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Article

A combined field and remote-sensing based methodology to assess the ecosystem service potential of urban rivers in developing countries

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Abstract: Natural rivers in urban areas bear significant potential to provide ecosystem services for the surrounding inhabitants. However, surface sealing by houses and street networks, urban drainage, disposal of waste and wastewater resulting from advancing urbanization usually lead to the deterioration of urban rivers and their riparian areas. This ultimately damages their ability to provide ecosystem services. This paper presents an innovative methodology for a rapid and low-cost assessment of the ecological status of urban rivers and riparian areas in developing countries under data scarce conditions. The methodology uses a combination of field data and freely available high-resolution satellite images to assess three ecological status categories: river hydromorphology, water quality, and riparian land cover. The focus here is on the assessment of proxies for biophysical structures and processes representing ecological functioning that enable urban rivers and riparian areas to provide ecosystem services. These proxies represent a combination of remote sensing land cover- and field-based indicators. Finally, the three ecological status categories are combined to quantify the potential of different river sections to provide regulating ecosystem services. The development and application of the methodology is demonstrated and visualized for each 100 m section of the Pochote River in the City of León, Nicaragua. This spatially distributed information of the ecosystem service potential of individual sections of the urban river and riparian areas can serve as important information for decision making regarding the protection, future use, and city development of these areas, as well as the targeted and tailor-made development of nature-based solutions such as green infrastructure.

Keywords: Urban rivers; ecological status; ecosystem services; developing countries; Nicaragua; nature-based solutions; green infrastructure

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1. Introduction

Ecosystem services are the direct and indirect benefits that people derive from various types of ecosystems. The maintenance and enhancement of ecosystem services is of central interest to societies. According to Potschin and Haines-Young [1], specific ecological and biophysical structures and processes, representing the status of an ecosystem (natural capital), can be conceptually linked to elements of human well-being. A good ecosystem status provides adequate biophysical structures (e.g. for habitats) and facilitates ecological processes (e.g. primary production). While a deteriorated ecosystem status has less potential to provide these functions which finally lead to benefits to human beings as ecosystem services.

Recently, there has been increasing scholarly interest (e.g. several special issues of international journals) in the area of ecology and ecosystem services provided by urban areas in the last decade [2–

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4]. Due to the high population density of urban areas there is potentially a high demand for ecosystem services, especially those provided in-situ [5]. However, urban areas have only recently been considered as potential provisioning areas of ecosystem services [6,7]. Many studies have focused either on mostly green spaces, urban green spaces in general [8], or hydrological ecosystem services of river basins [9]. In contrast, urban rivers and their potential to provide in-situ ecosystem services have not been considered to the same extent. This misses the fact that the potential of rivers and riparian areas in good ecological status to provide ecosystem services, due to their diversity in aquatic and terrestrial biocenosis and biotopes, is much higher compared to other ecosystems [10–12].

Despite urban rivers in developing countries being largely used for disposal of untreated waste and storm water discharge as well as local dump sites, they are still in relatively good condition. For example, hydromorphological changes such as channelization or artificial embankments of small and medium-size rivers are often not as advanced as in developed countries [13]. Especially in small and medium-sized towns, the river morphology and often also the riparian vegetation is in relatively good condition. With increasing urbanisation and often unguided urban development, however, the ecological potential of urban rivers is at increased risk of being lost [14]. Moreover, urban rivers and riparian areas are often encountered in urban-rural transitioning zones representing places of informal settlements. This can be explained because these areas represent still somehow rural living conditions, to satisfy basic needs for water and waste disposal, and offer the potential for agriculture for marginalized city dwellers. Since these areas are often prone to flooding and contamination, they are not priority areas for formal city development but are rather left aside.

The concept of ecosystem services encourages problem solving by highlighting the social benefits that intact water bodies and riparian areas can provide [15]. By identifying the potential for ecosystem services, it is assumed that urban water pollution could be reduced and urban rivers in developing and emerging countries could be maintained in more natural state. However, there is no widely-accepted methodology for how to evaluate the value of urban rivers and riparian areas in their ability to provide ecosystem services [16].

In this publication we present a methodology to assess the ecological status of urban rivers and riparian areas in developing countries under data scarce conditions in order to derive the potential to provide ecosystem services according to the internationally recognized Common International Classification of Ecosystem Services (CICES) [17]. As a first step, Urban River Ecosystem Services (URES) are defined according to CICES. This is the first attempt in the literature to extract URES based on the CICES. Then, a methodology to assess the ecological status of urban rivers and riparian areas based on a combination of low-cost field data and freely available high-resolution satellite images is developed for three ecological status categories: hydromorphology, river water quality, and riparian land cover. The focus here is on the assessment of commonly used proxies for biophysical structures and processes representing ecological functioning that enables urban rivers and riparian areas to provide ecosystem services. These proxies represent a combination of remote sensing land cover/land use-based and field-based indicators. With the combined use of land cover/land use-based and field-based indicators, the limitations of using only land-cover and land-use based indicators identified by scholars of the field [5] are overcome. These ecological status categories are related to the URES identified as suitable for the available methodology and data through individually weighted combinations of the status categories.

In a second step, this universal methodology is applied to the case study of the Pochote River in crossing the city of León, Nicaragua, for the regulating ecosystem services of this urban river and its riparian areas. As a result, the potential to provide each identified URES for every 100 m section of the considered river is quantified and can be visualized via geo-referencing. This spatially distributed information of URES potential of individual sections of the urban river and riparian areas can serve as important information for decision making regarding the protection, future use, and city development of these areas as well as the targeted and tailor-made development of nature-based solutions such as green infrastructure. The methodology presented in this publication also supports the rapid-appraisal of URES that can be applied by untrained professionals and with low resource

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investments. The study represents a first practical application of the CICES framework for an urban river ecosystem in a data-scarce region.

2. Materials and Methods

2.1 Study area and raw data

The Pochote River has its origin in the northern part and limits of the city of León. With about 180,000 inhabitants, León is Nicaragua's second-largest city located about 93 km northwest of the country's capital Managua [18]. While this origin area extends about 20 km to the North-East of the City, the river flows in South-West direction along the city boundary for about 6 km. A few kilometres after leaving the city limits, it confluents with the Chiquito River, another river of the City of León, forming a common river basin that leads to the Pacific Ocean. The climate of the study area is a tropical savannah climate with a pronounced dry season from November to April and a rainy season from May to October. The average monthly precipitation ranges from 300 to 500 mm. The average daily temperature varies from 27 to 29° C with the lowest values found between the months of December and February [9].

The current state of these water bodies is characterized by high levels of contamination due to the disposal of both domestic waste and waste water as well as industrial effluents stemming from the nearby tanneries and slaughterhouses. The Pochote River has recently become part of the urbanized area due to rapid urban expansion throughout the last decades.

The origin of the Pochote River inside the city is comprised of three channels, each having an approximated length of 1 km. Although they are located within a highly urbanized area, the access to the river is partly limited due to a canyon-like topography. On the mid-course, after the three channels have merged, a single stream channel forms meanders and floodplains. These hydro-morphological characteristics have led to different natural conditions surrounding the river and also influenced different formal and informal settlement patterns. The settlement diversity along the river shores changes in flow direction from formally and densely urbanized (1) to informal urban-rural transitional (2) and to formal rural settlements (3). Due to this urban and ecological diversity, a highly fragmented landscape exists. The most relevant water-related issues are a consequence of the inefficient operation of the local wastewater treatment plants and sewerage system as well as direct wastewater discharge from households alongshore, hydraulic stress due to surface runoff from sealed surfaces, and uncontrolled garbage burning and disposal [19].

Additionally, the clearing of riparian vegetation is increasingly a problem disturbing the ecology of the river. However, residents, especially those in more rural settlements along the river, use the river water and that of the numerous natural wells in short distance to the river course in their daily lives (e.g. for household duties and livestock needs) needs [19]. The natural wells deliver significant amounts of clear water to the river even during the dry season when the river is not fed by rainfall at all but only waste water from households. The contribution from natural wells leads to an important dilution of waste water and, together with the natural morphology of the river, results in a continuous improvement of the water quality downstream.

During a field survey from May to June 2017, the exact course of the Pochote River as well as geolocations of specific points of interest: solid waste disposal sites, waste water discharges, natural springs and tributaries as well as any constructive modification of the hydromorphology of the river channel (e.g. bridges, weirs, artificial embankments), were georeferenced and recorded. Additionally, a georeferenced photograph was taken for all points of interests, described and documented in an exhaustive photo documentation (see Figure A1 in Appendix A and [19]). The points of interest identified in May and June 2017 were validated during several other field surveys between September 2017 and April 2018. Field surveys conducted during both rainy (May – October) and dry season (November – April) revealed additional insights in the seasonality of river flow (e.g. in order to distinguish perennial and ephemeral streams) and permanence of sources of contamination (e.g. the discharge of untreated wastewater) throughout the year. The information gathered during these field survey represents the 'raw data' for the assessment of the ecological status of the Pochote River regarding hydromorphological quality and water quality. However, the data collection did not follow a predefined pattern (e.g. every 100 m along the river; see methodology section) since the objective of the field surveys was to geo-reference the river network, points of contamination, and specific characteristics of river morphology.

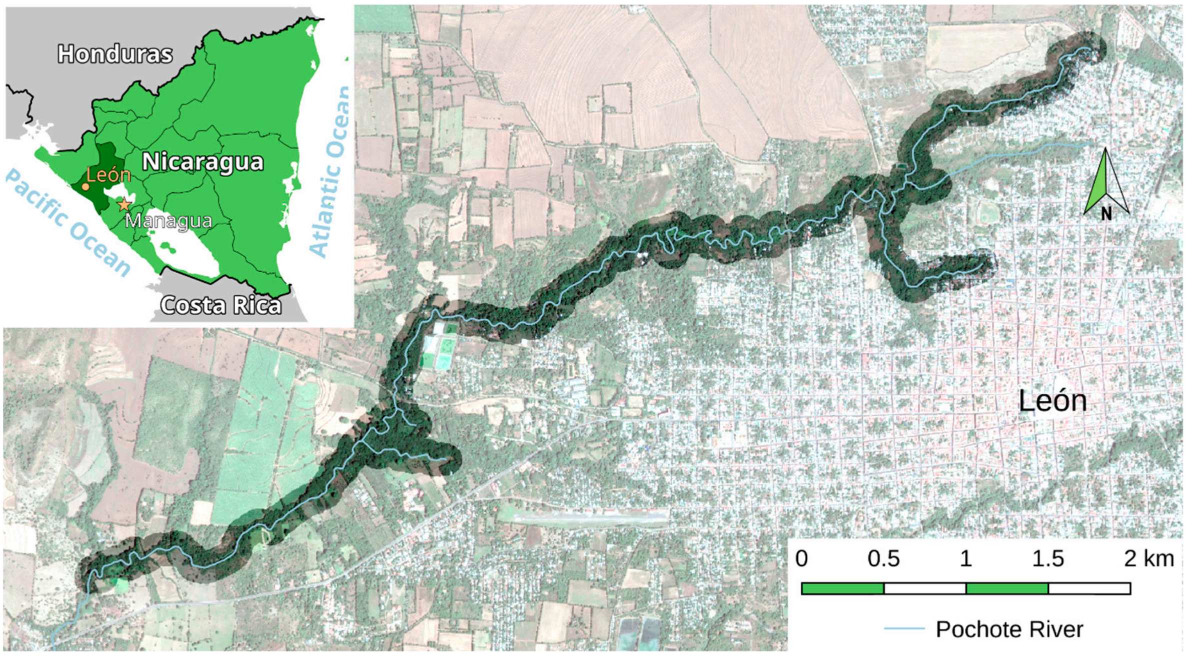

Figure 1. Overview of study area: Pochote River and City of León; Author's work

2.2 Methodology

The methodology described in this section was chosen because of the data scarcity in the project region. Such data scarcity is typical in developing countries.

Since Urban River Ecosystem Services (URES) are not explicitly specified yet, the first methodological step is to extract URES from the commonly applied ecosystem service classification CICES [17] and specify them further (see 'URES categorization' in Figure 2). Next, suitable available 'raw data' from the study area is selected. This includes satellite images, geo-referenced photographs, and GPS data from field surveys. This 'raw data' is used for determining three ecosystem status categories ('ecosystem status').

The three ecosystem status categories 'water quality', 'hydromorphology', and 'land cover' were chosen because these categories comprehensively cover different biotic and abiotic realms as well as the characteristics of an (urban) river corridor. The category 'water quality' provides information on the biotic conditions of the aquatic environment. It can be used to qualitatively assess the provision of ecosystem services related to aquatic life in a coherent manner. The ecosystem status category 'hydromorphology' covers the dynamics of the abiotic realm of the river corridor. It serves to assess the diversity of habitats and habitat conditions. Important natural hydrodynamics as well as habitat-changing or -dividing (man-made) disturbances of them (e.g. contouring or transversal structures such as artificial embankments or weirs) as well as the transition of river bed to riparian zone i.e. aquatic to terrestrial habitats are considered within this category. Finally, the 'land cover' category reflects the conditions of the riparian vegetation with the wider river corridor (100 m wide strip). To characterize the vegetative cover of the river corridor in ground work is very labor intensive and can hardly be done for a larger river section (in this case study an area of ca. 400,000 m²). For this reason, high resolution satellite images provided by Google Earth are used in our methodology to efficiently produce a land cover map of the riparian corridor that can be used to quantify the degree of undisturbed (high i.e. perennial) vegetation, disturbed (low i.e. seasonally disappearing) vegetation and anthropogenically transformed (built up) are. These land cover classes provide information on ecological structures and their specific ecosystem service-related function.

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Qualitative and also quantitative (e.g. in the case of land cover) information on these three categories can easily be redacted or collected at low-cost through field visits and freely available satellite images. Neither expert knowledge nor costly equipment is required for doing this. For this reason, we believe that it is a methodology that can be used by local government members or other public institutions in developing countries.

The ecosystem status is then examined for links to Urban River Ecosystem Services 'URES examination', using the indicators of Maes et. al [20,21] to assess specific URES for the (new) URES biome-related category. In the following, the links of ecosystem status categories to individual URES are defined as weighted multi-criteria equations and used to assess the URES potential of the Pochote River. Figure 2 illustrates the individual steps of the methodology.

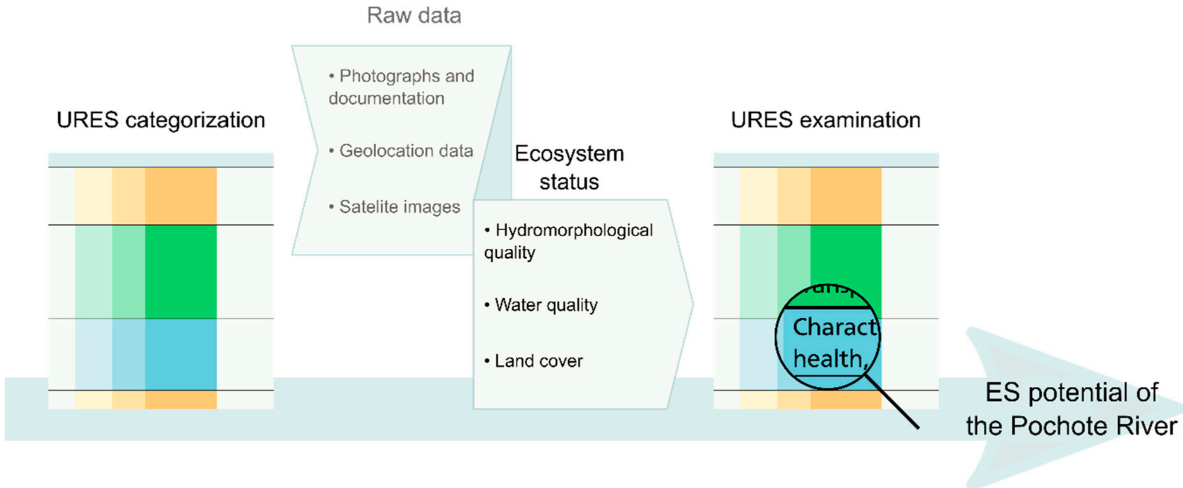

Figure 2. Methodology to assess the ecological status of urban rivers; Author's work

In the following, each methodological step from the establishment of a URES categorization over the assessment of ecosystem status to the examination of URES potential is explained.

2.2.1 Urban River Ecosystem Services Categorization

First, an identification and categorization for Urban River Ecosystem Services (URES) is required since this category of ES has not been explicitly defined. This newly defined category of URES represents a context-specific selection of ES classes defined in the Common International Classification of Ecosystem Services (CICES) [17], which is associated with urban terrestrial and aquatic ecosystems. To generate this new categorization, categorizations for urban ES and river ES classes (as part of the fresh water ES categorization of Maes et al. [20,21]) were combined except those ES classes with groundwater relation. Urban river ecosystems are also linked to the non-urban river ecosystems of the river by dynamic abiotic processes. In addition, urban ecosystems can be located anywhere in the city, including along the river (e.g. park trees and allotments). The idea of a simple combination of river ecosystem services and urban ecosystem services is based on these two circumstances. Groundwater-related services were not considered explicitly, because they are not considered part of river ecosystem services, although groundwater use by bank filtration is possible [2]. Only those services for which indicators are available have been selected to ensure unambiguity, consistency, and ease of use as indicators do not need to be developed. This selection has been adapted into the latest CICES version (CICES V5.1) using the CICES spreadsheet [22] representing the URES categorisation referred to in this publication (Table A1 in Appendix A).

2.2.2 Hydromorphological quality

To determine the hydromorphological quality of individual river sections, a method of the German state working committee LAWA [23] was used in combination with the geo-referenced photographic documentation and photographs from complementary field surveys. The LAWA

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method is intended for mapping the hydromorphological quality for small and medium-sized running waters. It has been successfully applied for many rivers in Germany [24]. However, due to the lack of data for the study area, the following subcategories could not be considered: 'Longitudinal banks (Längsbänke)', 'Special river course structures (Besondere Laufstrukturen)', 'Transversal banks (Querbänke)', 'Flow diversity (Strömungsdiversität)', 'Depth variance (Tiefenvarianz)', 'Substrate diversity (Substratdiversität)', 'Special river bed structure (Besondere Sohlenstruktur)', 'Special bank structures (Besondere Uferstrukturen)'. In addition, the category 'River environment (Gewässerumfeld)' was not considered to avoid duplication with the land cover assessment. Thus, with the exception of this category, 14 out of 22 subcategories of the LAWA method [23] were considered. The geographic information system QGIS (2.18 LTS, 2016-10 [25]) was used to illustrate the hydromorphological quality based on the LAWA quality classification (Figure 4). As required by the LAWA guidelines, the river was divided into 100 m sections (a total of 121 sections) and coloured according to the different hydromorphological quality classes: 1 = 'unchanged (unverändert)', 2 = 'slightly changed (gering verändert)', 3 = 'moderately changed (mäßig verändert)', 4 'significantly changed (deutlich verändert)'), 5 = 'strongly changed (stark verändert)', 6 = 'very strongly changed (sehr stark verändert)', 7 = 'totally changed (vollständig verändert)'. For the sections in which no photos and no specific local knowledge existed (48 sections), a linear adjustment of the previous and the following section was assumed.

2.2.3 Water quality

In order to assess the ecosystem status regarding water quality, a qualitative map with the sources of contamination was created using the available geo-referenced photo documentation [19] and additional site visits. This qualitative evaluation was mainly a visual analysis of the photographs and secondarily based on site descriptions of the geo-referenced photo documentation. For water quality rating a categorisation was generated; category 0 'barely or not polluted' for visibly clear water up to category 4 'highly polluted' for milky whitish coloured water and/or foaming water. The addition 'seasonally' was used if there were discharges in photos in the rainy season, but absent in photos of the dry season or if the photos gave cause for this addition for other reasons. The classes which were created for the classification can be seen in Table 1. The map resulting from this processing is shown in Figure 3.

Table 1. Classification of water quality; Author's work

#	class	Appearance of discharge
0	not or barely polluted	visibly clear water
1	seasonally polluted	brownish colored water, rainwater from surface runoff or does not fit in the other categories
2	polluted	
3	seasonally highly polluted	milky whitish colored water and or foaming water
4	highly polluted	

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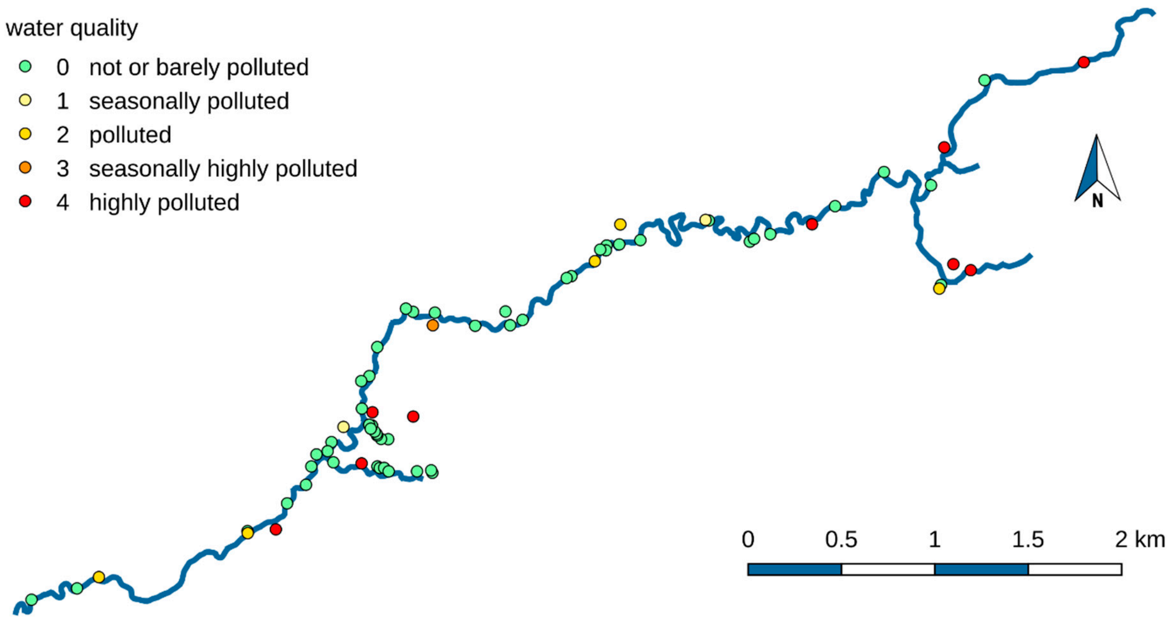

Figure 3. Location of photographs indicating degree of pollution of the Pochote River; Author's work based on field survey information [19].

To produce a map for the water quality from this map, the same 100 m sections that were already introduced for the hydromorphological quality classification were used. The classification of contamination has been maintained for water quality. The water quality of individual river branches contributing to the main river was assumed to be in class 1 (seasonally polluted) in the urban regions and class 0 (not or barely polluted) in the non-urban regions. This is based on the assumption that the proportion of urban surface water in the urban spring regions is likely to be relatively high – thus of poorer quality - due to surface sealing and in the non-urban spring regions it mainly consists of groundwater – assumed to be of better quality. Since no quantitative discharge data were available, the water quality at points of confluence of river branches and the main river was calculated using the volume ratio (*R*) between the (visual) discharge of the main river section and the discharge of a tributary or an affluent. This ratio was determined visually on the basis of photographs at 4 confluences of river branches, 59 spring water inflows (water quality class 0 in Figure 3) and 17 waste water discharges (water quality classes 1 - 4 in Figure 3). The pollution class for the river section after the confluence is calculated depending on the volume ratio and the pollution classes. To simplify the calculations, values between 0 and 1 were assigned to the individual water quality classes (Table 2). Additionally, a natural cleaning factor (*N*) was also assumed to clean the river from category 4 to category 0 in 10 km. The calculations were carried out starting at the sources of each river branch (source areas) that contributes to the main river. For each confluence with an affluent or a tributary, the water quality value of the river section was estimated using the aforementioned visual volume ratio (*R*) of the discharge to the previous section. This procedure is described below in formula (1) and (2).

$$WQ_j = (1 - R_{tr,j}) \cdot (WQ_{,j-1} \cdot (1 - \sum_i R_{di,i,j}) + \sum(WQ_{di,i,j} \cdot R_{di,i,j}) + WQ_{tr,j} \cdot R_{tr,j}) \quad (1)$$

i = Number of discharge in one section
j = Number of section
WQ_j = *Water quality value of section* [-]
WQ = Water quality value (with applied cleaning factor) [-]
WQ_{di} = *Water quality value of discharge* [-]
WQ_{tr} = *Water quality value of tributary* [-]
R_{tr} = *Visual Volume Ratio between the tributary and the main river* [-]
R_{di} = *Visual Volume Ratio between the discharge and the tributary/main river* [-]

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$$WQ = WQ_j + N * \frac{l}{100} \quad (2)$$

$N = Natural\ cleaning\ factor$ [1/m]

$l = Section\ length$ [m]

In addition, an upper limit for the water quality value of 1 was introduced as the quality cannot increase above this optimal value. After all calculations, the values were then assigned to the water quality classes (see Table 1) using class limit values.

2.2.4 Land-cover

A land cover analysis of 50m buffer strips on both sides of the river (study area; see Figure 1) was carried out in order to assess the vegetative status of the riparian corridor of the Pochote River. To be able to analyse even very small-scale structures and patches, which are very common in urban river environments, high resolution satellite images provided by Google Earth were used. An innovative methodology for land cover classification on the basis of these available, which are freely available for non-commercial uses, was developed.

First of all, an orthogonal bird's-eye view image of the study area was generated using Google Earth (Version: 7.3 Desktop) and exported in a jpg-format. The chosen image was taken during dry season, specifically on 26th of January, 2017 (Digital Globe, GeoEye1). The advantage provided by using an image during dry season is that is shows a greater contrast between the evergreen trees and other perennial vegetation and agriculture areas, making it easier to discriminate between these types of vegetation. In addition, the image is relatively up-to-date. The image was then edited for land cover classification with the GNU Image Manipulation Program (GIMP) (Version 2.8, 2017-05 [26]), a widely used software for image editing. At the beginning, the satellite image was imported into GIMP and roughly cropped to the study area. Then the 'Select by Color Tool' was used to select and colorize one area type after the other. After that small adjustments were necessary i.e. to have only three different colours in the selected area. This serves for easier handling and error minimization in QGIS. For the same purpose the colour palette was reduced to only three colours before being exported as a .png file with the '8bpc GRAY' pixel format. Then the original satellite image was opened with the 'Georeferencer GDAL' plugin and geo-referencing points were determined using the 'OpenLayers Plugin' [27]. These geo-referencing points were used to geo-reference (WGS84 ESPG: 4326) the produced map (exported .png file) to obtain the same dimensions as the original satellite image. The resulting raster was finally cropped to the study area (with a 50 m buffer zone on both sides of the river) and divided as well into 100 m sections in QGIS. For this purpose, the layer of the study area had to be divided into the same 100 m sections as the other two ecosystem status categories. Then the 100 m section layer could be cut with the raster to achieve the desired result. The resulting land cover map representing, in addition to Hydromorphological and water quality, the third ecosystem status category used to derive the ecosystem service potential of the Pochote River. In order to use the land cover classes as input data for the assessment of ecosystem service potential, the following unified values are assigned to the three land use classes 'high and perennial vegetation' = 1.0, 'low vegetation' = 0.6. and the 'built-up' = 0. These values are based on the assumption that 'built-up' area has no potential to provide ecosystem services at all (value 0), while 'high and perennial vegetation' has the full potential (value 1.0) to provide ecosystem services. 'Low vegetation' is considered as disturbed vegetation that can only provide a certain degree (here 0.6) of the total potential of ecosystem services. The value 0.6 was chosen to indicate that the potential of 'low vegetation' is still closer to the potential of 'high vegetation' than to that of the 'built-up' area.

Figure A2 in Appendix A contains a detailed step-by-step description of the work flow which was applied to reach the land cover classification for the study area.

2.2.5 Links between URES and ecosystem status categories

In order to calculate the potential of rivers to provide ecosystem services on the basis of ecosystem status categories using the previously determined conditions for each of the URES, it was

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necessary to normalize the different categories. As with the water quality category, values between 0 and 1 were chosen (Table 2), allowing the results of the status to be expressed in percentage.

Table 2. Transformation of classes in normalized values; Author's work

Hydromorphological quality			Water quality			Land cover	
class		value	class		value	class	value
1	unchanged	1.0	0	not or barely polluted	1.0	High vegetation	1.0
2	slightly unchanged	0.83	1	seasonally polluted	0.9		
3	moderately unchanged	0.67	2	polluted	0.6	low vegetation	0.6
4	significantly unchanged	0.50					
5	strongly unchanged	0.33	3	seasonally highly polluted	0.3		
6	very strongly unchanged	0.17					
7	totally changed	0.0	4	highly polluted	0.0	build-up area	0.0

Since the vegetation of the riparian zone is considered in the hydromorphological quality category ('Uferbewuchs') [23], land cover is mainly a factor influencing URES related to air quality. While the other two ecosystem status categories mainly relate to URES of the river itself, the effect of land cover on the river through prevention of soil erosion is estimated to be low compared to the other two ecosystem status categories. Even though the hydromorphological quality and the water quality both have a primary effect on the river, they have no interdependencies due to the method of data collection, since the water quality during the data collection is based on mixing ratios and not on the hydromorphological quality. Although the hydromorphological quality could have been included in the water quality calculation (e.g. through a hydromorphology dependent natural cleaning factor), its influence at the current degree of pollution was assumed to be small and the cost involved of incorporating both factors was greater compared to the expected benefit. As a result, the information on water quality, hydromorphological quality, and land cover are not strongly correlated based on their survey types. Therefore, the relationship of the individual ecosystem condition data to each other is determined below, in which they can be added together (with different weighting in the case that one ecosystem status category is more relevant for URES provision than the other) to represent the respective URES.

An initial analysis was carried out to determine which of the URES could best be linked (directly or indirectly) to the established ecosystem status categories. All of the URES that could not be reasonably related to three ecosystem status categories are not further considered in this study. However, the remaining URES chosen for further consideration are presented in Table 3. It follows a secondary analysis in which the filtered out URES indicators are examined for direct links with the ecosystem status categories. The three ecosystem status categories represent different biophysical structures and processes that link them directly to different ecosystem functions. A direct link is assumed when according to [22] an indicator for an URES can be related to at least one of the three ecosystem status categories. Direct links to several categories could be identified for the majority of the considered URES, but for some URES only one category or a dominant one could be found. Since the three ecosystem status categories 'water quality', 'land cover', and 'hydromorphology' cover different biotic and abiotic realms as well as characteristics of an (urban) river corridor, they can be complementarily linked to URES. The way how the three ecosystem status categories are linked to the considered URES will be explained and justified.

According to [22] the same indicators are commonly used for the services 'Bio-remediation by micro-organisms, algae, plants, and animals' and 'Filtration/sequestration/storage/accumulation by micro-organisms, algae, plants, and animals', ranging from indicators of the general ecological status and specific indicators of water quality and to the area occupied by riparian forests. Therefore, all three ecosystem status categories can be assigned to these two URES. Since all three also link to other different indicators (i.e. all cover their own area, they are added to one third each) [28].

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An indicator used for the service of ‘Noise attenuation’ [29] is the Leaf Area Index. This indicator can be linked to the ecosystem status category ‘land cover’. It seems reasonable to link high vegetation to better noise attenuation and low vegetation to less noise attenuation.

In the case of the ‘Hydrological cycle and water flow regulation (including flood control, and coastal protection)’ service, the indicator ‘water retention capacity by vegetation and soil’ can be linked with ‘land cover’ [28,29].

The ‘Maintaining nursery populations and habitats (including gene pool protection)’ service includes the indicators ‘Biodiversity value’ and ‘Ecological status Morphological status’ [28]. Since hydromorphology and water quality are both indicators of biodiversity within the river, and land cover an indicator for biodiversity outside the river, the ecosystem status categories hydromorphological and water quality are added together in equal parts and the resulting value is added 1:1 to land cover.

According to Maes et. al [28], the ‘Regulation of the chemical condition of freshwaters by living processes’ service is determined using the following indicators, ‘Chemical status’ and ‘Ecological status’. Although generally chemical status is indicated by the water quality, hardly any influences of the regulation of living processes are taken into account here. Biological treatment processes are only carried out before discharge into the sewage treatment plants, which are included in the calculation of the water quality because the water quality results from the quality of the discharges (pollution). In addition, as already described in the first two services of this chapter, the impact of land cover on air quality is considerably higher than on water. For these two reasons this URES is linked to the ecosystem status categories hydromorphology: water quality: land cover in relation to 3: 1: 1.

Since no temperature values were measured, only the ‘Leaf Area Index’ can be considered for the ‘Regulation of temperature and humidity, including ventilation and transpiration’ service [29]. Therefore, land cover is linked to this service as it is very similar to the Leaf Area Index.

There is a whole range of indicators for the 'Characteristics of living systems that enable activities promoting health, recuperation or enjoyment through passive or observational interactions' services [28,29]. The only indicator related to the ecosystem status categories considered here is 'bathing water quality', which could be determined by water quality. However, since there are so many various indicators here, it makes little sense to use water quality alone. Hence, this URES class will not be considered in this study.

Regarding the 'Characteristics of living systems that enable aesthetic experiences' service, surveys of the population on how beautiful they find the surroundings around the Pochote River have yet to be collected. It should also be noted that the river is difficult to access, as the authors noticed through visits of the river with locals. This study will not consider this service either.

For the indicators of ‘Surface water for drinking' and ‘Surface water for non-drinking purposes' services, there are no suitable connections with the ecosystem status categories identified here, especially since no flow data are available.

Table 3 summarizes the established weighted links between the ecosystem status categories and URES considered in this study.

Table 3. Relations between the URES and ecosystem status data; Author’s work

	Urban River Ecosystem Service ($URES_k$)	Weighting of ecosystem status categories		
		Hydromorphological quality (hq_k)	Water quality (wq_k)	Land cover (lc_k)
Regulating ES	Bio-remediation by micro-organisms, algae, plants, and animals	1	1	1
	Filtration/sequestration/storage/accumulation by micro-organisms, algae, plants, and animals	1	1	1
	Noise attenuation	-	-	1

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	Hydrological cycle and water flow regulation (Including flood control, and coastal protection)	-	-	1
	Maintaining nursery populations and habitats (Including gene pool protection)	1	1	2
	Regulation of the chemical condition of freshwaters by living processes	3	1	1
	Regulation of temperature and humidity, including ventilation and transpiration	-	-	1
Cultural ES	Characteristics of living systems that enable activities promoting health, recuperation, or enjoyment through passive or observational interactions	-	-	-
	Characteristics of living systems that enable aesthetic experiences	-	-	-
Provisioning ES	Surface water for drinking	-	-	-
	Surface water for non-drinking purposes	-	-	-

As can be seen in the table, indicators for provisioning and cultural URES could not be directly linked to the ecosystem status categories considered in this study and are therefore neglected.

The following formula shows how URES for each 100 m river section are calculated based on a weighted combination of values for the three ecosystem status categories:

$$URES_{j,k} = \frac{HQ_j \cdot hq_k + WQ_j \cdot wq_k + LC_j \cdot lc_k}{hq_k + wq_k + lc_k} \quad (3)$$

$k = Type\ of\ URES$

$j = Number\ of\ section$

$URES = Urban\ River\ Ecosystem\ Service$ [-]

$HQ = Hydromorphological\ quality\ value$ [-]

$hq = Hydromorphological\ quality\ weighting\ factor$ [-]

$WQ = Water\ quality\ value$ [-]

$wq = Water\ quality\ weighting\ factor$ [-]

$LC = Land\ cover\ value$ [-]

$lc = Land\ cover\ weighting\ factor$ [-]

3. Results

The application of the methodology described in the preceding section produced three ecosystem status maps (hydromorphological status, water quality and land cover), which are intermediate results, and potential URES maps, one for each of the ecosystem service assessed, which are final results.

The different ecosystem status maps already bear important insights on the degree of deterioration of the urban river and its riparian zone without going into a deeper interpretation of the status. This is done in the next step when the three ecosystem status information are combined to assess the URES potential. This final result highlights the potential provision of a variety of benefits from the river ecosystem to the local and regional population (ecosystem services). Since beneficiaries are not identified in this study, the following results point to potential ecosystem services that may be considered in the future.

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3.1 Ecosystem status categories

For the hydromorphological quality (Figure 4), the river can be classified as good almost over its entire length, as the hydromorphological quality rarely goes beyond class 3, with the exception of the densely populated area in the northeast and due to a few individual structural elements along the river. A strongly meandering section at the middle course of the river as well as the last tributary (stemming from the Botanic Garden) that confluences with the main river in the southwest are classified as "unchanged", reflecting the highest potential to provided hydromorphology related URES.

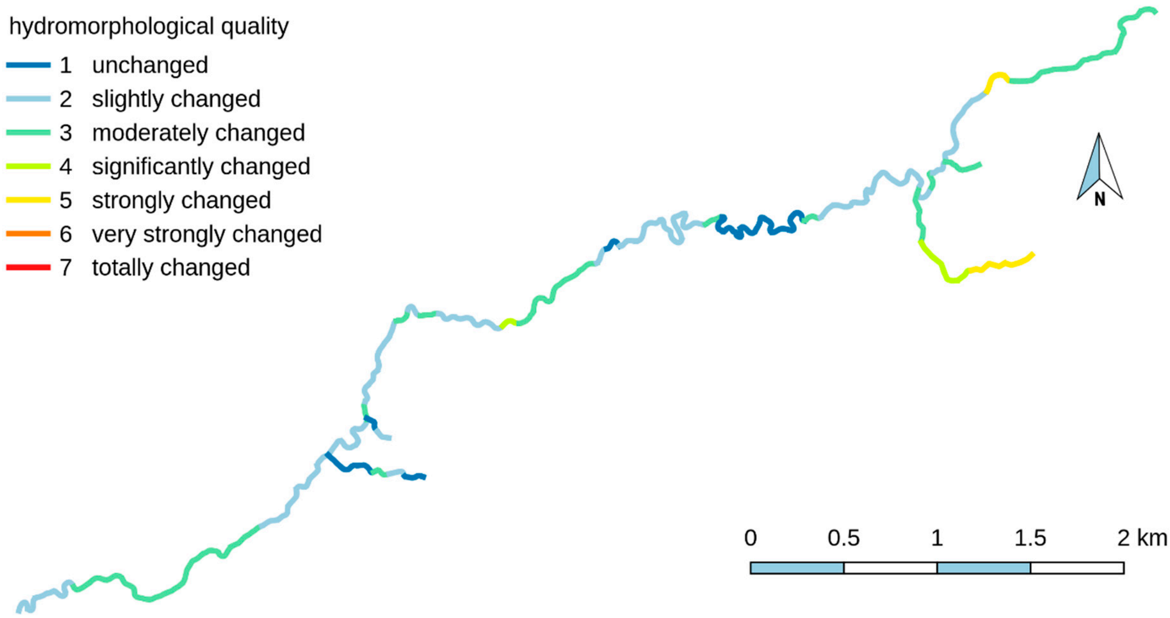

Figure 4. Hydromorphological quality of the Pochote River; Author's work

Figure 5 shows, based on the methodology presented in section 2.2.3, the water quality per 100 m river section in the study area. Similar to the hydromorphological quality, it is significantly worse in the densely populated area in the northwest. The presence of several highly polluted (classes 3 and 4) river sections within this area, and better water quality classes farther away from it, corresponds well to the empirical evidence from field surveys and seems logical. Abrupt improvements from one river section to the following one are a result from a high number of fresh water sources (natural wells) that reduce the concentration of contaminants due to dilution. From the strongly meandering middle course of the river on several natural wells contribute (apparently) clean water to the main river. This correlates with an increasing distance of the river to the urbanized area when flowing downstream. The downstream trend in cleaner river sections is explained by the self-purification of the river.

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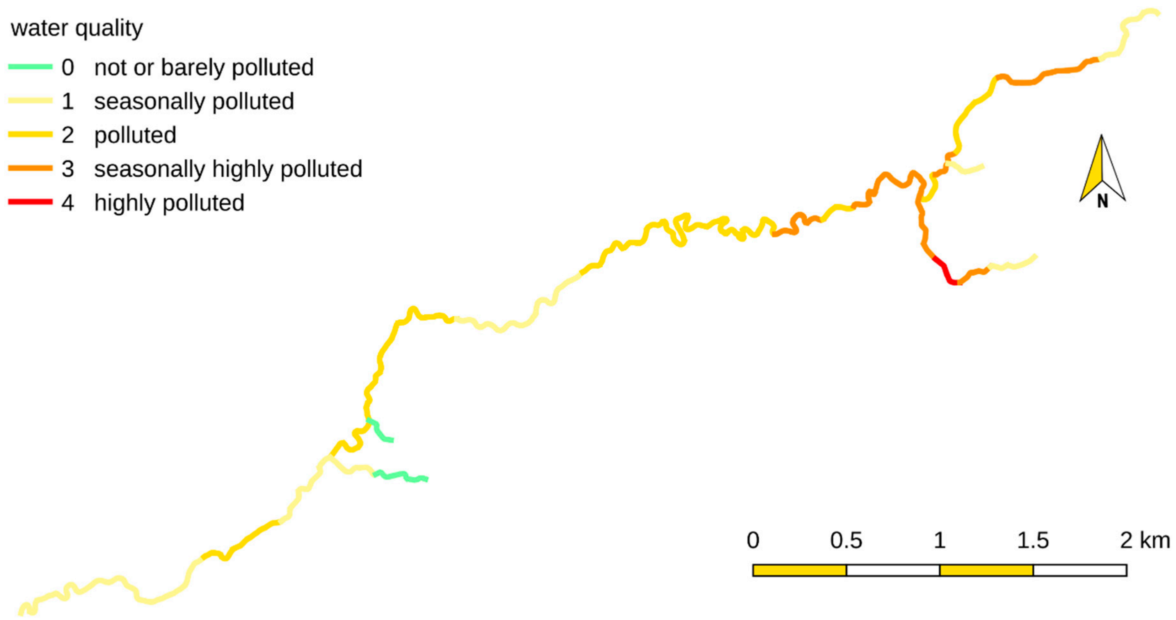

Figure 5. Water quality classes per 100 m section of the Pochote River; Author's work

Figure 6 illustrates the land cover for each 100 m long and 50 m wide section, high vegetation is shown in dark green (72%), low vegetation in light green (22%), and the built-up area in brown (6%). Here it becomes apparent that there is a relatively large amount of high vegetation around the river, which is a sign of a relatively good and undisturbed ecological status. However, in the northeast region, urbanization has reached the river corridor and the presence of low vegetation in these areas can be explained by cutting down of trees by the neighbouring population for fire and construction wood.

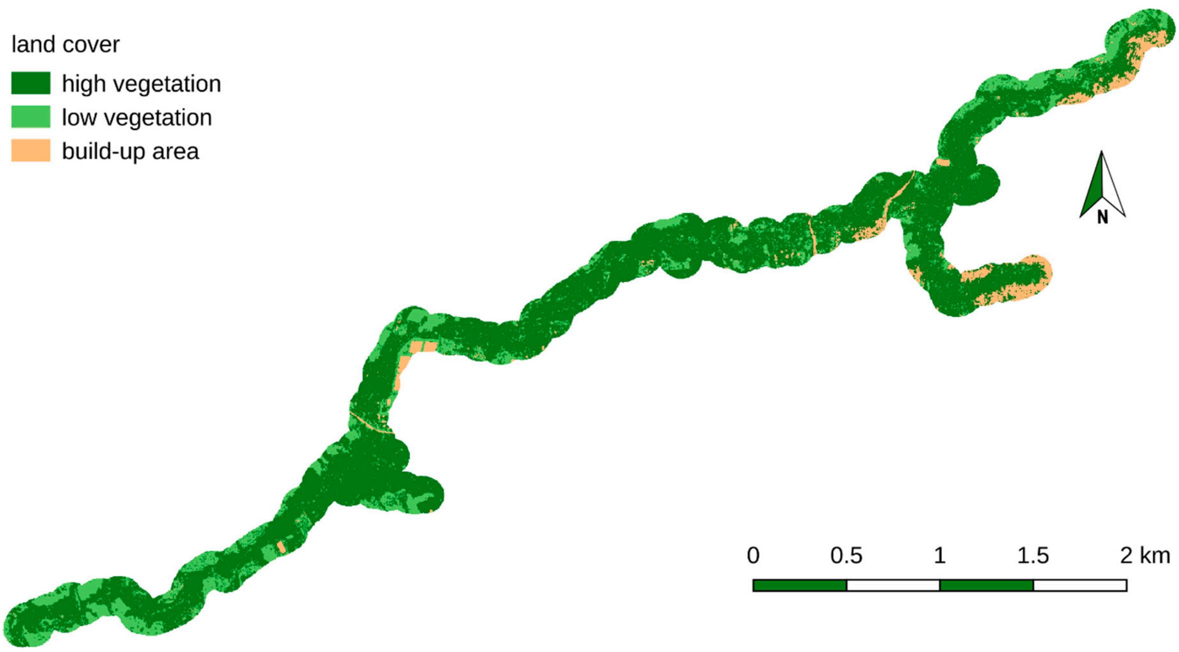

Figure 6. Land cover of the study area; Author's work

If all ecosystem status categories are compared with each other, it is also noticeable that the respectively better rated locations are congruent with each other. The same is seen for both the moderately and poorly rated sites.

3.2 Ecosystem Services potential of the Pochote River

Based on the previous considerations and calculations, maps illustrating the potential of individual river sections to provide URES were generated (Figure 7). The potential is expressed as a percentage of a theoretically possible potential for the entire study area (131 river sections). In this specific case of the Pochote River it can be seen that for the selected ecosystem services all have a relatively good potential.

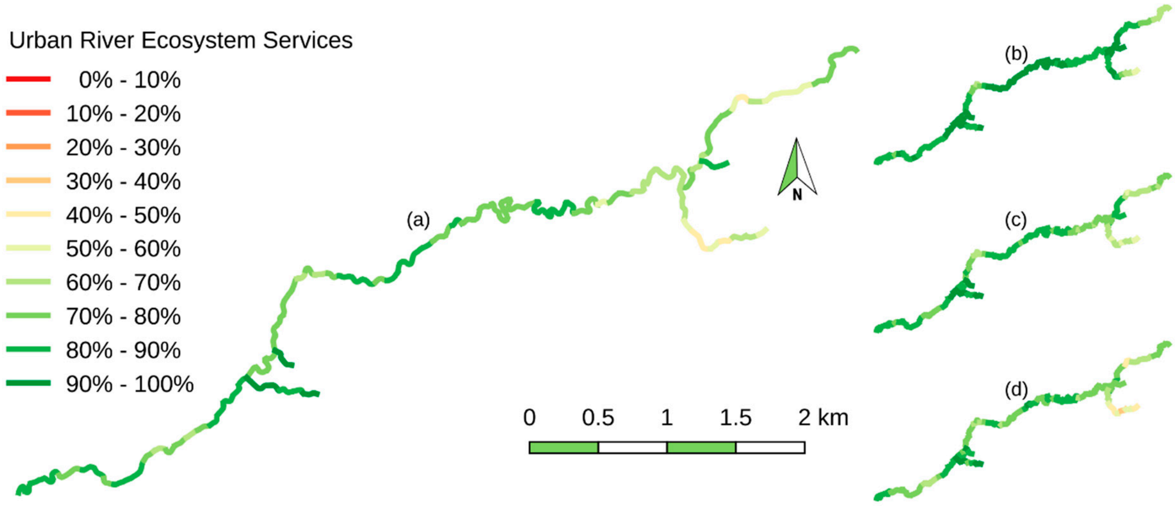

Figure 7. Ecosystem Services status maps of the Pochote River: (**a**) Bio-remediation by micro-organisms, algae, plants, and animals & Filtration/sequestration/storage/accumulation by micro-organisms, algae, plants, and animals; (**b**) Noise attenuation & Hydrological cycle and water flow regulation (Including flood control and coastal protection) & Regulation of temperature and humidity, including ventilation, and transpiration; (**c**) Maintaining nursery populations and habitats (Including gene pool protection); (**d**) Regulation of the chemical condition of freshwaters by living processes; Author's work

While Figure 7 shows a spatial distribution, Figure 8 represents distributive characteristics (maxima, minima, mean and median values, standard deviation) of all river sections as box plots for the assessed URES.

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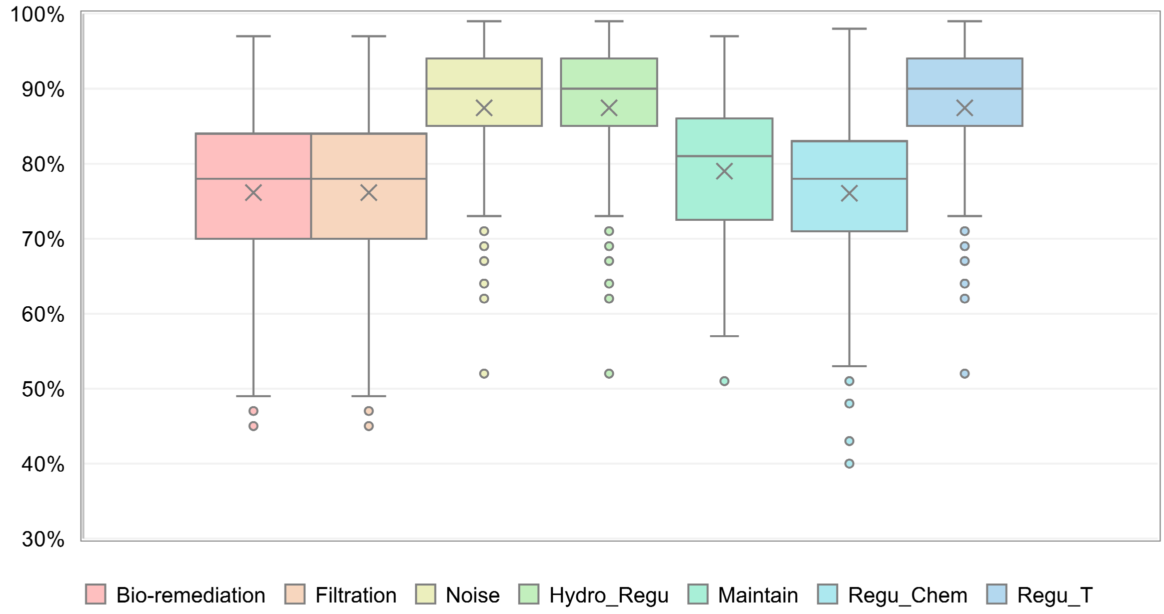

Figure 8. Ecosystem Services status of the Pochote River: 'Bio-remediation' stands for 'Bio-remediation by micro-organisms, algae, plants, and animals'; 'Filtration' means 'Filtration / sequestration / storage / accumulation by micro-organisms, algae, plants, and animals'; 'Noise' represents 'Noise attenuation'; 'Hydro_Regu' short for 'Hydrological cycle and water flow regulation'; 'Maintain' refers to 'Maintaining nursery populations and habitats'; 'Regu_Chem' signifies 'Regulation of the chemical condition of freshwaters by living processes'; 'Regu_T' equals 'Regulation of temperature and humidity, including ventilation and transpiration'; Author's work

Since several URES are linked in the same way to the three ecosystem status categories, their statistical distributions are the same. This is revealed in the box plots in Figure 8.

As can be seen, there are outliers of lower URES potential for all URES. These outliers represent river sections close to built-up areas which are suffering from urban contamination and loss vegetative cover. The outliers for noise attenuation, hydrological regulation and regulation of temperature/humidity are most pronounced. Here the impact of a severe land cover loss is the reason for a low URES potential. However, for the same URES the majority of river sections have an URES potential above 90% highlighting that large parts of the river corridor still preserve a high amount of high vegetation and low or no urban impact so far. Moreover, there are individual river sections with a potential above 90% for all URES. The lowest median potential has the river in the provision of the URES 'Bio-remediation', 'Filtration' and 'Regulation of Chemical Condition'. The absolute lowest potential of a URES of all river sections is related to the provision of 'Regulation of Chemical Condition' with 40% resulting from poor water quality and altered land cover in addition to a strongly changed hydromorphology.

4. Discussion

The objective of this article is to introduce a low-cost and easy to use methodology to assess the potential of urban rivers and riparian areas to provide ecosystem services. The methodology is based on the use of a combination of easily obtained field information and readily accessible remote-sensing data. The following discussion will focus on the representativeness of the data used as well as the advantages and disadvantages of the developed methodology. Possibilities for improvements in data collection, use of data, and application of the methodology are considered. The established link between revealed ecosystem status data and urban ecosystem service potential will also be critically discussed. This represents the basis for the interpretation and discussion of the results. Finally, future research directions are highlighted.

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4.1 Potential of the Pochote River to provide Ecosystem Services

Although the selected URES are in relatively good condition, there is still potential for improvement. Looking at the ES status maps (ecosystem status for the different categories; see Figure 5-7) it is noticeable that the biggest negative influence on the URES, in the case of the Pochote River, is water quality. This indicates that there is still great potential for improvement of the river, as it is relatively easier and quicker to improve water quality, in comparison to restoring riparian vegetation/reverse surface sealing and the poor hydromophological quality. Even if the river is in general in a relatively good condition, it is still relatively variable over the entire route. This results in different potentials which is clearly evident from the ecosystem services status maps (Figure 7). So it would be possible to use the area in the northeast preferably for local recreation. In contrast the area in the southwest where the two tributaries are still very close to nature would be worthwhile returning it completely to nature in order to use it for educational purposes or to promote natural cleaning. In addition to the location of the hotspots, the general picture of the quality of the URES (Figure 8) shows that there are only a few outliers downwards. The fact that the median of each of the URES is above the mean value also confirms the relatively good quality of the URES considered. It should also be noted that the median for all URES considered is between 78% and 90% and thus relatively high.

The degree of the relationship between ecosystem status and URES is debatable, but there definitively is a relationship. The relationships and weighting established in this publication can be interpreted as a rough estimation of the potential to provide ecosystem services. The relationship was established on a relatively detailed ES "class" level of CICES. A more detailed consideration of specific "class types", as established with CICES version 5.1. [17], within these CICES classes would imply a quantitative assessment of class types (e.g. flood volume attenuated) and would rather lead into a detailed assessment and not an analysis of potential as it was done for this study. However, a further elaboration with more detailed consideration of the ecosystem status categories could provide information to assess class types.

4.2 Discussion and recommendation of improvements regarding the data and methodology used

The principal idea of the methodology for the assessment of the potential to provide URES presented here, is that it should be based on either readily available or easily collectable data at low cost. For this reason, the data described in section 2 was used and the methodology accordingly (data-driven) developed. However, the results are only as good as input data and suitability of methodology applied. These two aspects need to be discussed in detail.

Regarding the raw data on the ecological status of the river, not for every 100 m section data in form of photographs and the geo-localized photo documentation was available. Therefore, with some exceptions, a linear approximation between the evaluated 100 m sections was assumed. In order to advance the methodology, a photo should be taken from a specified angle at suitable intervals, e.g. every 50 or 100 meters. This standardization could provide superior hydromorphological quality evaluation.

To determine the water quality, the number of data was sufficient for this simple type of survey, as data were available for each discharge. However, with the applied visual classification, the use of a standardized color scale could improve the data quality and reduce potential subjectivity in visual color interpretation with little additional effort.

Even though the land cover scores provided relatively high resolution (ca. 1.5 m x 1.5 m geo-localized pixels), it was still a semi-automatic method. No general statements can be made about the accuracy of the new development of the land cover classification. This is due to the fact that this methodology is to a certain extent trial and error and that the application of the classification has been adjusted until its result has been considered satisfactory for the observation area. A random check of four different sections in the study area using the original Google map showed an accuracy of 95.6% to 99.8%. So it would be desirable for future applications to develop a guidance with precise settings to increase the degree of automatisation and applicability of this method as well as to quantify the accuracy of this method in general.

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Thus, the data described here is of relatively good quality and/or the methods of collecting them can be easily improved. However, as soon as the transformation into the URES takes place, several assumptions are made. Since all these data can be collected quickly and inexpensively, the URES survey method is well suited for a rough analysis of the current state of the study area and should also be regarded as such. Thus, this method can be used for the purpose of searching for a suitable field of research or action. Furthermore, the ES status maps should not be regarded as a general state of ecosystem services in the study area, as only a small selection of the URES was covered. It should also be mentioned that these are only 'Regulation & Maintenance' URES. But, the underlying ecosystem status data can be extended with little effort so that statements can be made about cultural URES. For example, the land cover map can be used to derive a value for the population density per area and its distance to the river and thus a potential for the URES 'Physical and experiential interactions with natural environment'. There may also be census data available that can replace the population density value derived from the map and further enhance the quality of the data. Data for the 'Intellectual and representative interactions with natural environment' URES can also be collected in the same way, although adjustments must be made depending on the URES. For some, the distance between schools or universities to the river leads to the desired result, while for others the survey can remain unchanged. For the schools as well as for the universities it would be even more helpful to know how many students or scientific staff they have, as this can provided quantitative information on the number of potential beneficiaries.

There is a general problem of lacking data and indicators to assess the large variety of URES, especially in developing countries. The methodology proposed here can help to structure and formalize the assessment of the ecological status of urban rivers and their riparian corridors in a simple but still sufficiently sound manner. Already the information on the ecological status, reflected in three categories that represent different biotic and abiotic realms and characteristics of an (urban) river corridor, facilitates the identification of deterioration of ecosystems due to urbanization. This alone can guide decision-making with regard to establishing protection zones and/or regulating urban development. Linking the ecosystem status categories to URES to evaluate the potential of river sections to provide URES can then assist to stress the benefits from urban rivers in good ecological status establishing the basis to argue for the protection and sustainable uses of urban rivers. In a next step, this service provision potential could be contrasted with potential beneficiaries to identify specific supply and demand relationships [9]. At this point other URES, including provisioning and cultural, may be included to identify additional benefits beyond those assed in this study and other beneficiaries. An indicator set for the assessment of cultural ecosystem service of riverscapes has recently been developed for Germany [30] which may contribute additional ecosystem status categories or links to URES, although it has not been developed specifically for urban riverscapes.

5. Conclusions

Rivers and their riparian zones represent often the only remaining natural-like spaces in urban areas of developing countries. In a landscape transition from rural to urban land uses, the original importance of rivers (to provide water for households, irrigation and animals) vanishes and a transformation of them into wastewater channels typically occurs. While intact semi-urban or urban rivers can have a significant regulative and recreational function, the frequently rapid and uncoordinated urbanization process poses a significant threat of losing these areas and the benefits to the population they may provide. Hence, establishing the specific category of Urban River Ecosystem Services, as done in this contribution, to stress this important ecosystem-society link seems useful. The methodology presented here allows local decision makers, e.g. city administrations or water companies, to translate data and information from field surveys combined with easily accessible remote-sensing data into three ecosystem status information. The resulting maps represent a baseline of the ecosystem status of an urban river. The subsequent weighted combination of them facilitates then the assessment of the potential of different river sections to provide specific ecosystem services to the population. This may serve as a guidance to identify hotspots of loss and high

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provisioning areas of ecosystem services. The ecosystem service concept has been developed as a strong communication tool for the benefits that ecosystems provide. Especially in urban contexts, where dynamics and pressure on ecosystems are extraordinary, the highlighting of ecosystem service potential may contribute to a sustainable use and protection of vulnerable ecosystems.

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Appendix A

Photo documentation of the Río Pochote

Section I

Figure 2: Overview map of the first section (OpenStreetMap)

On the days 29.05.2017 and 15.06.2017 was the investigation of the third section of the Río Pochote. This part crosses in total ten districts. In this head part are four strands, which build the main influent of the river. The parts, which are close to the neighbourhood are strongly anthropogenic influenced.

Photo documentation of the Río Pochote

Photo number	Identification (QGIS)	Date
1	Spring	09.05.2017

Photo number	Identification (QGIS)	Date
2, 3	River part	09.05.2017

Figure A1. Cutout of a photo Documentation of the Pochote River [19]

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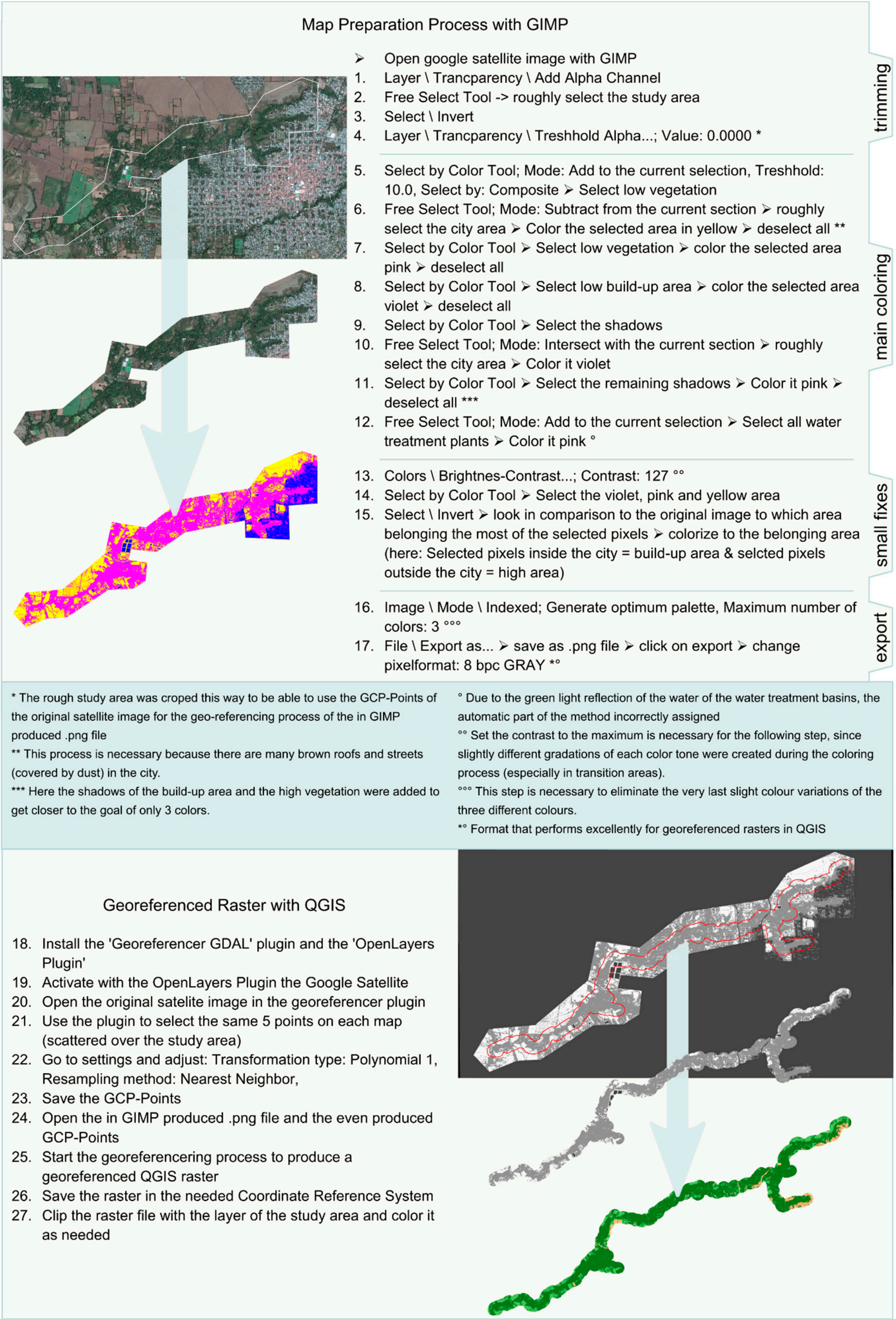

Figure A2. Manual of producing a land cover map with the software GIMP and QGIS; Author's work

Appendix A

Table A1. Urban river Ecosystem Services Classification according to CICES 5.1. Author's work adapted from Haines-Young and Potschin [21] and Maes et al. [27,28].

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Section	Division	Group	Class	Indicator
Provisioning (Biotic)	Biomass	Cultivated terrestrial plants for nutrition, materials or energy	Cultivated terrestrial plants (including fungi, algae) grown for nutritional purposes	- Production of food (ton ha^{-1} $year^{-1}$) - Surface of community gardens/small plots for self-consumption (ha)
		Wild plants (terrestrial and aquatic) for nutrition, materials or energy	Wild plants (terrestrial and aquatic, including fungi, algae) used for nutrition	- Wild plants used in gastronomy, cosmetic, pharmaceutical uses (data on industries collecting the plants)
			Fibres and other materials from wild plants for direct use or processing (excluding genetic materials)	
		Reared aquatic animals for nutrition, materials or energy	Animals reared by in-situ aquaculture for nutritional purposes	- Freshwater aquaculture production (e.g. sturgeon and caviar production)
			Fibres and other materials from animals grown by in-situ aquaculture for direct use or processing (excluding genetic materials)	
			Animals reared by in-situ aquaculture as an energy source	
		Wild animals (terrestrial and aquatic) for nutrition, materials or energy	Wild animals (terrestrial and aquatic) used for nutritional purposes	- Fish production (catch in tons by commercial and recreational fisheries) - Number of fisherman and hunters of waterfowls (anglers, professional and amateur fishermen) - Status of fish population (Species composition, Age Structure, Biomass kg/ha)
		Mediation of wastes or toxic substances of	Bio-remediation by micro-organisms, algae, plants, and animals	

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Regulation & Maintenance (Biotic)	Transformation of biochemical or physical inputs to ecosystems	anthropogenic origin by living processes	Filtration/sequestration/storage/accumulation by micro-organisms, algae, plants, and animals	- Indicators of water quality (microbiological data for bathing waters, BOD_5 nitrate conc, phosphate conc, oxygen conditions, saprobiological status) - Nutrient loads - Ecological status - Trophic status - Area occupied by riparian forests - Number and efficiency of treatment plants - Waste treated - Pollutants removed by vegetation (in leaves, stems and roots) (kg ha^{-1} $year^{-1}$) - Dry deposition velocity (mm s^{-1}) - Population exposed to high concentration of pollutants (% on surface area)
		Mediation of nuisances of anthropogenic origin	Noise attenuation	- Leaf Area Index + distance to roads (m) - Noise reduction rates applied to UGI within a defined road buffer dB(A) m^{-2} vegetation unit
	Regulation of physical, chemical, biological conditions	Regulation of baseline flows and extreme events	Buffering and attenuation of mass movement	- Sediment retention
			Hydrological cycle and water flow regulation (Including flood control, and coastal protection)	- Hydrological flow data - Share of green areas in zones in danger of floods (%) - Population exposed to flood risk (% per unit area) - Areas exposed to flooding (ha) - Holding capacity flood risk maps - Conservation of river and lakes banks
		Lifecycle maintenance, habitat and gene pool protection	Pollination (or 'gamete' dispersal in a marine context)	- Capacity of ecosystems to sustain insect pollinators activity (dimensionless) - Relative abundance (number over area or over length)
		Lifecycle maintenance, habitat and gene pool protection	Maintaining nursery populations and habitats (Including gene pool protection)	- Biodiversity value (Species diversity or abundance, endemics or red list species and spawning location) - Ecological status Morphological status

		Pest and disease control	Pest control (including invasive species)	- Alien species (Introduced riparian and aquatic plants - Number of introduced aquatic invertebrates - Number of introduced vertebrates in rivers and riparian areas
		Regulation of soil quality	Weathering processes and their effect on soil quality	- Fluvisols surface
		Water conditions	Regulation of the chemical condition of freshwaters by living processes	- Chemical status - Ecological status
		Atmospheric composition and conditions	Regulation of chemical composition of atmosphere and oceans	- C sequestration (Annual increase in - Carbon sequestration in living biomass of riparian forest - Carbon sequestered by plantations of Populus - Organic carbon stored in fluvisols)
			Regulation of temperature and humidity, including ventilation and transpiration	
Cultural (Biotic)	Direct, in-situ and outdoor interactions with living systems that depend on presence in the environmental setting	Physical and experiential interactions with natural environment	Characteristics of living systems that that enable activities promoting health, recuperation or enjoyment through active or immersive interactions	- Number of visitors (to National Parks including lakes or rivers) - National Parks and Natura 2000 sites - Known bird watching sites Waterfowl
			Characteristics of living systems that enable activities promoting health, recuperation or enjoyment through passive or observational interactions	- Number of visitors - bathing areas and Number beaches - Fishing reserves - Fish abundance - Fish monetary value from angling - Number fishing licenses - Quality of fresh waters for fishing
		Intellectual and representative interactions with natural environment	Characteristics of living systems that enable scientific investigation or the creation of traditional ecological knowledge	- Monitoring sites (by scientists) - Number of scientific projects, articles, studies - Classified sites (world heritage, label European tourism)
			Characteristics of living systems that enable education and training	- Number of visitors - National Parks and Natura 2000 sites

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			Characteristics of living systems that are resonant in terms of culture or heritage	- Number of visitors - Natural heritage and cultural sites - Number of annual cultural activities organized
			Elements of living systems used for entertainment or representation	- Number of visitors (surface or number of wetlands located next to a bike path)
			Characteristics of living systems that enable aesthetic experiences	- Number of visitors - Contrasting landscapes (lakes close to mountains) - Proximity to urban areas of scenic rivers or lakes
	Indirect, remote, often indoor interactions with living systems that do not require presence in the environmental setting	Spiritual, symbolic and other interactions with natural environment	Elements of living systems that have symbolic meaning	- National species or habitat types
			Elements of living systems that have sacred or religious meaning	- sacred/religious sites (catastrophic events, religious places)
		Other biotic characteristics that have a non-use value	Characteristics or features of living systems that have an existence value	- Number of visitors (to National Parks including lakes) - Number of fishing licenses
			Characteristics or features of living systems that have an option or bequest value	- Number of association registered on animals, plants, environment, naturism
Provisioning (Abiotic)	Water	Surface water used for nutrition, materials or energy	Surface water for drinking	- Drinking water provision (m^3 ha^{-1} year^{-1}) - Drinking water consumption (m^3 year^{-1}) - Surface water availability - Water abstracted
			Surface water used as a material (non-drinking purposes)	- Water provision (m^3 ha^{-1} year^{-1}) - Water consumption per sector (m^3 year^{-1}) - Surface water availability - Water abstracted - Volume of water bodies

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