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IDENTIFICATION OF WATER RECHARGE ZONES AND THEIR RELATIONSHIP WITH LAND USE CHANGE IN THE REJO RIVER BASIN CAJAMARCA - PERU

Walter Ricardo Roncal Briones[1]*, José Arturo Bringas Sánchez[2], José Alejandro Romero Rojas[1], Segundo Sánchez Tello[2], Mariela Núñez Figueroa[3], Mario Ruiz Ramos[2]

[1]Universidad Nacional de Cajamarca, Perú
[2]Universidad Nacional de Jaén, Perú
[3]Universidad Nacional Autónoma de Chota, Perú

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Corresponding Author: Walter Ricardo Roncal Briones (wroncal@unc.edu.p)

ABSTRACT

This research work was carried out with the general objective of identifying water recharge zones and their relationship with land use change in the Rejo river basin (2011 and 2020), located near the city of Cajamarca. The methodology for the classification of land uses proposed by the Ministry of the Environment (2015), CORINE (Coordination of information of the Environment) Land Cover adapted for Peru; for the identification of water recharge zones, it was based on the equation proposed by Matus (2009) and for the relationship between the variables, a spatial analysis was carried out to visualize and analyze the distribution of the recharge zones in relation to changes in land use. The results indicate that the variation in the water recharge zones in the Rejo river basin has been "Moderate" in the years (2011 and 2020), the basin has not presented significant variation in its water recharge capacity because the land use has not presented a great variation either, likewise, it is influenced by management practices; however, it was also identified that areas with "very low" recharge have increased (12.75 ha) and areas with "high" recharge have decreased (-251.87 ha), suggesting a possible influence of different land uses and management practices on the water recharge of the basin. It is concluded that water recharge zones have a direct relationship with land use change, however, there is an inverse relationship with the land use of mining extraction areas, which decrease water recharge.

KEYWORDS: Watershed, Water Recharge Zones, Land Uses, Spatial Analysis.

1. INTRODUCTION

The distribution and management of water in our country is very irregular, often irrational use, pollution or unsustainable management has caused water supply problems in many places. The lack of knowledge and awareness of the functioning of the water regime and the misuse of water resources disturb the country's communities and threaten their development; affecting water sources, reducing their flow and polluting rivers, lakes and other natural sources of water.

Similarly, the excessive exploitation of forests and pastures seriously threatens ecosystem functions, since vegetation with its roots promotes infiltration and retention, replenishing groundwater essential for water supply; Likewise, through the process of transpiration, the vegetation cover produces a large amount of water vapor that is then condensed and subsequently discharged as precipitation, causing erosion and transport of soil particles and sediments that will be dragged by surface runoff, aggravating the problem of pollution and sedimentation of the riverbed. which causes a decrease in its capacity to conduct high volumes of runoff that can cause overflows and floods.

As for water recharge zones, these are areas with the capacity to naturally infiltrate water from precipitation or surface runoff, and with this, they allow feeding aquifers where underground flows move horizontally towards different bodies of water such as lakes, rivers, springs and oceans (INAB, 2005).

It should be noted that aquifer recharge is a complex phenomenon, with numerous ramifications and interconnections in terms of processes and relationships with other phases of the hydrological cycle; in order to reach practical results, at the appropriate temporal and spatial scale for each case, these processes must be considered in a simplified and aggregated way, but as far as possible with a clear physical support (Custodio, 2019).

It is important to make it clear that the delimitation of Potential Groundwater Recharge Zones (GWPZ) is influenced by multiple factors such as precipitation, lithology, soil texture, slope, elevation, distribution of the water table, drainage systems, among others (Magesh et al., 2011; Magesh et al., 2012; Thapa et al., 2017; Narayanan & Venugopal, 2021).

For the development of the research, the specific objectives were to evaluate the change in land use in the Rejo river basin in a period of 20 years and to determine the water recharge zones in the Rejo – Cajamarca river basin, with this, it seeks to obtain key information that allows understanding the functioning and dynamics of the water recharge zones and the effects of land use change on it process.

The Rejo River basin faces multiple challenges that hinder effective management of water resources, encountering difficulties such as; overgrazing with cattle and cattle with extensive livestock practice, which causes soil compaction and erosion, the change of land use from natural pastures to intensive agriculture, drainage and drying of wetlands to expand cultivation area, afforestation with exotic species and forest fires in grassland areas due to inadequate practices of the local population. These challenges negatively affect the management of water resources in the basin.

It is important to note that mining activity has been taking place for years in the upper part of this basin, which further aggravates the situation by modifying the territory and the natural movement of groundwater.

In this sense, it is relevant to investigate and characterize the water recharge areas in this basin in order to adequately protect them and manage resources in a sustainable way, seeking to safeguard the integrity of the Rejo river basin and guarantee a safe and sustainable water supply for the communities and the surrounding ecosystem.

In this context and in order to promote adequate management of the basin, the following research questions are formulated:

Main question.

What are the water recharge zones and their relationship with land use change in the Rejo Cajamarca river basin?

Secondary question.

What is the percentage of land use change during 2011 and 2020 in the Rejo River basin?

What are the water recharge areas in the Rejo River basin?

Research Hypothesis: There is a direct relationship between water recharge zones and land use change in the Rejo River basin – Cajamarca

2. MATERIALS AND METHODS

Location of the basin

The study was carried out in the hydrographic basin of the Rejo River, which has an approximate area of 22,747.0 hectares. Geographically, the area is located in the UTM boundaries 749323.7 E – 9222688.3 N, 766720.1E – 9237405.7 N, 775914.6E – 9228178.4 N and 755948.9 E – 9216318.4 N. The altitudinal limits vary from 2,632 to 3,800 meters above sea level (National Water Authority, 2015)

Politically, the Rejo River basin is located in the provinces of San Pablo and Cajamarca, both belonging to the department of Cajamarca, located in the northern part of Peru.

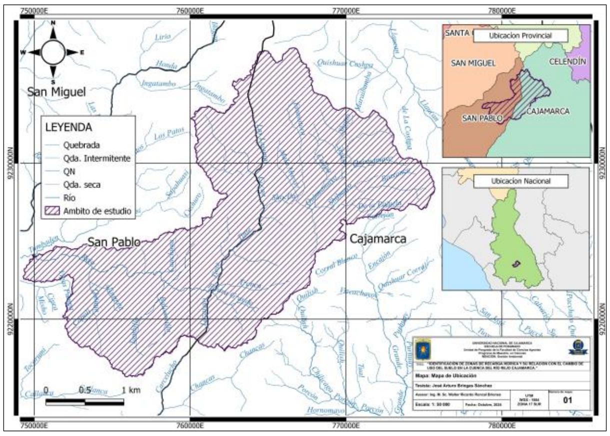

Figure 01. Location of the Rejo River Basin.

Methodology

For data collection, the analysis and recording of soil types of the hydrographic basin was used as techniques, having as its main instrument the measurement of texture, in addition geological maps, slopes, and vegetation cover were analyzed.

For the identification of the land cover for the years 2011 and 2020, information was collected from the USGS (United States Geological Survey) website http://earthexplorer.usgs.gov/. From where the Lansat satellite images were downloaded and the land cover and land use were classified using the methodology proposed by the Ministry of the Environment (2015), CORINE (Coordination of information of the Environment) Land Cover adapted for Peru (MINAM, 2014), For the identification of water recharge zones, the study was based on the equation proposed by Matus (2009) adapting it in some nominal aspects to the use of our region:

ZR = 0.27 (Slope) + 0.23 (Texture) + 0.12 (Geology) + 0.25 (Soil Type) + 0.13 (Land Use)

Where: ZR = recharge potential. (0.27, 0.23, 0.12, 0.25, 0.13, represent the relative importance of each of the variables)

3. RESULTS AND DISCUSSION

Land use change in the Rejo river basin.

Land use was identified for the year 2011 and 2020 and land cover and land use were classified, finding 7 types of cover using the methodology described above.

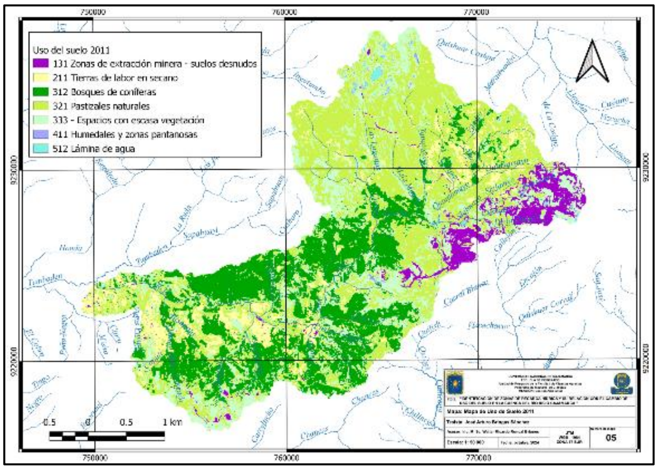

Figure 02. Land use of the Rejo River basin for the year 2011.

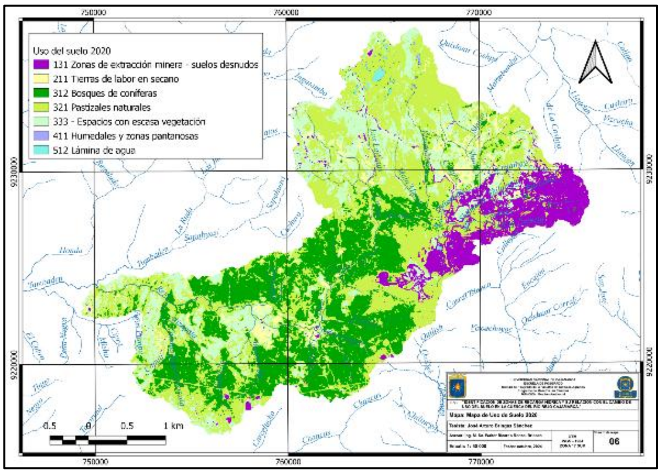

Figure 03. Land use of the Rejo River basin for the year 2020.

The results shown in figures 2 and 3 allowed the analysis corresponding to the variations in the dynamics of land use with respect to the periods studied. Based on the classifications and categorizations generated for each time period (2011 and 2020), significant changes during the periods considered for this research were evaluated.

Table 01. Land use change zones in the periods 2011 and 2020.

CODE	DESCRIPTION	2011		2020		Area Difference (ha)	D (%)
		ha	%	has	%		
131	Mining and hydrocarbon extraction areas	1,112.38	4.93	2,145.76	9.51	1,033.38	92.9
211	Transient Crops	1,793.65	7.95	977.95	4.33	-815.7	-45.48
321	Forest plantation	5,727.12	25.38	6,044.76	26.79	317.64	5.55
331	Herbazal	8,526.33	37.79	9,108.52	40.37	582.19	6.83
333	Secondary vegetation or transition	5,222.85	23.15	4,169.77	18.48	-1,053.08	-20.16

411	Swampy areas	103.48	0.46	51.65	0.23	-51.83	-50.09
512	Natural lagoons, lakes and swamps	79.28	0.35	66.68	0.30	-12.6	-15.89
	Total	**22,565.09**	100.	**22,565.09**	100	**-**	**-**

Table 1 shows the following areas of land use changes in 2011 and 2020:

Mining and Hydrocarbons Areas

This area experienced a significant increase in its use, going from 1,112.38 hectares in 2011 to 2,145.76 hectares in 2020, which represents an increase of 92.90% in the affected area. This increase is due to the expansion of Minera Yanacocha's extractive activity, which is located in the upper part of the basin, which is described in the First Technical Report Supporting the II Modification of the Yanacocha Environmental Impact Study (Fajardo and Torres, 2022).

Transient Crops

This area experienced a significant decrease, going from 1,793.65 hectares in 2011 to 977.95 hectares in 2020, which represents a decline of 45.48% in the affected area. This decline is related to the decrease in agricultural production in the region and changes in agricultural practices, According to INEI data, the agricultural sector in Cajamarca contracted 3.6% during 2020, while agriculture at the national level registered a positive growth of 0.8%. Although the region's agricultural production managed to recover in 2021, growing 2.2% compared to 2019, the impact of the pandemic may have affected the cultivated area in the following years. The main crops identified in the study area are barley and wheat, which occupy the rainfed slopes with one harvest per year; Corn and potatoes occupy the best soils, usually under irrigation.

There are hectares that are not worked, mainly because of limited access to water, which is not necessarily due to a reduced water supply, but possibly to poor management of water resources. This cause is reflected in the use of agricultural land, whether rainfed or irrigated. While rainfed agriculture depends on rainfall, being very vulnerable to weather changes (limiting agricultural activity), irrigated agriculture has a secure water supply and is also more productive (World Bank, 2020).

Forest Plantation

The "Forest Plantation" area experienced a moderate increase, going from 5,727.12 hectares in 2011 to 6,044.76 hectares in 2020. This represents an increase of 5.55% in the affected area, these increases are related to the forestry activity promoted by the Regional Government with the project "REFORESTATION IN THE HIGH ANDEAN AREAS OF THE PROVINCES OF SAN PABLO AND SAN MIGUEL, CAJAMARCA", (SNIP Code: 156230). The proposed goal for this project is the planting of 1,650,000 seedlings (pine and alder) in 1,500 hectares, which implies an investment amount of 3,984,254.65 nuevos soles. (Cajamarca Regional Government, 2013)

Herbazal

This area experienced an even more significant increase, going from 8,526.33 hectares in 2011 to 9,108.52 hectares in 2020. This represents a 6.83% increase in the affected area. The increase in the area of grassland is mainly due to the expansion of livestock activity, the abandonment of farmland, the degradation of natural ecosystems and possible changes in soil management practices in the region, in the study areas the main herbaceous species identified is the ichu (*Stipa ichu*).

The department of Cajamarca is characterized by having an important livestock activity, mainly cattle and sheep. According to data from the Ministry of Agriculture and Irrigation (MINAGRI), the livestock population in Cajamarca has increased in recent years, which has led to a greater demand for natural pastures and grazing land (MINAGRI, 2022).

Secondary or Transitional Vegetation

The "Secondary Vegetation or Transition" area experienced a significant decrease, going from 5,222.85 hectares in 2011 to 4,169.77 hectares in 2020. This represents a 20.16% decline in the affected area. The decline in secondary vegetation or transition is mainly due to the expansion of mining activity, the conversion of wetlands to other land uses by anthropic activities and possibly the interruption of natural regeneration processes.

Between 2001 and 2021, Peru has experienced the loss of 5.4 million hectares of its natural vegetation, according to data from MapBiomas Peru; In 2021, 3 million hectares of secondary vegetation were counted. The most affected biomes were the Amazon and the Andes, which accounted for 53% and 42% of the total loss, respectively (Instituto del Bien Común, 2024).

Swampy Areas

This area experienced the most significant decrease, going from 103.48 hectares in 2011 to 51.65 hectares in 2020, representing a 50.09% decrease in this area, the loss of the surface of swampy areas in the basin is mainly due to the expansion of mining activity, changes in land use, drainage and drying of wetlands due to anthropic activities such as agriculture and livestock as well as the impacts of climate change and the lack of adequate conservation policies in the region.

Natural Lagoons, Lakes and Swamps

The area of "Natural Lagoons, Lakes and Swamps" experienced a moderate decline, going from 79.28 hectares in 2011 to 66.68 hectares in 2020. This represents a decline of 15.89% in the affected area, the decline in the surface of lagoons, lakes and natural swamps in the basin is mainly due to the expansion of mining and hydrocarbon activity, changes in land use and possible variations in hydrological regimes, as well as pollution and sedimentation processes that could be affecting these aquatic ecosystems.

The decrease in the area of transitional crops and the decrease in the area of secondary vegetation or transition are the result of the expansion of mining activity, and according to the authors Nutini et. al (2013), the expansion of mining extraction; It may possibly be a major cause of the decrease in the area of secondary vegetation or transition.

Authors Biazin and Sterk (2013) comment that vulnerability to drought can drive changes in land use and cover. In addition, authors Findell et. al (2017) point out that change in land use and cover can have a significant impact on regional climate extremes.

The decrease in the area of swampy areas and lagoons, lakes and natural marshes is the result of urban, agricultural and grazing expansion, as well as forest fires and the expansion of mining. These activities involve the alteration or destruction of aquatic ecosystems and the conversion of natural areas into urban areas (Mercado-García et al., 2023)

It is difficult to predict whether these trends will continue in the future, as they depend on many factors, including changes in government policies and economic conditions. However, it is important to monitor land cover and trends of change to better understand the environmental and social impacts of human activity in the Cajamarca region.

Identification of water recharge areas in the Rejo river basin.

For the identification of water recharge areas, the study was based on the equation proposed by Matus (2009), adapting it to our region, the main factors (Slope, Texture, Geology, soil type, Land Use) elements that intervene in water recharge were weighted according to the equation:

Weighting of the factors involved in water recharge

a) Pending

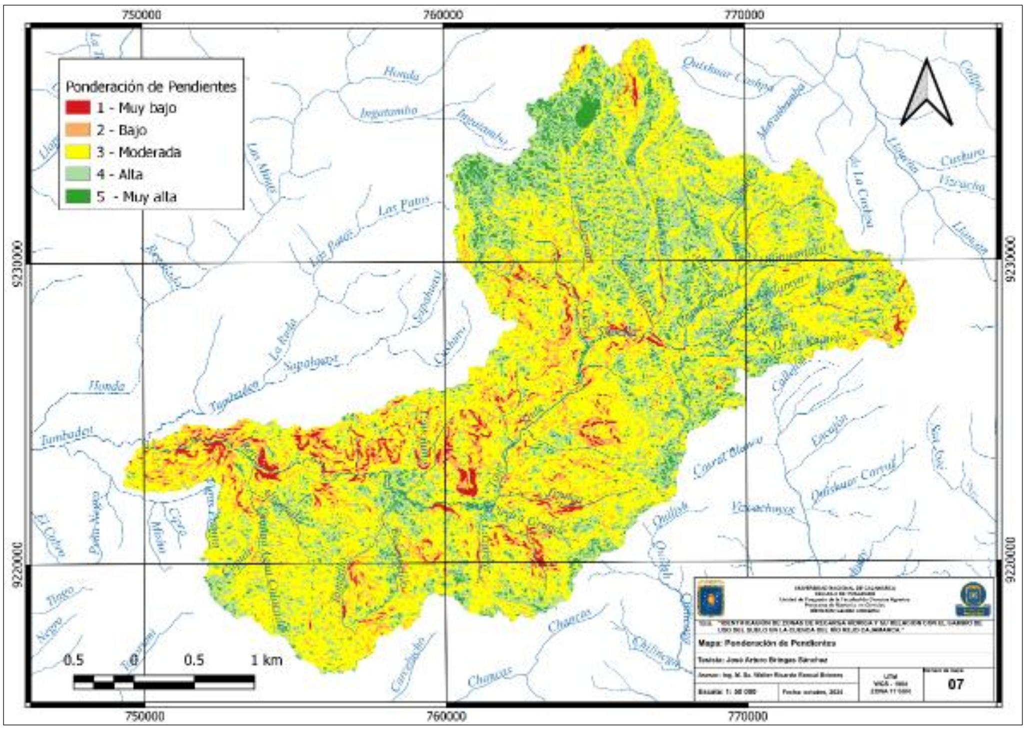

Figure 04. Weighting of slopes in the Rejo river basin

Table 02. Weighting of slopes in the Rejo river basin.

Pending Identified (%)	Weighting	Area (ha)	%
Greater than 65%	5 (Very High)	617.37	2.74
45 – 65	4 (High)	1,992.38	8.83
15 – 45	3 (Moderate)	12,695.45	56.26
6 – 15	2 (Low)	5,761.98	25.53
0 – 6	1 (Very low)	1,497.91	6.64
	Total	**22,565.09**	**100**

b) Texture

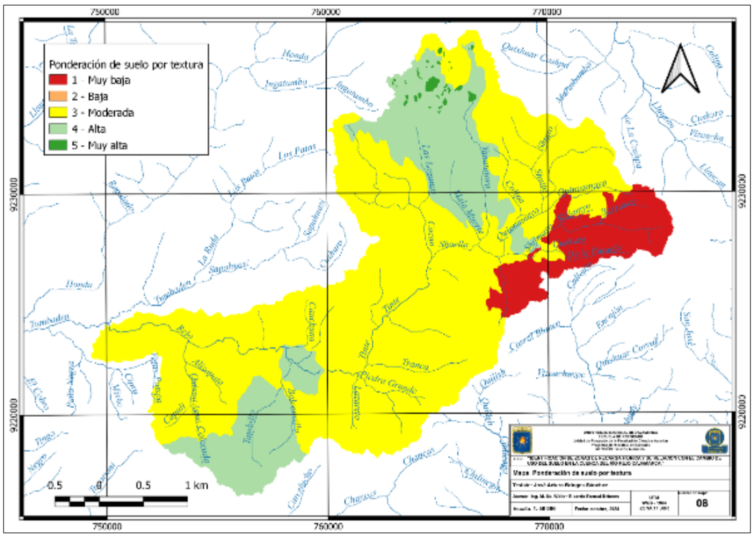

Figure 05. Soil weighting by texture in the Rejo river basin

Table 03. Soil weighting by texture in the Rejo river basin

.Texture Identified	Weighting	Area (ha)	%
Sheets of water bodies	5 (Very High)	97.84	0.43
Moderate Thick	4 (High)	4,745.01	21.03
Sandy loam	3 (Moderate)	15,786.92	69.96
-	2 (Low)	0.00	0.00
Mining areas	1 (Very low)	1,935.32	8.58
	Total	**22565.09**	**100**

* No texture was identified for weighting 2 (low)

c) Geology

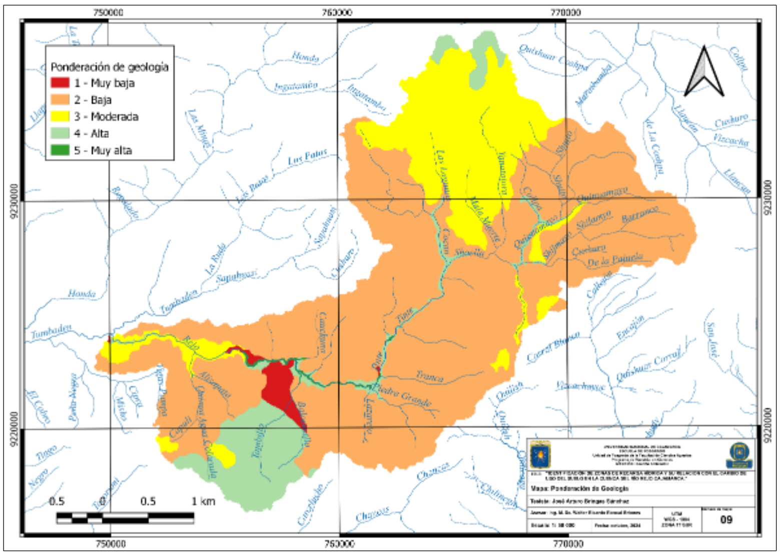

Figure 06. Geology weighting in the Rejo river basin

Table 04. Weighting of geology in the Rejo river basin.

Geology identified	Weighting	Area (ha)	%
Grava, arena, silt	5 (Very High)	79.12	0.35
Sand, siltQuartz sandstone, siltSiltClayclay, sandstone	4 (High)	2,182.39	9.67
Andesite, block, ash, ash tuff Block, gravel, sand gravel, block Andesitic porphyry Volcanoclastic, ash tuff	3 (Moderate)	4,492.15	19.91
AndesiteBlockBlock, ashDaciteAsh tuff, block, ashVitreous tuba, block, ash Unit Yanacocha volcanic center Hydrothermal alteration	2 (Low)	15,480.01	68.60
Limestone, shale	1 (Very low)	331.42	1.47
	Total	**22,565.09**	**100**

d) Soil Type

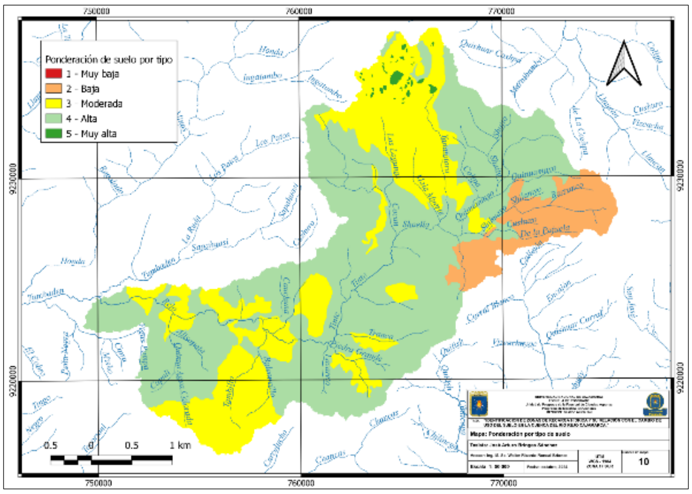

Figure 07. Weighting by soil type in the Rejo river basin

Table 05. Weighting by soil type in the Rejo river basin.

Soil type identified	Weighting	Area (ha)	%
(Sheets bodies of water)	5 (Very High)	97.20	0.43
Andosol/C, Andosol/D, Andosol/A, Andosol/F, Paramo Andosol/C, Paramo Andosol/D, Paramo Andosol/A	4 (High)	13,793.92	61.13
Leptosol/B, Leptosol/C, Leptosol/D, Leptosol/E, Leptosol/F, Regosol/B, Regosol/C, Regosol/D,Regosol/E	3 (Moderate)	6,739.01	29.86
Miscellaneous mine/A, Miscellaneous mine/B, Miscellaneous mine/C, Miscellaneous mine/D, Miscellaneous mine/E	2 (Low)	1,934.96	8.58
	1 (Very low)	0.00	0.00
	Total	**22,565.09**	**100.00**

* No soil type was identified for weighting 1 (Very low)

e) Land Use 2011

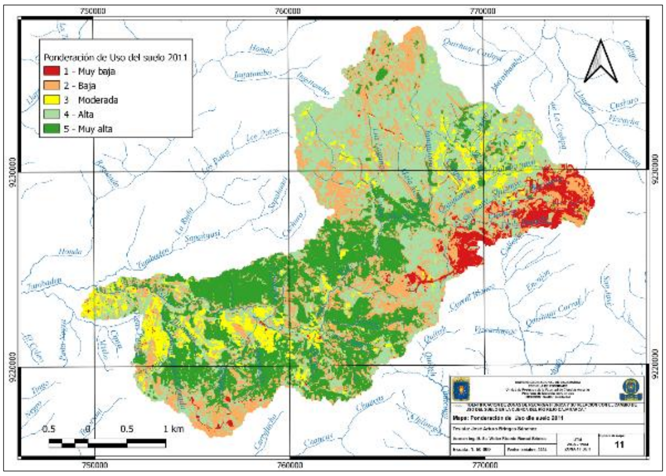

Figure 08. 2011 Land Cover Weighting of the Rejo River Basin

Table 06. Weighting of land cover for the year 2011 of the Rejo river basin.

Identified land use	Weighting	Area (ha)	%
Sheets (bodies) of water; wetlands and wetlands; coniferous forests	5 (Very High)	5,899.28	26.14
Grasslands	4 (High)	8,542.94	37.86
Rainfed farmland	3 (Moderate)	1,791.64	7.94
Spaces with sparse vegetation	2 (Low)	5,226.23	23.16
Mining areas – bare soils	1 (Very low)	1,105.00	4.90
	Total	**22565.09**	**100.00**

f) Land Use 2020

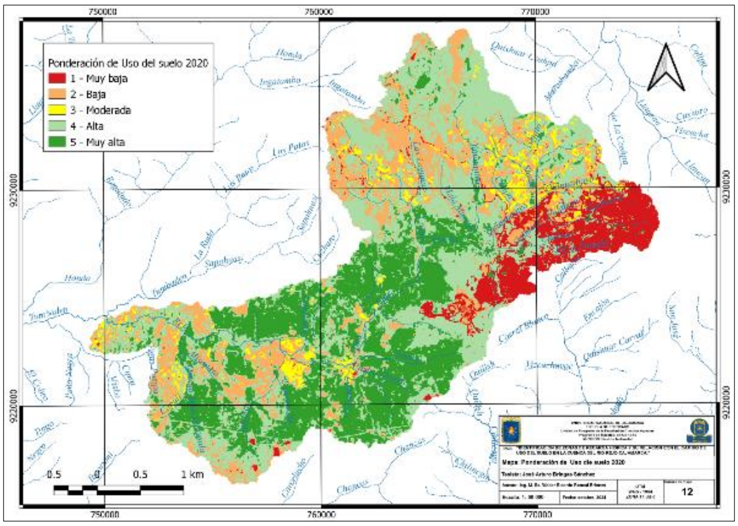

Figure 09. Weighting of land cover for the year 2020 of the Rejo river basin

Table 07. 2020 land cover weighting of the Rejo river basin.

Identified land use	Weighting	Area (Ha)	%
- Sheets (bodies) of water; wetlands and wetlands; coniferous forests	5 (Very High)	6,152.36	27.26
- Grasslands	4 (High)	9,117.72	40.41
- Rainfed farmland	3 (Moderate)	969.81	4.30
- Spaces with sparse vegetation	2 (Low)	4,177.98	18.52
- Mining areas – bare soils	1 (Very low)	2,147.22	9.52
Total		**22565.09**	**100.00**

Water recharge areas in the Rejo river basin

As a result of the application of the equation proposed by Matus (2008), the following results are obtained where the following factors were used: Slope, Texture, Geology, soil type and Land Use.

a) Water recharge for 2011.

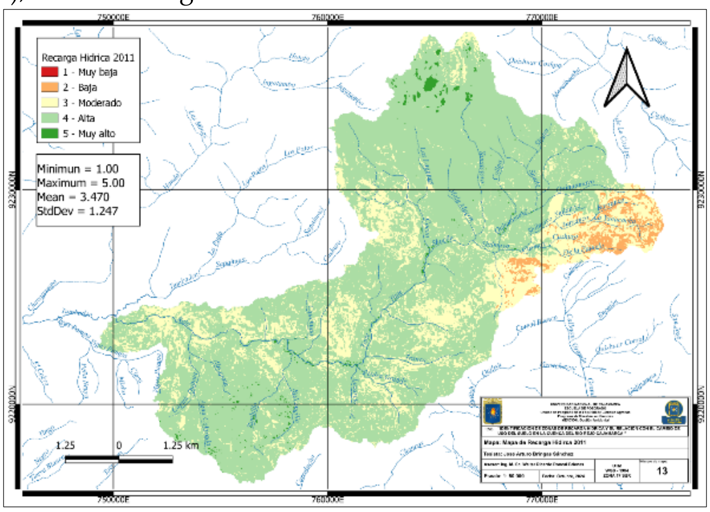

Figure 10. Water recharge in 2011 in the Rejo river basin

Table 08. Recharge areas for the year 2011 in the Rejo river basin.

Recharge Possible	Area (ha)	%
Very low	6.24	0.03
Low	1,928.64	8.55
Moderate	15,251.03	67.59
High	5,342.81	23.68
Very high	36.37	0.16
Total	**22,565.09**	**100.00**

The range with the highest percentage of areas corresponds to the possibility of recharging "Moderate", with 67.59% of the total, followed by the "High" range, with 23.68%. The statistical mean of the distribution is 3,470, indicating that most areas are concentrated in the "Moderate" range. The standard deviation of 1.247, suggesting moderate variability in the distribution of areas between the different ranges.

Based on the application of the equation proposed by Matus (2008) and its interpretation based on Table No. 07, the main recharge areas were identified, distributed throughout the basin. In the east orientation there is evidence of a possibility of "Low" recharge, which extends towards the center of the basin. In the center and southeast, the "Moderate" recharge range predominates, while the "High" range is mainly observed in the center and west. Finally, the areas with the possibility of "Very High" recharging are located in the North.

b) Water recharge for the year 2020.

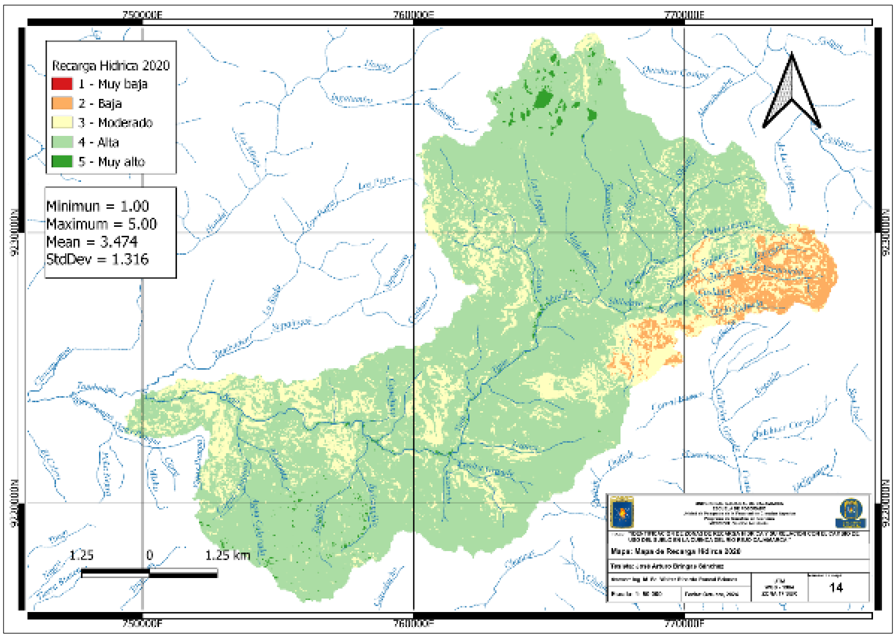

Figure 11. Water recharge year 2020 in the Rejo river basin.

Table 09. Water recharge areas for 2020 in the Rejo river basin

Recharge Possible	Area (ha)	%
Very low	18.99	0.08
Low	1,931.33	8.56
Moderate	15,480.65	68.60
High	5,090.94	22.56
Very high	43.18	0.19
Total	**22,565.09**	**100.00**

The main recharge areas distributed throughout the basin for the year 2020 were identified. In the East, a "Low" recharge possibility is observed, which extends towards the center-East. In the south-central zone and in scattered areas of the north, the "Moderate" range predominates, covering a significant strip of the basin. The "High" range covers much of the center and West, while the "Very High" range is located in small areas of the North.

In the centre of the basin, the presence of forest plantations (Granja Porcón) promotes areas of high recharge. These forest covers, during **their** development, capture approximately 50% of rainfall, which contributes significantly to maintaining and regulating hydrological patterns (Villegas, 2004).

The data show that the range of water recharge has an average value of 3,474, based on the interpretation of Figure 11, which indicates that a large part of the area is classified as "Moderate". The standard deviation of 1.316 reflects a moderate dispersion in the distribution of areas between the different ranges. The range with the highest percentage corresponds to the possibility of recharging "Moderate", with 68.60%, followed by the "High" range, with 22.56%.

List of water recharge zones identified with land use change.

Table 10. Water recharge zones and their relationship with land use change in the Rejo river basin.

Weighting	2011		2020		Area Difference	
	(ha)	%	(ha)	%	(ha)	D (%)
1 Very low	6.24	0.03	18.99	0.08	12.75	0.06
2 Down	1928.64	8.55	1931.33	8.56	2.69	0.01
3 Media	15251.03	67.59	15480.65	68.60	229.62	1.02
4 Discharge	5342.81	23.68	5090.94	22.56	-251.87	-1.12
5 Very High	36.37	0.16	43.18	0.19	6.81	0.03
Total	**22565.09**		**22565.09**			

In this regard, Martínez (2020) considers that land use change, especially deforestation and the conversion of natural areas into agricultural or urban areas, can significantly affect water recharge. Maintaining forest cover is crucial to ensure water flow in water recharge areas (Jiménez et al., 2021). In addition, land use change can influence the dynamics of water recharge, which highlights the importance of considering this factor in environmental management (Jiménez et al., 2021).

Likewise, according to the article "Water recharge areas and their importance for integrated water resource management" (Sánchez et al., 2015), the decrease in vegetation cover and the expansion of agriculture and urbanization can reduce the capacity of water infiltration and, therefore, reduce water recharge. In this sense, the identification and protection of water recharge areas should be a priority in the planning and management of water resources at the basin level.

The study of Industrial Rock and Mineral Resources for Economic and Social Inclusion and Development in the Cajamarca Region concludes that vegetation conservation and proper soil management can promote water infiltration and, therefore, water recharge (INGEMMET, 2020).

The results of this research indicate that the variation in the water recharge zones in the Rejo river basin has been mainly "Moderate" during the years analyzed (2011 and 2020), that is, of the 22565.09 hectares of surface area of the basin, 15480.65 hectares have not presented significant variation in their water recharge capacity. which is influenced by different land uses and management practices. However, it was also identified that areas with "very low" recharge have increased (12.75 ha) and areas with "high" recharge have decreased (-251.87 ha), indicating a negative influence caused by different land uses and management practices in the basin, indicating that there could be negative consequences on water availability in the future.

4. CONCLUSIONS AND RECOMMENDATIONS

From the evaluation in the years 2011 and 2020 for land use, a decrease was observed in "Secondary or Transition Vegetation" (-20.16%); in the "Transitory Crops" (-45.48%); "Swampy Areas" (-50.09%) and "Natural Lagoons, Lakes and Swamps" (-15.89%). On the other hand, the "Mining and Hydrocarbon Extraction Areas" (92.9%); "Forest Plantations" (5.5%) and "Grassland" (6.83).

It was determined that the water recharge areas in the Rejo River basin for the year 2011 present a "Moderate" recharge level (67.59%), for the year 2020 it remains with the same "moderate" level (68.60%), observing only a slight variation in the percentages.

A direct and positive relationship was identified between water recharge zones and certain changes in land use, specifically in areas of forest plantation, grassland and secondary vegetation or in transition. These land uses, which also occupy the largest area in the basin, favor water recharge. In contrast, a direct negative relationship was observed with the areas destined for mining extraction, which demonstrate an adverse impact by influencing the decrease in water recharge.

It is recommended to implement conservation and restoration measures (reforestation, terraces, infiltration ditches and living barriers) of the water recharge areas in the "very low" and "low" variation zone to avoid negative impacts on water availability in the Rejo river basin.

The delimitation of critical areas for water recharge is recommended in order to adequately protect them and avoid negative impacts on the hydrological cycle

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