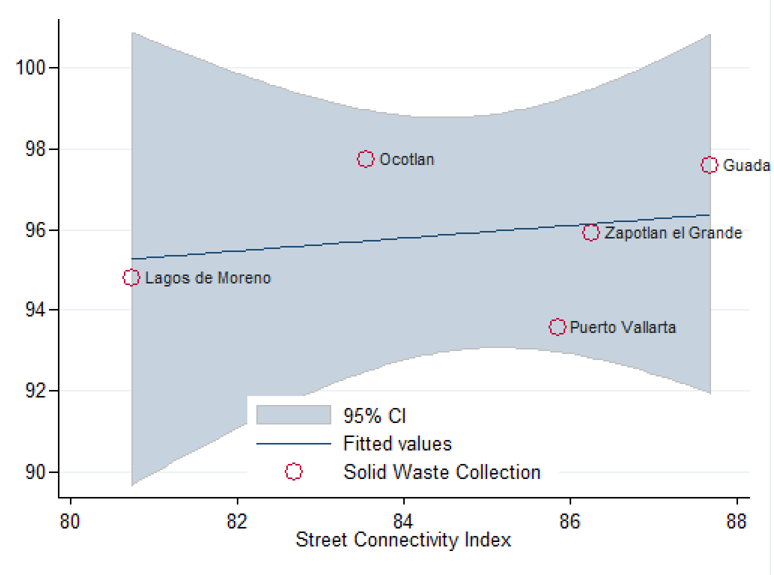
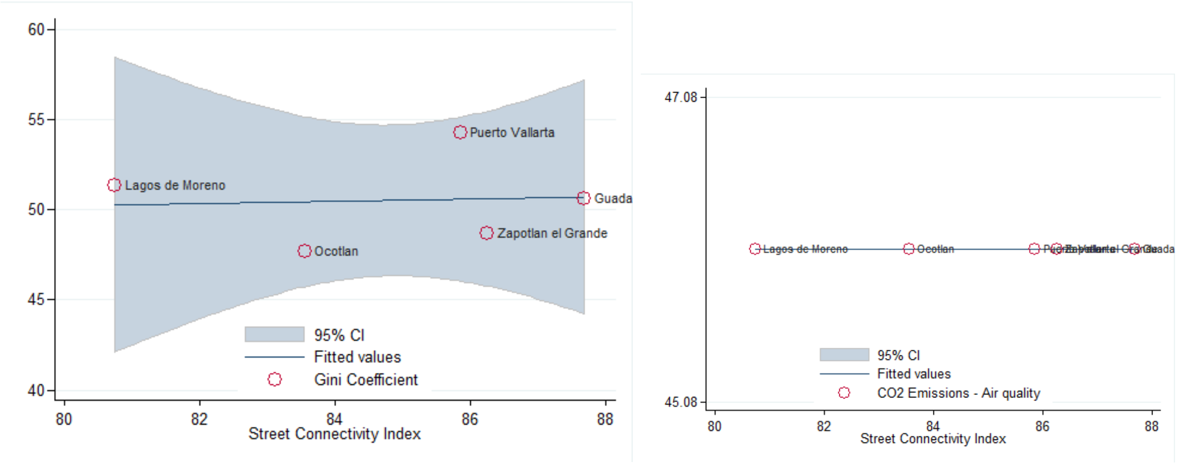


Figure 27: Relationship between street connectivity and solid waste collection



There was no relationship between street connectivity and some of the other components of the city prosperity index such as the Gini coefficient and air quality as measured by carbon dioxide emissions as shown in figure 28. This may probably be due to the fact that these indicators cannot be measured accurately at a municipal level.

Figure 28: Relationship between street connectivity and Gini coefficeient and air pollution



Conclusion

The study finds comparable street connectivity index scores across the six municipalities suggesting a common land use and town planning philosophy in the municipalities. On a global scale the overall performance of the six municipalities on the street connectivity index scores is good. The only major differences are observed at the intra-city analysis by the various typologies. For example, SCI is lower when open spaces are included in all the municipalities. In Lagos de Moreno, the SCI is 74 when open space is included and 85 when open space is excluded. As expected, open spaces and vacant land have lower percentage of land allocated to streets, lower street density and intersection density compared to other urban typologies. When examined independently, open spaces and vacant spaces have much lower SCI than all other municipal typologies. The SCI for open space is 37 in Lagos de Moreno and Zapotlán el Grande; 31, 39, 40 and 32 in Tepatitlán, Puerto Vallarta, Octolan and Guadalajara respectively.

Non-residential areas have the second lowest level of street connectivity scores. Non-residential areas include educational institutions, transportation hubs, hospitals, industrial parks and offices. These facilities are usually built over large plot of land and may be poorly served with street and intersections. In occasions where streets exist, they may not be accessible to the general public further reducing connectivity within the urban areas. For the six municipalities studied, SCI within non-residential areas ranges from 41 in Puerto Vallarta to 72 in Octolan.

Atomistic subdivisions have moderate to high level of SCI in the six municipalities. Atomistic developments usually have non defined layout since they were not subdivided before residential developments took place. Generally atomistic areas usually include residential developments besides housing projects. Streets and intersections in atomistic developments are irregular, road widths also vary and plot sizes may be inconsistent. Land formerly in the urban fringes, that was converted from agricultural to residential areas also form atomistic developments.

The UN has recommended 100 intersections per square km, the intersections per km squared in Lagos de Moreno range from 51 to 324 intersections per square km. Housing developments and atomistic developments have the highest number of street intersections per km^2. Open space and non-residential areas have lowest number of intersections.

In conclusion, providing for social needs will require comprehensive policy action, greater resource efficiency and capitalising on the known technologies and sustainable urban planning and design practices that will provide cost savings, better shelter, job growth and an improved ability to sustain lives and livelihoods in Mexican cities or municipalities. This report highlights clearly some areas of focus and investments using a sample of six municipalities. Results from this study show that Mexico’s cities and the built environment are clearly interconnected. Appropriate and informed spatial planning and designs, better building codes, land-use policies and energy efficiency standards will have clear consequences on the ‘morphology’ of the Mexican cities/municipalities.

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Annex A: Metadata/ descriptions of the indicators used in the Street connectivity index.

Street Intersection Density - Metadata

Indicator:	**Street Intersection Density**
Scope	Basic CPI
Rationale:	Walkability in a city depends on block sizes and intersections that provide places where cars must stop, and pedestrians can cross. The greater the intersection density, the smaller the blocks and the more walkable the neighborhood (Ewing, 1999). However, the size of blocks is not sufficient to determine walkability in a city. The traffic regulation and control for all intersections with priority to pedestrian is very important to facilitate walking (Institute for Transportation and Development Policy, 2013). A prosperous city seeks to find a proper block size to promote walkability.
Definition:	Number of street intersections per one square kilometer of land
Unit [ ]	# / km^2
Methodology:	1. Obtain the street network map of the urban area 2. Verify the topology: each street segment must be properly connected to other segments. 3. Obtain the start and end point of each segment. 4. Collect events from start and end points: collect the multiple endpoints at an intersection together and count the number of endpoints at each intersection. 5. Exclude points with less than 3 events, i.e. the dead ends or broken segment ends. 6. Count the remaining points and divide by the urban area in km^2.
Source:	Local or City urban planning authorities based on cartography
Benchmark	X^*= 100 intersections per km^2, based on UN-HABITAT Global Urban Observatory estimation (2013).
Standardization: 3	$\mathit{Street\ intersection\ density}^{(S)} = 100\left(1-\left\lvert\frac{\mathit{Street\ intersection\ density}-X^*}{X^*}\right\rvert\right)$ $\mathit{Street\ intersection\ density}^{(S)} = 100\left(1-\left\lvert\frac{\mathit{Street\ intersection\ density}-100}{100}\right\rvert\right)$ Decision:

	$Street\ intersection\ density^{(S)} = \begin{cases} 0, if\ Street\ intersection\ density < 0 \\ Street\ intersection\ density^{(S)}, \quad If\ \ 0 \leq Street\ intersection\ density < \\ 100, \quad If\ Street\ intersection\ density \geq 100 \end{cases}$
Limitations:	This indicator is measured to determine whether a city is permeable enough to guarantee walkability. However, it assumes that all the intersections are secure for pedestrians, which in reality (in some cities) might not be true.
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Street Density - Metadata

Indicator:	**Street Density**
Scope	Basic CPI
Rationale:	The proportion of urban areas dedicated to streets and public spaces is a crucial feature of the spatial plans of cities. The road network is the integrative and dynamic factor between the population and socioeconomic activities. It's a structuring component of geographic space and defines the socio-dynamics of an area being conditioned by the spatial pattern, which restricts the location of roads and human settlements (UN-Habitat, 2013). Short and direct pedestrian and cycling routes require a highly connected network of paths and streets around small, permeable blocks. These features are primarily important for walking and for transit station accessibility, which can be easily discouraged by detours. (ITDP, 2013) Cities that have adequate street and public spaces and greater connectivity are more livable and economically productive (UN-Habitat, 2013). A prosperous city seeks a tight network of paths and streets offering multiple routes to many destinations that also make walking and cycling trips varied and

enjoyable. (ITDP, 2013).

Definition: Number of kilometers of urban streets per square kilometer of land

Unit [ ] km / km^2

Methodology:

1. Select the streets included in the urban area only
2. Count the number of kilometers of the urban streets
3. Divide the number of kilometers by the total urban surface.

$$Street\ density = \frac{Total\ lenght\ of\ urban\ streets}{Total\ of\ urban\ surface}$$

Source: Local or City urban planning authorities based on cartography

Benchmark X^*= 20 kilometers of urban streets per km^2.

Based on UN-HABITAT Global Urban Observatory estimations (2013).

Standardization:

5

$$Street\ density^{(S)} = 100\left(1 - \left|\frac{Street\ density - X^*}{X^*}\right|\right)$$

$$Street\ density^{(S)} = 100\left(1 - \left|\frac{Street\ density - 20}{20}\right|\right)$$

Decision:

$$Street\ density^{(S)} = \begin{cases} 0, & if\ Street\ density = 0\ or\ Street\ density = 2 * 20 \\ Street\ density^{(S)}, & If\ \ 0 < Street\ density < 2 * 20 \\ 100, & If\ Street\ density = 20 \end{cases}$$

Limitations: Because this is a measure of "permeability," this indicator includes all kind of streets (i.e. primary and secondary). Walkability is based on the permeability, which is guaranteed by all the streets in a city. Hence, this measure must be combined with the intersection density indicator. This is because many parallel streets without intersections might produce adequate street density but insufficient permeability.

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Land Allocated to Streets - Metadata

Indicator:	**Land Allocated to Streets**
Scope	Basic CPI
Rationale:	Transportation systems consume large amounts of land from spaces allocated for both the circulation and parking of vehicles. Land must be allocated for complementary facilities such as public transport terminals, stations, offices and warehouses related to transportation (CAF, 2010). When cities are shaped for people, personal motor vehicles become largely unnecessary for day-to-day city living. Walking, cycling and the use of high-capacity transit are easy and convenient, and can be supplemented by a variety of intermediary transit modes such as rented vehicles that are much less space-intensive. Valuable urban spaces can be reclaimed from unnecessary roads and parking, and reallocated to more socially and economically productive uses (ITDP, 2013). However, an adequate proportion of land dedicated to streets may guarantee enough space to have a proper mobility system, because it is over those streets where the development of a new public transport system could take place in the future. A prosperous city seeks an optimal allocation of land dedicated to streets to guarantee good performance of the mobility system, share space among modes and to avoid sizeable extensions of spaces dedicated to personal motor vehicles. Cities that have adequate street and public spaces and connectivity are more livable and productive.
Definition:	Total area of urban surface allocated to streets.

Unit [ ] %

Methodology:

1. Select only the streets included in the urban area
2. Estimate the total urban surface allocated to streets
3. Divide the number of square kilometers of urban streets by the total square kilometers of urban surface.

$$Land\ allocated\ to\ streets = 100\left[\frac{Total\ surface\ of\ urban\ streets}{Total\ surface\ of\ urban\ area}\right]$$

Source: Local or city urban planning authorities based on cartography

Benchmark

Min = 6%

Max = 36%

Based on UN-HABITAT Global Urban Observatory estimations (2013), Page. 4.

Standardization : 2.1

$$Land\ allocated\ to\ streets^{(S)} = 100\left[\frac{Land\ allocated\ to\ streets\ - Min}{Max - Min}\right]$$

$$Land\ allocated\ to\ streets^{(S)} = 100\left[\frac{Land\ allocated\ to\ streets\ - 6}{36 - 6}\right]$$

Decision:

$$Land\ allocated\ to\ streets^{(S)} = \begin{cases} 100, & If\ Land\ allocated\ to\ streets\ \geq 36 \\ Land\ allocated\ to\ streets^{(S)}, & If\ \ 6 < Land\ allocated\ to\ streets\ < 36 \\ 0, & If\ Land\ allocated\ to\ streets\ \leq 6 \end{cases}$$

Limitations: It's challenging to obtain complete information about city streets. It's sometimes necessary to make assumptions about street dimensions, and remote sensing data could be useful in these cases.

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Indicator: **Proportion of city population (or total urban area) living (or located) less than 400m away from the Open Public Space**

Scope Basic CPI

Rationale: Open Public Space (OPS) alludes to Public Space with "Open" features. This is the non-built up public areas within the city's urban footprint. Also "Open area" concept is related to free access. In most of the countries around the world, the concept of "open public area" is related to "green area" (green areas are defined as public and private areas that have flora such as plants, trees and grass). However, OPS include but is not limited to green area. Nevertheless, the two principal roles an open public area must provide are to provide a healthy social interaction space and to contribute to air quality and a healthy environment (WHO, 2012).

People living in towns and cities should have an accessible natural green space or an open public space less than 400 meters from home (Natural England; see also The Wildlife Trust & Natural England, 2009; Harrison et al., 1995; Barker, 1997; Handley et al., 2003; Wray et al., 2005; [1]). This indicator looks at how accessible these open public spaces are to the population. It also takes into the way in which total public area is distributed across the city.

A prosperous city has enough open public area for its population, it is properly distributed and people have easy access to it.

Definition: According to POT Medellin (2013), Sandalack & Alaniz (2010) and Project for Public Spaces [2], the elements which can be considered as open public space are:

- Park: open space inside a municipal territory. Its objective is to provide free air recreation and contact with nature. The principal characteristic is the significant proportion of green area in the zone.
- Civic parks: open space created as the result of building agglomeration around an open area, which later was transformed to a representative and civic area. It has a considerable proportion of nature, specifically gardens. It is a good place for cultural events and passive recreation.
- Square: open space created as a result of building agglomeration around an open area. Its main characteristics are the significant proportion of architectonic elements and the interaction between those buildings and the open area. Squares are usually public spaces that are relevant for the city due to their location, territorial development and/or cultural importance.
- Recreational green area: public green areas that contribute to environmental preservation. All recreational green areas have to guarantee accessibility and have to be linked to urban areas. Their main functions are ornament and passive recreation.
- Facility public area: open space meeting and recreational facilities that are part of the land for city's facilities (a facility is defined such as places which are elementary in all cities. Places that all cities have to have; e.g.: public libraries, stadium, public sports centres, etc.). This land complies with the following characteristics: public property, free transit and access, and active and passive recreation. (e.g.: public area outside a stadium)

Unit [ ] %

Methodology: **Methodology A**:

$$Accessibility\ to\ open\ public\ area$$

$$= 100 \times \frac{population\ less\ than\ 400m\ away\ from\ open\ public\ area}{city\ population}$$

"Population" is referring to every person that lives less than 400m away from an open public area, nevertheless it is complicated to get data of every person that complies with that characteristic, and almost no city has that information available. If the information is available, the best is to estimate the indicator with that information; otherwise, Methodology "B" must be followed.

Methodology B

Percentage of urban area that is located less than 400 meters away from an open public space.

$$Accessibility\ to\ open\ public\ area$$

$$= 100\frac{urban\ area\ less\ than\ 400m\ away\ open\ public\ area}{total\ urban\ area}$$

To calculate the indicator it is necessary to use a map of urban open public areas and to follow these steps:

- Delineate a buffer of 400 meters from the open public spaces polygons.
- Merge and clip with urban perimeter.
- Calculate areas inside the 400 meters buffer.
- Calculate the proportion of urban area located inside the buffer.

Remote sensing imagery can be used to identify intra-urban open public areas when no other information is available.

Source: Local urban planning authorities.

Benchmark Min= 0%
Max = 100%

Standardization: Not required.

Limitations Types of Open Public Space vary across cities; however the types listed in this indicator are usually the most accepted ones. Contemporary constraints on mobility and behavior need to be examined before physical distance in order to measure effectively the accessibility to open public space. There are social and cultural constraints on access, anxiety and fears for personal safety are some of them (Harrison et al., 1995)

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Annex B: Street connectivity for the different municipalities.

Lagos de Moreno		Shares (%)	Average street width (m)	LAS	SD	ID	SCI
Including Open Space			10.19	37.89	85.3	100.0	74.38
Excluding Open Space			9.99	55.39	86.8	100.0	80.74
By Land Use	Open Space	39.43%	9.30	11.01	50.0	51.0	37.33
	Non-residential	12.82%	12.33	32.15	63.5	80.6	58.72
	Atomistic	16.59%	9.34	48.28	90.4	100.0	79.55
	Informal subdivision	12.68%	9.77	59.94	77.3	100.0	79.09
	Formal subdivision	15.56%	9.87	72.48	59.5	100.0	77.32
	Housing Project	2.21%	9.37	87.43	28.0	100.0	71.81
	Vacant	0.70%	11.23	85.50	59.1	100.0	81.55
By Built-up density	Low	24.08%	8.90	28.91	82.4	95.3	68.87
	Medium	7.72%	11.92	59.31	99.8	100.0	86.36
	High	68.20%	9.63	72.91	55.2	100.0	76.05

Open public space per capita 0.4
Accessibility to Open public area 25.7
Green area per capita 1.8

Zapotlán el Grande		Shares (%)	Average street width (m)	LAS	SD	ID	SCI
Including Open Space			12.62	49.41	82.5	100.0	77.31
Excluding Open Space			12.02	65.63	93.1	100.0	86.25
By Land Use	Open Space	33.84%	12.38	17.83	45.8	46.2	36.63
	Non-residential	14.69%	15.94	54.05	69.7	71.7	65.16
	Atomistic	5.38%	10.92	43.90	87.7	95.4	75.70
	Informal subdivision	7.76%	11.87	87.75	63.8	100.0	83.86
	Formal subdivision	36.63%	11.28	67.74	83.4	100.0	83.70
	Housing Project	1.69%	11.16	87.91	54.9	100.0	80.95
	Vacant	0.00%	-	20.00	0.0	0.0	6.67
By Built-up density	Low	2.14%	9.22	28.69	79.2	70.6	59.51
	Medium	9.99%	11.95	70.36	86.6	100.0	85.65
	High	87.87%	11.32	69.74	81.1	100.0	83.62

Open public space per capita 2.7
Accessibility to Open public area 33.9
Green area per capita 3.8

Tepatitlán		Shares (%)	Average street width (m)	LAS	SD	ID	SCI
Including Open Space			12.37	42.67	76.0	90.9	69.87
Excluding Open Space			11.78	66.57	89.8	100.0	85.45
By Land Use	Open Space	44.63%	12.48	13.02	39.7	39.1	30.60
	Non-residential	12.36%	14.72	52.57	73.9	80.6	69.02
	Atomistic	1.30%	9.11	31.24	84.4	94.5	70.04
	Informal subdivision	14.71%	11.49	58.38	97.7	100.0	85.36
	Formal subdivision	22.40%	11.61	79.96	70.9	100.0	83.62
	Housing Project	0.00%		20.00	0.0	0.0	6.67
	Vacant	4.61%	9.62	75.16	51.6	100.0	75.60
By Built-up density	Low	14.90%	11.51	42.22	81.1	44.2	55.85
	Medium	6.14%	11.54	54.94	97.4	97.2	83.17
	High	78.95%	11.51	76.48	74.3	100.0	83.59
Open public space per capita 1.6 Accessibility to Open public area 51.6 Green area per capita - **							

Puerto Vallarta		Shares (%)	Average street width (m)	LAS	SD	ID	SCI
Including Open Space			12.18	48.71	84.6	100.0	77.78
Excluding Open Space			11.86	64.91	92.6	100.0	85.85
By Land Use	Open Space	32.14%	11.62	14.51	44.6	57.3	38.79
	Non-residential	17.26%	18.82	29.57	39.5	53.0	40.70
	Atomistic	2.94%	9.72	45.77	98.6	92.2	78.83
	Informal subdivision	21.81%	10.33	76.51	59.9	100.0	78.80
	Formal subdivision	23.04%	12.21	85.45	70.4	100.0	85.29
	Housing Project	1.62%	13.55	33.09	58.8	47.1	46.33
	Vacant	1.19%	8.17	57.56	57.6	100.0	71.71
By Built-up density	Low	7.46%	10.71	33.28	74.6	52.9	53.60
	Medium	15.56%	14.04	80.13	93.0	100.0	91.05
	High	76.98%	10.81	81.16	59.7	100.0	80.28
Open public space per capita 1.8 Accessibility to Open public area 41.8 Green area per capita 6.6							

Ocotlan		Shares (%)	Average street width (m)	LAS	SD	ID	SCI
Including Open Space			11.71	44.74	82.9	100.0	75.90
Excluding Open Space			11.05	62.16	88.5	100.0	83.55
By Land Use	Open Space	39.20%	13.11	20.57	46.4	53.7	40.22
	Non-residential	16.98%	13.50	47.18	74.7	93.3	71.71
	Atomistic	1.16%	8.15	34.85	99.1	100.0	77.97
	Informal subdivision	16.95%	9.87	58.14	81.2	100.0	79.80
	Formal subdivision	25.22%	10.96	75.21	69.7	100.0	81.64
	Housing Project	0.00%		20.00	0.0	0.0	6.67
	Vacant	0.49%	10.08	100.00	1.4	100.0	67.13
By Built-up density	Low	12.67%	10.29	57.00	87.8	100.0	81.59
	Medium	15.95%	10.11	55.41	88.2	100.0	81.19
	High	71.39%	10.60	71.99	69.8	100.0	80.60

Open public space per capita 1.8
Accessibility to Open public area 24.1
Green area per capita 2.6

Guadalajara		Shares (%)	Average street width (m)	LAS	SD	ID	SCI
Including Open Space			12.86	50.92	82.7	100.0	77.88
Excluding Open Space			12.61	69.70	93.3	100.0	87.68
By Land Use	Open Space	30.74%	11.34	11.60	41.8	43.4	32.25
	Non-residential	18.51%	19.34	60.27	62.2	61.3	61.27
	Atomistic	5.30%	11.26	40.89	81.1	91.5	71.19
	Informal subdivision	8.41%	9.20	61.01	68.0	100.0	76.33
	Formal subdivision	32.35%	12.11	79.16	77.2	100.0	85.46
	Housing Project	4.53%	10.80	90.51	46.5	100.0	79.00
	Vacant	0.15%	7.68	72.04	20.2	100.0	64.08
By Built-up density	Low	10.88%	11.43	34.70	71.7	77.5	61.33
	Medium	11.18%	12.58	60.70	96.2	100.0	85.64
	High	77.93%	11.26	80.31	66.4	100.0	82.23

Open public space per capita 7.2
Accessibility to Open public area 46.9
Green area per capita 16.9

Annex C: City prosperity index indicators for the different municipalities.

Indicator	Guadalajara	Lagos de Moreno	Ocotlan	Puerto Vallarta	Tepatitlan	Zapotlan el Grande
City Product per Capita	48.3	32.6	42.0	36.5	-	19.7
Old Age Dependency	45.4	57.1	54.2	73.2	-	52.1
Economic Density	41.3	10.5	17.3	9.6	-	2.1
Unemployment Rate	82.3	72.5	81.3	77.8	-	82.4
Employment to Population ratio	64.5	53.1	53.7	76.3	-	62.3
Improved Shelter	94.9	91.2	96.4	88.2	-	88.2
Access to Improved Water	98.8	90.4	85.8	92.3	-	96.5
Sufficient Living Area	100.0	100.0	100.0	100.0	-	100.0
Population Density	73.6	34.2	42.4	36.5	-	17.2
Physicians Density	98.2	55.8	53.8	59.8	-	70.4
Internet Access	38.7	17.4	5.3	97.0	-	27.0
Average Broadband Speed	40.2	40.2	40.2	40.2	-	40.2
Length of Mass Transport Network	44.73	-	-	-	-	-
Traffic Fatalities	-	-	-	50.18	-	-
Per Capita Public Transport Vehicles	4.4	1.9	1.3	6.3	-	3.4
Life expectancy at birth	71.8	71.8	71.8	71.8	-	71.8
Under-Five Mortality Rate	59.5	59.4	51.6	54.0	-	63.0
Literacy Rate	96.9	91.1	93.7	96.1	-	94.8
Mean Years of Schooling	78.9	61.5	68.9	70.2	-	74.4
Homicide rate	68.5	56.6	63.0	69.4	-	72.7
Gini Coefficient	50.6	51.3	47.7	54.3	-	48.7
Poverty rate	54.0	37.5	48.2	33.9	-	54.0
Slum Household	94.9	73.1	81.9	76.4	-	85.6
Youth Unemployment	77.6	65.4	77.6	77.5	-	81.1
Equitable Secondary School Enrolment	93.4	89.2	91.7	93.3	-	89.7
Number of Monitoring stations	37.5	-		-	-	-
PM2.5 Concentration - Air quality	96.3	95.0	100.0	65.0	-	100.0
CO2 Emissions - Air quality	46.1	46.1	46.1	46.1	-	46.1
Solid Waste Collection	97.6	94.8	97.7	93.6	-	95.9
Waste water treatment	73.2	27.5	51.2	100.0	-	69.1
Share of renewable energy	-	-	-	-	-	-
Voter Turnout	51.9	49.6	49.2	44.3	-	53.4
Local Expenditure Efficiency	95.6	100.0	97.0	100.0	-	100.0
Own revenue collection	25.2	20.8	39.8	37.6	-	22.1

Sub-national Debt	100.0	100.0	100.0	100.0	-	100.0
Urban Sprawl	-	44.71	6.47	28.87	-	-
City Prosperity Index	59.1	52.1	53.5	55.1	-	50.0
Street Connectivity Index	87.7	80.7	83.6	85.9	85.5	86.3
Population	1495189	153817	92967	255681	136123	100534
Accessibility to open public spaces	46.9	25.7	24.1	41.8	51.6	33.9
Un-serviced area	362.0	17.5	14.0	29.4	10.5	12.6
Open public space per capita	7.2	0.4	1.8	1.8	1.6	2.7
Area in square kilometres	681.6	23.6	18.4	50.5	21.7	19.1

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