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Human threats to the freshwater ecosystems in the Napo Watershed

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RESUMEN

La integridad ecológica de un río puede ser altamente afectada por la presencia humana y las actividades que surgen de esta. Debido a esto, la intensidad de las actividades humanas puede servir como indicador para determinar la integridad ecológica de ecosistemas acuáticos en áreas donde datos de campo no han sido colectados. Tal análisis fue llevado a cabo en la Cuenca del Río Napo, un hábitat muy heterogéneo que presenta alta variabilidad en integridad ecológica fluvial y en presencia humana. Datos de la composición de comunidades de macroinvertebrados acuáticos, integridad de la ribera, calidad delhábitat fluvial, pH y conductividad, fueron registrados en 64 sitios para determinar integridad ecológica en cada sitio.Actividades humanas, incluyendo asentamientos humanos, vías de acceso principales, actividad petrolera, concesiones mineras, centrales hidroeléctricas, centrales termoeléctricas, uso de suelo para agricultura, consumo de agua y piscícolas, fueron ilustradas en mapas. La integridad ecológica y el nivel de amenaza humana fueron comparados en cada sitio para determinar correlación. Actividad petrolera y vías, las cuales actuaron como mejores indicadores de integridad ecológica, fueron usadas para crear un modelo predictivo de integridad a través de la Cuenca. Los resultados pueden actuar como herramientas para establecer áreas prioritarias de conservación en sistemas de manejo.

ABSTRACT

The ecological integrity of a river or stream can be highly impacted by human presence and the activities that arise from it. Hence, the intensity of human activities can act as a predictor to determine freshwater ecosystem integrity in areas where field data has not been gathered. Such analysis was performed at the Napo Watershed, a very heterogeneous environment that presents high variability in river ecological integrity and human presence. Data regarding macroinvertebrate community composition, riparian integrity, fluvial habitat quality, pH and conductivity were recorded at 64 sites throughout the watershed to determine ecological integrity at each site. Human threats, including human settlements, main roads, oil activity, mining concessions, hydroelectric plants, thermoelectric plants, agricultural land use, water consumption and fisheries, were mapped. Ecological integrity and level of human threat at each site were compared to determine a correlation. Oil activity and roads, which acted as best indicators of ecological integrity, were chosen to create a model that predicted integrity throughout the watershed. Results can be tools to establish priority conservation areas in management systems.

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INTRODUCTION

A great number of people is dependent on services provided by freshwater ecosystems such as rivers and streams (Aylward *et al*. 2005). Among those that have been identified, some of the most relevant services are the provision of water and food supplies for humans and other species, the purification of water, flood and drought mitigation, and nutrient delivery as well as habitat for thousand of species that live beneath the surface of a stream or along its riparian zone (Postel and Richter 2003). For humans, freshwater ecosystemsprovide natural beauty to landscapes as well as recreational activities that can be a source of livelihood through tourism.These services are provided by healthy freshwater ecosystems and with human pressures on the rise, this quality is at risk. Though most conservation efforts have focused on terrestrial ecosystems, the ecological importance of streams and their vulnerability to changing environments make freshwater ecosystem conservation imperative.

Freshwater ecosystems face a series of threats, most of which arise directly or indirectly from human activities. According to Dudgeon *et al.* (2006), freshwater ecosystem threats can be grouped into five categories: overexploitation, water pollution, destruction or degradation of habitat and invasion of exotic species. Though most human activities that result in these impacts are not directed at rivers or are intended to alter their environment, modifications to the elements or processes on which freshwater ecosystems are dependent, can bring severe negative effects upon the system as a whole.Proof that the degree in which these ecosystems are being degraded is bringing irreversible ecological consequences, is the rate of extinction if riverine species. It is known that 227 species of vertebrates that carry out their life cycles along rivers have become extinct and populations of remaining species have experienced an average decline of 54%, with higher percentages reported in tropical latitudes (Dudgeon *et al*. 2006). These figures could be much higher for invertebrate species,or for species of other taxa whose conservation state is unknown, or are yet to be described. Additionally, with a growing human population, a higher demand of freshwater for consumption and other uses is to be expected, leading to further depletion of this resource and the biodiversity that is dependent of it (Shiklomanov 1998).

Rivers and streams contain immense biodiversity. Primary producers, such as algae and cyanobacteria, introduce energy into the intricate food webs that take place in these ecosystems (Cushing and Allan 2001); macroinvertebrates, including insects, crustaceans and mollusks, that can be primary consumers or predators, make way for the existence of larger organisms; vertebrates such as fish, and amphibians during part of their life cycle, can be found in these habitats throughout the year; some species of mammals and birds inhabit the surrounding lands of rivers and streams, which act as their source of water and energy (Allan and Castillo 2007). Though it is thought that most rivers in the world have experienced some sort of alteration (Dudgeon *et al*. 2006), there are certain rivers that maintain a relatively natural condition that can be used as a reference to assess the state of other rivers that have been more intensely modified by human practices. It is from these rivers, which can be used as reference sites, that biological and ecological indices are developed to quantitatively grade the health of other sites.

There are several biological, ecological and physicochemical properties that can help determine the condition of a river. These properties can be combined to evaluate the ecological integrity of the ecosystem. Ecological integrity can be described as “the capacity of an ecosystem to support and maintain a balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of similar, undisturbed ecosystems in the region" (Karr and Dudley 1981). Ecological integrity can be determined by biotic indices and physicochemical properties, though when this information is lacking there are other factors that can act as indicators of the condition of the ecosystem. Such an indicator is human presence. The condition of a stream and the human disturbances that are acting upon it, can be determined by the human presence and land-use patterns that are taking place along the watershed (Allan and Castillo 2007).

According to Allan and Castillo (2007), there are six main environmental factors that arise from land-use patterns resulting from anthropogenic activities: these are sedimentation, nutrient enrichment, contaminant pollution, hydrologic alteration, riparian clearing/canopy opening, and loss of large wood. Common effects resulting from these factors include changes in community composition, increased mortality rates of native species, increased pollutant concentrations, altered drainage systems and channel dynamics, among others (Foley *et al*. 2005). Land-use involves a variety of human activities that can lead to some or all of the environmental threats mentioned above in varying intensities that respond to specific cases.

Further ecological degrading could be expected if rates of human alteration remain the same. As a preventive measure, conservation efforts must be directed to areas that remain unaffected and have the potential to offset the effects of areas that have been modified and are sources of environmental degradation. These areas must be identified through planning exercises that incorporate biological and ecological conditions along the stream, as well as the use that is being given to the land that surrounds it. Although these exercises are often carried out at local scales, in which the environmental, social and political conditions are relatively simple, there is less experience when considering large watersheds that incorporate ample altitudinal gradients, heterogeneous biogeographical formations, and a diversity of stakeholders. Moreover, large-scale planning exercises that combine some type of spatial analysis of the condition of biological communities and of the distribution and intensity of human threats usually lack field validation, which results in high degree of uncertainty regarding their biological meaning and usefulness in term of conservation planning.

Ecuador is a country of substantial water resources that are as essential to human needs as they are for the rich biodiversity that is found in them. In particular, Ecuadorian highland ecosystems act as the most important source of water uptake and storage (Josse*et al*. 1999), giving rise to a large number of rivers and streams that house a great amount of species, many of which are endemic due to the particular environmental conditions found in the Andes and its flanks (Jacobsen *et al*. 2003). Although biological and ecological understanding of freshwater ecosystems is growing (Ibarra *et al*. 2010), in Ecuador little is known about the current state of rivers and streams and how the expanding urban, industrial and agricultural frontiers could be affecting these freshwater resources and the life that depends on them.

The Napo watershed is of particular interest since an altitudinal gradient of 5000m is comprised into a relatively small area, giving rise to a wide variety of terrestrial and aquatic ecosystems. Historically, Eastern Ecuador has not beenas affected by colonization and agriculture as the western region; however,urban settlements, oil drilling, miningand hydroelectric projects could threaten the integrity of its ecosystems. By understanding the current state of these ecosystems and the cause forvariation in their integrity, I intend to generate information to guide land use planning and management initiatives that aim to conserve the rich biological value of the Napo Watershed and ensure a sustainable use of its water resources.

In this context, the main objective of this study is to analyze the intensity and spatial distribution of anthropogenic threats to freshwater ecosystems in the Napo watershed, thorough the development and validation of a geographical model. Through the use of an extensive independent data set on ecological integrity of the watershed, I will also assess the accuracy of the threats model in terms of its ability to predict the condition of freshwater ecosystems.

SPECIFIC OBJECTIVES

1. To characterize the current levels of ecological integrity of streams and rivers throughout the Napo basin.

2. To establish the main environmental threats to freshwater ecosystems by generating GIS maps depicting the distribution and intensity of impact of human activities in the Napo Basin.

3. To develop and validate a model that links the condition of the rivers to threatening activities that are taking place along the watershed to determine how human practices are affecting their ecological integrity.

JUSTIFICATION

With a growing human population, demand for land and the activities that take place upon it, are bound to increase. These activities, which often involve land modification, usually result in ecological degradation. Rivers in the Napo Basin, which provide possibly the most important of ecosystem services -freshwater-, are not exempt from this degradation. Limiting the expansion of urban and agricultural frontiers is a hard task. The most practical way to reduce the environmental impact that results from human activities is to elaborate strategic conservation and land use plans based on zonification, in which areas that remain the least affected, and could help offset the anthropogenic impacts from more developed, surrounding areas, are designated as priority areas to direct conservation efforts. The purpose of this study is to work in the entire Napo Watershed to determine and map human activities of high ecological risk that could be taking part in the degradation of these ecosystems. By identifying and characterizing the spatial distribution of major threats to freshwater ecosystems, priority conservation areas can be established which can be used as a basis to develop a conservation portfolio to prevent further environmental degradation of these rivers from which a great number of communities and ecosystems depends on.

STUDY AREA

The Napo Watershed is located in the northeastern region of Ecuador, within the Amazon Basin (Fig. 1). It covers a wide altitudinal gradient, ranging from 200m in the eastern lowlands to 5700m in the Ecuadorian Andes. Major tributaries of the Napo River are the Jantunyaku, Misahualli, Coca, and Tiputini rivers, born in the eastern Ecuadorian Andes, which include several major volcanoes such as Antisana and Cotopaxi. The Napo watershed is vast (approximately 59000 km^2) and encompasses a wide range of climatic regimes and ecosystem types, from wet páramos in the higher altitudes, to several types of montane and piedmont forests in the mid and lower slopes of the mountain range. Though a number of protected areas such as the Cayambe-Coca, Sumaco Napo-Galeras andYasuni National Parks are found within the basin, the land is widely used for agricultural, mining and oil extraction activities (Sierra 2000).

To characterize ecological integrity along the watershed, 64 data collection sites were established throughout the altitudinal gradient of 600 to 4000 m (Annex 1). Sites from 1800 to 4000 m corresponded to streams sampled in the context of the EVOTRAC project (Poff*et al.* 2010). To cover the streams and rivers of the lower portion of the watershed (600 to 1800 m), 48 additional sites were included. In both cases, sites were set to cover heterogeneous characteristics of the rivers and streams found in the area with no set distances between them.

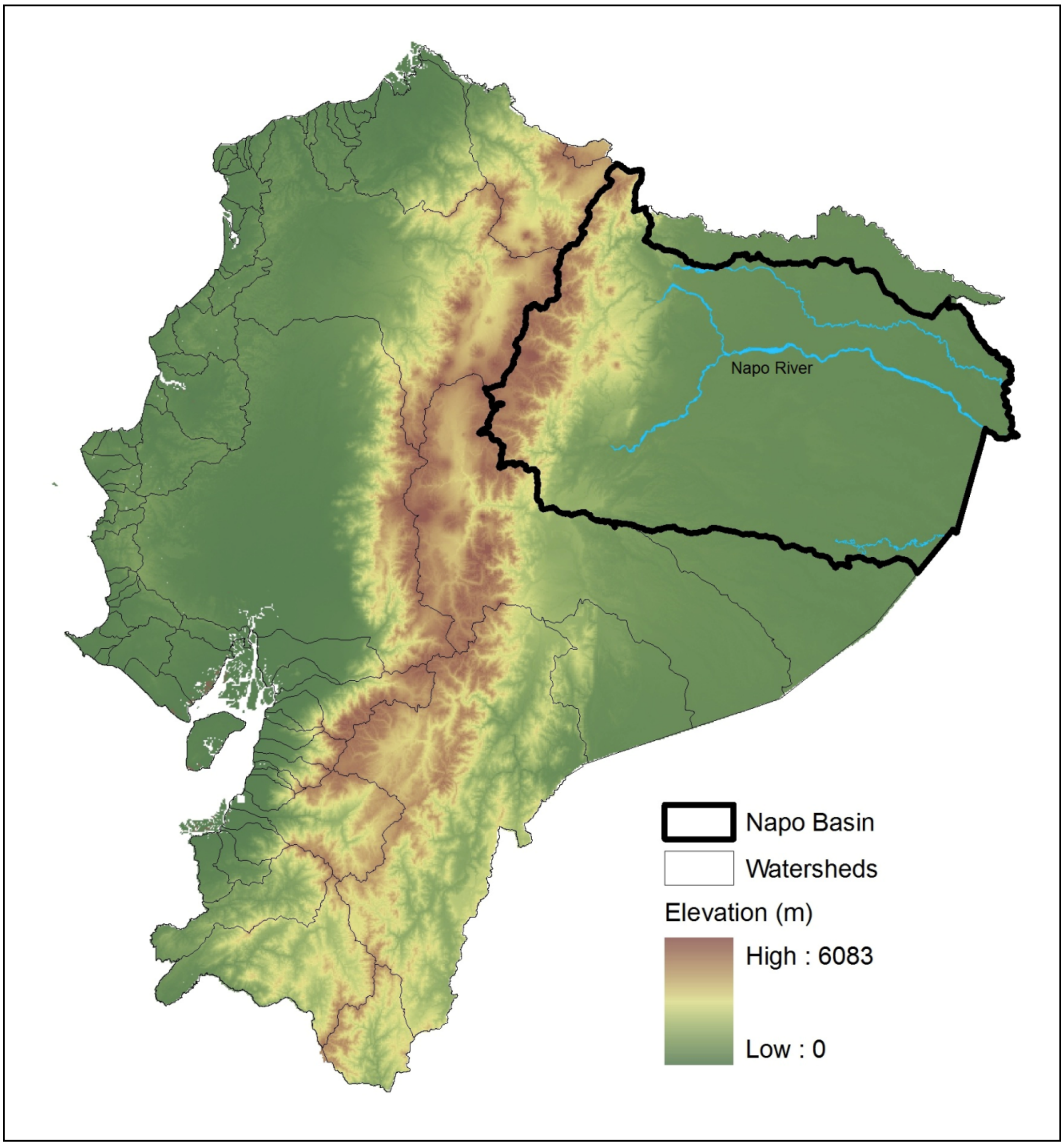


Figure 1. Napo Watershed (outlined).

METHODS

1. Ecological Integrity

Although ecological integrity is a generalized concept, the parameters with which it is measured vary from one ecosystem to another, especially when it comes to indicator species (Carignan and Villard 2002). In this study, the assessment of ecological integrity was performed under parameters that have been pre-established to fit specific characteristics of the eastern Ecuadorian high and mid lands (Acosta *et al.* 2009).

To determine the ecological integrity of the Napo Basin, five parameters were integrated: stream biological composition (ABI/ASPT), riparian integrity (QBR-And), fluvial habitat quality (IHF), water conductivity and pH. Each parameter was graded under a variety of standards to generate an 'ecological integrity' index (Table 1).

1.1 Ecological Integrity Data Analyses

Bioindicators. Regarding biological community composition, data collected by the EVOTRAC project on macroinvertebrate species diversity was used. The purpose of EVOTRAC was to determine the biological vulnerability of pristine rivers under conditions of climate change. This study focused on biological responses to changing environments without taking into consideration human influences over communities of altered areas (Poff*et al.* 2010). To include the latter, water samples were obtained from additional streams that have been impacted by human activities and are situated nearby modified land, as well as other lowland streams that were not part of the EVOTRAC study. From samples obtained at EVOTRAC sites, as well as additional altered and lowland streams, aquatic macroinvertebrates were classified into families and rated by their physiological tolerance according to the Andean Biotic Index (ABI) (Annex 2) to determine the Average Score Per Taxa (ASPT), which indicates the biological integrity of the stream.The ABI Index was developed from rivers and streams of the Ecuadorian highlands (2200-3800 m) (Acosta *et al*. 2009) but due to the lack of an index for physiological tolerance of freshwater macroinvertebrates of the Ecuadorian lowlands,I applied the index under the assumption that it would be the most adequate, availableindicator to be used for the area.

*Environmental variables.*To establish an adequate pH range, the standards under the Ecuadorian Environmental Quality and Effluent Discharge: Water Resources (Ministerio del Ambiente 2003) were applied.In terms of conductivity, high conductivity was considered to be inversely proportional to water qualitydue to the relationship of electrical conductivity with dissolved solids, which are common indicators of water pollution (Das *et al.* 2005). Fluvial Habitat Index (IHF) (Annex 3) analyses habitat heterogeneity by incorporating variables such as stream velocity, depth, frequency of riffles, substrate diversity, substrate composition, and primary producer composition (Pardo *et al*. 2002).The QBR-And index (Annex 4) incorporates four parameters: degree of riverbank vegetation coverage, structure of vegetation cover, quality of the cover, and degree of naturalness of the riverbank. Both indexes were evaluated under the CERA protocol, which integrates ecological, chemical and biological analyses to evaluate riverine condition (Acosta *et al*. 2009).

*Table 1.*Parameters used to calculate ecological integrity, how they were scored and transformed to elaborate an Ecological Integrity Index.

Ecological Integrity Parameter	**Standard Index Scoring**	**Ecological Integrity Index Scoring**
Stream Biological Diversity	Based on Average Score Per Taxa (∑ tolerance index of families/ number of families found at site).	2.0/2.0
Riparian Integrity	Based on the QBR-And Index, which rates the condition of riparian vegetation over 100.	1.0/1.0
Fluvial Habitat Quality	Based on the IHF Index, which rated the condition of the fluvial habitat over 100.	1.0/1.0
Conductivity (µS/cm)	Conductivity measurements were normalized to fit a 0-1.0 scale.	1.0/1.0
pH	Streams that presented a pH of 5-9 received a scored of 1.0. Streams that did not meet these standards received a 0.	1.0/1.0
	Total	**6.0/6.0**

Calculating ecological integrity. Environmental variables and ASPT were combined to formulate and index that portrays the state of rivers (Table 1). The ecological integrity index used in this study attempted to incorporate three main components of healthy freshwater ecosystem: biological (ASPT), ecological (IHF and QBR-And) and chemical properties (Conductivity and pH). Each of these three components was allocated equivalent weights from the total Ecological Integrity Index score. River condition was mapped based on the formulated ecological integrity index, which was categorized to five levels of quality (Table 2).

Table 2. Categories of ecosystem quality based on the Ecological Integrity Index.

Ecological Integrity Index Score	**Ecosystem Quality**
>5.01	Excellent
4.51-5.00	Good
4.01-4.50	Moderate
3.51-4.00	Poor
<3.50	Very Poor

2. Human Threat Maps

To assist in identifying possible sources of environmental degradation along rivers and streams, a series of maps were generated to depict the spatial intensity of the most prevalent anthropogenic pressures (Table 3).Potential impacts of human activity were mapped using ArcGis®, based on data generated by public and private institutions. Additional informationwas gathered through interviews and visits to information centers in the main cities and towns of the Napo Basin. In Table 3,the main human threats are listed along with the main data sources that were used for this study.

Table 3. Main anthropogenic threats

Threat	**Geographical data source**	**Additional information gathered**
Human settlements (ind./m^2)	INEC, Instituto Geográfico Militar	Municipal offices at main cities and towns
Main roads	Instituto Geográfico Militar	None
Agricultural land use	Ministerio del Ambiente del Ecuador (MAE)	None
Oil concessions and activity	Sistema de Indicadores de Pasivos Ambientales y Sociales (SIPAS)-MAE, Instituto Geográfico Militar	None
Previous oil contamination incidents	SIPAS	News Articles
Mining concessions	Agencia de Regulación y Control Minero (ARCOM)	None
Human water use and consumption	SENAGUA (Water concessions)	Municipal offices at main cities and towns
Hydroelectric power plants	Consejo Nacional de Electricidad (CONELEC)	None
Thermoelectric power plants	CONELEC	None
Fisheries	SENAGUA	None

Information on some of the threats was subdivided into categories (Table 4). Within each threat, subcategories represent different levels of impact and they were given weights that represent their contribution to the final human threats map. The weights given to each subcategory were based in scientific literature as well as input provided by experts in the field. Subcategories in each field added to a total of 1, which represented the maximum weight of the threat. Additionally, differences in intensity of impact between threats should be considered. To incorporate these differences, each threat was given a weight in relation to the impact imposed by other threats. To determine the relative weight of impact of each threat, comparison matrices were elaborated, as suggested by Saaty (2008) under the criteria of: 1) water quality, 2) hydrological alteration, 3) biological impact and 4) riparian alteration. To incorporate the radius of impact, each threat was given a buffer zone that was used when elaborating the final map (Figure 2).

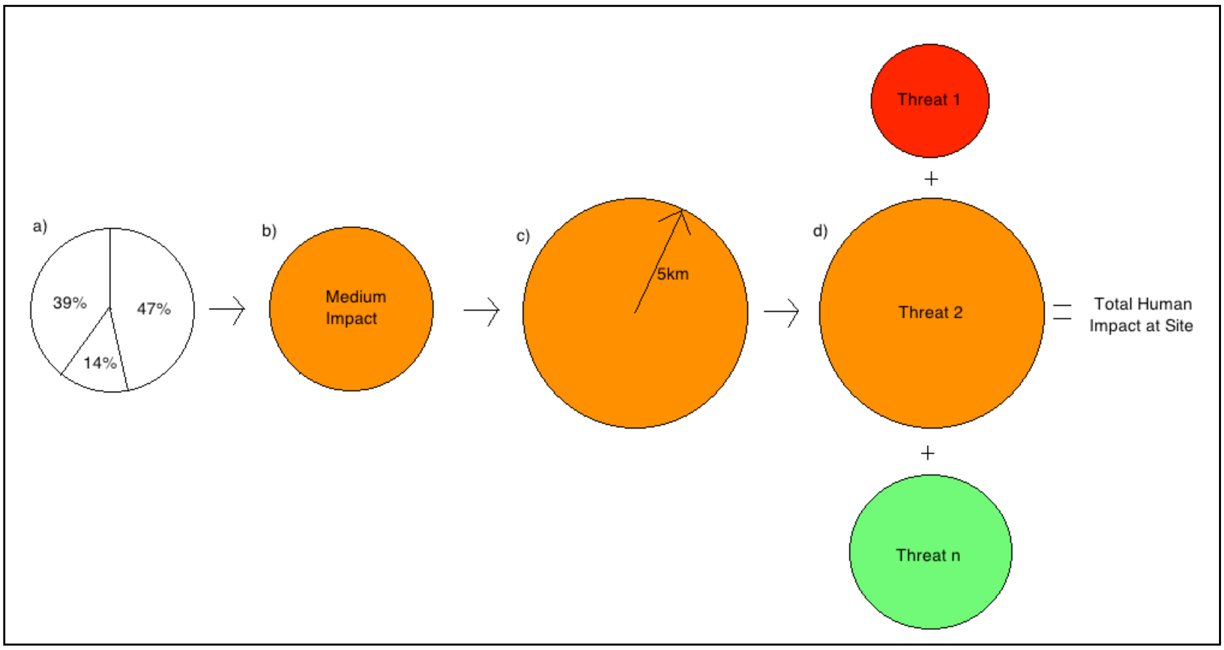


Figure 2. Steps to calculating total human impact: a) determining the contribution of impact of each subcategory within the threat, b) evaluating the level of impact of the threat in relation to other threats, c) determining the its spatial reach (buffer zone), d) adding all threats to obtain total human impact.

Table 4. Intra and inter weighing of each threat to formulate final human threat map.

Threat	**Subcategories and their weights**	**Threat input to the final map**	**Distance of buffer zone**
Human Settlements	Scaled human density	0.201	10km (urban area), 3km (towns)
Main Roads	Primary road (0.5) + Secondary road (0.3) + Local Road (0.2)	0.026	1km
Agricultural Land Use	Permanent, Semipermanent and annual crops (0.6)+agriculture and livestock mosaic and grasslands (0.4)	0.148	5km
Oil Activity	Wells (0.35) + Pipelines (0.1) + Oil Spills (0.3) + Pools (0.25)	0.106	1.5km (wells), 30m (pipelines), 5km (spills and pools)
Mining	Construction materials (0.6)+ Metals (0.4)+ Non metals (0.1)	0.153	5km
Human Water Consumption	Scaled volume extracted	0.074	1km
Hydroelectric Power Plants (size based on generated power)	Operating 0.75* (Large 0.5 + Medium sized 0.3 + Small 0.2) + Under construction 0.25* (Large 0.5+ Medium 0.3+ Small 0.2)	0.132	Scaled to plant size, with a maximum of 30km
Thermoelectric Power Plants	Scaled generated power	0.032	2km
Fisheries	Scaled water volume	0.069	1km
	Total Threat	**1.00**	

2.1 Water Use Interviews

Water consumption and use by humans poses an additional pressure that alters hydrological, chemical and ecological patterns of rivers and streams. This is why, in order to complement maps depicting where human threats are concentrated and understand the water usage situation, interviews were held at sevenof the largest human settlements along the Napo watershed. Cities and towns included in this survey were Papallacta, Oyacachi, El Chaco, Baeza, Lago Agrio, Francisco de Orellana (Coca) and Tena. Interviews were held at municipal offices and environmental agencies to gather information regarding total community water usage and water storage and treatment systems (Annex 5).

3. Ecological Integrity Predictive Models

Statistical analyses can be used to assess if ecological integrity acts as a response variable to some, or all, human threats analyzed, and the results can be used as a source to generate predictive models. The predictive models generated, presented as maps, depict ecological integrity at the full extension of rivers and streams found at the Napo Basin where data have not been gathered and show which areas have been most affected by human practices. A previous study performed in California which included predictive models (Hawkings *et al*. 2000), has found human threat levels to be an adequate predictor of ecological integrity based on the number of observed taxa, including only logging as a predictive variable. Herein, I incorporated multiple predictive variables (human threats), which could lead to a more accurate prediction of ecological integrity.

Maps that depict the distribution and intensity of human threats at large spatial scales have been commonly used in land-use planning or in the designation of conservation units in large landscapes. The assumption in these exercises is that the representation of threats derived from human activities at the watershed scale, have a correlation with the state of ecological integrity at lower spatial scales. Although the validity of this assumption is crucial in terms of the usefulness of these models, it has been seldom validated. In this context, for this study I aimed to determine if the spatial depiction of human activities at the watershed level was correlated with the ecological integrity of stream and river ecosystems at the local scale. To do so, multiple stepwise regressions were run in which the individual activities depicted in our threats map (*e.g*. roads, oil exploitation, human settlements, agricultural fields) were used as predictors of the ecological integrity measured in the streams. As this type of model can be affected by the lack of independence between sampling points that lie close to each other in the landscape, we included an independent categorical variable ("group") that grouped all sampling sites that were within 12 km of each other. This distance was determined to be an adequate distance that clustered sites located at the same river or sub-basin and separated sites that did not share the same small-scale water system. In this way, we controlled the portion of the variation in ecological integrity that could be attributed to the proximity of some sampling sites. To allow an independent evaluation of our statistical model, we trained the model using information from only 48 streams (75%), randomly selected from our data set. Once this regression model was ready, we used it to predict the ecological integrity of the remaining 16 sampling points (25%), based on the levels of threats that the map assigned to each of them. Finally, we used a paired-T test to compare the predicted ecological integrity from these sampling points, with the ecological integrity as measures in the field. The model generated by the stepwise multiple regressions illustrated the threats that acted as best predictors, as well as their coefficients, to establish the equation to determine ecological integrity throughout the basin.

RESULTS

Ecological Integrity

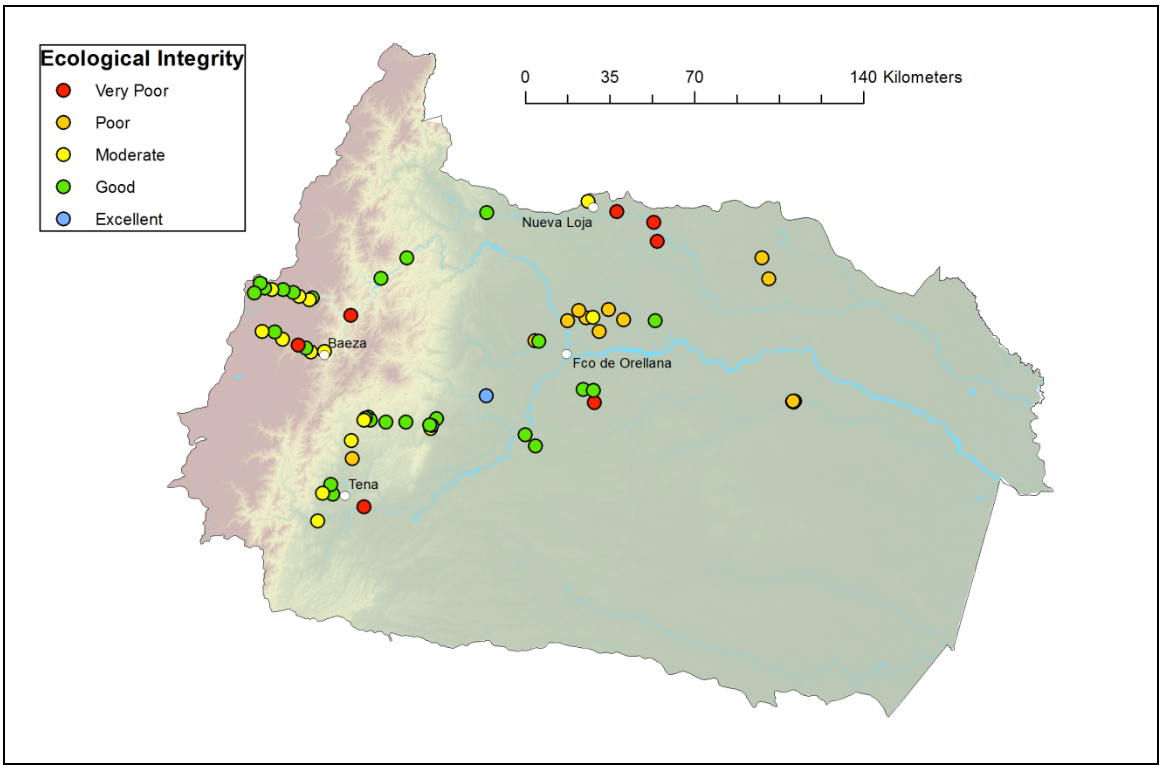


Figure 3. Ecological integrity based on data gathered at the 64 sites located in the Napo watershed.

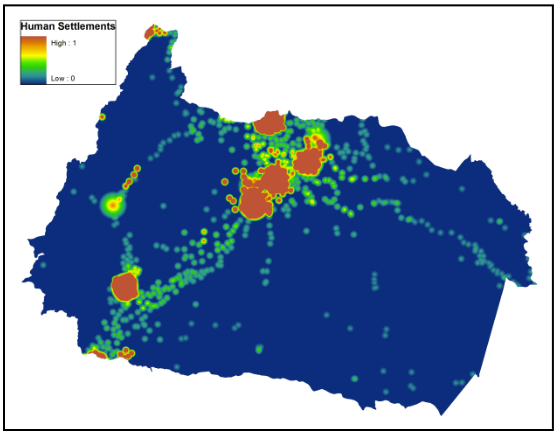
Of the 64 sites analyzed, 27 presented ‘good’ ecological integrity. The second most numerous category was ‘moderate’ with 16 sites, followed by ‘poor’’ with 11, ‘very poor’ with 8 and the least represented was ‘excellent’ with 2 sites falling within the category.

Water samples taken from rivers at higher altitudes, such as the Papallacta and Oyacachi areas, presented the highest number of conglomerated sites with ‘good’ and ‘excellent’ ecological integrity, with the exception of two sites that presented ‘poor’ ecological integrity. These two sites were located closer to the larger urban areas of Baeza and El Chaco. Sites located near the three largest human settlements of Lago Agrio (Nueva Loja), Francisco de Orellana (Coca) and Tena showed great variation. Near the northernmost city of Lago Agrio, sites rated primarily as of ‘very poor’ integrity, with two reaching the level of ‘moderate’, whilesites with ‘poor’ ecological integrity were predominant near the city of Francisco de Orellana. The city of Tena was the exception among the largest cities, with most sites rating as ‘good’ and ‘moderate’.

At more secluded areas, sites located near Sumaco Napo-Galeras National Park, north of Tena, presented ‘good’ ecological integrity. Secluded sites located lower down the altitudinal range, such as those found near Tarapoa at the northeastern area of the watershed, presented a larger proportion of sites with ‘moderate’ to ‘poor’ ecological integrity. At Tiputini, within the Yasuní National Park, though being found at a secluded area, most sites had ‘poor’ ecological integrity, with two sites falling within this category.

Human ThreatMaps

a)



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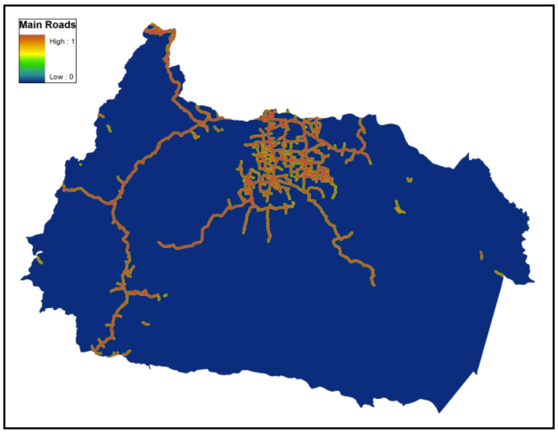

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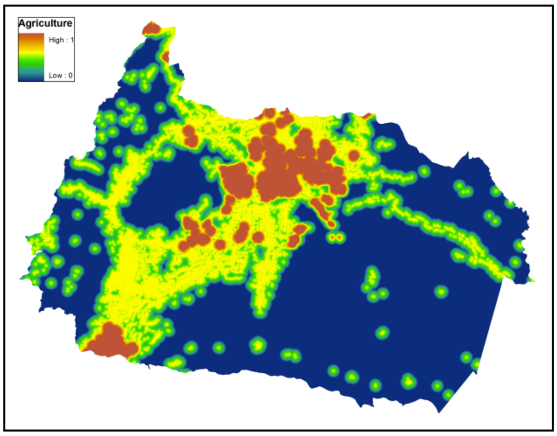

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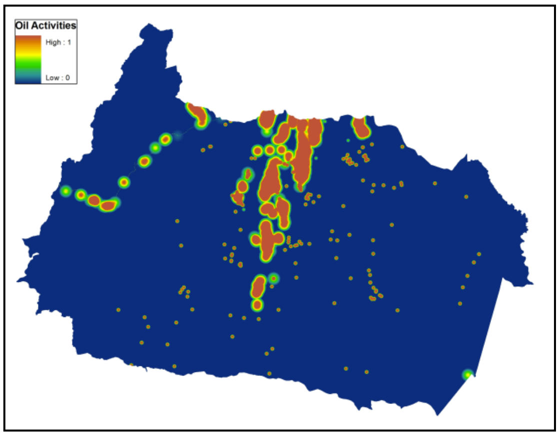

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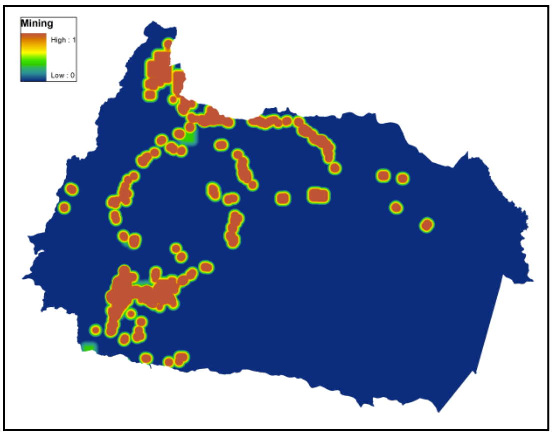

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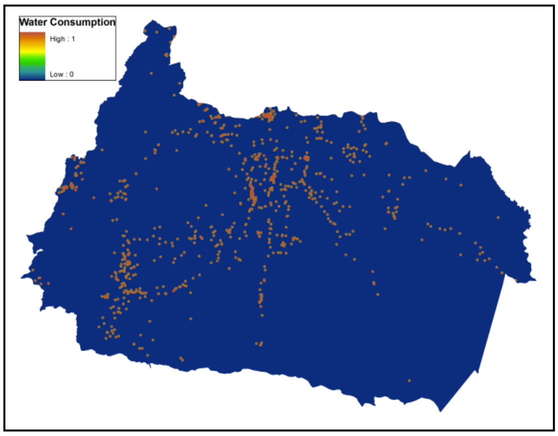

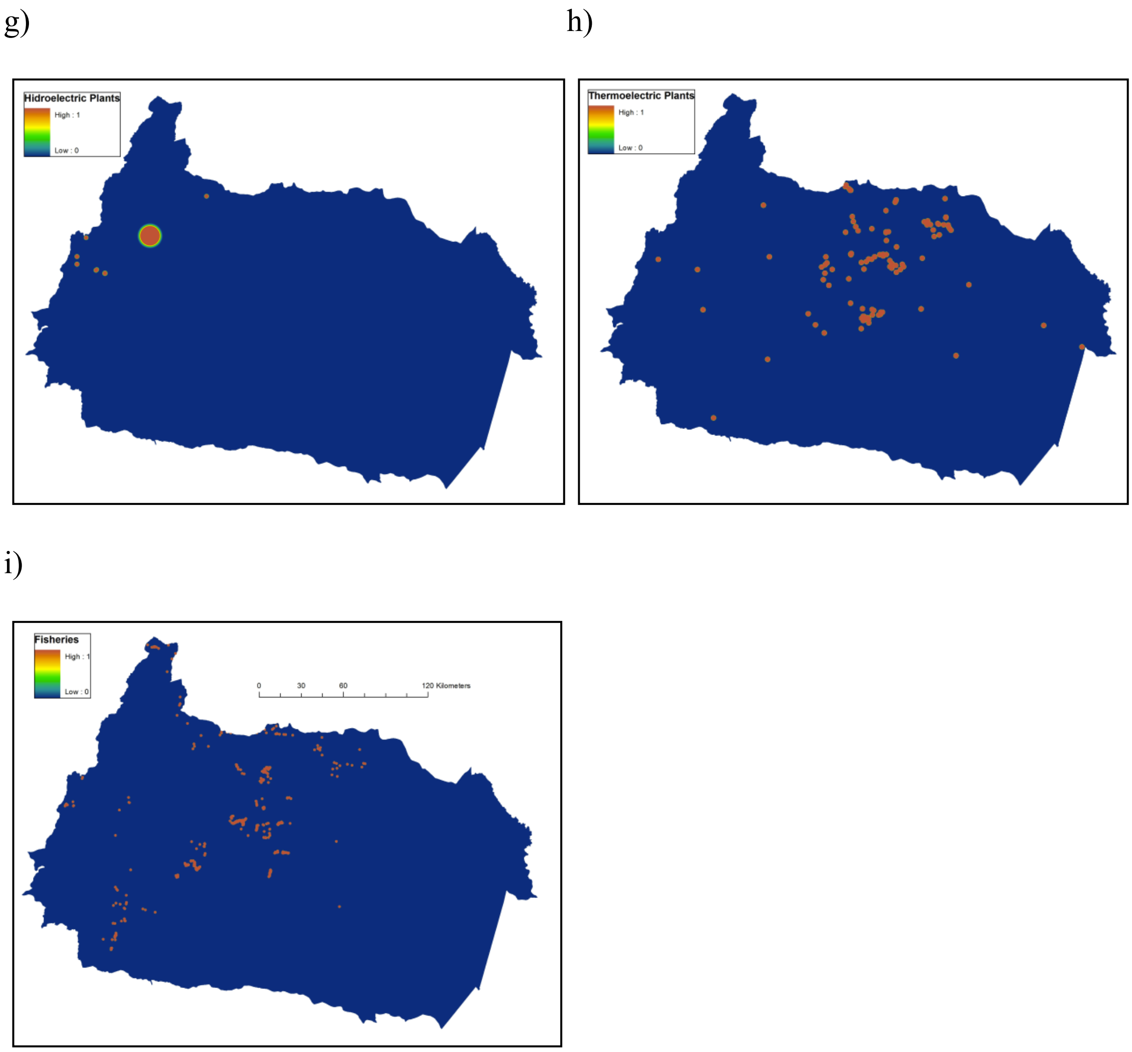

*Figure 4.*Degree of main anthropogenic threats to freshwater ecosystems in the Napo Watershed. a)Human settlements b) Main roads c)Agricultural land use d)Oil extraction activities and previous spills e)Mining concessions f)Human water use and consumption g)Hydroelectric power plants h) Thermoelectric power plants i) Fisheries.

Most ecological impact resulting from human activities were represented in the maps as very punctual impacts with limited reach throughout the watershed. Such was the case with main roads, water consumption, hydroelectric plants, thermoelectric plants and fisheries. These activities showed more limited reach regardless of the quantity of data pertaining to each group. Though geographically restricted, specific areas where these human activities are taking place, showed a high level of impact, represented by red color.Threat arising from human settlements, oil activity, mining, and agricultural land use were more significantly widespread, due mainly to lengthier buffer areas around the point of impact.

Generally, the human threat maps presented in this study, showed a pattern of higher levels of threat in areas where roads were present. This was true for more domestic activities such as water consumption and mosaic agriculture, as well as for industrial activities such as oil and mineral extraction. Exceptions to this geographical pattern could be found in the less populated, eastern area of the watershed, in cases of oil concession water consumption and agricultural land use, though the impact was limited and very punctual.

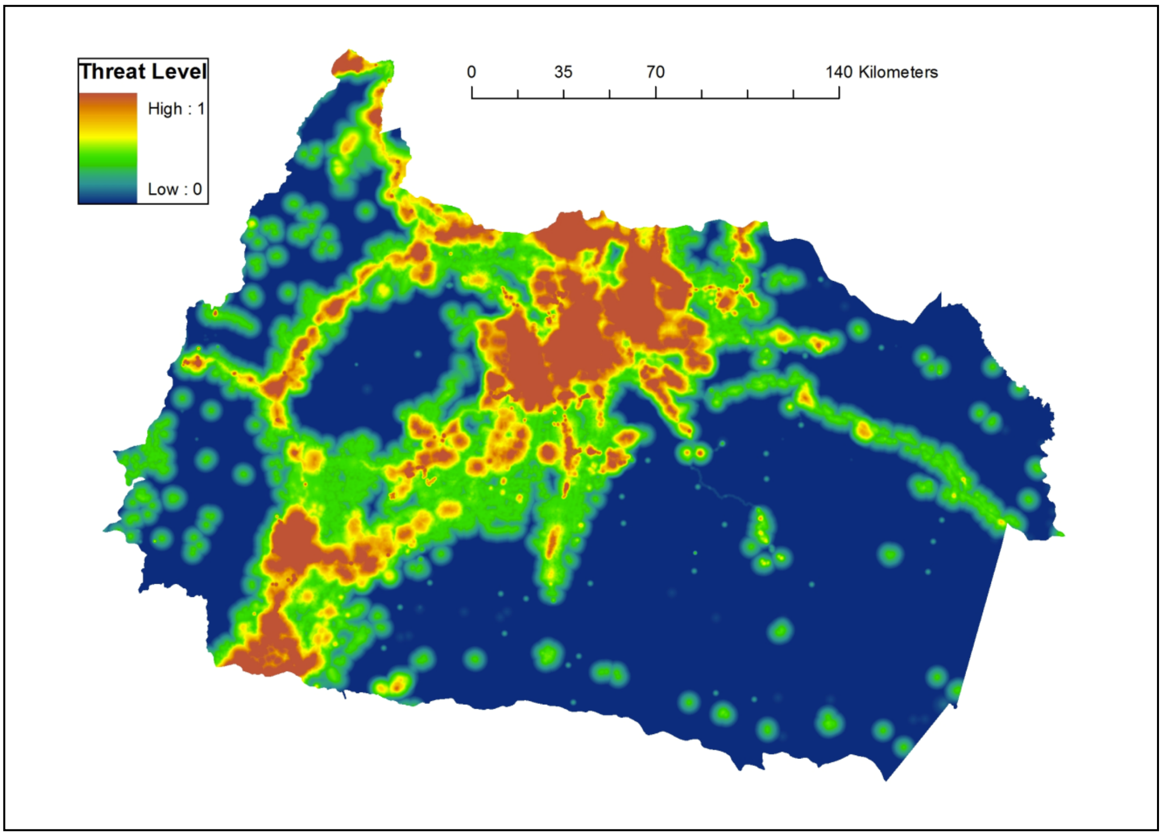

Figure 5. Level of threat to freshwater ecosystems arising from human activities taking place in the Napo Watershed.

As a general pattern, highest environmental threat from human activities was presented as a north-south band along the intermediate altitudes of the basin. This band is consistent with the presence of the three largest cities of the basin and the main roads that connect them. The area with the most widespread high level of threat was located at, and along a 30-40 km radius of the cities of Francisco de Orellana and Lago Agrio. This is a result of the added presence human settlements, agricultural, and oil drilling threat, as well as extensive road development. The area of Tena presented high intensity of threat due to similar reasons, except for the area presenting significant mining activity and lessened oil drilling.

Areas around the roads connecting Papallacta, Baeza and Lago Agrio presented less widespread, though similarly intensive threat. This can be attributed to human settlements located along roads, agricultural activity, hydroelectric plants, including the macro-project of Coca Codo Sinclair, as well as this area being the pathway where the main oil pipelines were situated to transport extracted crude. Scattered areas of less intensive threat along the highlands and eastern basin arise from the presence of small human settlements, agricultural areas, minor water extraction concessions and limited-impact thermoelectric plants.

Water use interviews were a means to obtain water consumption information, which was added to the map, as well as to validate the information regarding other threats that are taking place in the area. Information obtained demonstrated that a main concern in highland communities was the quantity of water, while in lowland cities, concern centers around water quality. In cities such as Coca and Lago Agrio, oil drilling is the activity that is considered to cause most impact on water quality, while in Tena mining seems to hold higher community concern. This qualitative analysis is congruent to information gathered on threats for these cities.

Ecological Integrity Model

Statistical analysis showed that there was a negative correlation (R= -0.39;P=0.01) between total human threats and ecological integrity (Annex 7), meaning that areas that according to the watershed-scale map, experience more human activity, presented lower ecological integrity as measured at local scale. By correlation analyses, roads proved to be the highest source of impact for macroinvertebrate community composition (ASPT); land use and human settlements had a more significant negative effect on riparian integrity

(QBR-And); land use altered fluvial habitat as well; higher conductivity was observed in areas adjacent to human settlements and oil wells; finally, pH did not show to be correlated to any particular human activity in the area (Annex 8). Through multiple regression analyses, it was established that though the mentioned threats affected each component of ecological integrity differently, oil activity and main roads were the best indicators of the state of freshwater ecosystems.

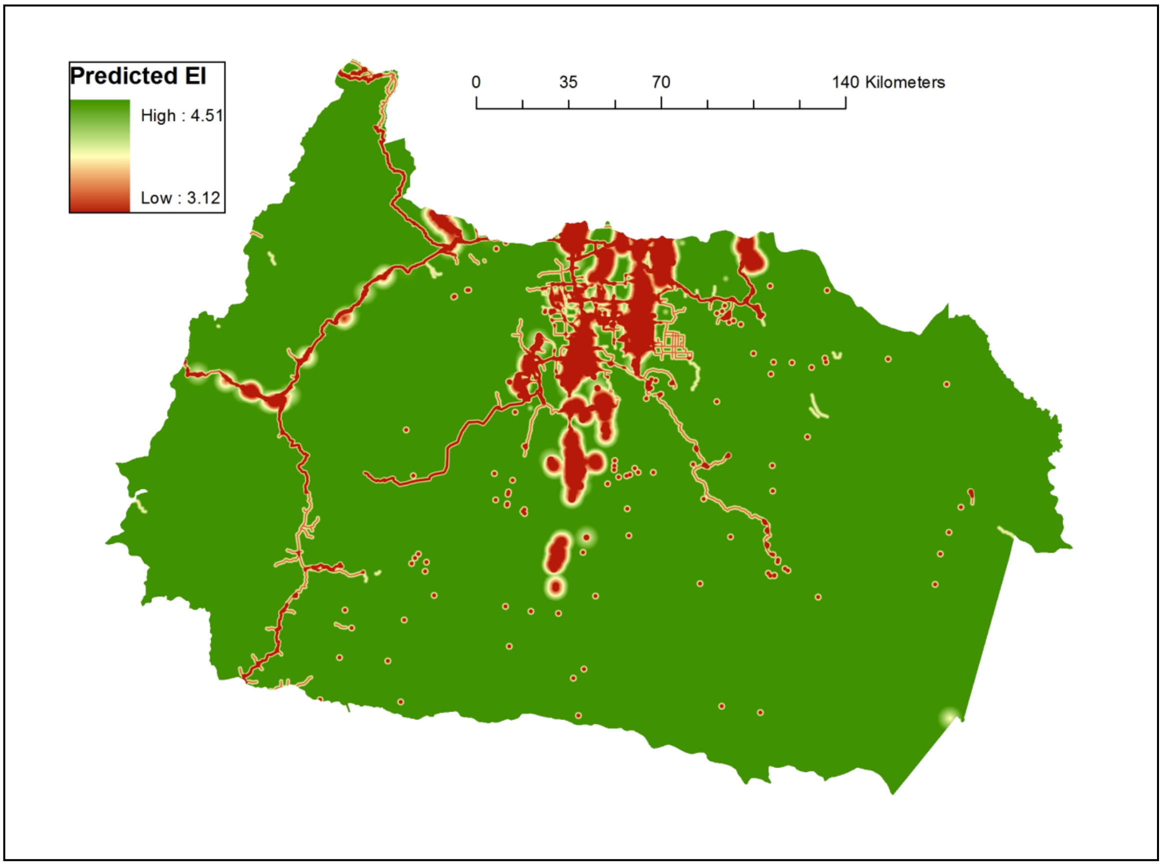

*Figure 6.*Predictive model of freshwater ecosystem ecological integrity in the Napo Watershed as determined by the presence of roads and human settlements.

The stepwise regression analysis established that main roads and oil activity were the best predictors of ecological integrity with significance levels of 0.002 and 0.019

respectively (Table 5). Resulting coefficients (Table 6)provided the following equation to calculate ecological integrity based on oil activity and road data:

EI = 4.592 - 0.942 (threat by oil activity) – 0.985 (threat by road)

*Table 5.*Stepwise regression model summary with oil activity and main roads as predictor variables.

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.524[b]	.275	.251	.497933955	.070	5.844	1	61	.019

Table 6. Model coefficients.

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	4.592	.088		52.215	.000
	MainRoads	-.942	.291	-.371	-3.243	.002
	Oil Activity	-.895	.370	-.276	-2.417	.019

When verifying the model with a paired t-test to compare predicted ecological integrity predicted with ecological integrity measured in the field, the 25% of measured data used as the test set proved to have no significant difference (*t*=-0.81; *df*=16; *P*=043) with the predicted values formulated with the 75% training set of values, therefore validating the predictive model.

The map developed with the model shows a concentration in low predicted ecological at the center of the watershed (Figure 6). This area is densely populated and contains the largest cities, which leads to a network or roads that are intensifying the predicted impact. Additionally, this area has undergone intensive oil exploitation and experienced oil spill incidents. Areas of low ecological integrity scattered throughout the basin are being depicted due widespread, remotely located oil wells.

DISCUSSION

In general terms, a larger proportionof sites located at higher altitudes presented moderate to good ecological integrity. This could be attributed to geographical, as well as anthropological reasons. In terms of geomorphological conditions, Ecuadorian highlands present steep slopes, leading to rivers with a more heterogeneous fluvial habitat that allows for the formation of recurring riffles and rapids(Rosgen 1994). These conditions permit faster river restoration (Newbury 1995), allowing them to regain healthier ecosystem qualities in areas that have been affected by human activity. Additionally, the high levels of ecological integrity of rivers at higher altitude could be attributed to their proximity to their source. Rivers at lower altitudes may accumulate contaminants that have not been able to be filtered out or metabolized by organisms, and other sources of impact that have taken place upstream. Taking this into account, rivers found at higher altitudes have occurred for shorter distances and therefore been less exposed to activities nearby that could have a negative impact over the river. Lastly, physical and climatic conditions of land at higher altitudes could constrain the expansion of human settlements in the area, as well the productive activities that arise from human presence. This last argument will be discussed when analyzing human activities that represent threats to the freshwater ecosystems in the area.

Rivers located in secludedareas generally presented a larger proportion of sites with good water quality as well.This could be attributed to some of these sites being located within protected areas such as the Oyacachi sites in the Cayambe-Coca National Park, and the Guacamayo sites located within the Sumaco Napo-Galeras National Park. Another factor that could contribute to this pattern is that lower human densities at more secluded areas represent less human activities that could impact the condition of freshwater ecosystems. Exceptions to this pattern were the sites located near the Tiputini Biodiversity Station at Yasuní National Park, where we recorded 'poor' ecological integrity, yet the human threat map showed that the area was lightly impacted. The primary reason for this lower ecological integrity was that half of these sites did not meet the criterion for acceptable water quality, as their pH was lower than 5, and their fluvial habitat index was particularly low. Due to the nature of vegetation in the region, lowland rivers are exposed to humic substances which are sources of a lower pH (Ertel*et al*. 1986), additionally, decreased water velocity, as well as a sediment-rich substrate, could be attributed to low IHF ratings, decreasing the calculated ecological integrity of Tiputini sites When working with a watershed as large as the Napo Basin, one could expect to encounter highly heterogeneous conditions, especially when dealing with such a wide altitudinal gradient. These heterogeneous conditions could mean that river ecosystems will present highly diverse characteristics as well. Since the ASPT biological index for aquatic macroinvertebrates did not prove to be particularly low at the Tiputini sites, I suggest that an alternative ecological integrity index, with criteria that would be more appropriate to lowland freshwater ecosystems, specifically for pH and IHF should be applied to asses ecological integrity in the area.

Most human threats included in the map follow the trend of being most intense where there is presence of roads. Road development allows access for the formation of human settlements and the production activities that are linked to them (Chomitz and Gray 1996), especially in areas such as the ones found in the eastern Napo Basin, which are commonly known to be relatively inaccessible due to rough terrain and dense vegetation. The human settlements map was very similar to the agricultural activities, water consumption and fisheries maps. This indicates that these activities are arising from human presence in the area and are most probably locally conducted.In terms of energy production, hydroelectric and thermoelectric plants were also located by the main roads, showing that roads are a determinant as to where these plants are placed, which is near easily accessible areas. Extractive activities, such as oil drilling, are threats that show a different distribution. Oil drilling seemed to respond to where oil fields are found and not necessarily near human settlements. Nevertheless, roads to gain access to oil fields are usually developed which in the future will lead to human colonization and an expansion of all other activities that are linked to human presence (Chomitz and Gray 1996). Mining activities portrayed in the map show a similar pattern to human settlement, with few exceptions where extraction is taking place in secluded areas. It must be pointed out that there is significant illegal mining taking place (interview with MAE-Tena 2013), which could lead to a slightly different distribution of the threats in more distant areas that are not being reported. In general terms, most human threats tended to be conglomerated, increasing the contrast between affected and unaffected land, which can be a key element in determining which areas can be labeled as conservation priority areas.

Oil activity and main roads were the most effective variables to represent ecological integrity. These were unexpected results when it comes to oil activity since its distribution did not follow the common pattern of other threats analyzed.Oil activity as a good predictive variable is a case to be analyzed, especially at sites that showed low ecological integrity and are not experiencing other sources of impact. There could be a variety of reasons as to why oil activity is closely related to low ecological integrity, including ecosystem degradation, deforestation and chemical contamination (O’Rourke and Connolly 2003). It is hard to determine with the level of analysis undertaken in this project what might be the source of impact from oil activity to freshwater ecosystems, additional tests that can include more in-depth water quality analyses and field observation might help elucidate and provide an explanation. Additional to oil activity, roads were also good indicators of ecological integrity. Roads were not heavily weighed when incorporating them in the cumulative threat map, but proved to be another accurate indicator of low ecological integrity. Though roads are in most cases not the direct cause of impact, this could be interpreted as them effectively being the catalysts for other forms of anthropogenic disturbances and therefore adequately representing areas that are being more highly impacted.It has been shown that roads act as precursors to the establishment of human activities that can be environmentally harmful by allowing access to areas that were previously undisturbed (Suárez *et al*. 2012). These results could also lead to the assumption that areas that have not been as impacted, could experience environmental degradation if road development wasto take place there.

Developing models to estimate the environmental condition of ecosystems by using human impact as the predicting variable is not innovative. Other studies have performed a similar exercise by analyzing factors that are known to have an effect on the environment under study and applying them as tool that has been useful in projecting the ecosystem's current level of disturbance (Mattson and Angermeier 2007). An element that these studies have often lacked is field validation, by performing in situ evaluation of the level of impact to later be compared to the model. This study attempted to do so with favorable results that showed that the predicted data did not significantly differ from actual environmental condition. These results have not only provided a representation of environmental integrity where field information is lacking, as previous studies have done before, but haveshown that the methodology applied is a useful and accurate tool to predict field conditions.

This project analyzed a very large and diverse area, in ecological, geographical and anthropological terms. When dealing with such a scale, the resolution of what is taking place at particular sites can be lost. In this compilation of data, though there was an overall significant correlation between ecological integrity and human impacts, there were certain sites where the level of human threat found did not express their ecological integrity. This project was meant to provide an overall image of the ecological condition of the whole basin in rough terms, and be able to predict which areas remain the most unaffected and which are experiencing more intense disturbances. When wanting to analyze a specific case, a more thorough analysis of the area and its surroundings might be required to explain the ecological condition of the river or stream. Additionally, due to the large scale of the project, certain human threats could not be depicted by the ecological integrity index. Such is the case with hydroelectric plants. It is understood that the construction of hydroelectric plants modifies the hydrological characteristics of a river, bringing negative results such as obstructedgene flow, flooding and modified river hydrology (Nilsson and Berggren 2000). In this analysis, only three sites were located near hydroelectric plants. The lack of sufficient data did not allow the chosen statistical analysis to be run and thus it could not be expected that hydroelectric plants could be used as a predictor to ecological integrity. To understand how hydroelectric plants can affect river integrity a much finer scaled analysis would need to be performed.

CONCLUSIONS

The measure of ecological integrity, composed of aquatic macroinvertebratediversity analysis, riparian integrity, fluvial habitat quality and water chemistry components such as pH and conductivity, presented high variability throughout the spread of the Napo Basin. This variability could be attributed to the diversity of ecogeographic regions in the area. On the other hand, high ecological variability could be a response to heterogeneous distributions in human presence and productive activities. Such was the case in the Napo Watershed. When comparing ecological integrity to nine human activities that could represent a threat to freshwater ecosystems, ecological integrity proved to be a response of the negative impact brought upon theseecosystems by human activities. In other words, at areas where human presence was more significant, ecological integrity was lower.

Though ecological integrity responded to human threat, it did not respond to all types ofthreat proportionally. Human threats, such as hydroelectric plants, thermoelectric plants and water consumption, did not act as adequate indicators of ecological integrity under this analysis. On the other hand, threats such asoil activity and main roads, proved to be elements that explained the variability in ecological integrity in the area. Thus a combination of the best indicators of ecological integrity, oil activity and main roads, were determined to be most adequately fit to elaborate a model of the whole basin, predicting ecological integrity in areas where data has not been gathered in situ.

This model can be used to establish conservation priority areas. The model incorporates data gathered at the field, with human activity information to develop a map that shows areas that have possibly been disturbed, at different intensities. Depending on the conservation system chosen, which could range from investing efforts into protecting more pristine areas or working with communities to reduce sources of impact, or developing a management plan that involves both actions, this model can help determine which actions should be applied at each area of the basin.

Gathering field data often requires significant investments in terms of time and financial resources. This study used field data to determine which sources of information could help portray the state of freshwater ecosystems without the need of doing fieldwork. Such tool could be useful when making management decisions, like establishing conservation priority areas, or simply wanting to analyze predicted ecological integrity and working under a strict time or financial budgets. Results showed that oil activities and roads act as accurate predictors of ecological integrity, thus could be used in other cases and areas of the world that share similar characteristics, when this information is available. As with other untested models, which are used as a predictive tool, caution should be applied, as their representation of reality could not be precise.

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ANNEXES

*Annex 1.*Site location, including latitude and longitude (UTM) as well as altitude (m).

Site	Altitude (m)	Latitude	Longitude
Tip22	231	372475	9929811
Tara1	236	361756	9980275
Tip21	237	372144	9929493
Tara2	244	358949	9988961
In30	248	291881	9958579
Tip36	251	371575	9929690
Pun33	253	265355	9954785
Shu33	253	315058	9963084
Chi36	262	301824	9963357
Lag32	263	314360	9865855
Wam34	264	286416	9964163
Ris35	266	285243	9934600
Coca5	275	266866	9954590
Lag2	275	315714	9995705
Coc34	278	278821	9963043
Tip37	278	371874	9929846
Auc35	279	289931	9929154
Coca2	280	295641	9967600
In31	280	261349	9915821
Lag31	280	299157	8110000
Coca4	283	289379	9934279
Coca1	285	283375	9967305
Coca3	294	289277	9964449
Coca6	312	265532	9911359
Lag1	356	287259	1238100
Lor41	410	245081	9931930
Ten4	430	194732	9886009
Lag51	473	245300	7699000
Ten 52	539	175479	9880100
Ten3	546	181806	9891204
Sum8	553	224615	9922434
Ten2	621	180950	9895290
Sum3	623	222290	9918523
Sum2	687	222594	9919686
Ten1	708	177478	9891553
Arc71	744	189759	9905870
Holl6	758	221897	9919786
Ten5	929	189334	9913401
Holl4	1038	196101	9922885

Holl3	1076	196502	9923066
Sum6	1120	197287	9921778
Sum1	1136	212054	9921009
Sum7	1184	203777	9921048
Holl2	1189	195183	9922548
Cha4	1243	212354	9988987
Cha3	1284	201651	9980423
Holl1	1308	194544	9921748
Cha1	1508	189210	9965057
Pap10	1847	178205	9950160
Pap 7	1987	172591	9949969
Pap 6	2134	170631	9951735
Oy3	2236	173294	9972369
Pap11	2297	167377	9952796
Oy1	2372	171980	9971531
Pap 2	2518	828947	9955243
Oy4	2609	167686	9972994
Pap 9	2708	825646	9958343
Oy10	2838	833318	9974598
Pap 5	2973	820408	9958415
Oy12	3012	829027	9975771
Oy9	3199	824427	9975736
Oy11	3417	821416	9976413
Oy8	3623	819648	9978432
Oy7	3863	817270	9974445

Annex 2. Biotic Index (rated out of 10) used to calculate ASPT. Higher indexes indicate less physiological tolerance.

Taxon	**Biotic Index**	**Taxon**	**Biotic Index**
Aeshnidae	6	Lampyridae	5
Ancyclidae	6	Leptoceridae	8
Anomalopsychidae	10	Leptohyphidae	7
Arctiidae	5	Leptophlebiidae	10
Athericidae	10	Libellulidae	6
Atriplectididae	10	Limnaeidae	3
Baetidae	4	Limnephilidae	7
Belostomatidae	4	Limoniidae	4
Blattodea	7	Lutrochidae	6
Blepharoceridae	10	Megapodagrionidae	6
Calamoceratidae	10	Muscidae	2
Calopterygidae	8	Naucoridae	5
Cambaridae	6	Nepidae	5
Ceratopogonidae	4	Notonectidae	5
Chironomidae	2	Odontoceridae	10
Chrysomelidae	4	Oligochaeta	1
Coenagrionidae	6	Oligoneuridae	10
Corixidae	5	Ostracoda	3
Corydalidae	6	Panorbidae	3
Cossidae	7	Perlidae	10
Culicidae	2	Philopotamidae	8
Curculionidae	4	Physidae	3
Dicteriadidae	7	Planaridae	5
Dixidae	4	Plastystictidae	9
Dolichopodidae	4	Pleidae	6
Dryopidae	5	Polycentropodidae	8
Dysticidae	3	Polymitarcyidae	9
Elmidae	5	Polythoridae	10
Empididae	4	Protoneuridae	7
Ephydridae	2	Psephenidae	5
Euthyplociidae	9	Psychodidae	3
Gerridae	5	Ptilodactylidae	5
Glossosomatidae	7	Ptychopteridae	4
Gomphidae	8	Pyralidae	4
Gripopterygidae	10	Scirtidae	5
Gyrinidae	3	Simulidae	5
Helicopsychidae	10	Sphaeriidae	3
Hirudinea	3	Staphylinidae	3
Hyalellidae	6	Stratiomyidae	4
Hydracarina	4	Symphidae	1
Hydraenidae	5	Tabanidae	4

Hydrobiidae	3	Tanyderidae	3
Hydrobiosidae	8	Tortricidae	6
Hydrophilidae	3	Tipulidae	5
Hydropsychidae	5	Veliidae	5
Hydroptilidae	6	Xiphocentronidae	8

Annex 3. IHF Index form to evaluate each site.

IHF

1. Inclusión de rápidos

Piedras, cantos y gravas no fijadas por sedimentos finos.	10
Piedras, cantos y gravas poco fijadas por sedimentos finos.	5
Piedras, cantos y gravas medianamente fijadas por sedimentos finos.	0

TOTAL

2. Frecuencia de rápidos

Alta frecuencia de rápidos	10
Escasa frecuencia de rápidos	8
Frecuencia de rápidos ocasional	6
Casi no existencia de rápidos	4
Sólo pozas	2

TOTAL (una)

3. Composicion del sustrato

% Bloques y piedras	1-10 %	2
	>10%	5
% Cantos y gravas	1-10 %	2
	>10%	5
% Arena	1-10 %	2
	>10%	5
% Limo y arcilla	1-10 %	2
	>10%	5
	Total (sumar)	

4. Regimenes de velocidad/profundidad

4 categorías (lento-profundo, lento-superficial, rápido-profundo y rápido-superficial)	10
Sólo 3 de las 4 categorías	8
Sólo 2 de las 4 categorías	6
Sólo 1 de las 4 categorías	4

TOTAL (una)

5. Porcentaje de sombra en el cauce

Sombreado con ventanas	10
Sombra total	7
Grandes claros	5
Expuesto	3

TOTAL (una)

6. Elementos de heterogeneidad - si hay ausencia de hojarasca el valor debe ser 0 *

Hojarasca		abundante	4
		escasa	2

Presencia de troncos y ramas	2
Raíces expuestas	2
Diques naturales	2
	Total (sumar)

7. Cobertura de vegetación acuática *

Algas + briofitas (líquenes + musgos) - material flotante	10-50%	10
	<10% o >50%	5
	ausencia total	0
Vegetación pegadas a las rocas	10-50%	10
	<10% o >50%	5
	ausencia total	0
Plantas acuáticas/semi-acuáticas	10-50%	10
	<10% o >50%	5
	ausencia total	0
	Total (sumar)	

Puntuación total	**/100**

Annex 4. QBR- And Index form to evaluate each site.

	Grado de cubierta de la zona de ribera Puntuación bloque 1
Puntuación	
25	> 80 % de cubierta vegetal de la ribera (Gramíneas y/o matorral y/o "almohadillas")
10	50-80 % de cubierta vegetal de la ribera
5	10-50 % de cubierta vegetal de la ribera
0	< 10 % de cubierta vegetal de la ribera
10	si la conectividad entre la vegetación de ribera y la comunidad vegetal adyacente es total
5	si la conectividad entre la vegetación de ribera y la comunidad vegetal adyacente es >50%
-5	Si la conectividad entre la vegetación de ribera y la comunidad vegetal adyacente es entre el 25-50%
-5	Si se presentan evidencias de quema de pajonal de gramíneas de ribera <50%
-10	Si se presentan evidencias de quema de pajonal de gramíneas de ribera >50%
	Calidad de la cubierta Puntuación bloque 2
Puntuación	
25	Todas las especies vegetales de ribera autóctonas (gramíneas, matorral o almohadillas)
10	Ribera con <25% de la cobertura con especies de introducidas (Eucalyptus spp., Pinus spp.) o especies
	arbustivas secundarias (por efecto de sobrepastoreo)
5	Ribera entre 25-80% de la cobertura con especies introducidas o con arbustivas secundarias
0	Ribera con >80% de especies introducidas o arbustivas secundarias
	Grado de naturalidad del canal fluvial Puntuación bloque 3
Puntuación	
25	El canal del río no ha estado modificado
10	Modificaciones de las terrazas adyacentes al lecho del río con reducción del canal
5	Signos de alteración y estructuras rígidas intermitentes que modifican el canal del río
0	Río canalizado en la totalidad del tramo
-10	si existe alguna estructura sólida dentro del lecho del río
-10	si existe alguna presa o otra infraestructura transversal en el lecho del río
-5	si hay basuras en el tramo de muestreo de forma puntual pero abundantes
-10	si hay un basurero permanente en el tramo estudiado
	Puntuación final:
	Nivel de calidad QBR-And
	Vegetaciòn de ribera sin alteraciones. calidad muy buena. estado natural ≥ 96

Vegetación ligeramente perturbado. calidad buena 76-95
Inicio de alteración importante. calidad intermedia 51-75
Alteración fuerte. mala calidad 26-50
Degradación extrema. calidad pésima ≤ 25

Annex 5. Water Use Questionnaire.

Basic Information	
Date:	
Institution:	
Name:	
Position:	
Questions	
1)¿De donde se obtiene el agua para usos humanos del poblado de _________?	
2)¿Existe algún sistema de almacenamiento de agua para consumo humano? De ser así, ¿en qué consiste este sistema de almacenamiento?	
3) ¿Existe algún sistema de tratamiento de agua para el consumo humano? De ser así, ¿en qué consiste este sistema de tratamiento?	
4) ¿En qué cantidad se calcula el agua que es consumida por el poblado?	
5) ¿Cuáles son las actividades principales para las cuales es dirigida esta agua? ¿Existen estimados de la cantidad de agua que es dirigida para estas actividades?	
6) Según la percepción general de la población, ¿se considera que el agua obtenida de ríos para uso humano está en un buen estado?	
7) ¿Cuál es el origen de los problemas relacionados al uso de agua en el sector en términos de cantidad y calidad del agua?	
8) ¿Existe algún sistema de tratamiento de aguas residuales? De no ser así, ¿existen iniciativas para levantar un proyecto de tratamiento de afluentes que son liberados a cuerpos de agua?	

Annex 6. Data on ecological integrity components. Color codes represent water quality and are categorized as: blue- excellent, green- good, yellow- moderate, orange- poor, and red- very poor.

							EI Index
Site	ASPT (ABI)	QBR-And	IHF	pH	Conducti-vivity (uS/cm)	Tempera-ture	6.0/6.0
Tip22	6.36	100.00	81.00	5.80	36.50	25.2	4.98
Tara1	2.80	100.00	47.00	5.08	36.00	24.3	3.93
Tip21	5.06	100.00	62.00	5.09	55.40	24.8	4.45
Tara2	5.64	100.00	45.00	4.74	14.80	25	3.56
In30	5.75	50.00	71.00	6.48	114.40	25.8	3.96
Tip36	5.19	100.00	54.00	4.40	39.10	25.6	3.46
Pun33	5.82	50.00	63.00	6.55	92.30	25.6	3.98
Shu33	6.05	95.00	82.00	5.72	82.20	24.7	4.70
Chi36	5.67	65.00	62.00	6.57	132.10	26	3.93
Lag32	3.50	40.00	55.00	3.56	35.60	25.7	2.55
Wam34	5.95	55.00	57.00	6.83	107.10	25.9	3.93
Ris35	7.06	90.00	59.00	5.67	43.80	25.1	4.77
Coca5	5.73	95.00	70.00	6.38	70.00	25.2	4.56
Lag2	4.78	30.00	55.00	5.93	143.90	25.5	3.29
Coc34	2.00	85.00	68.00	5.61	83.10	25	3.65
Tip37	5.57	100.00	54.00	3.90	45.30	25.6	3.51
Auc35	6.00	45.00	76.00	4.08	22.70	25.8	3.36
Coca2	4.92	25.00	58.00	6.01	76.30	26.1	3.56
In31	5.76	95.00	78.00	7.10	51.70	24.7	4.72
Lag31	5.57	45.00	63.00	4.25	38.70	27	3.08
Coca4	6.00	95.00	86.00	5.89	32.70	25.6	4.92
Coca1	3.86	90.00	72.00	5.81	127.60	25.6	3.94
Coca3	4.75	75.00	63.00	5.05	27.50	25.5	4.26
Coca6	6.08	100.00	77.00	5.15	19.10	24.2	4.95
Lag1	5.08	100.00	51.00	5.79	62.50	24.9	4.32
Lor41	6.25	100.00	90.00	5.78	28.20	25.2	5.08
Ten4	5.70	40.00	44.00	7.20	264.80	26.90	3.01
Lag51	5.00	95.00	74.00	5.00	8.70	23.1	4.69
Ten 52	6.26	87.00	95.00	4.53	14.90	24.24	4.05
Ten3	6.62	60.00	73.00	5.87	40.70	25.20	4.53
Sum8	5.73	95.00	90.00	6.67	60.30	23.6	4.80
Ten2	5.92	90.00	87.00	5.19	30.20	24.10	4.87
Sum3	5.88	85.00	56.00	6.69	74.10	23.7	4.34
Sum2	3.88	90.00	65.00	5.91	61.60	23.1	4.12
Ten1	5.67	80.00	75.00	5.75	76.40	24.10	4.43
Arc71	5.40	55.00	70.00	6.32	105.70	23.3	3.96

Holl6	5.50	100.00	87.00	6.17	18.70	22.00	4.93
Ten5	6.05	50.00	78.00	5.06	27.10	21.50	4.42
Holl4	6.27	95.00	87.00	5.86	25.30	20.50	5.01
Holl3	6.54	80.00	76.00	5.88	23.90	19.30	4.81
Sum6	6.09	80.00	62.00	5.72	20.60	20.7	4.59
Sum1	5.83	95.00	69.00	5.69	20.30	20.10	4.76
Sum7	5.63	85.00	72.00	6.21	20.00	20.9	4.65
Holl2	6.08	95.00	80.00	6.07	13.50	18.30	4.95
Cha4	6.06	90.00	89.00	5.75	86.80	19.8	4.70
Cha3	5.96	90.00	75.00	6.75	94.50	20.2	4.52
Holl1	6.07	65.00	60.00	6.09	15.00	20.00	4.44
Cha1	5.40	60.00	72.00	7.78	271.40	19.2	3.40
Pap10	5.48	90.00	70.00	7.83	81.81	14.15	4.42
Pap 7	5.89	75.00	83.00	8.10	97.48	18.46	4.42
Pap 6	6.48	100.00	95.00	8.33	118.02	14.91	4.83
Oy3	5.96	95.00	86.00	7.78	94.40	12.81	4.68
Pap11	5.50	45.00	56.00	8.11	206.80	14.3	3.36
Oy1	5.38	95.00	77.00	7.83	170.00	12.68	4.18
Pap 2	5.45	74.00	95.00	8.30	137.12	13.4	4.29
Oy4	5.68	65.00	84.00	7.45	44.70	12.44	4.49
Pap 9	5.70	95.00	98.00	8.32	63.98	9.95	4.86
Oy10	6.04	95.00	75.00	7.84	54.00	9.30	4.74
Pap 5	5.74	80.00	75.00	8.52	110.93	9.30	4.31
Oy12	5.96	85.00	65.00	7.85	43.60	9.12	4.56
Oy9	4.95	80.00	85.00	8.02	60.90	7.42	4.44
Oy11	5.59	95.00	82.00	7.68	22.30	7.95	4.84
Oy8	5.63	75.00	90.00	7.82	34.10	6.95	4.68
Oy7	4.61	100.00	84.00	7.81	46.30	7	4.62

Annex 7. Correlation between ecological integrity (EI) and human threats.

			EI	Total Threats
Spearman's rho	EI	Correlation Coefficient	1.000	-.390**
		Sig. (2-tailed)	.	.001
		N	64	64
	Total Threats	Correlation Coefficient	-.390**	1.000
		Sig. (2-tailed)	.001	.
		N	64	64
	Human Settlements	Correlation Coefficient	-.456**	.737**
		Sig. (2-tailed)	.000	.000
		N	64	64
	Fisheries	Correlation Coefficient	-.123	.225
		Sig. (2-tailed)	.334	.074
		N	64	64
	Water Consumption	Correlation Coefficient	-.142	-.089
		Sig. (2-tailed)	.264	.483
		N	64	64
	Hydroelectric Plants	Correlation Coefficient	.102	.054
		Sig. (2-tailed)	.421	.671
		N	64	64
	Mining	Correlation Coefficient	-.055	.413**
		Sig. (2-tailed)	.664	.001
		N	64	64
	Oil Activity	Correlation Coefficient	-.331**	.585**
		Sig. (2-tailed)	.008	.000
		N	64	64
	Thermoelectric Plants	Correlation Coefficient	-.194	.220
		Sig. (2-tailed)	.124	.081
		N	64	64
	Agriculture	Correlation Coefficient	-.333**	.716**
		Sig. (2-tailed)	.007	.000
		N	64	64
	Main Roads	Correlation Coefficient	-.421**	.523**
		Sig. (2-tailed)	.001	.000
		N	64	64
	Altitude	Correlation Coefficient	.315*	-.370**
		Sig. (2-tailed)	.011	.003
		N	64	64

Annex 8. Correlation test on ecological integrity components and threats.

			ASPT	QBR-And	IHF	pH	Conductivity
Spearman's Rho	Human Settlements	Correlation Coefficient	-0.218	$-.457^{**}$	-0.21	-0.049	$-.319^{*}$
		Sig. (2-tailed)	0.084	0	0.096	0.701	0.01
		N	64	64	64	64	64
	Fisheries	Correlation Coefficient	0.066	-0.166	-0.198	-0.159	-0.054
		Sig. (2-tailed)	0.607	0.19	0.117	0.209	0.673
		N	64	64	64	64	64
	Water Consumption	Correlation Coefficient	0.07	-0.095	-0.075	-0.216	0.144
		Sig. (2-tailed)	0.581	0.454	0.557	0.086	0.255
		N	64	64	64	64	64
	Hydroelectric Plants	Correlation Coefficient	0.078	0.082	0.202	0.078	-0.18
		Sig. (2-tailed)	0.538	0.519	0.109	0.542	0.155
		N	64	64	64	64	64
	Mining	Correlation Coefficient	0.134	$-.254^{*}$	-0.088	-0.011	0.082
		Sig. (2-tailed)	0.292	0.043	0.49	0.933	0.517
		N	64	64	64	64	64
	Oil Activities	Correlation Coefficient	-0.164	-0.229	-0.228	-0.068	$-.294^{*}$
		Sig. (2-tailed)	0.194	0.068	0.07	0.594	0.018
		N	64	64	64	64	64
	Thermoelectric Plants	Correlation Coefficient	-0.136	0.138	$-.265^{*}$	-0.179	0.146
		Sig. (2-tailed)	0.283	0.275	0.034	0.156	0.251
		N	64	64	64	64	64
	Agriculture	Correlation Coefficient	-0.147	$-.461^{**}$	$-.307^{*}$	0.093	-0.164
		Sig. (2-tailed)	0.246	0	0.014	0.463	0.196
		N	64	64	64	64	64

	Main Roads	Correlation Coefficient	-.272*	-.328**	-0.209	-0.02	-.353**
		Sig. (2-tailed)	0.029	0.008	0.098	0.876	0.004
		N	64	64	64	64	64