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Research Article

Palcayaco watershed management through environmental zoning in Huancavelica, Peru

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Abstract
The technical and integrated participation of the population in environmental zoning and soil and water conservation techniques and management is a sustainable alternative for watershed management. The objective of the research was to develop an environmental zoning map for the Palcayaco watershed in Huancavelica, Peru (from its socioeconomic aspects to its technical recommendations). The research work was deductive, where all the necessary data were delimited, described, inventoried, recapitulated and extracted to describe the morphometric parameters, biophysical and socioeconomic situation, environmental zoning and techniques for soil and water conservation. Results: the watershed was perennial, an average slope of 29.65%, a time of concentration of 180.6 min and a balanced hypsometric curve type (B). It also had low population density, unpaved roads, scarce basic services, and poor education and health services infrastructure. The watershed presented different ecoregions, life zones, climatic classification and altitudinal sector, current land use for agricultural, livestock and silvopastoral production, steep type, forest pasture use and protection capacity. The conflict area was in good use, and economic-ecological zoning was in protection, conservation, recovery, water, productive, and urban-industrial. The environmental zoning designed for the Palcayaco watershed preserved the most important natural resources for rural communities, improving their biophysical and socioeconomic status. Through soil and water conservation techniques and management, it will prevent the degradation of the watershed for a better and sustainable future.

Keywords: Biophysical and socioeconomic situation, Environmental zoning, Morphometric parameters, Soil and water conservation

INTRODUCTION

The watershed is the unit of analysis and planning for land management (James *et al.*, 2019; Villegas, 2014), potential natural resource use, and environmental impact assessment (Brown and Quinn, 2018; Guo *et al.*, 2021; Wu *et al.*, 2019), and sustainable management and intervention units (Wang *et al.*, 2016). The watershed has natural resource potential, but at the same time, it is argued that these resources should be preserved for future generations (Deng *et al.*, 2017; Sun *et al.*, 2020; Wang *et al.*, 2016). Watershed management has evolved through various stages of development (Le Page *et al.*, 2020; Reddy, 2019; Reddy *et al.*, 2019). It is now considered "participatory and integrated" management with the engagement of local people for economic, social and environmental development (Baliram, 2020; Reddy, 2019; Sun *et al.*, 2020).

Environmental zoning consists of analyzing the environment by identifying the biophysical and socioeconomic and even political characteristics of the territorial space (Boris and Gimenez, 2015; Boschet and Rambonilaza, 2015; Breton, 2014; Reddy, 2019). The objective of watershed zoning addresses the issues of current land use, biological resources and water (Boris and Gimenez, 2015; Boschet and Rambonilaza, 2015; Wu *et al.*, 2019). It considers the interrelation of these elements considering an integrated approach (Guo *et al.*, 2021; James *et al.*, 2019; Wang *et al.*, 2016). Environmental zoning has managed to present some controversial issues, such as the deterioration of available natural resources (Baliram, 2020; dos Santos *et al.*, 2020), the spatial distribution of the population and its anthropogenic impacts (Boris and Gimenez, 2015; Wang *et al.*, 2016; Wu *et al.*, 2019), efficient and productive activities, demographic and cultural characterization (Baliram, 2020; James *et al.*, 2019). Zoning integrates different variables in its description, for example, current use consists of the physical manipulation of the soil (Breton, 2014), land use capacity (mentioned by different government institutions) (Brown and Quinn, 2018; Deng *et al.*, 2017; Villegas, 2014), soil classification according to its optimal use, edaphological and ecological characteristics (Tiga, 2019); level of natural cover provided naturally by the soil (of non-anthropic origin) (Senisterra *et al.*, 2015; Sohoulande, 2018), soil conflict identifying by incompatible post-environmental zones (good use, underuse and overuse) and areas protected by governmental institutions (foreign or local laws) (Boschet and Rambonilaza, 2015; Deng *et al.*, 2017; Tiga, 2019).

The importance of Environmental zoning is to identify potential zones of intervention for the protection, administration, management and conservation of the environment (Baliram, 2020; dos Santos *et al.*, 2020; Wu *et al.*, 2020) without neglecting the "basic needs of the population" (Sun *et al.*, 2020). These areas are classified using criteria and experiences conducted elsewhere (in South Asian countries such as India, Nepal, and Bhutan (Reddy, 2019); Anantapur district of Andhra Pradesh in India (Baliram, 2020) and Santa Cruz Province in Argentina (Boris and Gimenez, 2015)) providing essential information for watershed management (Le Page *et al.*, 2020). Therefore, any designed environmental criteria or zones would contribute to solving territorial problems (Baliram, 2020; Reddy *et al.*, 2019; Sun *et al.*, 2020). For a watershed to function as management, it has to start from the concept of "watershed" followed by its "morphometric parameters" (Quesada and Zamorano, 2019), "hydrographic network" (James *et al.*, 2019) and the implementation of "potential areas of intervention" with the participation and integration of populations in their "socioeconomic and biophysical" situations (Deng *et al.*, 2017; Reddy *et al.*, 2019). All of these concepts are considered economic, social and environmental pillars for environmental zoning (James *et al.*, 2019; Reddy *et al.*, 2019).

According to Senisterra *et al.* (2015) and Quesada and Zamorano (2019), the most important parameters for managing the “General River, Costa Rica” watershed begin with linear forms, flow type, surface area, slope, variables calculated using formulas and the hypsometric curve. Research conducted by Deng *et al.* (2017) in the Yangtze River watershed in China, Reddy (2019) in watersheds in Afghanistan, and Senisterra *et al.* (2015) in the rural mountain range watershed of Argentina mentioned that the parameters of watersheds predict the water resources demanded by the inhabitants and their basic applications (Boschet and Rambonilaza, 2015). Zoning ensures knowledge and effective territory protection based on its natural values (Reddy *et al.*, 2019) and its suitability for use, carrying capacity and reception (Sohoulande, 2018). Wang *et al.* (2016) mentioned that there are also two important criteria for watershed management "socioeconomic and biophysical situation". For example, the highest population density is located at the mouth of the watershed (Quesada and Zamorano, 2019). This result was corroborated by Coral (2016) in the Buena Vista River Watershed, Ecuador, because its lower part is less steep and this helped with socioeconomic development. These socioeconomic aspects intervene within the watershed to organize potential territorial spaces to be intervened for better urban and rural development (Boschet and Rambonilaza, 2015; Brown and Quinn, 2018; Coral, 2016). Reddy *et al.* (2019), Sun *et al.* (2020) and Wu *et al.* (2020) stated that the biophysical states within watersheds are the environmental scenarios (such as climate, altitude, life zone, soil characteristics, etc.). A biophysical setting within the watershed helps and benefits the development, conservation and protection of many species (flora and fauna) (Sun *et al.*, 2020). In addition, these environmental settings benefit agricultural crop production (Reddy *et al.*, 2019).

Today, watershed management integrates several cartographic scenarios or layers (Baliram, 2020; Wang *et al.*, 2016). All these cartographic scenarios are geoprocessing by Geographic Information System (GIS) (Senisterra *et al.*, 2015; Tiga, 2019). Similarly, Tiga (2019) in the Aburrá Antioquia River watershed, Colombia and dos Santos *et al.* (2020) in the Socorro Vacaria River Watershed, Brazil, were able to carry out cartographic territorial planning using GIS demonstrating scenarios for natural resource management without modifying institutional and technical normative-legislative actions for the watershed (Boris and Gimenez, 2015; Castañeda, 2014). All these biophysical and socioeconomic scenarios can be easily interpreted by GIS (Baliram, 2020; Hidalgo, 2014; Wang *et al.*, 2016). Soil and water conservation techniques and management are also integrated into sustainable watershed development (Baliram, 2020; Vasconcelos and Momm, 2020). This helps to diagnose conservation areas (Baliram, 2020; Blanco and Lal, 2010). The integrated vision of the entire watershed has the advantage of working on the system and its interrelationships, projecting through soil and water management and conservation practices (Baliram, 2020; Vasconcelos and Momm, 2020). Activities such as biological, agronomic and physical or mechanical are currently involved in watershed management (Baliram, 2020; Orsag, 2010). The objective of the present study was to analyze the Palcayaco watershed starting from its morphometric parameters, hydrographic network, hypsometric curve, bio-physical and socioeconomic situation, and to design environmental zoning applying soil and water conservation management techniques.

MATERIALS AND METHODS

Description of the watershed

The Palcayaco watershed is located in the district of San Marcos de Rocchac, province of Tayacaja - Huancavelica. The geographic data of the watershed are Longitude 74°51'51.72 "W, Latitude 12°6'29.26 "S UTM coordinates: WGS 84; 18L, 514759.62mE and 8661486.15mS. The watershed has an area of 5416.28 hectares at 2811 meters above sea level. It is 245.20 km from the capital Lima-Peru and 77.25 km from the capital of Huancavelica (Fig. 1).

Data processing

The watershed was delimited with the help of a GPS WGS 84 zone 18L, importing it into ArcGis software creating the shapefile and using ArcToolbox commands to determine the morphometric parameters and hydrographic network (Mohebbi and Mohebbi, 2021). Socioeconomic data (population density, communication routes, education, basic services and medical service) were collected through a rural survey. The biophysical parameters (altitudinal sector, soils, current use, greater use capacity of soils according to the "Regulation of Land Classification by Capacity of Major Use: Supreme Decree N0 017-2009-AG" (Legal norms, 2009), life zones, slope distribution, among others) were determined using their biotic and abiotic conditions. Environmental Zoning (EZ) was carried out through the relationship, intersection and discrimination between the socioeconomic, biophysical, conflict areas and economic-ecological zoning parameters.

Environmental zoning criteria

The "Innovative Land Use Planning Techniques. A Handbook for Sustainable Development" (Williams *et al.*, 2008), as well as some additional criteria by Hall (2020), were used for Environmental zoning.

Conservation Zone (C-Z): Minimal intervention, use of goods and services: natural resources.

Water Protection Zone (WP-Z): Main rivers, secondary lakes and lagoons.

Forest Protection Zone (FP-Z): Protection of forest resources.

Strict Protection Zone (SP-Z): Ecosystems with little or no intervention.

Restoration Zone (Rs-Z): Protection zones degraded in its entirety and in conflicts.

Recovery Zone (Rc-Z): Areas of high risk and low quality for a coating.

Sustainable Use Zone (SU-Z): Areas of direct use, agricultural, human or industrial settlements.

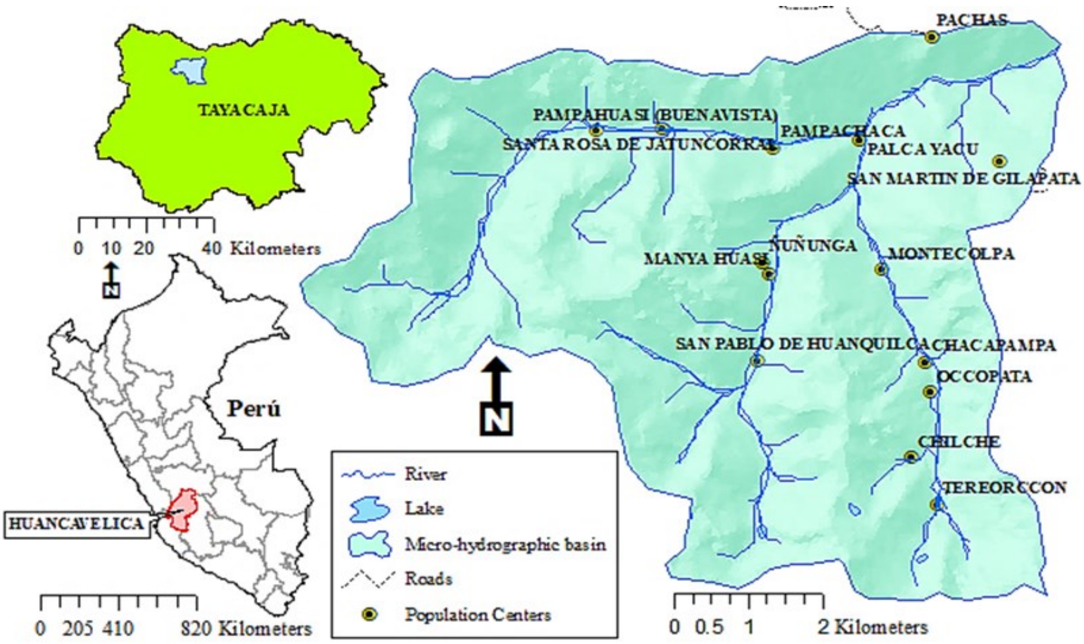

Fig. 1. *Geographical location map of the Palcayaco watershed*

Wild Zone (W-Z): areas of little intervention, of an administrative nature, but less vulnerable.
Special Use Zone (SpU-Z): Areas occupied by human settlements, natural areas for other purposes.

Soil and water management and conservation techniques

Blanco (2010) and Orsag (2010) described multiple conservation techniques and management in soil and water, natural resources and biodiversity that were applied in many case studies. These techniques were:
Mechanical and physical practices: Dead and live barriers, infiltration ditches, slope ditches, terraces and gully control.
Biological practices: Reforestation and afforestation, planting with the aid of ditches, planting with the aid of terraces, bio-traps, trellises or rhomboids.
Agronomic practices: Choice of crops according to their suitability, crop rotation, contour and furrow planting, strip-tillage, conservation tillage and minimum and zero tillage.

RESULTS

Morphometric parameters, hydrographic network and hypsometric curve

The most important parameters of the watershed were perimeter of 36.89km, stream order 4, watershed width 11.3km, perennial stream type, the total area of 5416.28 Ha, the average slope of the watershed of 29.65%, moderately flattened compactness coefficient and concentration of 180.5 min slow. The summary of the parameters and hydrographic network is shown in Table 1.
The hypsometric curve and the height frequency polygon confirmed that the watershed is of "type B", being in a state of equilibrium and maturity (Fig. 2). The frequency polygon presented the largest area in 3717 -

Table 1. Morphometric parameters and hydrographic network of the Palcayaco watershed.

Morphometric parameters and hydrographic network			
Linear	**Results**	**Units**	**Category**
Watershed width	11,3	Km	
Elevation E	512917,491	m	
Elevation N	8659221,35	m	
Z elevation or mean	3792,54	m.a.s.l.	
Perimeter	36,89	Km	
Main channel length	13,27	Km	Medium
Axial length	10,7	Km	
Middle width	5,01	Km	
Sum of total stream length	56,73	Km	
Current order	4	Unit	Half
Runoff number	100	Unit	Low
Current type	Perennial Stream		
Superficial	**Results**	**Units**	**Category**
Watershed area	5416,28	Ha	
Area between contour lines	205944,72	Km^2*m	
Unevenness	**Results**	**Units**	**Category**
Channel elevation difference	2549	m	
Average slope of the water network	2,26	%	
Average slope of the main channel	19,24	%	Moderate
Average slope of the watershed	29,65	%	Steep
Variables calculated using formulas	**Results**	**Units**	**Category**
Drainage density	1,06	Dg	Low
Current density	1,86	Kc	
Gravelius coefficient of compactness	1,39	Kg	Oval-round to oval oblong
Massivity coefficient	70	Cm	Mountainous
Elongation index	0,97	Il	Little elongated
Horton form factor – kf	0,48	Kf	Moderately flat
Compactness coefficient – kc	1,41	Kc	Oval-round to oval oblong
Concentration time	180,5	min	Slow

km: kilometers; m.a.s.l.: meters above sea level; m: meters; %: percentage; Dg: drainage density; Kc: current density; Kg: Gravelius coefficient; Cm: massivity coefficient; Il: elongation index, Ff: Horton factor, min: minutes.

Table 2. Edaphology characteristics of the Palcayaco watershed

Sh	Sd	hP	Sto	Drainage	Per	Erosion	O.M.	A. (Ha)	A. (%)
A - BC	Moderately deep	(6,6 - 7,3) - Neutral	(1) - Burdensome	(D) - Moderate	(D) - Moderate	Very light - Light	Less than 2% (Low)	644,73	11,90
A - C1 - C2 - R		(7,4 - 7,8) - Slightly alkaline					2 - 4% - (Medium)	2993,7	55,27
A - C1	Superficial	(6,0 - 6,5) - Slightly acidic	(0) - Free to Slightly burdensome	(E) - Imperfect	(C) - Moderately Slow		Greater than 4% (High)	84,19	1,55
A - C1 - C2		(6,6 - 7,3) - Neutral	(1) - Burdensome	(D) - Moderate	(D) - Moderate	Moderate - Severe	Less than 2% (Low)	106,89	1,97
A - C1 - C2	Moderately deep	(6,0 - 6,5) - Slightly acidic	(0) - Free to Slightly burdensome			Light - Moderate		1416,5	26,15
Ap - C1 - C2	Superficial	(6,6 - 7,3) - Neutral	(1) - Burdensome	(B) - Somewhat Excessive	(E) - Moderately Fast	Very light - Light	2 - 4% - (Medium)	164,05	3,03
Urban areas								1,50	0,03
Lake								4,64	0,09
Total								**5416,28**	**100**

Sh: Soil horizons; Sd: Soil depth; Sto: Stoniness (0: free to slightly stony, 1: moderately stony); Drainage and Per: Permeability (B: somewhat excessive, D: moderate; E: imperfect); O.M.: Organic Material; hP: hydrogen potential.

3890 m.a.s.l. with 867 ha. The average elevation of the area delimited by 2 contour lines and the area between two contour lines were 3792.53 m.a.s.l. and 205944.73 Km^2*m, respectively.

Socioeconomic situation

Population density

The Palcayaco watershed had 14 population centres where "Montecolpa" was one of the highest population densities while the rest were dispersed populations. The population density of the entire watershed was 0.13 inhabitants/km^2.

Communication (Communication roads)

The main access to the watershed was via a dirt road connecting Huancayo, Vilkacoto, Huari, Trancapampa, Paccha and San Marcos de Rocchac, with an approximate length of 67 km. The 14 communities had connections and the total length was 20.13 km. These roads were not paved.

Education (Educational centres: Initial, primary and secondary)

Within the watershed, 13 educational centers were identified, 5 of which were nursery schools. There were also 7 primary education centers and only one secondary school, "Juan Velazco Alvarado" in Montecolpa.

Health service and public telephone

The watershed had two health services, "Montecolpa" and "Pachas". The first one served all the inhabitants of the watershed (the type of health facility is impatient). While "Pachas" is located on the border of the capital of the district of "San Marcos de Rocchac", the health facility was non-inpatient.

Coverage of basic services and housing (Drinking water and electricity)

The constructions of the houses were made of adobe (earth, water and straw species "*Stipa ichu* (Ruiz and Pav.) Kunth") followed by stone elements with mud and in the last years, the predominant constructions were made of brick and cement. The preference for roofing materials was divided between tile, corrugated iron and thatch. In the entire watershed, there were 551 houses, where 94.56% had basic services while 5.44% did not have basic services.

Biophysical situation

Natural ecoregions and life zone

The watershed had two domains: Andean Domain - Puna Patagonian Province (Puna and High Andes) Puna Ecoregion and Amazonian Domain - Yungas Province (high jungle) High Jungle Ecoregion (Yungas). It has three life zones: "very humid tropical montane forest", "subalpine tropical pluvial paramo" and humid tropical montane forest.

Climatic classification and Altitudinal sector

The climatic classification was: Temperate climatic zone, very rainy, abundant rain in all seasons, relative humidity classified as humid (A(r)B'2H3); Semi-frigid climatic zone, rainy climate, with little rain in winter, with relative humidity classified as humid (B(i)D'H3) and Cold climatic zone, rainy, with little rain in autumn and winter, with relative humidity classified as humid (B(o, i) C'H3). These elevation levels are classified according to their altitudes: Yunga, Quechua, Suni, Puna and Janca (Fig. 3-A, H, J, C).

Soil characteristics

Table 2 shows the general characteristics of the soil (according to its horizons) within the watershed. The longest horizon was A-C1-C2-R moderately deep, (7.4 - 7.8) slightly alkaline, onerous, moderate drainage, moderate stony, light erosion, with 2 - 4% organic matter being an average area of 2993.74 Ha with 55.27%. The horizon with the smallest area was A-C1 with a slight acidity of 6 - 6.5; low porosity, imperfect drainage, moderately slow permeability, slight erosion, organic matter of 4% being high with an extension of 84.19 Ha of 1.55% (Fig. 3K).

Current land use

The current land use corresponds to the appropriate use given by the inhabitants within the watershed according to their "basic needs". For the year 2022, the current land use is shown in Table 3 and Fig. 3B. Land use was categorized as agriculture, pastures, forestry, protection, areas occupied by rural zones and bodies of water.

Major land use capacity and Slope distribution

Classifying the soil according to its capacity was very important as it indicated which surfaces were used correctly. Three different soil classes were found (P: pasture 4010.29 Ha, F: forest 437.84 Ha and X: protection 962.01 Ha) and are summarized in the table (Table 5 and Figure 3D).

The distribution of soil slope was carried out according to the Regulation of Land Classification Capacity by its Major Use Capacity "Supreme Decree No.017-2009-AG"; therefore, areas with slopes from 2% to 75% were found. Within the watershed, the soils with the steepest slope (71.17%) were found (Table 4 and Fig. 3G).

Environmental zoning analysis

Conflict Areas: The description of the land conflict within the watershed presented highly utilized soils in a sustainable manner, which were identified from Table 6 and Fig. 3F.

Analysis of the Ecological and Economic Zoning: Before carrying out potential areas of intervention, that is, sustainable environmental zoning, an analysis of the ecological and economic zoning was carried out within the Palcayaco watershed to determine if the environ-

Table 3. Current land use within of the Palcayaco watershed

Description	Category	Area Ha	Area %
Crops *Hordeum vulgare, Triticum spp, Zea mays, Vicia faba*, forage grasses, *Medicago sativa, Lolium hybridum* and *Avena sativa*	A	98,31	1,82
Crop Intervention *Hordeum vulgare, Triticum spp, Zea mays*, forage grasses, *Medicago sativa, Lolium hybridum, Avena sativa* and *Solanum tuberosum*	A	398,06	7,35
Eroded Areas with Little Vegetation (*Stipa ichu* (Ruiz and Pav.) Kunth and Other Herbs)	P	1273,48	23,51
Rocky Outcrop Predominance Areas with Sparse Vegetation (Grasses and Shrubs)	P	101,08	1,87
Vegetable Cover With Species *Buddleja incana* (Ruiz and Pav.), *Escallonia myrtilloides* (L.f.), *Escallonia resinosa* ((Ruiz and Pav.) Pers.), *Polylepis racemosa* (Ruiz and Pav.) and *Polylepis incana* (Ruiz and Pav.) associated with herbs.	P	427,17	7,89
Grasslands That Were Used for Grazing and Burning *Stipa ichu* (Ruiz and Pav.) Kunth	P	2496,64	46,1
Trees Made Up of Andean Species *Polylepis racemosa* (Ruiz and Pav.) and *Polylepis incana* (Ruiz and Pav.)	F	332,87	6,15
Exposed Rocks, No or Little Vegetation Development, High Andean Zones and Steep Slopes	X	198,34	3,64
Low Soils of the Swampy Type, Soil with Moss and Decomposed Vegetative Material	X	84,19	1,55
Urban Infrastructure and Areas with Other Use		1,5	0,03
Areas Occupied by Bodies of Water, Lagoons		4,64	0,09
Total		**5416,28**	**100**

Category A: agricultural soil, P: pasture soil, F: forest use soils, X: soils without any vegetation cover.

Table 4. Soil slope within the Palcayaco watershed

Slope Classes			
%´	**Class**	**Area Ha**	**Area %**
≤ 2	Flat or almost level	349,05	6,44
2 - 4	Slightly inclined	24,18	0,45
4 - 8	Moderately inclined	37,67	0,70
8 - 15	Strongly inclined	140,95	2,60
15 - 25	Moderately steep	819,16	15,12
25 - 50	Steep	3854,82	71,17
50 - 75	Very steep	190,46	3,52
≥ 75	Extremely steep	0	0
Total		**5416,28**	**100**

%´: Percentage of ground slope.

Table 5. Greater soil capability of use within the Palcayaco watershed

Group	Class	Subclass	Symbol	Area Ha	Area %
P	Average agrological potential in Pastures	Land suitable for pastures of medium agrological quality limited by erosion, soil and climate, associated with protection lands limited by erosion and soil.	P2esc-Xes	298,01	5,50
		Land suitable for pastures of medium agrological quality limited by soil and erosion, associated with protection lands limited by soil and erosion.	P2se-Xse	208,26	3,85
		Land suitable for pastures of medium agrological quality limited by erosion, soil, associated with protection lands limited by erosion and soil.	P2es-Xes	3480,51	64,26
		Land suitable for pastures of medium agrological quality limited by soil and erosion, associated with protection lands.	P2se-X	22,12	0,41
	Low agrological potential in Pastures	Land suitable for pastures of low agrological quality limited by soil, erosion and climate, associated with protection lands.	P3sec-X	1,39	0,03
F	Medium Forest Potential	Land suitable for forest production of medium agrological quality limited by erosion and soil, associated with protected land limited by erosion and soil.	F2es-Xes	393,66	7,27
		Land suitable for forest production of medium agrological quality limited by soil and erosion, associated with protection lands.	F2se-X	44,18	0,82
X	Protection lands and Pasture lands	Protected lands limited by erosion and soil, associated with lands suitable for pastures of medium agrological quality limited by erosion.	Xes-P2e	16,17	0,03
	Protected Lands and Forest Lands	Protected lands limited by erosion and soil, associated with lands suitable for forest production of medium agrological quality, limited by erosion and soil.	Xes-F2es	0,06	0,00
	Protection lands	Protected lands limited by erosion and soil.	Xes	945,78	17,46
Urban area				1,50	0,03
Lake				4,64	0,09
Total				**5416,28**	**100**

Characteristics of the capacity for greater use within the Palcayaco watershed; classified was made through the Regulation of Land Capacity for its Greater Use Capacity "Supreme Decree No. 017-2009-AG".

Table 6. Soil conflict within the Palcayaco watershed

Description	Code	Area Ha	Area %
Sub Use	SU	556,00	10,27
About Use	Ab-U	1340,95	24,76
Good Use	GU	3513,19	64,86
Miscellany		6,14	0,11
Total		5416,28	100

Miscellaneous areas correspond to bodies of water within the watershed

mental zoning proposal is favourable and sustainable for the populated centres. The sub-model of land use conflicts arises from the analysis of ecological and economic zoning, also taking into consideration the current use of land and the capacity for greater land use. Ecological and economic zones of protection and ecological conservation were found, which present an area, followed by an ecological and economic recovery zone, as well as ecological and economic productive zones and zones of diverse uses (Table 7 and Fig. 3I).

Environmental Zoning- Soil and water management and conservation practices: Ten environmental zoning categories were proposed within the watershed. The protection, management and conservation of soil and water will be managed in a manageable and sustainable manner. Environmental zoning was classified according to basic needs, current use, major land use, land use conflicts and other activities carried out by the population centres for their basic needs. Sustainable land use in the watershed is proposed. So each environmental zoning proposed a soil and water conservation management where each practice was carried out through the edaphological and topographical characteristics of the soil such as mechanical or physical, biological and agronomic practices (Table 8 and Fig. 3L).

DISCUSSION

Morphometric parameters and hydrographic network

The analysis of the morphometric parameters of the watershed was identified as a watershed in an equilibrium state of type (B). The concentration time was slow because the mainstream slope was not very steep and its length was medium. The largest area in relation to the altitudes was located at 3770 m.a.s.l. and the smallest concentration of area was located at 2270 m.a.s.l. In relation to the research carried out by Quesada and Zamorano, (2019) in the General River watershed, Costa Rica; the Palcayaco watershed turned out to be more homogeneous in its hydrographic parameters and characteristics. Meanwhile, the average slope of the Palcayaco watershed was 29,65 compared to the General River watershed, which maintained a range of 15-26° of inclination; this confirms that under different geographic scenarios, watersheds can have similar ranges of slope. The Palcayaco watershed presented four ef-

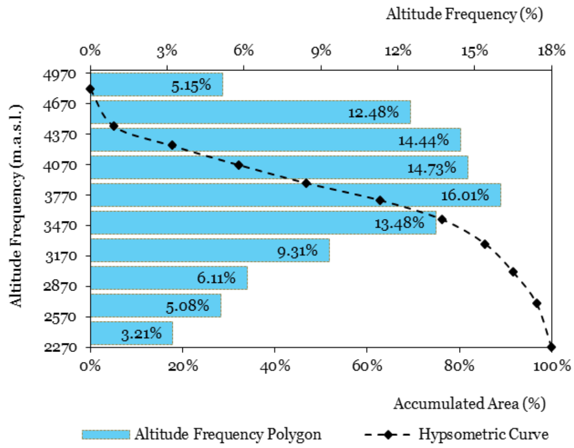

Fig. 2. *Hypsometric curve and frequency of altitudes of the Palcayaco watershed*

Table 7. Ecological economic zoning of the Palcayaco watershed

Ecological Economic Zoning (ZEE)	ZEE Subclassified	Areas Ha	Area %
Ecological Protection And Conservation Zones	Zone of Very High Bioecological Value with Hydro-energetic and Metallic Mining Potential	1042,58	19,25
Recovery Zones	Zone degraded by agriculture in protection lands with Hydroenergetic and Metallic Mining Potential	520,07	9,60
Productive Zones	Zone for Forest Production with Medium Potential	3847,49	71,04
Water System Zones	Lakes	4,64	0,09
Areas With Urban and/or Industrial Vocation	Urban Occupation Zone	1,5	0,03
Total		**5416,28**	**100**

Class and subclass of the economic and ecological zoning within the watershed.

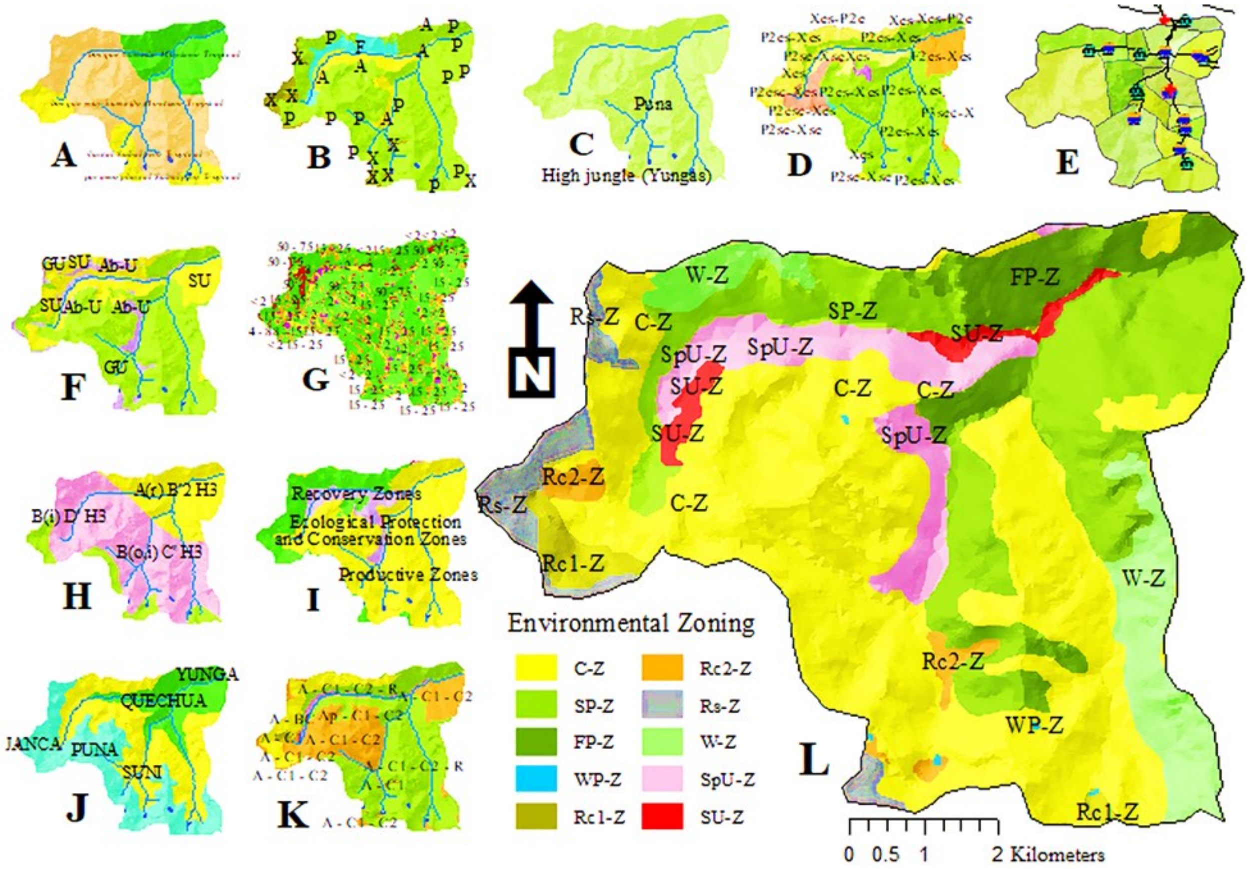

Fig. 3. *Biophysical states and environmental zoning of the Palcayaco watershed*

fluents which represent the order of the water currents, which is lower (> seven effluents) compared to the Azufral River watershed, according to research conducted by Hidalgo (2014) in Colombia. Unlike all the previous studies that did not have a vision that morphometric parameters of the watersheds are important for the management of watersheds with a prioritization approach, the present study affirms that the Palcayaco watershed presented a moderately flattened and little elongated shape and is very mountainous.

Biophysical and socioeconomic situation

Socioeconomic situation

There is a low population density in the Palcayaco watershed, which is different from the study conducted by Breton, Bernardo (2014) in the Huara commune of the First Region of Tarapacá, Chile, where the density was 0.15 inhabitants/km2 > 0.13 inhabitants/km2 in Palcayaco. It could be said that the low population density in the Palcayaco watershed was due to environmental conditions or geographical location, as Quezada and Zamora (2019) affirmed in the General River watershed, Costa Rica; or to its low economic, biophysical, social, and political development and as Boschet and Rambonilaza (2015) affirmed in the Neste River watershed in southwestern France. The only difference was that the Palcayaco watershed had only one direct road to the district capital of San Marcos de Rocchac. The road in the Palcayaco watershed was not paved, which was a problem for vehicle transportation and food trade. An important piece of information from Wang *et al.* (2016) suggests that educational institutions should study the issue of Integrated Management of Watershed through in-person or online services. This is a sad fact for the Palcayaco watershed, as it lacks the knowledge to undertake this issue and cannot benefit from educational institutions that could provide such services. In the health centres, there were only two medical institutions that were not fully equipped to attend emergency cases such as hospitalization of patients for childbirth and serious injuries. The watershed had only one public wireless telephone service, which was very important for the entire watershed since it is a fundamental good for communication-based on basic needs. On the other hand, basic services such as electricity, water and sewage were not entirely favourable.

Biophysical state

Peru is a mega-diverse country, which makes it very special in its environmental setting. Therefore, its biophysical situation differs in its totality from different countries, and this can be noticed in its results. Several investigations differentiate the natural regions of the Palcayaco basin. For example, Quesada and Zamo-

Table 8. Environmental zoning and soil and water management and conservation techniques for the Palcayaco watershed

Usage zone	Type of soil and water management and conservation	Area Ha	Area %
Sustainable Use Zone [SU-Z] Crops of *Hordeum vulgare*, *Triticum spp*, *Zea mays*, *Solanum tuberosum*, *Vicia faba*, pastos forrajeros, *Medicago sativa*, *Lolium hybridum* and *Avena sativa*.	Crop rotation, planting in contours and furrows (live hedges), strip or strip crops and minimal and zero conservation tillage.	98,32	1,82
Special Use Zone [SpU-Z] Crop intervention with urban areas such as *Hordeum vulgare*, *Triticum spp*, *Zea mays*, *Solanum tuberosum*, *Medicago sativa*, *Lolium hybridum*, *Avena sativa* and forage grasses.	Crop rotation, contour and furrow planting (living fences and windbreaks), minimal and zero tillage and slow formation terraces.	399,56	7,38
Recovery Zone-1 [Rc1-Z] Area with a predominance of rocky outcrop with little and medium vegetation (grasses and shrubs)	Live and dead barriers, slow-forming terraces, infiltration ditches, biotraps, planting aid from narrow terraces, and animal manure.	103,03	1,90
Strict Protection Zone [SP-Z] Tree area made up of native species *Polylepis racemosa* (Ruiz and Pav.), *Polylepis incana* (Ruiz and Pav.)	Infiltration, afforestation and reforestation trenches.	332,77	6,14
Forest Protection Zone [FP-Z] Eroded areas with little vegetation *Stipa ichu* (Ruiz and Pav.) Kunth, *Eucalyptus globulus* Labill., *Pinus radiata* D.Don, *Polylepis racemosa* (Ruiz and Pav.), *Prunus serotina* subsp. capuli (Cav.) McVaugh among others.	Afforestation and reforestation, planting with the help of infiltration ditches and narrow terraces.	1271,43	23,47
Wild Zone [W-Z] Plant cover with species *Escallonia myrtilloides* (Ruiz and Pav.), *Polylepis racemosa* (Ruiz and Pav.), *Polylepis incana* (Ruiz and Pav.) associated with herbs and Andean flora.	Community intervention only. Through the management and conservation technique of soils and special waters.	427,17	7,89
Conservation Zone [C-Z] Grasslands that were used for grazing and burning *Stipa ichu* (Ruiz and Pav.) Kunth.	Live and dead barriers, slow formation terraces, infiltration ditches, silvopastoral practices with animal manure.	2496,83	46,10
Recovery Zone-2 [Rc2-Z] Low-lying, swampy-type soils with moss and decomposed vegetative material.	Edge with stones, Afforestation and Reforestation.	84,19	1,55
Restoration Zone [Rs-Z] Exposed rocks with little or no vegetation development in high Andean areas and steep slopes.	Control of gullies (dikes with native species of the place), terraces of slow formation, plantation with narrow terraces, biotraps, shoulders, trellises or rhomboids plus fertilizer and animal.	198,34	3,66
Water Protection Zone [WP-Z] Areas occupied by bodies of water, lagoons and the edge of river banks.	Afforestation and reforestation with native species of the place in its surroundings.	4,64	0,09
Total		**5416,28**	**100**

Note: the table summarizes the environmental zoning of the Palcayaco watershed, with its respective soil and water management and conservation tasks

rano (2019) identified five natural regions (Mountain Zone - Talamanca Mountain Range, Alluvial Plain, Accumulative Proluvial Slope, Minor Ridges - Brunqueña Ridge, and Partially Covered Mountain Foothills - Proluvial Debris). In contrast, there were only two natural regions in the Palcayaco basin, the Andean Domain and the Amazonian Domain. The present study affirms that each basin presents different geographic scenarios with their own natural regions. It was noticed that the altitudinal levels found in the watershed were 5 (starting from the neck of the watershed to the headwaters). In the edaphological characteristics, the soil was totally different due to the fact that the geographical area has different types of soils and this difference was clarified through the "Land Classification Regulation for its Higher Use Capacity": Supreme Decree N°.017- 2009-AG". In this way, it is clarified that each country presents different characteristics of analysis and evaluation of soils according to their carrying capacity. For this reason, the different capacities that the soils presented for their use can be mentioned. Likewise, it has also been observed that each basin in the world presents different types of climates. For example, research carried out by Breton (2014) identified four types of climates (High

Steppe, Marginal High Desert, Interior Desert, and Cloudy Desert), while Castañeda (2014) identified four types of climates (warm, temperate, paramo, and cold). However, the Palcayaco basin only presented different types of climates, which sets it apart from the rest of the basins. The life zones found in the watershed were the very humid tropical montane forest, subalpine tropical rain paramo and very humid tropical montane forest, these life zones were favourable for the development of flora and fauna where the communities currently intervened in them.

Environmental zoning and its potential areas of intervention

Potential areas of intervention are said to be environmental zoning that by means of soil and water management and conservation techniques, the hydrographic watershed was managed in a sustainable way. In other words, a potential area is incomplete without the intervention of the human hand to carry out environmental zoning in a sustainable way, plus the management and conservation of soils and water. In environmental zoning we can mention the differences in the classification of zones made by different research authors. 10 environmental zones were determined for the Palcayaco watershed, each with its respective management and conservation of soils and waters. The environmental zoning was elaborated according to the basic necessities of first necessity for the populated centre's followed by the current use of the land, conflict of land and capacity of greater use of land.

Previous studies conducted zonation of watersheds to conserve ecosystem services. Coral (2016) conducted zonation for Rio Buena Vista in Ecuador, Brown Quinn (2018) located in the northern part of the state of South Carolina (USA) and Breton (2014) carried out territorial planning in the Huara Commune in the first region of Tarapacá, Chile. Boris and Gimenez (2015) focused on diagnosis, planning, and coordinated management of water resources in Santa Cruz Patagonia Austral in Argentina. Quesada and Zamorano (2019) aimed to prevent geomorphological risks in the General River in Costa Rica, while Boschet and Rambonilaza (2015) conducted zonation for urban-rural management in the Neste River watershed in the southwest of France. However, none of them ever mentioned the "*basic needs of rural or peasant communities*." This is why the Palcayaco watershed emphasized this term. People's basic needs depend on their available resources, not unaccounted benefits. This is why many investigations discarded people's basic needs before developing zoning plans.

In the sustainable use zone, it is proposed to use techniques such as crop rotation, contour planting and furrows (living fences and windbreaks), and strip crops or strips of minimal and zero conservation tillage. All of which will help to reduce erosion of the soil and the protection of those intruders that do not help to improve the production of staple foods. It is also suggested in the special use zone to practice the soil management and conservation technique through crop rotation, planting in contours and furrows (living fences and windbreaks), slow formation terraces and minimal or zero tillage. Why are there special-use zones? It is because the population migrated to areas where the slope of the soil is almost flat and that reduces the cultivation areas in areas where agricultural food production is better developed. To avoid this problem, we must take as an example the work of dos Santos *et al.* (2020) in the Socorro Vacaria river basin, Brazil, where they designed a special zoning for crops. Therefore, the Palcayaco basin should design a special zoning for agriculture and socioeconomic development for future reference. But with a new approach to control agricultural expansion "ecozoning" suggested by Wu *et al.* (2020).

In the recovery zone-1 it can be seen that it had problems of loss of soil cover, making the rocky outcrop with little and medium vegetation (grasses and shrubs), and the suggested practices is through living barriers to avoid erosion, formation terraces slow, biotraps, also planted with the help of narrow terraces and organic material that will help to improve the organic material of the soil, which is the fertilizer of farm animals, the fertilizer of the animals and without forgetting the management of silvopastoral systems will help to recover the soil of the watershed. In the strict protection zone, native species such as *Polylepis spp*, among other species, were identified. Why was strict protection zone established? It was due to natural resources and a survey carried out among the watershed's inhabitants. They suggested that the area is a native forest of the place that has been in place for many years and that is why the area does not have the intervention of the people doing the conservation of wild fauna and flora. But even that, due to the needs of the residents, they are collecting the trees for use as firewood by afforesting these areas. It has also been observed that they carry out scientific research, such as research projects related to the native forests of the Peruvian highlands, which is why it is called a strict protection zone (although that does not prevent us from proposing management and conservation practices of soils and waters such as infiltration, afforestation and reforestation zones to conserve wild flora and fauna).

In the forest protection zone, problems were identified, such as eroded areas with scarce vegetation with species of *Eucalyptus globulus* Labill., *Pinus radiata* D. Don, *Polylepis racemosa* (Ruiz and Pav.), *Prunus serotina subsp. capuli* (Cav. McVaugh), etc., among grasses and shrubs that the inhabitants require. That is why it is proposed to carry out practices such as afforestation and reforestation of endemic species followed by infiltration ditches, not so wide only to conserve a little water and avoid the hydric stress of trees, shrubs and grasses, and also narrow terraces. Wild areas were identified which contain vegetation cover with shrub species, *Escallonia myrtilloides* (Ruiz and Pav.), *Polylepis racemosa* (Ruiz and Pav.) and *Polylepis incana* (Ruiz and Pav.), associated with herbs and shrubs also with wild fauna. Wild fauna was also identified, composed of almost extinct species of the place due to the illegal hunting of animals. This area did not have the help of state programs such as conserving wild and native flora and fauna, so there is no sanction for those who extract these resources. Even this is recommended to the authorities of the watershed or populated centres that carry out some activities to conserve these natural resources, becoming a communal intervention only resorting to the competent authority and seeking help from state programs to recover the habitat of the flora and wildlife.

In the conservation area, problems were identified, such as the burning of the species *Stipa ichu* (Ruiz and Pav.) Kunth, intensive overgrazing and almost ephemeral grasslands, which is why it is suggested to carry out practices such as living and dead barriers, slow formation terraces for pastures and forages, infiltration ditches, silvopastoral practices and animal manure. In recovery zone-2, a special problem was identified -the terrain was swampy, mossy soil and the vegetative material was decomposed, making the soil very muddy. This soil was very swampy, so a conservation technique such as stone barriers, afforestation, and reforestation to its surroundings was suggested to observe if the soil achieves its stability. A restoration zone was also identified, which is composed of the problem of exposed rocks with little or no plant development in the high Andean zone of steep slopes. The most appropriate practice for this type of area is the control of gullies (dikes with native species of the place), slowly forming terraces, planting with narrow terraces, biotraps, shoulders, trellises or rhomboids and more compost from farm animals. All of this may help to restore the area and its environment. It cannot guaranteed or affirmed its complete recovery. It will only help reduce excessive soil erosion, which is why many techniques can be mentioned for its recovery, although a lot of help is needed to conserve and recover this area.

The water protection zone is composed of bodies of water, lagoons and the edge of the river banks. Here it is suggested to the population that they carry out practices such as afforestation and reforestation with species of greater erosive stability, avoiding the erosion of the edges of the riverbank and around the lakes. It should be remembered that the increasing current of the rivers could cause the overflow and flooding of urban areas and the loss of crops in the watershed, which is why great care must be taken when carrying out this practice. All these soil and water management and conservation techniques carried out in environmental zoning are not proposed in any research source, which is why here we must mention if, when proposing environmental zones for a geographical area, it is directly related to the management practice and conservation in order to provide a better quality of life for the inhabitants and the sustainable management of the watershed, and if the present study also proposes an economic and ecological zoning, it only proposes the economic needs of the inhabitants without fixing the third and most important of the area such as the conservation of native and wild natural resources of the place. Therefore, it can differentiate that each researcher proposes environmental zoning according to the problems encountered. A very important contribution to the technique of soil and water management and conservation is the research carried out by Le Page *et al.* (2020) in the Medjerda River basin in Tunisia, where they suggested creating hydrological simulation models to monitor the risks and increasing demand for available water resources in the Palcayaco basin and that of the contribution of Mengie *et al.* (2019) in the Gumara basin, in the Upper Blue Nile of Ethiopia, where they suggested implementing soil and water conservation techniques. Therefore, previous experiences carried out in different parts of the world gave their point of view on the sustainable importance that watersheds provide to the population. Hence, this research carried out in the Palcayaco watershed will be a source of inspiration for further studies throughout Peru and the worldwide.

Conclusion

The Palcayaco watershed was of type (B: Evenly balanced and mature), being in a state of equilibrium and maturity stage, perennial stream type and the water system's concentration time was 180.6 min without water shortage. The socioeconomic situation (roads, medical centre, education, basic services, population density) was favourable for the development of the population centres. The biophysical situation proved to be very productive for the current land use and wildlife protection. Environmental zoning, soil and water conservation, and management practices efficiently and effectively improved the inhabitants' quality of life, making the watershed manageable and sustainable. It is recommended to create small dams in the western part of the watershed to protect water resources and reduce the loss of water that animals refresh their thirst after grazing. The population centre is proposed to hold basic information meetings to raise awareness on soil and water management and conservation issues to protect environmental zoning. Encouraging tourism and scientific research in strictly protected zones and wilderness areas is recommended, which would support the State and the authorities better to protect native species such as flora and fauna. It is recommended to plant timber species to avoid the constant loss of the strict conservation area of *Polylepis spp*. Forests and the watershed's inhabitants constantly follow up on the proposed environmental zoning to improve all the activities within their primary needs and thus achieve the sustainable management projected in this research.

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Conflict of interest

The authors declare that they have no conflict of interest.

REFERENCES

1. Baliram, C. (2020). Sustainable Watershed Development. A Case Study of Semi-arid Region in Maharashtra State of India. In *SpringerBriefs in Water Science and Technology* (Springer N). Springer. https://doi.org/10.1007/978-3-030-47244-3
2. Blanco, H. & Lal, R. (2010). Principles of soil conservation and management. In Springer (Ed.), *Springer Science* (Springer). Springer. https://doi.org/10.1007/978-1-4020-8709-7
3. Boris, D. & Gimenez, M. (2015). Zonificación y codificación hidrográfica en Santa Cruz (Patagonia Austral, Argentina). *CONAGUA (XXV National Water Congress) 2015*, *25* (19 de Junio), 1-14.
4. Boschet, C., & Rambonilaza, T. (2015). Integrating water resource management and land-use planning at the rural-urban interface: Insights from a political economy approach. *Water Resources and Economics*, *9*, 45–59. https://doi.org/10.1016/j.wre.2014.11.005
5. Breton, B. (2014). Propuesta de zonificación para la comuna de Huara-Primera Región. *Líder: Revista Labor Interdisciplinaria de Desarrollo Regional*, *24*(24), 63–93.
6. Brown, M. G., & Quinn, J. E. (2018). Zoning does not improve the availability of ecosystem services in urban watersheds. A case study from Upstate South Carolina, USA. *Ecosystem Services*, *34*, 254–265. https://doi.org/10.1016/j.ecoser.2018.04.009
7. Castañeda, P. (2014). Zonificación climatológica según el modelo Caldas – Lang de la cuenca Rio Negro mediante el uso del sistema de información geográfica SIG. *Militar University of New Granada*, 1–21.
8. Coral, A. (2016). Zonificación en cuencas hidrográficas para la implementación de políticas de incentivos a la conservación y restauración de ecosistemas. Caso Cuenca Hidrográfica del Río Buena Vista, Ecuador. *Entorno Geográfico*, *12*, 50–68. https://doi.org/10.25100/eg.v0i12.3544
9. Deng, F., Lin, T., Zhao, Y., & Yuan, Y. (2017). Zoning and analysis of control units for water pollution control in the Yangtze River Basin, China. *Sustainability (Switzerland)*, *9*(8), 1–14. https://doi.org/10.3390/su9081374
10. dos Santos, G. M., Cemin, G., Bortolin, T. A., & Schneider, V. E. (2020). Edaphoclimatic zoning: Methodology and application to apple cultivation in a Brazilian watershed. *Revista Brasileira de Cartografia*, *72*(2), 190–200. https://doi.org/10.14393/rbcv72n2-48890
11. Guo, X., Tankpa, V., Wang, L., Ma, F., & Wang, Y. (2021). Framework of multi-level regionalization schemes based on non-point source pollution to advance the environmental management of small watersheds. *Environmental Science and Pollution Research*, *28*(24), 1–16. https://doi.org/10.1007/s11356-020-12000-7
12. Hall, J. (2020). The Planning Board in New Hampshire. A Handbook for Local Officials. In OSI (Ed.), *NH Office of Strategic Initiatives* (Concord, N, Vol. 1, Issue March). NH Office of Strategic Initiatives.
13. Hidalgo, H. (2014). Zonificación de susceptibilidad por fenómenos de remoción en masa mediante geoprocesamiento con herramientas SIG en la cuenca del Río Azufral. *Militar University of New Granada*, *8 de Julio*, 1–22.
14. James, A. J., Batchelor, J., Bassi, N., & Milne, G. (2019). Catchment assessment and planning for improving effectiveness of watershed development interventions: A case study from South Gujarat. *From Catchment Management to Managing River Basins*, *1*, 103–147. https://doi.org/10.1016/b978-0-12-814851-8.00005-7
15. Le Page, M., Fakir, Y., & Aouissi, J. (2020). Modeling for integrated water resources management in the Mediterranean region. *Water Resources in the Mediterranean Region*, 157–190. https://doi.org/10.1016/b978-0-12-818086-0.00007-8
16. Legal norms. (2009). Reglamento de Clasificación de Tierras por Capacidad de Uso Mayor: Decreto Supremo N°.017-2009-AG. In El peruano (pp. 401820–401837). El peruano. https://www.serfor.gob.pe/pdf/normatividad/2009/decresup/DS NÂ° 017-2009-AG (Reglamento de Clasif de Tierras).
17. Mengie, B., Teshome, Y., & Dereje, T. (2019). Effects of soil and water conservation practices on soil physico-chemical properties in Gumara watershed , Upper Blue Nile Basin, Ethiopia. *Ecological Processes*, *8*(36), 1–14. https://doi.org/10.1186/s13717-019-0188-2
18. Mohebbi, A., & Mohebbi, G. (2021). Investigation and zoning of geo-environmental risk around the western edge of Khareshk village's oil transmission line, Iran. *Earth Science Informatics*, *14*(3), 1367–1381. https://doi.org/10.1007/s12145-021-00645-y
19. Orsag, V. (2010). The soil resource Principles for its management and conservation. In Fobomade (Ed.), *Bolivian Forum on Environment and Development (Fobomade)* (Fobomade). Heifer Internacional Bolivia.
20. Quesada, A., & Zamorano, J. (2019). Zonificación de procesos de ladera e inundaciones a partir de un análisis morfométrico en la cuenca alta del río General, Costa Rica. *Investigaciones Geograficas*, *99*, 2448–7279.

https://doi.org/10.14350/rig.59843

21. Reddy, V. R. (2019). Watershed management in Afghanistan: Lessons from South Asia. *From Catchment Management to Managing River Basins*, *1*, 55–85. https://doi.org/10.1016/b978-0-12-814851-8.00003-3
22. Reddy, V. R., Syme, G. J., & Tallapragada, C. (2019). Module I: Key features of sustainable watersheds. *Integrated Approaches to Sustainable Watershed Management in Xeric Environments*, 7–18. https://doi.org/10.1016/b978-0-12-815275-1.00002-4
23. Senisterra, G. E., Gaspari, F. J., & Delgado, M. I. (2015). Zonificación de la vulnerabilidad ambiental en una cuenca serrana rural, Argentina. *Revista Estudios Ambientales*, *3* (1), 38–58.
24. Sohoulande, D. (2018). Toward an integrated watershed zoning framework based on the spatio-temporal variability of land-cover and climate: Application in the Volta river basin. *Environmental Development*, *28*, 55–66. https://doi.org/10.1016/j.envdev.2018.09.006
25. Sun, Y., Hao, R., Qiao, J., & Xue, H. (2020). Function zoning and spatial management of small watersheds based on ecosystem disservice bundles. *Journal of Cleaner Production*, *255*, 1–10. https://doi.org/10.1016/j.jclepro.2020.120285
26. Tiga, R. (2019). Determinación de la zonificación ambiental y la implementación de sistemas de información geográfica –SIG según guía técnica para la formulación de los planes de ordenación y manejo de cuencas hidrográficas (POMCAS). Estudio de caso: cuenca hidrográfica d. *Militar University of New Granada*, *15*, 1–22.
27. Vasconcelos, V., & Momm, S. (2020). Rapid Environmental Planning Methodology: Developing Strategies for the Planners' Education. *Journal of Education for Sustainable Development*, *14*(2), 271–296. https://doi.org/10.1177/0973408220980853
28. Villegas, E. (2014). Las unidades de planificación y gestión territorial como directriz para la zonificación urbana. *Agora U.S.B.*, *14*(2), 551–581. https://doi.org/10.21500/16578031.67
29. Wang, G., Mang, S., Cai, H., Liu, S., Zhang, Z., Wang, L., & Innes, J. L. (2016). Integrated watershed management: evolution, development and emerging trends. *Journal of Forestry Research*, *27*(5), 967–994. https://doi.org/10.1007/s11676-016-0293-3
30. Williams, E., McMillan, B., Russell, C., Gruttemeyer, P., & Miller, T. (2008). Innovative Land Use Planning Techniques. A Handbook For Sustainable Development. In EPA (Ed.), *N.H. Department of Environmental Services* (U.S. Envir, Vol. 1, Issue October). U.S. Environmental Protection Agency.
31. Wu, S., Yin, P., Wang, M., Zhou, L., & Geng, R. (2020). A new watershed eco-zoning scheme for evaluate agricultural nonpoint source pollution at national scale. *Journal of Cleaner Production*, *273*, 1–10. https://doi.org/10.1016/j.jclepro.2020.123033
32. Wu, W., Gao, P., Xu, Q., Zheng, T., Zhang, J., Wang, J., Liu, N., Bi, J., Zhou, Y., & Jiang, H. (2019). How to allocate discharge permits more fairly in China?-A new perspective from watershed and regional allocation comparison on socio-natural equality. *Science of the Total Environment*, *684*, 390–401. https://doi.org/10.1016/j.scitotenv.2019.05.104