Hydro Urban Units – a Meso Scale Approach for Integrated Planning

Bernd Eisenberg, Eva Nemcova, Rossana Poblet, Antje Stokman

(Dr.-Ing. Bernd Eisenberg, Institute of Landscape Planning and Ecology, bernd.eisenberg@ilpoe.uni-stuttgart.de)
(Dipl.-Ing. Eva Nemcova, Institute of Landscape Planning and Ecology, eva.nemcova@ilpoe.uni-stuttgart.de)
(M.Arch Rossana Poblet, Institute of Landscape Planning and Ecology, rossana.poblet@ilpoe.uni-stuttgart.de
(Prof. Antje Stokman, Institute of Landscape Planning and Ecology, antje.stokman@ilpoe.uni-stuttgart.de

1 ABSTRACT

Metropolitan Lima is one of the the world‘s largest megacities located in an arid climate. Water-related problems and opportunities vary greatly from place to place due to diverse natural and urban contexts. They require different solutions to integrate the urban water cycle and the (green) open space system. An integrated planning approach called “Lima Ecological Infrastructure Strategy” (LEIS) was developed within the LiWa-research project to address the specific challenges. Its aim is to provide guiding principles for a water sensitive urban and open space development, in order to contribute to the improvement and protection of the urban water cycle. A GIS-based planning tool assists in analizing the city and in localizing the various potentials and threats for Lima´s sustainable urban development. In order to reflect the diverse conditions in Metropolitan Lima, considering the natural and man-made forces, the city is analyzed with a meso scale approach through hydro-urban units.

The unit’s geometry is based on sectors for water provison and further characteristics of the built and natural environment including open space and the availability of divergent water sources were assigned. Several aspects were considered and information such as topography, natural and man-made water sources, population density and growth rates, state of water infrastructure, structure of urban pattern and open space and environmental functions were aggregated or disaggregated and transfered to the approx. 450 hydro-urban units of similar size that are linked to the water supply. The meso scale units allow to show the city like a mosaic, with enough information to differentiate them according to the characteristics but not too detailed information that distract from the overall comparison.

This approach allows urban planning as well as water management institutions – which are both partners of the LiWa research project – to recognize the relationship between water sources and the urban structure and as a consequence, planning activities can be harmonized in a better way and development scenarios can be evaluated. For areas with specific hydro-urban characteristics, site-specific water sensitive design solutions for the integration of the urban water cycle and open space are developed in the next stage, which if applied in a larger scale create the ecological infrastructure of the city.

2 INTRODUCTION

The Peruvian capital Lima, situated on a desert coast along the Pacific Ocean, is considered one of the most vulnerable cities in the world due to the effects of climate change. With an average precipitation of 9 mm per year, it depends solely on its three rivers, Rio Rimac, Rio Lurin and Rio Chillon, which are fed from water transfers, rain and glaciers in the Andes that are melting rapidly because of climate change. Lima was initially founded in the Rimac River valley, but today the metropolitan area of Lima and Callao with its more than 9,45 million inhabitants extends over extensive desert areas, dry hills and surrounding valleys.

Although there is almost no rain, Lima´s climate is very humid due to the effects caused by the interface of the Humboldt cold current and the Equatorial hot current over the Pacific Ocean in the West and the high Andes mountains on the East. Average annual humidity along the coast is between 80 and 88 % and in the higher altitudes still has more than 70 % as an average, with almost 100 % from June through December (Atlas Ambiental 2011). As a result the whole metropolitan area is coated with fog, that hangs constantly over the city and turns some of the desert hills into temporary, herb-rich meadow biotops called loma.

The fast population growth, lack of implementation of urban or regional planning instruments, economic crisis and other factors have led to a vast expansion of informal settlements. These settlements lack many basic urban services such as water supply, waste disposal and wastewater infrastructure, which has caused environmental degradation. In the last 70 years the urban development has been characterized by informal occupation. The non-implementation of planning instruments due to prioritization of open markets has brought to the city urban speculation and urban sprawl that has guided urban development. Productive and agricultural land as well as some parks were replaced by new urbanizations. In addition to that, the agencies in charge of water management and urban planning were neither sharing a joint vision nor coordinating their actions due to belonging to different management bodies. For these reasons urban planning is very weak and the last metropolitan urban development plan already expired in 2010 – however a first regional plan for the city has been developed and approved in 2012, preparing as the next step the development of the metropolitan urban development plan that should guide the city towards a new urban development model.

City structure, open space and the urban water cycle

Water management in Lima is led by a state owned enterprise called Servicio de Agua Potable y Alcantarillado de Lima (SEDAPAL), which is in charge of providing potable water and wastewater services. Many settlements in the peri-urban areas lack basic urban services such as water supply, waste disposal and wastewater infrastructure, which has caused environmental degradation. About one million people, mainly living in the hilly and peri-urban areas, are not connected to the public water supply networks. They receive drinking water, often of very bad quality, from private water vendors at high prices. SEDAPAL invests in large infrastructural projects to increase the water supply by bringing the water from the Atlantic water basin by tunnels through the Andes to the Pacific water basin.

Although there is a limited amount of water resources and many people lack access to safe water and sanitation, most parks and road greenery of Lima and Callao are irrigated with potable water. Due to a change in pricing potable water for irrigation, the pressure is continuously shifting towards utilization of treated wastewater for irrigation. Moscoso (2011) states in his study that only 15 % of the wastewater is treated and only 10 % of that which has been treated is reused for irrigation of green areas in Lima. The existing wastewater treatment system often cannot meet the quality demand of treated wastewater suitable for irrigation, leading to calls for modernization and investments into improvement of treatment systems to provide water of sufficient quality. Many municipalities and administrative bodies are building small wastewater treatment plants to cover their needs for water for irrigation without a coordinated plan with SEDAPAL. These facilities often fail in function due to lack of knowledge for maintenance and management capacity. Polluted rivers are concreted and channelized and irrigation channels are covered due to pollution without considering them an integral part of the open space system, as a potential source of water and a drainage system needed during rainy events in the upper parts of the watershed.

There have been attempts to utilize different sources of water for greening the city than just potable water. The discussion about reuse of wastewater has focused so far mainly on suitable technologies of the treatment facilities to provide sufficient amount of water for irrigation. However, the question of how to make use of the treated outflow of the existing, large-scale plants and where to allocate new, decentralized facilities is also high on the agenda. But little has been discussed about the actual design of the open space and its water demand. The current design practice fails to exploit the potentials of open space design to decrease the over-absorption of water resources, improve water quality of the degraded and polluted seasonal rivers, irrigation channels and groundwater. Lima's hydrological conditions and water infrastructure as well as the design of open space and green areas need radical rethinking to make urban and natural systems perform in concert with one another and keep up with the increasing water demand for a growing, more liveable and green city.

3 LIMA ECOLOGICAL INFRASTRUCTURE STRATEGY

A planning approach called "Lima Ecological Infrastructure Strategy" (LEIS) was developed within the BMBF[1] megacity project "Sustainable Water and Wastewater Management in Urban Growth Centres coping with Climate Change – Concepts for Metropolitan Lima (Perú)" (LiWa) to address the specific challenges.[2] The approach follows the question of how to integrate water management and open space planning.

The ecological infrastructure is based on the green infrastructure concept and it can be described as a multifunctional system of open spaces that, due to its multiple functions, serves as integral urban structure providing essential infrastructural services (Benedict & Mahon 2004; Ahern 2007; Mell 2010). A further methodological and conceptual background derives from water-sensitive urban design (Feyen et al. 2009; Hoyer et al. 2011). It is assumed that the coordinated designation of multifunctional open spaces, as proposed in the ecological infrastructure strategy, tackles the urban development challenges in a more

[1] German Federal Ministry of Education and Research

[2] The web page of the project gives an overview of the whole project www.lima-water.de. For an overview of the challenges see also Schütze & Robletto (2010).

efficient way than conventional land use planning approaches. Therefore it can guide the urban development in a more sustainable way.

LEIS-Principles

The aim of formulating guiding principles for future open space design is to proactively contribute to the improvement and protection of the urban water cycle. The principles integrate multiple scales. On the metropolitan level, principles for a ecological infrastructure have been defined and harmonized with the Regional Concerted Development Plan 2012-2025. Those principles are translated into policies that will integrate the future urban planning and water management at macro, meso and micro scale.

They argue to

- protect, develop and implement ecological infrastructure, considering availability and integral management of water resources;
- protect and consolidate agricultural land and add value to improve ecosystem performance;
- transform high risk areas as part of the ecological infrastructure;
- promote water sensitive urban development that considers water catchment, saving, treatment and reuse of water in the city and develop water sensitive urban design according to water sources.

LEIS-Manual

On the site level, recommendations for prototypical water-sensitive solutions for different urban areas of Lima are developed. They are based on an a survey of several existing open spaces and new design projects to show how water sources and vegetation are dealt with in the open space design and management. Based on this survey, prototypical water-sensitive design solutions for different water sources in different spatial situations (=> hydro urban characteristics) are presented, which if applied in a larger scale create together the ecological infrastructure of the city.

LEIS-Tool

In order to localize for instance the areas with high irrigation demand and the various potentials for water saving, re-use of treated wastewater and multifunctional open space design, a GIS-based meso scale analyses of the metropolitan area is conducted. The objectives for the LEIS-Tool analyses are defined by both the LEIS manual and the LEIS principles alike – e.g. identification and quantification of all water sources – linking the overarching principles with programmes and prototypical projects on the ground.

With this approach integrated planning is not only applied in the sense that there is an integration of water management and urban planning, but also with regard to the integration of scales and most importantly through the interlink between the three components of the Lima Ecological Infrastructure Strategy.

4 MESO SCALE APPROACH – THE CITY AS A MOSAIC

4.1 Methodology

How to integrate water management and open space planning and why?

The lack of a unified view of the city that is shared by urban and open space planners and water management a like is one obstacle to integrated planning. The methodology developed in the research project and outlined in this paper leads to the creation of meso scale spatial units that define different typologies of urban spaces in relationship with the urban water cycle and provide guidance for the planning processes of both disciplines.

What information is available?

Due to the availability of satellite imagery with a resolution of up to 50 cm every level of detail that is needed for spatial planning can be captured. Furthermore extensive data about the socioeconomic situation is available (COOPI 2011), Google Earth communities contribute to specialised fields of interest and a new municipal administration updates important planning information.

Why is there a need for a less detailed meso scale approach and what means meso-scale in this context?

Despite the partially very detailed information, the problem of divergent spatial information depending on the field of interest, multiple scales, changing resolution and the incompletness of information remains. This issue has been addressed by the planning institutions as challenges for integrated spatial analyses and there are recent examples that have developed solutions to overcome this problem – for large scale / country wide socioeconomic evaluation (Huyssteen et al 2009), and for geospatial analysis across scales, borders, sectors and disciplines (Naude et al., 2008).[3]

In the case of Lima, this common problematic is coupled with weak metropolitan planning institutions, historically fairly independent district municipalities and a strong sectoral organisation of spatial, social and infrastructure issues. Basic cadastral information of divergent sources are compeeting and a unified view on the city is lacking. The administrative districts of Lima and Callao are too diverse in terms of different urban conditions to be useful for any city wide comparison. On top of this, the provincial division between Lima and Callao force administrative borders onto the city that are hardly recognizable on the ground but have a strong influence for the availability and the harmonisation of information. At the same time, watershed outlines are in the case of Lima – a city without rain – not sufficient for spatial differentiation.

Meso scale as it is understood in this paper means the intermediate scale between the urban planner's block scale and the regional planners city scale.[4] For the people of Lima this intermediate scale is usually represented by the districts, even though they are by nature too heterogenous to be equally compared, with population ranging from 20.000 in the smallest district of La Punta to almost 1 million in the district of San Juan de Lurigancho.

The GIS-procedures of overlaying information, clustering, disaggregating and aggregating could be performed related to any homogenous spatial unit. The extensive SIRAD study (COOPI 2011) has shown the potential for a fine sclae block based analyses of risks and vulnerability. For raster based analyses the formerly known contrains with regard to fine scale resolution diminish. Processing power of standard computers would already allow for high resolution analyses (2 – 10 meters) of a raster based model and could facilitate suitability analyses with regard to the urban water cycle and open space planning. However the problem is not the level of detail of certain information but the divergence of information with regard to accuracy and timeliness and the lack of a unified perception.

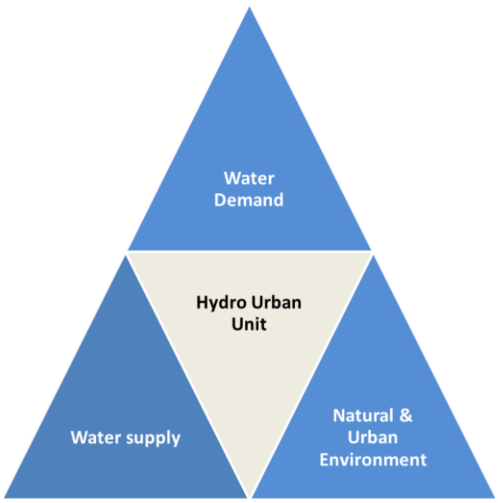

Figure 1: Combination of relevant characteristics in hydro urban unit.

Furthermore the key information in this case is the water, the consumption and the potential supply, and one of the key actors is the water company, which led to the decision to choose as a meso scale unit the water management sectors that are used by the water company SEDAPAL for managing the distribution of potable water. SEDAPAL is responsible for the water and wastewater services throughout the largest part of the metropolitan area, it is therefore in the situation of also holding partially more detailed and farther stretching spatial information than the actual planning institutions. There are 450 sectors with an average population of 20.000 and an average size of 95.500 m². They are covering the SEDAPAL service area which extends over

[3] Avelar et al. (2009) have applied remote sensing analyses in order to pre assess the distribution of socio-economic classes in Lima on a meso scale level.

[4] Within the LiWa-Project, that actually covers all three Lima watersheds from the Ocean to the Andes in order to model climate change effects, macro, meso and micro scale are again used slightly different, with the whole metropolitan area of Lima and Callao being described as meso scale.

almost the whole built up area of Lima and Callao. A few sectors had to be added in order to cover the whole area of investigation with similar sized descrete spatial units.

Altogehter these units describe the city according to the water sources and the characteristics of the built and natural environments including open spaces. The hydro urban units consist of aggregated and disaggregated information, derived from topography, natural and man-made water sources, population statistics, the state of water infrastructure and structure of urban pattern and open space and environmental functions. They can be ordered into the spheres of "Water Demand", "Water Supply" and "Natural and urban environment" including population and society (fig.1). The combination of certain information results in specific hydro urban characteristics, the combination of all relevant aspects eventually leads to a set of distinct hydro urban typologies that are understood by urban planners and water management as a basis for their analyses, programms and projects.

Figure 2 shows an example for two sets of information that are assigned to the the mediating spatial unit, the HUU, through processes of aggregation and disaggregation. While in the one example the information about the level of connectedness of households to the sewage system is available in a fine scale (block), population growth trends as the other example are only estimated on the district level and therefore rather coarse. After processing the information can be combined in one spatial entity which is neither the block nor the district but the hydro urban unit.

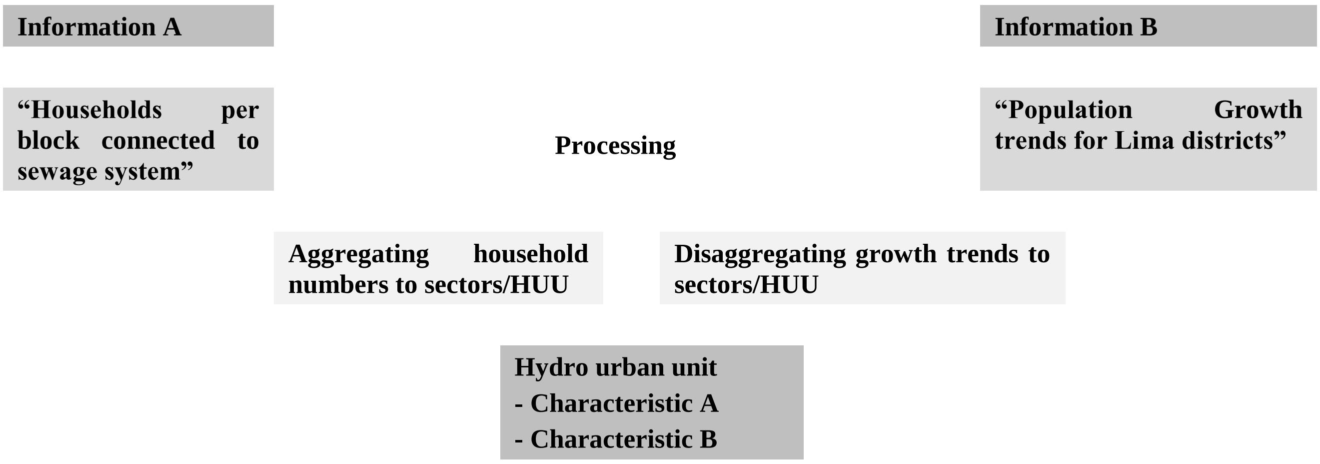

Figure 2: Processing information for hydro urban units.

4.2 Application

The usability of this approach will be shown with the following planning task that is derived from the principles of the Lima Ecological Infrastructure Strategy. One of the principles states: Protect, develop and implement ecological infrastructure considering availability and integral management of water resources. This results e.g. in a need to quantify the demand for the irrigation of green open spaces in Lima areas and the estimation of the potential supply for the irrigation of green areas.

Water demand

In a first step the water demand for irrigating green areas is quantified. Although there is detailed information about the irrigation of crops and the specific water demand for certain species, general numbers for the actual water consumption for green areas are not available. Within the LiWa-project divergent numbers for the demand of water were estimated. In a general survey Mosoco (2011) estimated 1,95 m³/m²/year. Based on an analyses of actual water supply information from SEDAPAL for 800 green areas, an average consumption of 1,49 m³/m²/year was identified by the author.[5] The district of Villa El Salvador in the sandy south of Lima estimates a demand between 2,5 and 2,7 m³/m²/year as an average for the district parks and 3,1 m³/m²/year for grass surfaces (Municipalidad de Villa el Salvador 2012).

Estimations for the demand based on real needs of intensive lawn vegetation result in only about 1 m³/m²/year which leads – depending on the type of irrigation – to 1,25 (pressurized irrigation) to 2

[5] The sample consists of monthly consumption rates between May 2011 and May 2012 and the dataset includes the size of the actual serviced area. It is therefore assumed that it mirrors quite well the "normal" demand for irrigation including the standard management.

m³/m²/year (gravity irrigation). This leads to the assumption that besides the real need for the vegetation and the demand depending on the irrigation regime a third component that may be called "other losses" has to be considered. However for the estimation of the water demand the figure 1,5 m³/m²/year that is based on actual consumption data is taken, without speculating on the amount of "other losses".

Green open spaces

The main source of information for the green open spaces in Lima and Callao that are collected in the green catalogue[6] has been adopted from a dataset provided by SEDAPAL (12/2012). It quantifies the total green area that is serviced by SEDAPAL stretching over the whole area of Lima and Callao. The second source is the first draft of the green inventory which was put together by SERPAR and IMP and was supported by the LiWa project (9/2012). The green inventory was updated with Google Earth (visual comparison) and attributed according to coverage with vegetation, hard surface or bare soil. Other sources of informationen with less detail had to be taken for Callao and two Lima districts, because of availability reasons. Altogether a heterogeneous situation with regard to legal zoning status, ownership, real shape, vegetation coverage and categorization. Therefore the only comparable information was a rather crude differentiation in linear green areas, parks of all sizes and functions and the larger zonal and metropolitan parks (incl. Zoo) summing up to altogether 3.500 ha.[7]

Type	Area m²	Area ha
Linear green areas (mainly along streets)	8.216.672	822
Parks and other green areas	22.969.977	2.297
Zonal /Metropolitan Parks & Zoo	3.917.340	392
Total	**35.103.989**	**3.510**

Table 1: Green areas in Lima and Callao (ILPE 2013)

Considering a demand of 1,5 m³/m²/year and a total area of 35.100.000 m² a total water demand of 52.650.000 m³ or 1,67 m³/sec for the irrigation of green open spaces – without agricultural land – can be assumed. In comparison the total amount of potable water distributed through the water pipes was 18,22 m³/sec in 2011.

The future demand for irrigation is calculated depending on three factors:

a) Enhancement of irrigation regime and adaptation of water sensitive design schemes for open spaces

The water management in parks is presently not very efficient. To estimate a potential for a reduction, the two irrigation systems that are presently most often used in Lima can be compared. The by far most often used gravity irrigation is only 50 % efficient the pressurized irrigation has an efficiency of 85 %.
Theoretically a complete compensation of gravity irrigation with pressurized irrigation would lead to a reduction of the water demand of roughly 40 %. However this situation can hardly be achieved and a realistic reduction of water consumption through a better irrigation regime and the adaptation of water sensitive design schemes for open spaces as proposed in the LEIS-Manual, lies rather with 10-15 % in a time span of 10 years. Therefore for any future water demand 1,35 m³/m²/year is taken for further calculations.

a) Population growth

The last census for Lima by the Instituto Nacional de Estadística e Informática (INEI) was in 2007. There is no more recent census data available, but there are estimations by INEI about the future development of the whole country and its departments. INEI's estimated number for population growth until the year 2021 for the whole metropolitan region of Lima and Callao were broken down to growth rates for districts by IMP based primarily on district growth trends of the past (IMP 2011).

From 8.470.000 inhabitants in 2007 to 9.450.000 in 2012 to estimated 10.850.000 inhabitants in 2021 the city's population is expected to grow by more than a fourth within 15 years.

[6] Within the project a collection of various information with regard to green areas is compiled in the green catalogue. It is not the green inventory that is presently being updated for the Municipality of Lima.

[7] Other studies, like the recently published survey by Ludena summarize about 2.550 ha for Lima alone (Ludena 2013) which is, considering the approx. 460 ha that are in Callao, 500 ha less than in this study.

But the growth is heterogeneously distributed over the city with a population that remains constant in consolidated districts to areas with an increase of 50 % up to 240 %. Within this project a further disaggregation from districts to sectors (hydro urban units) took place in order to show the process spatially distributed in a better resolution.[8]

b) Ratio m^2 green area per inhabitant

The current ratio of m^2 of green public spaces per inhabitant in Metropolitan Lima and Callao ranges from 2,4 – 3,7 m^2/inhabitant depending on the data source and the selection of the areas that account for "public green". Within the LiWa-project the higher numbers were chosen because they include all the linear green areas along streets with mostly decorative functions but nevertheless a considerable water demand.

In the public debate in Lima much higher ratios are considered, such as the 8 m^2 per inhabitant as proposed by the World Health Organisation is often used as the target indicator (Ludena 2013). In the Regional Concerted Plan for Lima an intermediate ratio of 5 m^2/inhabitant is envisaged (IMP 2012, 361), this figure is therefore used in this study. Table 2 shows first the calculations for the whole city based on a status quo extrapolation with 4 m^2/inh. also for the future population and than the calculations based on the intermediate goal of 5 m^2/inh . In the lower part of the table the ratios are calculated for each hydro urban unit in order include the local conditions that vary greatly within the city.[9] This lead ultimately to higher numbers because in this case the green areas in HUU with more than the 4 or respectively 5 m^2/inh. do not compensate for a deficit in another HUU.

4.3 Analyses

According to population growth until 2021, and a ratio of 5m^2 green area/ inhabitant, the quantification of the future demand for green areas results in 6.130 ha of green open spaces and 5,65 m^2/inh. for the whole city and would have a water demand of approximately. 2,62 m^3/sec (table 2). The map of the hydro urban units (fig. 3a) shows a very diverse image of the city with a great demand for an increase in the South of Lima and the North East but large areas which lie in the centre and the consolidated districts with only little demand.

According to Moscoso (2011), presently only a 10th of the treated waste water is used for irrigation of green areas and agricultural land, which amounts to roughly 0,3 m^3/sec. It is widely acknowleged that there needs to be an increase in the use of treated waste water, but the question is how and where. An increase of the re-use of treated waste water could in theory compensate for instance the demand that results from the population growth. But is the water available where it is needed most?

Year/ irrigation regime	Water demand m^3/m^2/year	Population	Ratio green area m^2/inh. whole city	Green area total	Water dem. m^3/second
2012 – present	1,5	9.450.000	3,7 m^2/inh.	35.100.000	1,67
2021 – no change		10.850.000	4,0 m^2/inh.	43.400.000	2,06
2021 – water saving	1,35				1,86
2021 – no change	1,5		5,0 m^2/inh.	54.250.000	2,58
2021 – water saving	1,35				2,32
			Ratio green area m^2/inh. each HUU		
2021 – water saving	1,35		4,0 m^2/inh.	54.800.000	2,34
2021 – water saving			5,0 m^2/inh.	61.300.000	2,62

Table 2: Water demand changes according to irrigation regime and green ratio. Note the difference in total area, which is depending on the application of the ratio for the whole city or the more local hydro urban units.

[8] Further adjustment of the distribution of the growth trends within a district is needed, in order to identifiy the most likely expansion area.

[9] Ludena also points out the existing contrast related to the unequal distribution of green-open space in the city. For instance some districts reach over 15 m^2/inhabitant of green open space. However other districts located over desert or hilly areas reach an average of 0,2 to 2 m^2/inhabitant of green public space, confirming the lack of coherence and unsustainability of the current urban development (Ludena 2013).

To answer that question the second step of the analyses identifies the HUU with a high percentage of households that are not connected to the sewage system (fig. 3b). Therefore these areas are potential areas for the connection to new, decentralized treatment plants that first of all clean the waste water but also provide irrigation water. With follow up analyses specific areas can be outlined and the respective design prototypes for "wastewater treatment parks" and other proposals and designs that are adequate for these areas and which are developed within the LEIS-Manual, can be implemented.

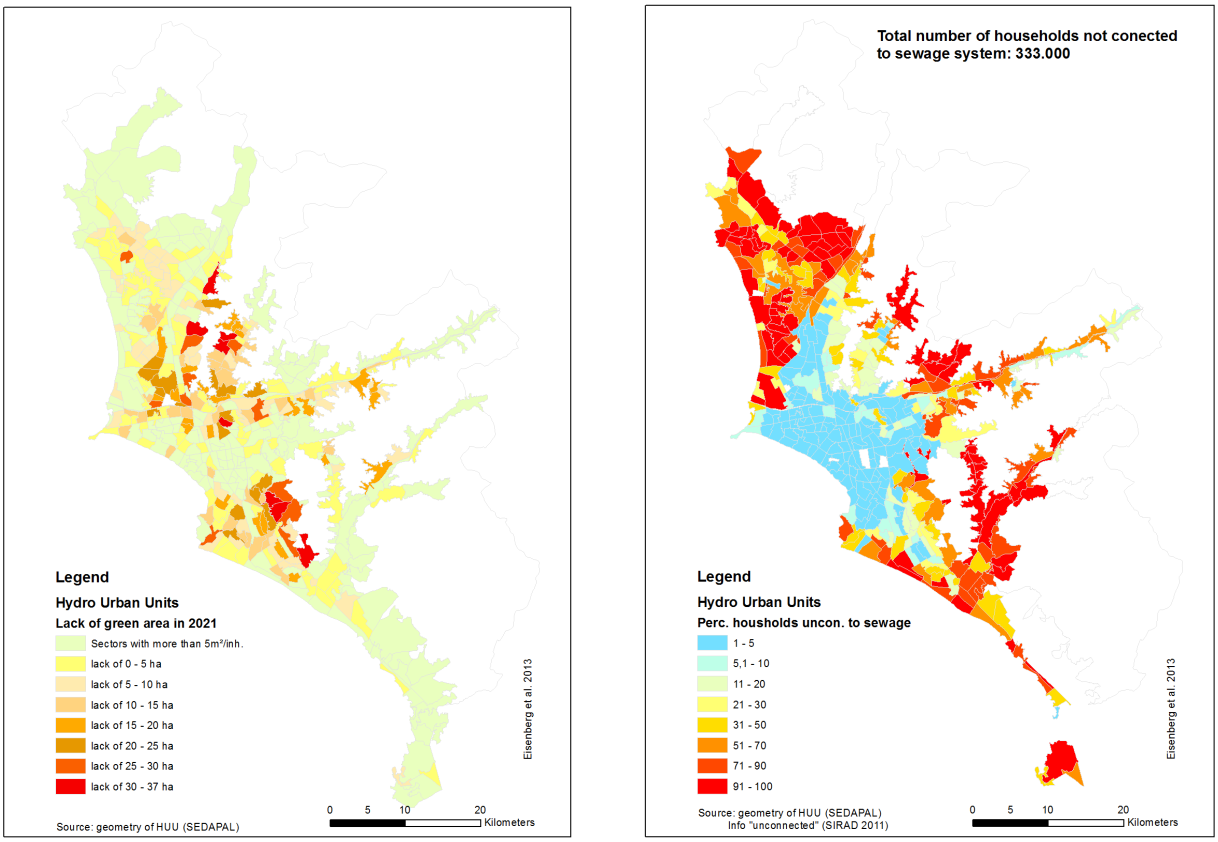

Fig. 3a: Lack of green areas in 2021 based on a ratio of 5m²/inh. in each sector/HUU. b) Percentage of households that are unconnected to the sewage system.

5 CONCLUSION

The Lima Ecological Infrastructure Strategy tries to bridge the sphere of general planning guidelines and principles for an integrated urban planning and water management to site-specific water sensitive design solutions. The question of what to aim for in order to integrate urban planning and water management is connected to the questions where to implement and how to do implement. This integrated approach is seen by the authors as an alternative route to tackle the fragmented planning that Lima's suffers from today.

The meso – scale analyses is adequate to localize specific demands for water consumption as well as the divergent potentials for water soruces. In a situation without updated population data, the disaggregation of general population growth trends is the only way to quantify future demand for green open spaces and localize it. The example presented in this paper shows only one of many possible solution to overcome the shortage of public green areas and and to identify potential water sources for irrigation at the same time. In this case the areas that are today unconnected to the sewage system are in the future potential catchment areas for waste water that can be treated and used for irrigation. More complex combinations of hydro urban characteristics will eventually be useful to identify distinct typologies that are understood by urban planners and water management alike and that may lead to a common vision of the metropolitan area of Lima and Callao.

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