

# Ecohydroclimatological Research Along the Catacocha-Zamora Transect, Loja and Zamora-Chinchipec, Ecuador

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## Abstract

Oñate-Valdivieso, F., & Ponce, V. M. (November-December, 2015). Ecohydroclimatological Research Along the Catacocha-Zamora Transect, Loja and Zamora-Chinchipec, Ecuador. *Water Technology and Sciences* (in Spanish), 6(6), 63-73.

This study reports on ecohydroclimatological research along the Catacocha-Zamora transect in the provinces of Loja and Zamora-Chinchipec, Ecuador. Mean annual precipitation varies between 400 mm in Catamayo, along the study transect, to 2 200 mm in Zamora, to the eastern limit. Altitudinal variations are also marked, between 1 230 m in Catamayo, to 2 930 m in Cerro del Consuelo, to 900 m in Zamora. Ecohydrological and hydroclimatological data are examined with the aim of developing relations to underpin the nascent field of ecohydroclimatology. Applications are envisioned in the management of tropical montane ecosystems.

**Keywords:** Ecohydrology, hydroclimatology, ecology, bioclimatology, climatology, tropical vegetation, Ecuador.

## Resumen

Oñate-Valdivieso, F., & Ponce, V. M. (noviembre-diciembre, 2015). Investigación ecohidroclimatológica en el transecto Catacocha-Zamora, Loja y Zamora Chinchipec, Ecuador. *Tecnología y Ciencias del Agua*, 6(6), 63-73.

Este estudio trata sobre una investigación sobre ecohidroclimatología a lo largo del transecto Catacocha-Zamora en las provincias de Loja y Zamora-Chinchipec, Ecuador. La media de precipitación anual varía entre 400 mm en Catamayo, a lo largo del transecto de estudio, hasta 2 200 mm en Zamora, hasta el límite oriental. Las variaciones altitudinales también son marcadas, entre 1 230 m en Catamayo, 2 930 m en el Cerro del Consuelo y 900 m en Zamora. Se examinan datos ecohidrológicos e hidroclimatológicos para desarrollar las relaciones que apoyen el nacimiento de la ecohidroclimatología. Se prevén aplicaciones en la gestión sostenible de ecosistemas tropicales de montaña.

**Palabras clave:** ecohidrología, hidroclimatología, ecología, bioclimatología, climatología, vegetación tropical, Ecuador.

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Received: 07/10/2014

Approved: 13/08/2015

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## Introduction

Ecuador is endowed by Nature with unmatched ecological diversity. This is due to: (1) its geographical location along the Equator, (2) its relative continental position next to the Pacific Ocean, and (3) the presence of the Andes Mountain Range, which crosses the middle of the country from North to South (Figure 1). This unusual combination of near-zero latitude, proximity to a very large moisture source, and wide altitudinal

range is responsible for a substantial ecological and biological diversity. Therefore, the region constitutes a veritable field laboratory for the study of tropical ecological, hydrological, and climatological relations.

The general objectives include describing the uniqueness of the chosen study region and its climatological and geomorphological characteristics, with aim to establish the appropriate foundations for the nascent field of ecohydroclimatology, interpreted as the seamless approach to ecology,

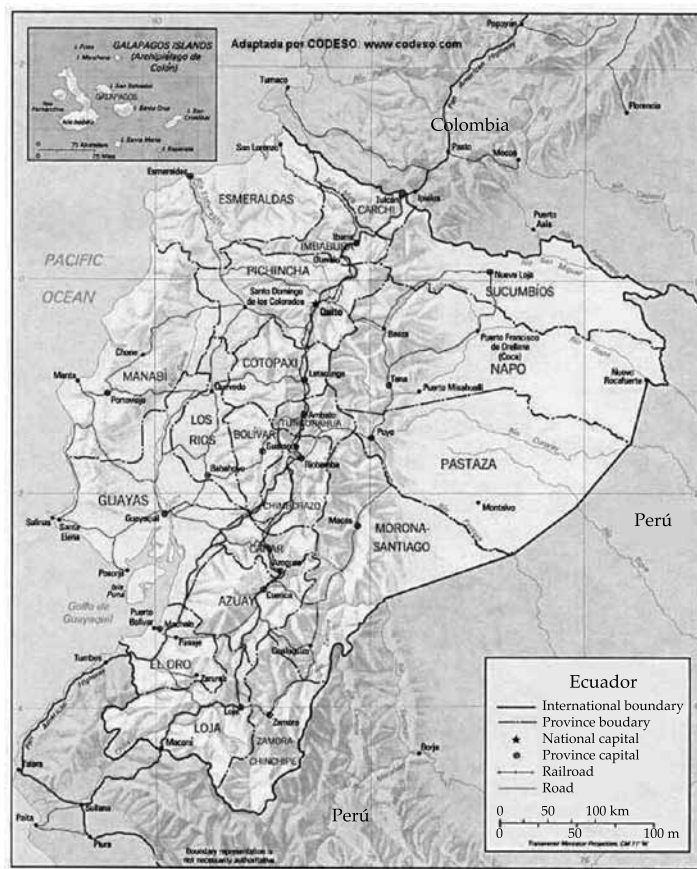


Figure 1. Map of Ecuador, showing Andes Mountain Range passing through the middle.

hydrology, and climatology. Specific objectives include the description of mean annual precipitation, terrain geology and geomorphology, relation of flora to distance to groundwater, and appropriate climatic indicators such as the various bioclimatological indexes.

This study focuses on the southern provinces of Loja and Zamora-Chinchipe (Figure 1). These regions feature marked gradients in mean annual precipitation within a relatively short distance. Figure 2 shows mean annual precipitation in Loja and Zamora-Chinchipe, varying between 200-400 mm in Loja to 3200-6400 mm in Zamora-Chinchipe. Thus, a transect of relatively limited length transversing these two provinces is appropriate for the study of ecohydroclimatological relations.

This study is part of a research program in ecohydroclimatology carried out jointly by San Diego State University (San Diego, California, USA) and the Universidad Tecnica Particular de Loja (Loja, Ecuador).

### Geographical Setting

The provinces of Loja and Zamora are located in southern Ecuador. Wolf (1892) has described the geology, geomorphology, and hydrography of Ecuador, including Loja and Zamora. The Andes Mountain Range transverses the study region, from the Sabanilla Knot, to the south of Loja, to the moorlands of Saraguro, toward the north.

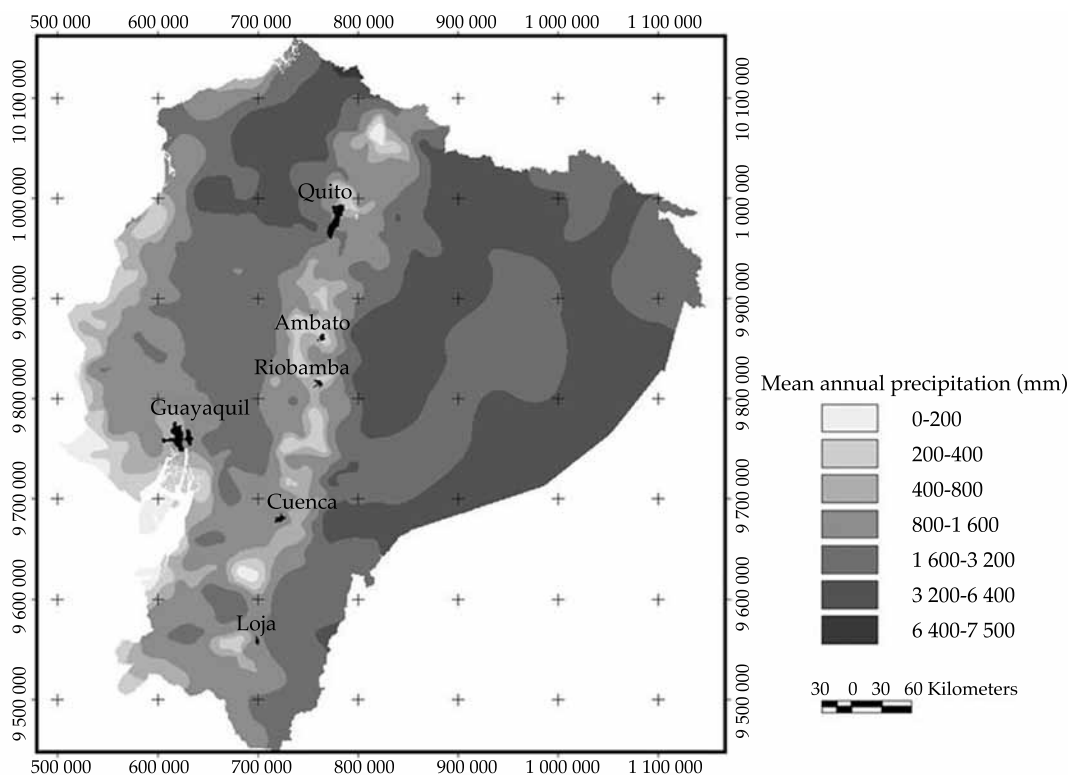


Figure 2. Mean annual precipitation in Ecuador.

From the Sabanilla Knot, the Santa Rosa Range takes off to the northwest and the Condor Range to the southeast. The Santa Rosa Range is narrow, low, and relatively small. From the Condor Range, several large branches take off toward the northeast.

From 4° 8' S latitude, south of the city of Loja, the Western Range runs parallel to the Eastern Range in a general northern direction. The Western Range is narrow, with short branches on both sides, rising up to 3000 m through most of its length. In contrast, the Eastern Range rises up to 4000 m. These two branches of the Andes are united by two transversal knots, the Cajanuma Knot to the south of Loja, and the Guagra-uma Knot to the north. The region comprised between the knots constitutes the valley of Loja.

The valley of Loja, oriented from north to south, is divided into two different sections.

The northern section is narrow, resembling a canyon. The southern section, properly the valley of Loja, is oval-shaped, with a total length comprising about 6 km and a maximum width of about 3 km.

The Malacatos River has its headwaters in the Cajanuma Knot, flowing north to meet the Zamora river at Loja proper, where it takes the name of the latter. Continuing to flow north through the Guagra-uma Knot, the Zamora river meets several tributaries along its course, eventually discharging into the Santiago river in the eastern lowlands of Zamora-Chinchipec province.

The interandean valley of Loja is small and low, at 2150 m altitud, with the city of Loja occupying the entire valley. The lowest point on the road (pass) from Loja through Cajanuma Knot to the south is at 2525 m altitud. The lowest point on the road from Loja to Catamayo to the

west is at 2786 m. This pass is next to Villonaco peak, which rises to about 3000 (Wolf, 1892).

### Conceptual Framework

This study sets the foundations to describe the characteristics of vegetative communities, using the interdisciplinary perspective of ecohydroclimatology. Several factors condition the type and density of vegetative communities across the landscape. The most important are:

#### *Mean Annual Precipitation*

Mean annual precipitation determines the humidity provinces (arid, semiarid, subhumid, or humid) (Holdridge, 1947). Plants respond readily to the presence of environmental moisture, including that in the air, land surface, vadose zone (unsaturated soil), and that flowing underground. Low relative humidity in the air is usually associated with low moisture levels on land surface and soil, together with the presence of ephemeral streams and relatively deep groundwater. Conversely, high relative humidity is usually associated with high moisture levels on the land surface and soil, coupled with perennial streams and shallow groundwater. In practice, these elements of the landscape are all related, with a common denominator: high environmental moisture means humid, while low moisture means arid.

#### *Terrain Geology and Geomorphology*

Next to climate type, terrain geology and geomorphology are generally a good indicator of vegetation type (Cole, 1960; Ponce & Da Cunha, 1993). Notwithstanding other factors, terrain geology and geomorphology determine the relation between surface water and groundwater. Plants may transpire either vadose water, groundwater, or both (Ponce, 2006). Land surface slope and rock/soil type determine the quantity of surface flow, surface detention and retention, infiltration rate, depth to water table, and groundwater replenishment. In addition,

drainage conditions, either exorheic, endorheic, or mixed exorheic-endorheic, by interacting with soil and groundwater salinity, determine the type and density of vegetative communities that prevail across the landscape.

#### *Proximity to Groundwater*

Vegetative communities referred to as *phreatophytes* specialize in satisfying their water needs directly from the underlying groundwater. In essence, shallow groundwater supports the growth of plants that habitually feed on groundwater (Meinzer, 1927). Thus, the presence of phreatophytes is a good indicator of shallow groundwater in the vicinity.

#### *Speed of Surface Drainage*

Land slopes vary widely, from larger than 30% in certain mountainous landscapes (Ponce, 2008), to near zero in some geologically controlled depositional landscapes or broad river valleys undergoing geologic subsidence (Ponce, 1995). Very mild terrain slopes lead to swamps and wetlands and their characteristic vegetative community structures, including the dynamics imposed by seasonal variations, floods and droughts, and more recently, anthropogenic climate change.

#### *Mean Annual Temperature*

Plants are naturally adapted to either wide (desert) or narrow (rainforest) variations in temperature. Mean annual temperature conditions the liveability and survivability of diverse vegetative communities across the landscape, from arid to humid.

#### *Seasonal Variations in Temperature*

Plants are naturally adapted to seasonal variations in temperature, which are conditioned by latitude, altitude, and continental location relative to the nearest moisture source. Desert plants readily adapt to wide variations in seasonal temperature, while rainforest plants do not.

## Annual Precipitation

The transect chosen for this study comprises the section between Catacocha, in central Loja province, to Zamora, in western Zamora-Chinchipe (Figure 3).

Figure 4 shows a map of mean annual precipitation for the study transect. Data from ten (10) climatological stations were used to develop this map. The stations are, from west to east: (1) Chaguarpamba, (2) Catacocha, (3) Nambacola, (4) El Cisne, (5) Catamayo, (6) El Tambo, (7) La Argelia (in Loja), (8) Cajanuma, (9) San Francisco, and (10) Zamora. The locations of the stations are shown in Figure 4.

Mean annual precipitation varies from 400 mm in Catamayo to 2200 mm in San Francisco, depicting a marked precipitation gradient. The straight distance between Catamayo and San Francisco is about 40 km, while the straight distance between Catacocha and Zamora is about

80 km. Significantly, the city of Loja, capital of the province of Loja, is located at midrange along the Catamayo-San Francisco subtransect.

Figure 5 shows an image of the Catacocha-Zamora transect, revealing the marked differences in vegetation along the transect. Albedo, a reliable indicator of the presence or absence of vegetation is estimated to vary between as high as 0.30 near Catamayo, to as low as 0.05 near San Francisco (Ponce, Lohani, & Huston, 1997). Figure 6 shows a longitudinal profile of the Catacocha-Zamora transect, corresponding to Figure 5. The Catacocha, Catamayo, Loja, and Zamora valleys are indicated in the profile.

Figure 7 shows an image of the Catamayo-Zamora transect, at somewhat larger scale than the previous image, again revealing the marked differences in vegetation type and density along the transect. Pulgar, Izco and Jadan (2010) have noted that mean annual precipitation at an isolated spot at Cerro El Consuelo, near San

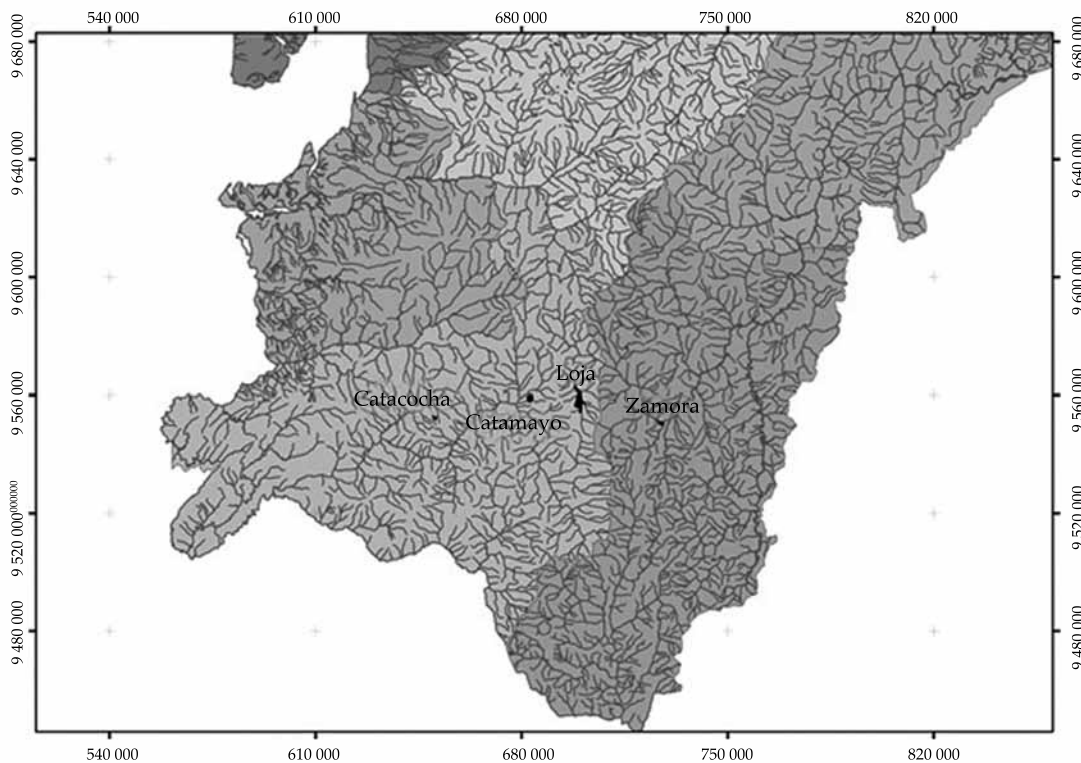


Figure 3. General location of the study transect in the Loja and Zamora-Chinchipe provinces.

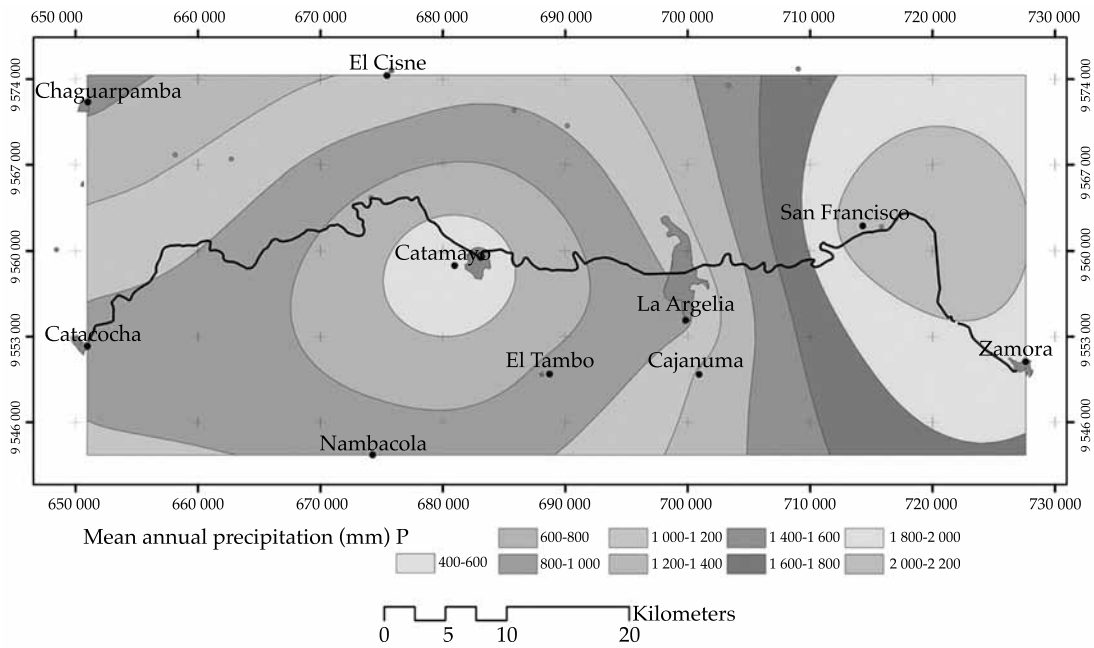


Figure 4. Mean annual precipitation isohyets for the Catacocha-Zamora transect.

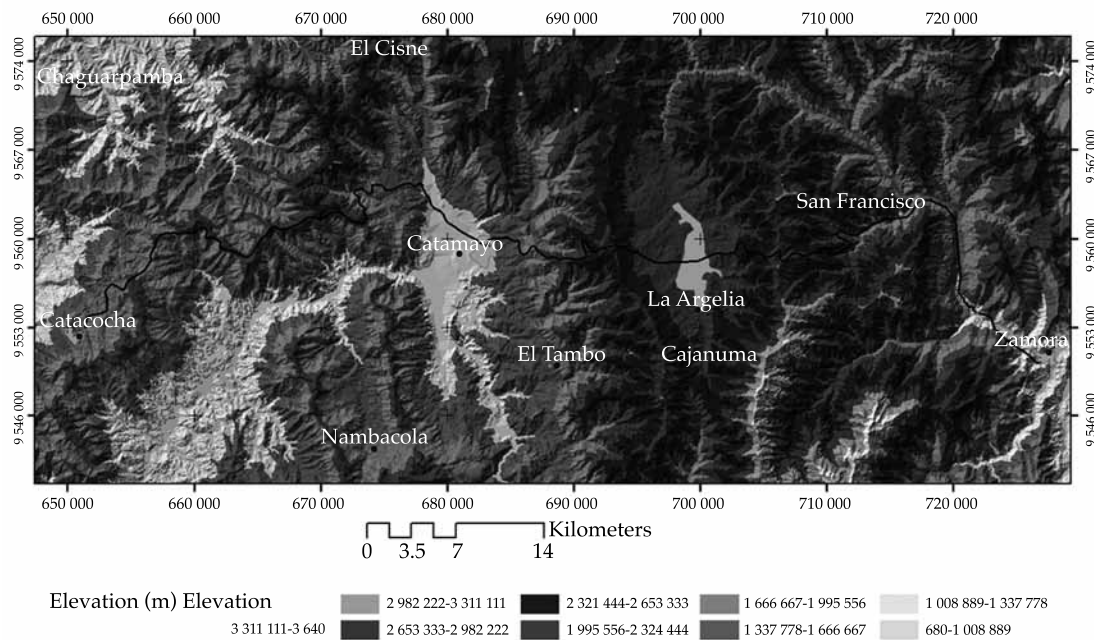


Figure 5. Topographic map comprising the Catacocha-Zamora transect.

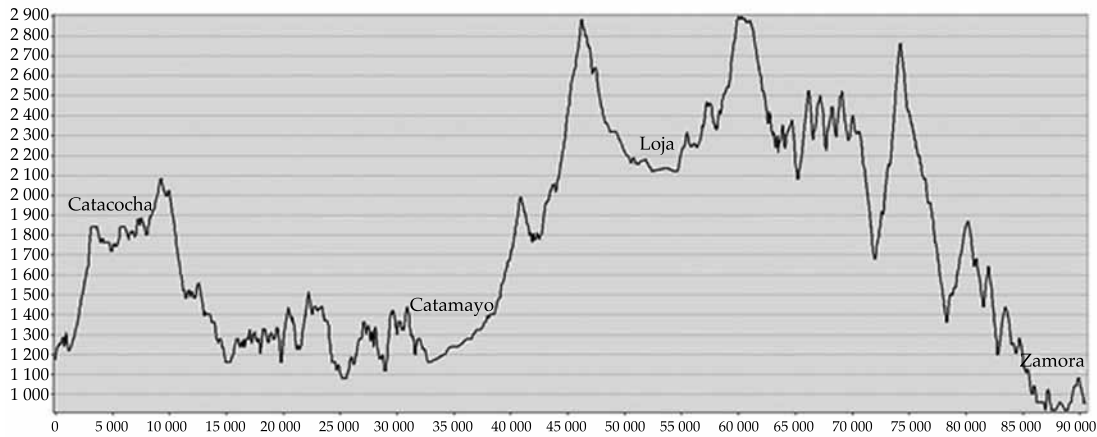


Figure 6. Longitudinal profile of Catacocha-Zamora transect.

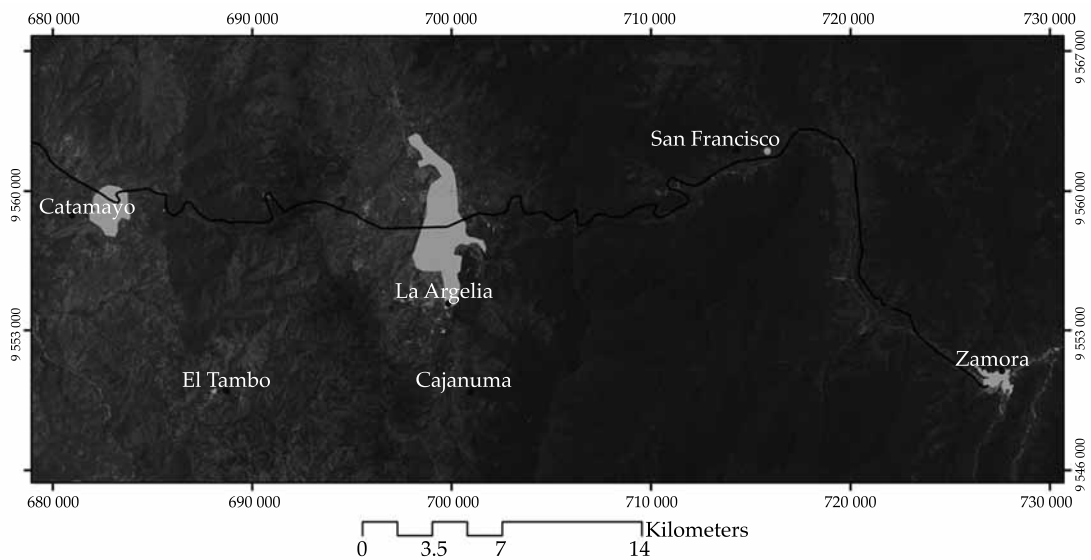


Figure 7. Image of the Catamayo-Zamora transect.

Francisco, has been measured at 6 259 mm. Also, they have documented the number of rainy months to vary from 1-2 for Catamayo (a hyperarid climate) to 11-12 for San Francisco (a hyperhumid climate) (Ponce, Pandey, & Ercan, 2000). Thus, the Catamayo-San Francisco subtransect appears to be optimal for the study of tropical ecohydroclimatological relations.

Figure 7 shows an image focused on the Loja valley, showing the marked differences in vegetation density from the mountains west of Loja to those east of Loja, a distance of less than 20 km. Mean annual precipitation (Figure 8) varies from 800-1000 mm to the west and 1600-1800 mm to the east.

## Vegetative Landscapes

Figures 8 and 9 show the contrast between typical landscapes and associated vegetative communities in Catamayo and Zamora, respectively. Figure 8 shows a hilly landscape covered with short semiarid shrubs and grasses, while Figure 9 shows a dense tropical montane humid forest, featuring relatively tall trees. Ongoing field research is aimed at identifying the spatial distribution, density, size, and other relevant characteristics of vegetative species and communities along the study transect.



Figure 8. Mountainous semiarid landscape in the vicinity of Catamayo, Loja province.



Figure 9. Vegetative communities along the road to Zamora, Zamora-Chinchipec province.

## Bioclimatological Indexes

Three indexes are used to study bioclimatological relations (Rivas-Martínez 2007):

### *Continentality index*

This index is equal to the average temperature of the hottest month  $T_{hot}$  minus the average temperature of the coldest month  $T_{cold}$ .

$$I_c = T_{hot} - T_{cold} \quad (1)$$

The following procedure is used to calculate  $T_{hot}$ :

The maximum daily temperature, for each month and year of record is identified, and the mean maximum monthly temperature is calculated.

The mean of the mean maximum monthly temperature is calculated for the entire record.

The month with the highest mean of the mean maximum monthly temperature is selected as the hottest month.

A similar procedure is applied to calculate  $T_{cold}$ .

The continentality index varies between  $I_c = 0$  for an extreme oceanic influence, to  $I_c = 65$  for an extreme continental influence.

### *Thermicity index*

This index is equal to the mean annual temperature  $T_{mean}$  plus the mean of the monthly minimum temperatures  $T_{min}$  plus the mean of the monthly maximum temperatures  $T_{max}$ . The sum is multiplied by 10.

$$I_t = 10 (T_{mean} + T_{min} + T_{max}) \quad (2)$$

The mean annual temperature is the mean of the (12) mean monthly average temperatures. The mean of the monthly minimum temperatures in the mean of the (12) mean monthly minimum temperatures. The mean of the monthly maximum temperatures in the mean of the (12) mean monthly maximum temperatures.



### Positive Temperature Index

This index is equal to the sum of all positive (nonnegative) mean monthly temperatures. The sum is multiplied by 10.

$$T_p = 10 (\sum T_{pos}) \quad (3)$$

Table 1 shows the classification of climates as a function of the continentality index. Table 2 shows the classification of climates as a function of the thermicity and positive temperature indexes. Table 3 shows the indexes calculated for the following stations: (1) Catacocha, (2) Catamayo, (3) La Argelia, and (4) Zamora. Table 4 shows the climatic classification for the stations considered in this study.

The low continentality index of the stations along the study transect justifies its classification as *ashyperoceanic* (Table 1). This is attributed primarily to its geographical location near the Equator, and secondarily to its near proximity to the Pacific Ocean.

### Summary

Ongoing ecohydroclimatological research along the Catacocha-Zamora transect in the provin-

ces of Loja and Zamora-Chinchi, Ecuador, is reported. Mean annual precipitation varies between 400 mm in Catamayo, along the study transect, to 2200 mm in Zamora, toward the eastern limit. Precipitation data indicates that mean annual precipitation may reach 6259 mm in an isolated point at Cerro del Consuelo, in the Podocarpus National Park, near Loja. Altitudinal variations are also quite marked, between 1230 m in Catamayo, to 2930 m in Cerro del Consuelo, to 900 m in Zamora. Ecohydrological and hydroclimatological data are examined with the aim of underpinning research in the nascent field of ecohydroclimatology.

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Table 1. Classification of climates based on continentality index.

Types	Continentality index $I_c$
Hyperoceanic	0-11
Oceanic	11-21
Continental	> 21

Table 2. Classification of climates based on thermicity and positive temperature indexes.

Type of climate	Thermicity index $I_t$	Positive temperature index $T_p$
Infratropical	710-890	2 900-3 700
Thermotropical	490-710	2 300-2 900
Mesotropical	320-490	1 700-2 300
Supratropical	160-320	950-1 700
Orotropical	120-160	450-950
Criorotropical		225-450

Table 3. Bioclimatological indexes for stations in the study region.

Description/Station	Catacocha	Catamayo	La Argelia	Zamora
Elevation (m)	1 840	1 230	2 160	970
Latitude (South)	4° 03' 07"	3° 59' 34"	4° 02' 11"	4° 05' 37"
Longitude (West)	79° 38' 29"	79° 22' 15"	79° 12' 04"	78° 57' 00"
Record length (yr)	17	16	37	28
Record period	1965-1981	1965-1980	1965-2001	1965-1992
Hottest month	October	September	November	November
Average temperature of the hottest month (°C)	18.81	24.05	16.12	22.85
Coldest month	March	July	July	July
Average temperature of the coldest month (°C)	17.52	23.58	14.76	20.45
Continental index $I_c$	1.29	0.47	1.36	2.40
Mean annual temperature $T_{mean}$ (°C)	18.23	23.79	15.71	21.80
Mean of the monthly minimum temperatures $T_{min}$ (°C)	11.06	13.86	7.44	13.24
Mean of the monthly maximum temperatures $T_{max}$ (°C)	26.06	33.33	24.68	31.85
Thermicity index $I_t$	553	710	478	669
Positive temperature index $T_p$	2 187	2 855	1 885	2 616

Table 4. Classification of stations based on bioclimatological indexes.

Index	Catacocha	Catamayo	La Argelia	Zamora
Continental index	Hyperoceanic	Hyperoceanic	Hyperoceanic	Hyperoceanic
Thermicity	Thermotropical	Thermotropical	Mesotropical	Thermotropical
Positive temperature	Mesotropical	Thermotropical	Mesotropical	Thermotropical

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