

TIPOLOGIES OF URBAN RAVINES FOR ADAPTIVE PLANNING TO CLIMATE CHANGE IN LOJA, ECUADOR ¹

TIPOLOGÍAS DE QUEBRADAS URBANAS PARA LA PLANIFICACIÓN ADAPTATIVA AL
CAMBIO CLIMÁTICO EN LOJA, ECUADOR

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Con las civilizaciones, el agua y su geografía marcaron patrones para construir redes urbanas como insumo de vida, producción de alimentos, transporte e identidad colectiva; sin embargo, en la actualidad estas redes azules han sido excluidas frente al proceso de urbanización, lo que ha llevado a su pérdida parcial o total por cambios de uso de suelo y ocupación indebida, lo que potencia amenazas y disminuye la capacidad de adaptación al cambio climático. Esta realidad se redibuja en Loja, ciudad andina del sur de Ecuador, atravesada por tres ríos y 44 quebradas, en un relieve irregular, donde la investigación buscó identificar y delimitar tipologías de quebradas que definan lineamientos para su planificación, con un enfoque urbano-ambiental adaptativo al cambio climático. La metodología se estructuró en dos fases: en la primera, a partir de información cartográfica, se identificaron y normalizaron seis variables que inciden en la adaptación urbana: movimientos en masa, sobreutilización, bosques y plantaciones, alcantarillado, consolidación urbana e índice de contaminación potencial difusa. En la segunda, con la participación de expertos y mediante el Proceso Analítico Jerárquico, se definieron las variables y pesos a considerar para evaluar la capacidad adaptativa de quebradas frente al cambio climático y, con ello, definir tipologías. Como resultado, se obtuvieron seis tipologías de quebradas urbanas, estableciéndose que el mayor número corresponde a “Riesgo Bajo - Cobertura Bajo - Infraestructura Medio”. Como variables decisivas al momento de priorizar quebradas, a criterio de los expertos, se consideraron movimientos en masa, bosques y plantaciones, y sobreutilización del suelo.

Palabras clave: aguas superficiales, tipología, planificación territorial, cambio climático

Across civilizations, water and geography shaped patterns in building urban networks, serving as inputs for life, food production, transportation, and collective identity. However, nowadays these blue networks have been excluded amid urbanization, leading to their partial or total loss due to changes in land use and improper occupation, which heightens threats and reduces the ability to adapt to climate change. This reality is redrawn in Loja, an Andean city in southern Ecuador, crossed by three rivers and 44 ravines in an irregular relief, where the research sought to identify and delimit ravine typologies to define planning guidelines using an urban-environmental approach adapted to climate change. The methodology was structured in two phases: in the first, based on cartographic information, six variables affecting urban adaptation were identified and normalized: landslides, overuse, forests and plantations, sewerage, urban consolidation, and the diffuse potential pollution index. In the second, with the participation of experts and through the Hierarchical Analytical Process, the variables and weights to be considered for evaluating the adaptive capacity of ravines in the face of climate change were defined, and, as a result, typologies were established. Thus, six urban ravine typologies were identified, with the largest group being “Low Risk - Low Coverage - Medium Infrastructure.” According to the experts, the decisive variables for prioritizing ravines were landslides, forests and plantations, and land overuse.

Keywords: surface waters, typology, territorial planning, climate change

I. INTRODUCTION

The effects of Climate Change, from now on CC, have repercussions on regional systems, evidencing that human activities and rapid urbanization contribute to the generation of greenhouse gases and the loss of permeable soils (Arellano & Roca, 2015). The replacement of natural drainage networks with impermeable surfaces increases runoff and flood risks (Vidal & Romero Aravena, 2010). As a result, strategic ecosystems, such as riverbanks, have been invaded for construction (Guastella et al., 2019), thereby reducing resilience to natural hazards.

In Latin America, several studies have addressed blue networks from specific approaches. It has been shown how urbanization in Andean basins severely alters the hydro-geomorphological balance of a region (Romero & Vásquez, 2005). From an ecosystem services perspective, the role of riparian areas as buffer zones is particularly evident in Santiago's Mapocho River (Vásquez, 2016). In the dense Buenos Aires context, Green-Blue Infrastructure [GBI] generates environmental, social, and economic benefits (Kozak et al., 2020), while in Quito (Secretariat of the Environment, 2025), the micro-watershed approach is incorporated into analyses of land-use protection, risk, and CC. This shows regional progress, but also the need for comprehensive approaches to characterize and organize urban ravines based on their adaptive capacity to CC at the intra-urban scale.

In this framework, this research is carried out in Loja, an Andean city in southern Ecuador, whose water system evidences the persistent impact of urban growth on its water courses (Municipality of Loja, 2021). The study sought to define typologies of resilient ravines, identify which variables are relevant to defining urban ravine typologies for adaptive intervention to CC, and assess the distribution and prevalence of these typologies in the case study. A methodology was proposed to standardize the variables affecting urban adaptation to CC, and, at the same time, establish, with the participation of experts on the subject and using the Analytical Hierarchy Process [AHP], the variables and weights that define the urban ravine typologies. The study's contribution is to support planning decision-making by identifying intervention priorities and differentiated levels of adaptive capacity in Andean urban contexts.

II. THEORETICAL FRAMEWORK

Adaptive planning in urban water systems has attracted growing scientific interest in addressing the impacts of CC (Rangwala, 2024). Regional planning is no longer limited to reducing risks or vulnerability, but includes various components of the socio-ecological system (Gallopin, 2003). In this regard, this explains how current cities are generating a negative metabolic

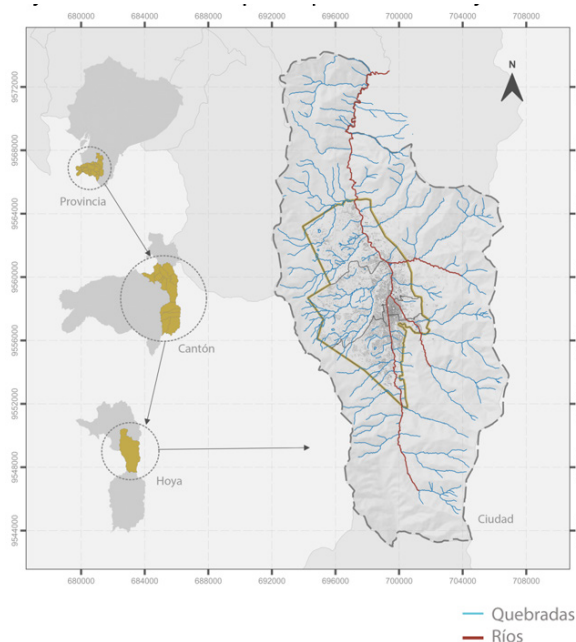


Figure 1. Case study: City of Loja. Source: Preparation by the authors.

process that accelerates as the urban sprawl spreads, without considering sustainable infrastructure (Delgado Ramos, 2014); therefore, it is imperative to approach CC from the region's multidimensional planning (Barton, 2009), as the climate and its effects are understood from the relationship between the natural environment and human beings.

Among the effects of CC, increases in rainfall frequency and intensity are evident (IPCC, 2023); hence, the sponge city model emerges as the dominant urban drainage strategy. This model absorbs rainwater and allows it to follow its natural course, avoiding the collapse of gray systems (Jiang & McBean, 2021) by optimizing the principles of natural accumulation, filtration, and purification (Yu et al., 2023). GBI is fundamental to this model because it provides thermal control, improves air quality, and manages floods (Venkataramanan et al., 2020). As for urban ravines, given their socio-ecological value, they have high potential to form this GBI (Sánchez-Almodóvar et al., 2023).

Beyond physical infrastructure, contemporary urban watershed planning incorporates resilience and adaptive capacity. Adaptive capacity is understood as the ability of a system (in this case, the ravine and its surroundings) to adjust to climatic changes, moderate potential damage, and leverage opportunities (Valera & Sharifi, 2025). In the Latin American context, this capacity directly depends on the quality of the available GBI, in which riparian vegetation not only regulates the hydrological cycle and temperature but also provides multifunctional support

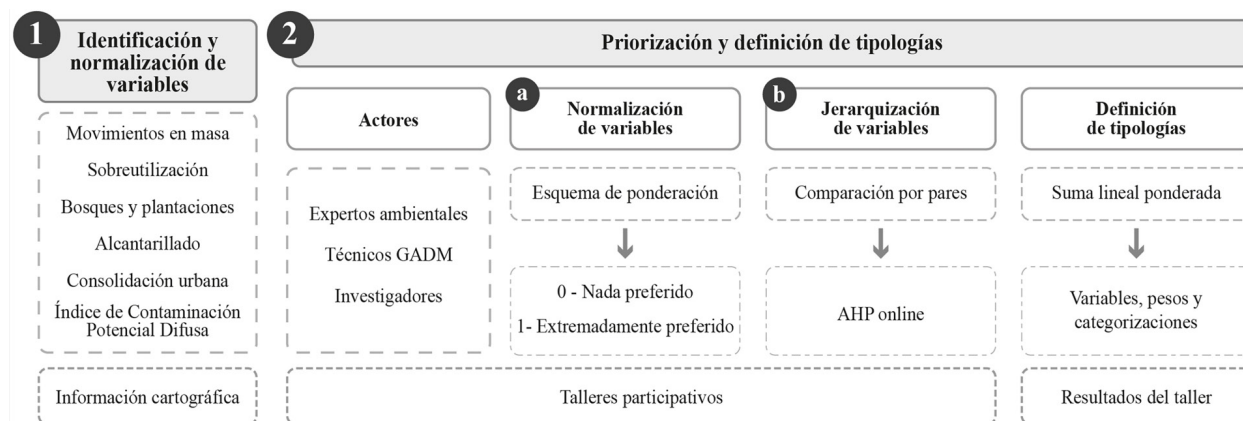


Figure 2. Methodological process of the research. Source: Preparation by the authors.

for ecological and social connectivity (Pradilla & Hack, 2024). Therefore, the characterization of ravines must not be limited to describing physical states, but rather it must interpret the interaction between the threat (risk) and the response capacity of the ecosystem (coverage) and society (infrastructure) to determine its real adaptation potential in the face of extreme events (Valera & Sharifi, 2025).

On the other hand, AHP has proven valuable for decision-making in regional planning under climate uncertainty, where multiple social, environmental, and economic objectives converge. Bousquet et al. (2023) identified AHP as one of the most widely used methods for planning nature-based solutions, in which experts participate in the criteria-weighting phase, and Geographic Information Systems (GIS) tools are used. Meerow and Newell (2017) developed the Green Infrastructure Spatial Planning model, which combines GIS-based multicriteria analysis with six benefit criteria and demonstrates the effectiveness of AHP in planning by relating spatial aspects to ecosystem services. At the same time, Kaur and Gupta (2022) proposed GBI using AHP-GIS for climate-adaptation-focused rainwater management.

III. CASE STUDY

The city of Loja, in southern Andean Ecuador's Loja province, was selected as a case study. It has 203,496 inhabitants (National Institute of Statistics and Censuses [INEC], 2022) spread over 5,732.51 hectares (Municipality of Loja, 2021). Figure 1 shows the location of the city in the context of the basin, canton, and province of Loja, as well as the water system consisting of three rivers and 44 ravines in an irregular relief. The rivers run for about 21.53 km, while the ravines run for about 104.34 km.

IV. METHODOLOGY

The research used a mixed-methods approach integrating quantitative spatial analysis and multicriteria decision-making methods. The process was developed in two phases: 1) identification and standardization of variables, and 2) prioritization and definition of typologies. The AHP method (Saaty, 1990) was used through participatory workshops and GIS for cartographic analysis (Figure 2).

Phase 1: Identification and standardization of variables

The six variables were grouped into three categories: risks, coverage, and infrastructure, according to complementary territorial analysis dimensions that evaluate ravine functionality and vulnerability (Canteiro et al., 2024; Li et al., 2022; Fu et al., 2021) in a previously obtained 200 m buffer. This buffer is justified because riparian zones are critical interfaces between terrestrial and aquatic systems, whose ecological and hydrological processes depend on the surrounding landscape, not only on the immediate water course (Gregory et al., 1991; Kupilas et al., 2021). The buffer considers the influence of the built environment, is consistent with zoning methodologies for water threats in Andean basins (Montenegro & Arteta, 2019), and aligns with buffer criteria required for ecological connectivity in Latin American cities (Pradilla & Hack, 2024).

Group 1. Risks - Dimension of natural threats

This focused on the region's intrinsic geomorphological hazards, incorporating susceptibility mapping to landslides that compromise soil stability. Landslide mapping (2008) of the Loja Municipal GAD was used, selecting 'Very high' and 'High' risks. The inclusion of both variables is critical, given that CC scenarios foresee intensified rainfall in the Andean region, which directly triggers landslides on unstable slopes, endangering the viability of gray infrastructure and necessitating preventive adaptation

measures (Alzate Buitrago, 2021). The representative percentage of these risks in each ravine was determined.

Group 2. Coverage - Ecological status dimension

The ecosystem's biophysical conditions were considered, including the integrity of the vegetation cover and the region's support capacity (overuse). Random Forest algorithms were used in the Google Earth Search Engine to perform a supervised classification of a PlanetScope image (3 m spatial resolution). The Standardized Difference Vegetation Index was used to spectrally discriminate between consolidated arboreal vegetation (forests/ plantations) and low-growing vegetation (shrub/herbaceous). Overuse was determined by evaluating land use conflicts. First, the host capacity of the environmental units (defined by land use, permeability, and slope) was calculated using an impact-aptitude matrix against potential activities ('Agriculture', 'Conservation' and 'Regeneration'). By comparing this capacity with the actual ground cover, four levels of conflict were identified and quantified (in area and percentage within the buffer): adequately used, light overuse, medium overuse, and light underuse.

Group 3. Infrastructure - Anthropic pressure dimension

The human interventions that modify the natural dynamics of the ravines were analyzed. The percentage of homes without sewerage was determined using information from the Sewer Network and Loja's Land Registry. An 'Intersection' was made between the houses and the buffer. The 'Connection by proximity' tool was used, taking into account that the distance is greater than or equal to 0, to determine the houses with sewerage at that distance. Urban consolidation was defined using the city's land registry mapping, in which the percentage of land with construction was estimated. The ICPD was calculated by cross-referencing data on land use, permeability, slope, and flow length to determine its average for each ravine.

Phase 2: Prioritization and definition of typologies

On May 31st, 2022, a multidisciplinary participatory workshop was held, involving stakeholders with technical, regulatory, and regional knowledge of the Loja basin. The expert panel comprised three strategic groups:

1. Local government technical experts: representatives of the Municipality of Loja with experience in regional management, sewerage, and urban planning.
2. Environmental experts: engineers and specialists with expertise in hydrological dynamics, vegetation cover, and climate risks.
3. Consulting team and researchers: academics in charge of methodological structuring and the spatial analysis of variables.

This workshop had two stages. The preparatory stage, in which the preliminary list of variables selected from the existing literature, expert knowledge, and field observations

was presented. A weighting outline was used; the group of experts established standardized values for the variables based on preferences (0 for not preferred at all and 1 for extremely preferred). To avoid arbitrary weighting of variables, the Analytical Hierarchy Process (AHP) was applied with the expert panel using the AHP Online tool (Goepel, 2018).

Weighted linear sum of typologies

A weighted linear sum was used to generate typologies, incorporating the variables and weights defined in the workshop, as well as the categorizations among them. The values (0 to 1) were standardized for the 200 m buffers of the 44 ravines. The results were classified as 'low' for those who scored between 0 and 0.33, 'medium' for those who scored between 0.34 and 0.66, and 'high' for those who scored between 0.67 and 1.

V. RESULTS

Characterization of ravines

Prior to the characterization, the ravine system was organized, labeling those not identified by the Municipality of Loja. It was possible to identify 44 ravines within the city's urban limits. Next, the results of the risk, coverage, and infrastructure analyses are presented, which allow defining homogeneous zones based on similarities in their biotic and physical components. Figure 3 shows that 4 ravines have between 20-30% of their area at 'very high' risk, 45% of the total, and 13 between 10-20% corresponding to 36%; while 12 ravines have between 15-30% of their area at 'high' risk, 55% of the total, and 26 of the 0-15% grouping in 21%.

The overuse analysis indicates that the buffer area has 57.9% adequate use, 27.8% light overuse, 13.9% medium overuse, and 0.4% light underuse. On the other hand, seven ravines have forest cover on more than 20% of their surface area, accounting for 31% of the total buffer area (Figure 4).

Figure 5 shows that 33% of homes in the buffer zone lack a sewer system; 19 ravines have fewer than 50% of their homes with the service. 11 ravines have a high degree of consolidation (more than 75% of plots built), representing 27% of smallholdings in the buffer. The ICPD ranges from 5.25 to 7.85, with the majority of the region (78%) showing medium to high values and 14% very high values.

Prioritization and weights of each factor

With the weighting conducted in the expert workshop, the variables are grouped into three categories: risks, coverage, and infrastructure. According to Table 1, at the global level, the variable landslides (high and very high risk) have the greatest influence in identifying the ravines to be intervened, followed by

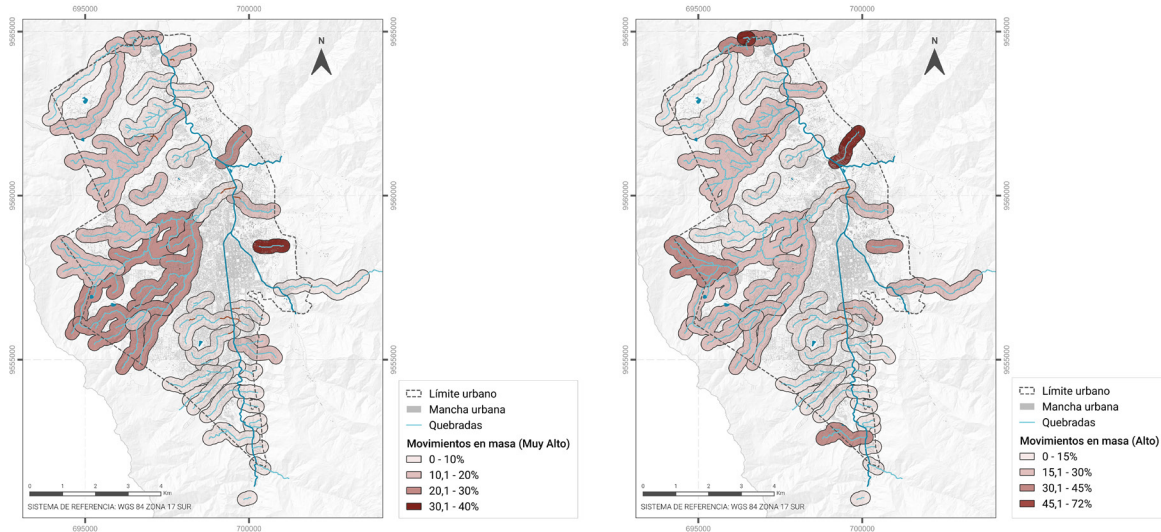


Figure 3. 'Very High' and 'High' landslides. Source: Prepared by the Authors based on GAD Municipal de Loja - Landslides (2008).

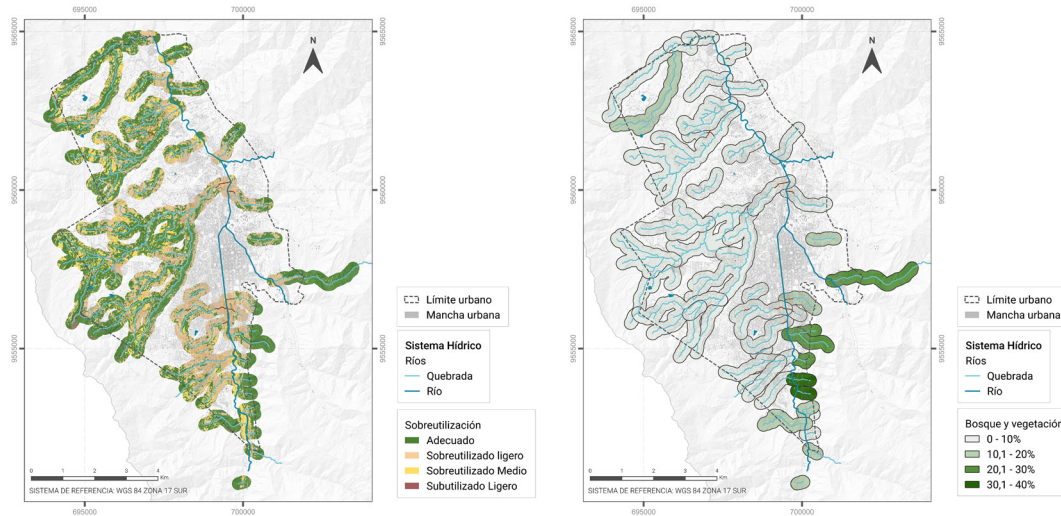


Figure 4. Overuse, forests, and plantations. Source: Preparation by the authors.

those with smaller forest and plantation areas and land overuse. A third minor group includes urban consolidation, ICPD, sewerage, shrubs, and grass, according to the key stakeholders' criteria.

Types of ravines

Next, the six types of urban ravines are described, represented in Figure 6 and detailed in Complementary Table 1 (Table C1). Both the categorized and interpretative typology related to its capacity to adapt to CC are presented.

- 'High risk, low coverage, medium infrastructure' – 'ravines with very low adaptive capacity': Four (10.5% of the system) are located on steep slopes, with high risk due to landslides, soil instability, mudslides, and floods. The vegetation cover is low due to the shift to agricultural and livestock uses in its protected areas. They are mostly confined to sectors of low urban consolidation.
- 'Medium risk, low coverage, medium infrastructure' - 'ravines with low adaptive capacity': 11 (43.5% of the

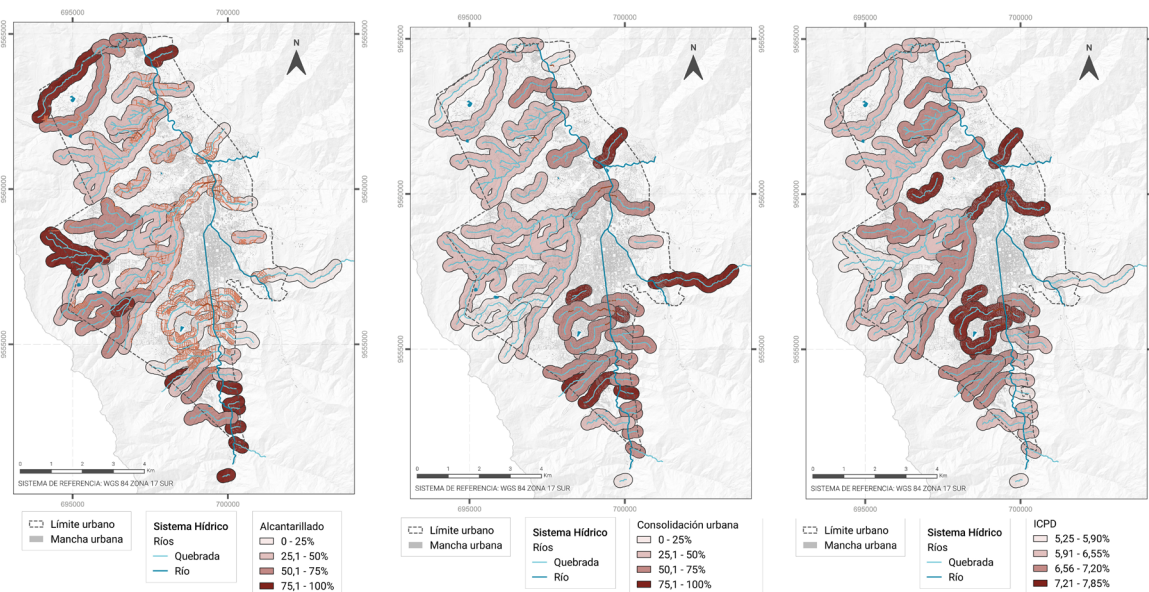


Figure 5. Sewerage, urban consolidation, and ICPD. Source: Prepared by the Authors.

Category	Weight (%)	Variable	Weight (%)	Factor
Risks	27	Landslides	27	1
Coverage	47	Forests and plantations	21	0.44
		Overuse	19	0.40
		Shrubs and grass	7	0.16
Infrastructure	26	Urban consolidation	10	0.38
		ICPD	8	0.32
		Sewerage	8	0.30

Table 1. Hierarchy of variables. Source: Preparation by the authors.

- system), located towards the west of the medium urban consolidation area. Low forest and native flora cover have been affected by urbanization. At the same time, important stretches of ravines that have been dammed up affect water ecosystems and vegetation. The average sewer coverage pollutes the water and its protective edges.
- 'Low risk, low coverage, high infrastructure' - 'ravines with conditional adaptation potential': Seven (9.5% of the system) are concentrated in the south west and run through the foothills with forests and native vegetation, being potential resources for water catchments. The low levels of sanitary infrastructure have a high and direct effect on the ravines.
- 'Low risk, low coverage, medium infrastructure' - 'ravines with adaptive capacity restricted by urban consolidation': 19 (34.8% of the system). They cover a large part of the city's consolidated area, so important sections have been channeled and buried, thereby modifying their natural routes and conditions. Consequently, they have low vegetation cover, land-use changes, and a lack of buffer zones, which pose direct risks to the surrounding inhabitants.
- 'Low risk, medium coverage, high infrastructure' - 'ravines with severely limited adaptive capacity': One (0.5% of the system) located towards the south center, whose natural characteristics were almost completely modified with the channelization and burial of its course. The presence of

neighborhoods without sewerage generates pollution and high alterations to natural ecosystems.

- 'Low risk, medium coverage, medium infrastructure' - 'ravines with intermediate adaptation': Three (1.2% of the system) are located towards the city center with characteristics of dominant urban consolidation. The presence of vegetation is average, and despite their location, they maintain protected areas that support regular vegetation and shrub cover, making it possible to restore and enhance them.

VI. DISCUSSION

The results showed that for the prioritization of the ravines to be intervened, the predominant influence of the landslides, forests and plantations variables, as well as land overuse stand out, all related to the importance of maintaining the permeability of vegetation cover on the edges of the ravines, as these green spaces along urban waterways could, among other benefits, moderate the impacts of urban heat islands, strengthen flood resilience and improve air quality (Inançoğlu et al., 2020).

The combination of variables and categories generated six types of ravines, whose interpretation of risk conditions, the state of ecosystem components, and the degree of urban transformation underpins their adaptive capacity to CC (Nieto-Cañarte et al., 2025; Ferrario et al., 2024). Two typologies stand out: ravines with very low adaptive capacity, which are the most critical and include four ravines, and ravines with low adaptive capacity, which include 11 ravines; in addition, due to the length of their course, they represent 54% of the system. This shows that the planning and recovery of ravines requires increasing vegetation cover and promoting appropriate land use, as well as going beyond gray engineering approaches that have also caused total deforestation of the alluvial riverine plains by nature-based solutions, which allow including the influence of vegetation and resilience in flood-prone areas (Vörösmarty et al., 2018). Moving from a vertical strategy to a more horizontal-natural approach that leaves room for the waterbody in the city (Warner et al., 2012) that promotes the restoration of spaces for floodplains and river channels to remain active and as free as possible, and the connectivity between the main stream of the river and the floodplain to generate self-sustaining ecosystems (Zingraff-Hamed et al., 2021), which should be considered in urban planning and in the regulation of the use and occupation of the city's land from a socio-ecological perspective.

On the other hand, the use of the AHP and the participation of experts and key actors in the prioritization of variables for decision-making is fundamental because it contributes to the knowledge of reality in participatory workshops in a structured and mathematical framework for multicriteria decision-making, which allows identifying and hierarchizing fundamental aspects (Pérez-Ramírez & Martínez-Damián, 2020). In addition,

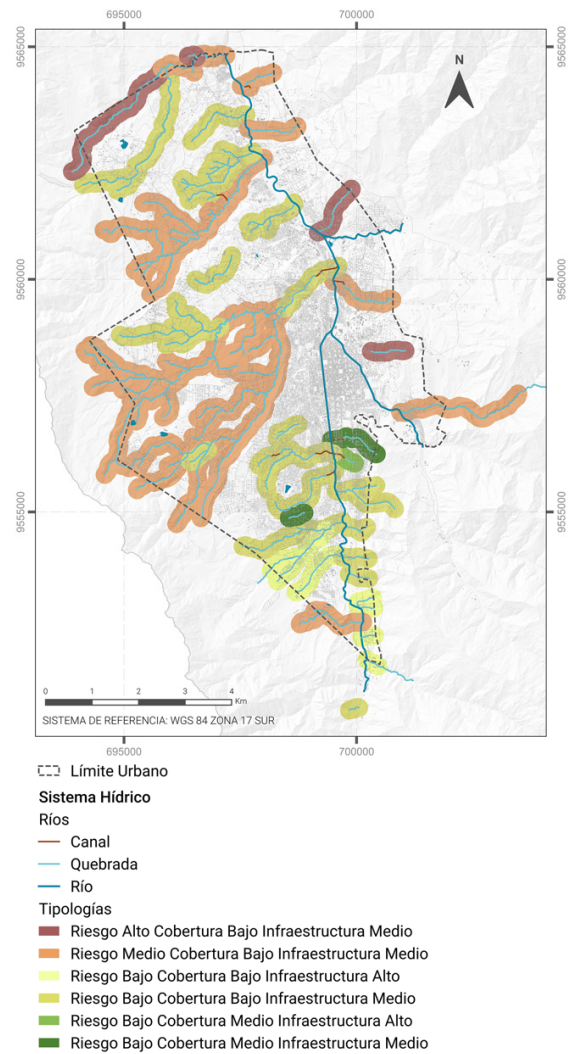


Figure 6. Typologies of the urban ravines of Loja. Source: Preparation by the authors.

its transparency can help manage tensions and conflicts of interest that may arise between different groups (Baladia et al., 2015). However, the AHP may introduce sources of bias, primarily stemming from the subjectivity of experts in paired comparisons, which can be influenced by leadership, consensus pressures, or power imbalances. In addition, the method assumes independence among criteria and may be sensitive to small variations in assessments (Mendoza et al., 2019). In this study, these limitations were addressed by selecting a diverse panel of participants, checking the consistency of the matrices, and conducting a collective discussion of the results. Thus, the contribution of the work lies in the systematic integration of the AHP with a participatory approach, offering a transparent

and replicable methodological framework to support decision-making in multi-stakeholder scenarios.

VII. CONCLUSIONS

The research questions are validated by defining ravine typologies using variables prioritized by key actors versus CC, and by considering their characterization and prevalence in the case study. Looking at risk, coverage, and infrastructure in an integrated manner determined the direct and scalar relationships of the ravines within a water system capable of addressing the impacts of CC, such as flood resilience and air quality improvement, among others. In this context, the research seeks to link urban inhabitants and ravines, seeking a healthy relationship that engages with the geography of water, and, from this, builds natural and semi-natural habitats that are resilient to CC, integrating responsible socio-economic uses. Finally, the research supports decision-making regarding CC in urban planning by defining ravine types based on their adaptive capacity, thereby facilitating the hierarchical organization of interventions across the region.

VIII. SUPPLEMENTARY MATERIAL

The supporting information can be downloaded at: https://issuu.com/clauidiagr/docs/tabla_suplementaria_s1, Table C1: Six typologies of urban streams. C.G. M.T. F.R. G.S.

IX. CONTRIBUTION OF AUTHORS CRediT:

Conceptualization, C.G.R., M.T.G., G.S.M.; Data curation, C.G.R., F.R.B., G.S.M.; Formal analysis, M.T.G.; Acquisition of financing, C.G.R., M.T.G., G.S.M.; Research, C.G.R., M.T.G., G.S.M.; Methodology, C.G.R., M.T.G., F.R.B., G.S.M.; Project Management, C.G.R.; Software, F.R.B.; Supervision, C.G.R., M.T.G., F.R.B., G.S.M.; Validation, C.G.R., M.T.G., F.R.B., G.S.M.; Visualization, C.G.R., F.R.B.; Writing – original draft, C.G.R., F.R.B.; Writing – revision and editing, C.G.R.

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