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ORIGINAL

Dietary transformation and health vulnerability following lake poopó degradation: a cross sectional study in the indigenous Uru Vilañeque Community

Transformación alimentaria y vulnerabilidad sanitaria tras la degradación del lago Poopó: estudio transversal en la comunidad indígena Uru Vilañeque

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ABSTRACT

Objective: To evaluate the association of occupational transformation, dietary transformation, and current environmental exposure with family health vulnerability in the Indigenous Uru Vilañeque community following the degradation of Lake Poopó, Bolivia. Methodology: A quantitative, observational, retrospective, and cross-sectional study was conducted using a census of 32 families. A 40-item structured survey was used to comparatively reconstruct previous and current conditions related to occupation, food consumption, household materials, diseases, and symptoms. Normalized indices of occupational transformation, dietary transformation, environmental transformation, current environmental risk, and health vulnerability were constructed. The analysis included descriptive statistics, Pearson correlations, ordinary least squares regression, Beta regression, and diagnostic tests. Results: Mean dietary transformation was 0.744, current environmental risk was 0.890, and global health vulnerability was 0.740. Dietary transformation showed the most consistent bivariate association with symptomatic vulnerability (r=0.440; p=0.012). In the reduced Beta regression re-estimated with 31 observations, dietary transformation remained positively and statistically significantly associated with symptomatic vulnerability (β=3.432; p=0.007), whereas the current environmental indicator was not significant (p=0.213). Comparison of Beta specifications on 29 complete cases favored the reduced model according to AIC and BIC. Conclusion: Among the families studied, dietary transformation was the socio-ecological dimension most closely associated with symptomatic vulnerability. The findings support integrating food systems, health, and socio-ecological adaptation when analyzing Indigenous communities affected by ecosystem degradation, while avoiding causal interpretations from a cross-sectional design.

Keywords: ecosystem degradation; health vulnerability; dietary transformation; Indigenous Peoples; Lake Poopó.

RESUMEN

Objetivo: Evaluar la asociación de la transformación ocupacional, la transformación alimentaria y la exposición ambiental actual con la vulnerabilidad sanitaria familiar en la comunidad indígena Uru Vilañeque después de la degradación del lago Poopó, Bolivia. Metodología: Se realizó un estudio cuantitativo, observacional, retrospectivo y transversal basado en un censo de 32 familias. Mediante una encuesta estructurada de 40 preguntas se reconstruyeron comparativamente condiciones previas y actuales relacionadas con ocupación, alimentación, uso de materiales domésticos, enfermedades y síntomas. Se construyeron índices normalizados de transformación ocupacional, transformación alimentaria, transformación ambiental, riesgo ambiental actual y vulnerabilidad sanitaria. El análisis incluyó estadística descriptiva, correlaciones de Pearson, regresión lineal ordinaria, regresión Beta y pruebas diagnósticas. Resultados: La transformación alimentaria alcanzó una media de 0,744, el riesgo ambiental actual 0,890 y la vulnerabilidad sanitaria global 0,740. La transformación alimentaria mostró la asociación bivariada más consistente con la vulnerabilidad sintomática (r=0,440; p=0,012). En la regresión Beta reducida reestimada con 31 observaciones, la transformación alimentaria mantuvo una asociación positiva y estadísticamente significativa (β=3,432; p=0,007), mientras que el indicador ambiental actual no alcanzó significación (p=0,213). La comparación de especificaciones Beta sobre 29 casos completos favoreció el modelo reducido por AIC y BIC. Conclusión: En las familias estudiadas, la transformación alimentaria fue la dimensión socioecológica más estrechamente asociada con la vulnerabilidad sintomática. Los hallazgos respaldan la necesidad de integrar sistemas alimentarios, salud y adaptación socioecológica en el análisis de comunidades indígenas afectadas por degradación ecosistémica, sin atribuir relaciones causales a un diseño transversal.

Palabras clave: degradación ecosistémica; vulnerabilidad sanitaria; transformación alimentaria; pueblos indígenas; lago Poopó.

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INTRODUCTION

Human health is linked to ecological systems that can sustain water, food, livelihoods, and environmental conditions suited to them. The planetary health perspective has shown that the degradation of natural systems can affect social and health determinants[1,2], while climate change and the transgression of Earth system boundaries unequally increase risks across populations and territories[3,4]. These processes do not occur in a vacuum; they interact with poverty, access to resources, productive transformations, and cultural changes, giving rise to differentiated exposures and vulnerabilities. Therefore, studying the link between ecosystem degradation and health requires considering not only direct biophysical damage but also transformations in the daily reorganization of households.

Indigenous peoples are particularly exposed to these transformations because of the historical relationship between territory, identity, ecological knowledge, subsistence, and food[5]. The international literature has documented that environmental deterioration can simultaneously affect food security, the continuity of traditional practices, livelihoods, and health conditions, while also highlighting the resilience and adaptive capacity of Indigenous peoples[6,7]. This dual condition is relevant so that communities are not interpreted solely in terms of vulnerability: socioecological changes generate restrictions but also adaptation responses that alter occupations, mobility, supply, and consumption patterns.

One of the most important intermediate processes is the transformation of food systems. For example, ecological changes, incorporation into markets, reduced supply of local food sources, or changes in subsistence activities can accelerate transitions from traditional diets to patterns more dependent on commercialized([8,9])and ultra-processed products[10,11]. There are transitions that not only involve changes in the composition of the diet but can modify food autonomy, food diversity, the frequency of food acquisition, and dependence on external chains.

Andean evidence adds further characteristics to the understanding of this relationship. In the indigenous population of Chile, nutritional transition changes and health outcomes linked to transformations in lifestyles have been documented (12); in Ecuador, evidence indicates that the promotion of traditional foods, agroecology, and support for local food systems are related to benefits for human and environmental health (13), or, as in the indigenous community of Caliata, biodiversity, local productive practices, and food sovereignty are shown to support culturally pertinent diets that are probably more sustainable (14).

A recent study on indigenous food sovereignty and autonomy points out that the ability to decide on the production, distribution, and consumption of food is a form of resistance to processes of food globalization[15]1. Additionally, among indigenous peoples in Brazil, urbanization and the transformation of ways of life have been associated with changes in cardiometabolic risk[16]. Taken together, this background supports the need to consider food as a pathway through which ecosystem degradation may be related to health outcomes.

Material changes in households also introduce new environmental exposures. The proliferation of plastics, packaging, and disposable materials is a visible component of contemporary changes in consumption. The literature has documented the presence of plastic particles in human blood and has raised important questions about their potential health consequences (17,18). However, a distinction must be drawn between the presence of plastic materials in the home, environmental exposure, internal dose, and biological effects. A household indicator of plastic use or presence is not a measure of microplastics in the body; therefore, its interpretation should remain at the level of contextual exposure that it actually represents.

In the case of Bolivia, Lake Poopó is a classic example of ecosystem decline in the Andean region. Indeed, this lake system supported productive, food-related, and cultural activities of the Uru peoples, but in recent times it has suffered a severe reduction in its aquatic area due to climatic, hydrological, and anthropogenic factors[19,20]. The decline in ecosystem functions altered the material conditions of surrounding communities and forced the restructuring of provisioning and subsistence systems. In this regard, the Uru Vilañeque community offers an opportunity to examine how occupational, dietary, and environmental transformations relate to health conditions in the family context.

Studying these dimensions simultaneously can yield more precise knowledge than studying each separately. Occupational transformation may act as a structural change in livelihoods; food transformation may be a more direct pathway for modifying daily exposures; and the environmental dimension may reflect changes in materials and consumption patterns. Comparing them makes it possible to determine whether all maintain similar associations with health vulnerability or whether any has a more consistent statistical relationship. This perspective aligns with ecosocial

and planetary health approaches, which recognize multiple levels of determination and do not assume that the relationship between environmental degradation and disease is linear (1,4,5).

Although the literature on environment, food, and health is growing, a gap remains in studies involving families that simultaneously compare the relative contribution of occupational, food, and environmental transformations in indigenous communities exposed to ecosystem deterioration. Therefore, the objective of this study was to evaluate the association of occupational transformation, food transformation, and current environmental exposure with family health vulnerability in the Uru Vilañeque community following the degradation of Lake Poopó. It was proposed that these dimensions would show associations of different magnitude with health vulnerability and that their comparison would allow identification of the dimension with the most consistent statistical relationship with the symptoms reported by families.

METHODS

A quantitative, observational, retrospective and cross-sectional study was conducted. The methodological presentation was organized taking as a reference transparency criteria for observational studies of the STROBE statement21. The research was carried out in the Uru Vilañeque community, located approximately 17 km west of the city of Challapata, Eduardo Abaroa province of the department of Oruro, Bolivia. The community is located around the coordinates 18°48'00" south latitude and 66°27'00" west longitude, at an approximate altitude of 3734 m a.s.l., within the socio-ecological system associated with Lake Poopó. This ecosystem has experienced during the last decades a progressive reduction of its water surface and severe episodes of desiccation, a condition that constitutes the environmental context of the study.

The unit of analysis was the family. The 32 families of the Uru Vilañeque community that took part in the information gathering were included, so the design corresponded to a community census and not to a probabilistic sample. Primary information was obtained from family representatives through direct interviews. Data collection was carried out between March and June 2026 in one single time period. The retrospective component was given by the comparative reconstruction of socioecological conditions prior to the desiccation of Lake Poopó and conditions observed or reported at the time of the study. Consequently, the retrospective temporality refers to information recalled about the previous period and not to a longitudinal follow-up of the same families.

Data collection used a structured survey of 40 questions, organized into 4 dimensions: occupational activities; food consumption; environmental exposure and use of household materials; and health vulnerability expressed through illnesses and symptoms reported by the families. The questions made it possible to compare the previous situation with the current situation and to identify processes of continuity, abandonment, substitution, or incorporation of activities, foods, materials, and sanitary conditions. Before final administration, the instrument was reviewed through preliminary interviews with community members to assess the relevance and comprehension of the questions. No formal pilot test was conducted, an aspect that was considered later when interpreting the precision of the measurements.

The construction of family indices followed general principles for composite indicators22. The procedure comprised 3 stages: construction of temporal trajectories, analytical recoding, and aggregation-normalization. For each family i and component j, the trajectory was represented as TRij=(E0ij,E1ij), where E0 corresponded to the state prior to desiccation and E1 to the current state. Subsequently, each trajectory was transformed into a binary variable Xij. The value 1 was assigned when the trajectory represented the presence of transformation, exposure, or vulnerability according to the index evaluated, and 0 when the condition was absent. This recoding made it possible to express heterogeneous components on a common analytical scale.

The components received equal weighting to avoid introducing differential weights without external empirical justification. Each index was calculated by simple additive aggregation, Ii=(ΣXij)/k, where Ii is the value of the index for family i, Xij corresponds to the recoded component, and k represents the total number of included components. All indices were normalized between 0 and 1; higher values indicate greater intensity of transformation, exposure, or vulnerability according to the corresponding construct. This strategy facilitates comparison between families and dimensions, although it should be interpreted as a composite measure of relative intensity and not as a clinical or diagnostic scale.

The Occupational Transformation Index, ITO, was constructed from 9 activities linked to family subsistence strategies and expresses the proportion of activities that showed change between both periods. The Food Transformation Index, ITA, integrated 18 food variables and represents the

intensity of modification in family dietary patterns. The Environmental Transformation Index, ITAmb, incorporated 10 variables related to the use of household materials and summarizes the historical change between the previous period and the current situation. For the health dimension, the Morbidity Vulnerability Index, IVE-M, was constructed with 6 reported diseases; the Symptomatic Vulnerability Index, IVE-S, with 9 symptoms; and the Global Vulnerability Index, IVE, integrated the morbidity and symptom dimensions.

To differentiate historical environmental transformation from contemporary environmental exposure, the Current Environmental Risk Index, ITAmb-R, was constructed during the analytical phase. This index used the 10 environmental variables and coded the current presence of plastic or disposable materials in the household. Therefore, ITAmb-R represents the relative intensity of the presence of the evaluated materials and not a measurement of internal exposure, pollutant concentration, or biological dose. Because its definition emerged during the analysis to resolve a conceptual difference between historical change and current exposure, its results were interpreted in an exploratory manner.

The statistical analysis was conducted sequentially. First, means, minimum and maximum values were calculated to describe family indices. In addition, when available, community-level aggregate values were compared with family means, with the aim of examining agreement between both descriptive scales. Second, bivariate associations between transformation dimensions and symptomatic vulnerability were evaluated using Pearson's correlation coefficient23. Values of r, p, and 95% confidence intervals were reported; the latter were calculated using Fisher's z transformation.

Third, multivariate models were estimated with IVE-S as the dependent variable. Ordinary linear regression was used as the reference specification, and Beta regression was used as an alternative, in accordance with the proportional and bounded nature of IVE-S24. The full model included ITO, ITA, and ITAmb-R. Based on statistical performance and the contribution of the variables, a reduced specification with ITA and ITAmb-R was evaluated. Since IVE-S could take values at the 0 and 1 boundaries, the observations were transformed to the open interval using $y^*=[y(n-1)+0.5]/n$, where n corresponded to the number of observations in the model. The Beta regression used a logit link to model the mean.

The comparison between the full and reduced Beta specifications was initially performed on the same analytical sample of 29 families with complete information for ITO, ITA, ITAmb-R and IVE-S. This decision avoided directly comparing information criteria calculated on different sets of observations. Log-verisimilitude, Akaike information criterion and Bayesian information criterion were considered, in addition to the significance of the coefficients and the parsimony of the model. Once the reduced specification was selected, it was reestimated with the 31 valid observations available for IVE-S, ITA and ITAmb-R in order to take advantage of the available information without altering the model's selection logic.

As a complementary sensitivity analysis of the reduced OLS model, multicollinearity was assessed using the variance inflation factor (25), heteroscedasticity using the Breusch-Pagan test (26), residual normality using the Shapiro-Wilk test (27), and functional specification using the Ramsey RESET test (28).

Table 1. Summary of the operationalization of family indices.

Index	Construct represented	Components	Range	Interpretation
ITO	Transformation of occupational and subsistence strategies	9 activities	0-1	A higher value indicates greater occupational transformation
ITA	Transformation of family food patterns and systems	18 food variables	0-1	A higher value indicates greater food transformation
ITAmb	Historical transformation in the use of domestic materials	10 environmental variables	0-1	A higher value indicates greater historical change
ITAmb-R	Current presence of plastics and disposable materials	10 environmental variables	0-1	A higher value indicates greater current presence of evaluated materials
IVE-M	Vulnerability due to reported morbidity	6 diseases	0-1	Higher values indicate a greater relative presence of diseases.
IVE-S	Reported symptomatic vulnerability	9 symptoms	0-1	Higher values indicate a greater relative presence of symptoms.
IVE	Global health vulnerability	Integration of morbidity and symptoms	0-1	Higher values indicate greater global vulnerability.

Note: The indices are normalized composite measures and are not equivalent to clinical scales or biological measurements of exposure.

These tests were used to evaluate the stability of the alternative linear structure rather than to validate assumptions specific to beta regression. A significance level of 0.05 was adopted. The indices were initially organized in Microsoft Excel, and statistical analyses were performed using R Statistical Software.

Because the research involved health and socioeconomic information from an Indigenous community, authorization was requested and obtained from the Indigenous and community authorities of Uru Vilañeque prior to the fieldwork. In presenting the results, the family remained the unit of analysis, and aggregate measures were used to describe community patterns and associations between indices.

RESULTS

Characterization of transformation and vulnerability indices

The 32 families were included in the descriptive analysis. Food transformation had a family mean of 0.744, higher than occupational transformation (0.654) and historical environmental transformation (0.538). ITAmb-R reached a mean of 0.890, the highest among the transformation and exposure dimensions considered. This value indicates that the materials included in the indicator were widely present in households, although it does not represent biological exposure intensity. In the health dimension, the global IVE had a mean of 0.740, whereas IVE-M and IVE-S reached 0.801 and 0.676, respectively.

The comparison between previously aggregated community values and household means showed small differences for ITO, ITA, and IVE. For ITO, the community value was 0.627 and the household mean was 0.654, with a difference of +0.027. For ITA, the values were 0.741 and 0.744, with a difference of +0.003. For IVE, the community value was 0.744 and the household mean was 0.740, with a difference of -0.004. The most marked discrepancy was observed for ITAmb, for which the community value was 0.648 and the household mean was 0.538. This difference was consistent with the need to distinguish between historical environmental transformation and contemporary environmental presence of materials, which motivated the exploratory use of ITAmb-R.

Table 2. Community values and family means of the indices.

Index	Community value	Family mean	Community-family difference
ITO	0,627	0,654	+0,027
ITA	0,741	0,744	+0,003
ITAmb	0,648	0,538	-0,110
ITAmb-R	—	0,890	—
IVE	0,744	0,740	-0,004
IVE-M	—	0,801	—
IVE-S	—	0,676	—

Note: ITAmb-R, IVE-M, and IVE-S did not have an equivalent aggregated community value for this comparison.

Bivariate associations

The correlation analysis showed a positive and statistically significant association between ITA and IVE-S (r=0,440; p=0,012; IC95%: 0,108 to 0,684). The magnitude of the association was moderate and greater than that observed for the other transformation dimensions with respect to IVE-S. ITO showed a weaker positive association with IVE-S (r=0,266; p=0,141; IC95%: -0,091 to 0,563), whereas ITAmb-R showed a practically null association (r=0,041; p=0,824; IC95%: -0,312 to 0,384). Consequently, food transformation was the only dimension with significant bivariate evidence of association with symptomatic vulnerability.

Relationships among the explanatory dimensions were also observed. ITO correlated with ITA (r=0.526; p=0.002) and ITA with ITAmb-R (r=0.454; p=0.009). These associations indicate that transformation processes are not completely independent and justify interpreting the multivariate coefficients as adjusted associations within a system of interrelated socioecological changes. In contrast, the relationship between ITO and ITAmb-R was weak and not significant (r=0.133; p=0.468).

Multivariate models of symptomatic vulnerability

In the full OLS model, estimated with 29 complete cases, no variable reached statistical significance at 5%. ITA presented the largest coefficient and the p-value closest to the conventional threshold (β=0.769; p=0.063), whereas ITO (β=0.062; p=0.773) and ITAmb-R (β=-0.493; p=0.310) showed weaker contributions. The model explained 19.5% of the variability observed in IVE-S, and the adjusted R^2 was 0.098; the global F test did not reach significance (p=0.138).

Table 3. Pearson correlations between transformation dimensions and symptomatic vulnerability, n=32.

Relationship	r	p	IC95%
ITO ↔ ITA	0,526	0,002	0.217 to 0.739
ITO ↔ ITAmb-R	0,133	0,468	-0.226 to 0.460
ITO ↔ IVE-S	0,266	0,141	-0.091 to 0.563
ITA ↔ ITAmb-R	0,454	0,009	0.125 to 0.693
ITA ↔ IVE-S	0,440	0,012	0.108 to 0.684
ITAmb-R ↔ IVE-S	0,041	0,824	-0.312 to 0.384

Note: Bilateral correlations. 95% confidence intervals were calculated using Fisher's z transformation.

The full Beta regression, estimated on the same 29 families, produced a different pattern for ITA. Food transformation showed a positive and significant association with IVE-S (β=3.143; p=0.041), while ITO (p=0.805) and ITAmb-R (p=0.229) were not significant. The model presented a log-likelihood of 9.193, AIC of -8.386, and BIC of -1.550. This result supported the evaluation of a more parsimonious specification without ITO.

The reduced OLS was estimated with 31 valid observations for ITA, ITAmb-R, and IVE-S. ITA maintained a positive and significant association (β=0.867; p=0.008), whereas ITAmb-R remained non-significant (β=-0.490; p=0.286). The model presented R^2=0.227, adjusted R^2=0.171, and a significant global F test (p=0.027). Although R^2 was higher than that of the full OLS, this difference was not used as direct evidence of superiority because both models were estimated with different sample sizes.

The final reduced Beta specification, re-estimated with 31 observations, confirmed the association of ITA with IVE-S (β=3.432; p=0.007), whereas ITAmb-R did not reach statistical significance (β=-2.169; p=0.213). The model presented a log-likelihood of 11.545, AIC of -15.090, BIC of -9.360, and pseudo-R^2 of 0.270. These criteria describe the fit of the final re-estimation, but they were not directly compared with the values of the full model of 29 observations.

Table 4. Main results of the symptomatic vulnerability models.

Model	n	ITO β (p)	ITA β (p)	ITAmb-R β (p)	Adjustment
Full OLS	29	0,062 (0,773)	0,769 (0,063)	-0,493 (0,310)	R^2 = 0.195; R^2adj = 0.098; p(F) = 0.138
Complete β	29	0,190 (0,805)	3,143 (0,041)	-2,144 (0,229)	AIC = -8.386; BIC = -1.550
Reduced OLS	31	—	0,867 (0,008)	-0,490 (0,286)	R^2 = 0.227; R^2adj = 0.171; p(F) = 0.027
Final reduced β	31	—	3,432 (0,007)	-2,169 (0,213)	AIC = -15.090; BIC = -9.360; pseudo-R^2 = 0.270

Note: AIC and BIC criteria were only formally compared across specifications estimated on the same analytical sample.

To select the Beta structure, the full and reduced specifications were compared on the common sample of 29 families. The reduced model presented AIC = -10.326 and BIC = -4.856, both lower than the values of the full model, AIC = -8.386 and BIC = -1.550. The log-likelihood changed from 9.193 to 9.163, and ITA remained significant in both specifications. The removal of ITO reduced complexity without a relevant loss of fit, so the reduced structure was considered the most parsimonious option.

The sensitivity analysis of the reduced OLS did not show relevant evidence of multicollinearity, with VIF=1.27, or of heteroscedasticity according to Breusch-Pagan (p=0.592). The Shapiro-Wilk test was compatible with residual normality at the 0.05 level (p=0.063), and Ramsey RESET provided no evidence of functional misspecification (p=0.757). Overall, these diagnostics supported the stability of the alternative linear structure, although they do not replace the criteria specific to Beta regression evaluation.

Table 5. Comparison of Beta specifications on one common sample of 29 families.

Indicator	Full β, n = 29	Reduced β, n = 29
Explanatory variables	3	2
Log-likelihood	9,193	9,163
AIC	-8,386	-10,326
BIC	-1,550	-4,856
ITA	p=0,041	p=0,014
Parsimony	Moderate	High

Note: The comparison on one common sample avoids attributing differences in AIC or BIC to changes in the number of observations.

DISCUSSION

The main finding of this study was the consistent association between dietary transformation and family symptomatic vulnerability. This relationship appeared both in the bivariate analysis, as well as in the reduced OLS and the Beta specifications, while occupational transformation and the current environmental indicator contributed to a statistically lesser extent. The convergence of the approaches is not proof of causality, but it does suggest that, within the variability observed among Uru Vilañeque families, the dimension that best discriminated the levels of reported symptoms was that of dietary changes. This is relevant because it shifts the focus from a reading of lake deterioration as an exclusively environmental problem toward the daily mechanisms through which socioecological transformation may be expressed in family life.

The interpretation is consistent with socio-ecological systems frameworks that posit that environmental changes can modify nutrition through simultaneous alterations in resource availability, market access, dependence on marketed foods, and consumption decisions8. The contemporary nutrition transition is characterized by a growing presence of ultra-processed products (9,10) and by transformations of food systems on a global scale11. In communities that historically depended on local ecosystem resources, the loss or reduction of these resources can modify not only which foods are consumed but also how they are obtained, with what frequency, and under what degree of market dependence. The ITA used in this study precisely summarizes the intensity of these family changes, so its association with IVE-S is conceptually plausible.

Latin American evidence reinforces this interpretation. Among Indigenous populations in Chile, the nutritional transition has been associated with profound changes in lifestyle and risk profiles for noncommunicable diseases (12). Although these studies assess different outcomes and contexts, they converge in showing that transformations in subsistence, market, and diet may be accompanied by changes in health. The present study does not measure nutritional status, obesity, or biomarkers; rather, its contribution lies at a different level: it shows that the intensity of household dietary transformation is associated with an index of self-reported symptoms in a community affected by ecosystem degradation.

The findings also engage with experiences of indigenous food systems in Ecuador. The promotion of traditional foods and agroecological strategies can simultaneously contribute to human health and environmental sustainability objectives (13). The Caliata experience highlights the relationship between food sovereignty, biodiversity, local production, and sustainable diets (14). Likewise, the review on indigenous food sovereignty and autonomy posits that maintaining decision-making capacity over production, distribution, and consumption constitutes a form of resistance to processes of food homogenization (15). In Brazil, urbanization and the transition toward more urban lifestyles have been examined in relation to indigenous cardiometabolic risk (16). Taken together, this literature suggests that the food dimension should not be reduced to counting the products consumed; it is part of broader relationships among territory, autonomy, culture, economy, and health.

Occupational transformation presented a considerable intensity, but not an independent association with IVE-S in the final models. From an ecosocial perspective, this difference can be interpreted with caution as a possible separation between structural determinants and closer mechanisms of vulnerability5. A reorganization of livelihoods can modify income, food availability, mobility, and market dependence without necessarily producing a direct and detectable relationship with symptoms in a cross-sectional study. In this sense, ITO could represent a more

structural level of transformation, while ITA would reflect changes closer to everyday practices. This interpretation is consistent with the observed correlation between ITO and ITA, although the design does not allow establishing a causal sequence or affirming statistical mediation.

The environmental dimension requires a particularly cautious interpretation. The original ITAmb marked a historical shift in the use of domestic materials; the analytical question sought to approximate contemporary environmental exposure. The reconstruction of ITAmb-R made it possible to differentiate both concepts, but its exploratory nature limits the confirmatory strength of the results. Furthermore, ITAmb-R records the presence of plastics and disposables in the home and the lack of internal exposure, environmental concentration, microplastics in tissues, and toxicological effects. Studies that have found plastic particles in human blood and reviews on microplastics demonstrate the emerging relevance of the problem, but also the need for specific measurements to attribute biological exposure or health risk17,18. Therefore, the fact that there is no association between ITAmb-R and IVE-S should not be understood as evidence that no environmental risk exists.

From a methodological standpoint, the behavior of ITAmb and ITAmb-R shows the importance of differentiating statistical validity and conceptual validity in composite indicators. An index can produce associations of considerable magnitude and, at the same time, not accurately represent the construct to be analyzed. Principles for constructing composite indicators emphasize that conceptual definition, selection of components, orientation of scales, and aggregation condition the interpretation of the result22. In this study, separating historical change from current presence made it possible to better align the environmental indicator with the analytical question, but it also made it necessary to recognize the exploratory nature of that decision.

The comparison of statistical models provides a second methodological consideration. Beta regression is appropriate for continuous proportional variables and made it possible to model IVE-S while respecting its bounded nature24. However, model selection had to be performed on the same sample so that AIC and BIC were comparable. For this reason, the decision among specifications was based on 29 complete cases, and only afterward was the reduced model re-estimated with 31 observations. This separation between selection and re-estimation prevents attributing to model structure differences that could be due to sample size. The results must, however, be interpreted within the scale of the study: with 32 families, the uncertainty intervals are relevant, and the coefficients should not be automatically extrapolated to other communities.

The implications for public health and socioecological adaptation relate to the need to integrate food, health, and livelihood recovery. In communities whose subsistence was historically linked to a local ecosystem, interventions focused solely on productive recovery may be insufficient if they do not consider access to healthy foods, local production, dietary diversity, cultural relevance, and food autonomy. Planetary health frameworks warn that health and environmental policies are closely connected1,2, while Indigenous literature emphasizes the importance of territory, cultural continuity, and community participation6,7. In the case of Uru Vilañeque, the results suggest that food systems should occupy an explicit place in future adaptation and health surveillance strategies.

The high mean of MBA-R also deserves practical attention, although it has not explained differences in IVE-S between families. When exposure is very frequent in almost the entire population, its ability to discriminate between households may be reduced due to lack of variability. Therefore, the practically zero relationship observed with IVE-S may reflect, at least in part, homogeneity in the presence of the materials evaluated. Future studies could replace indicators of presence with measurements of intensity, frequency of use, specific types of materials, water sources, waste, occupational exposure and, when feasible, environmental or clinical biomarkers. This extension would allow a more precise assessment of whether the environmental dimension contributes to health vulnerability by mechanisms other than those captured in this study.

The results should be interpreted in light of several limitations inherent in the design. The study included 32 families from a single community, which limits statistical precision and generalizability to other Uru peoples or Andean Indigenous communities. The retrospective component relies on participants' memory to reconstruct prior conditions; therefore, recall bias may exist. Diseases and symptoms were reported by families and do not correspond to verified clinical diagnoses or biomarkers. The instrument was preliminarily reviewed with community members, but it did not undergo a formal pilot test or psychometric reliability assessment. Likewise, the equal weighting of components enhances the transparency of the index but assumes that all components contribute equally to the construct.

Such limitations do not entirely eliminate the observed pattern, although they constrain its relevance. The strength of the study lies in the community census, the simultaneous comparison of various socioecological dimensions of the community, and the simultaneous use of different

bivariate and multivariate analyses. Future researchers should conduct longitudinal designs, in which temporality also permits these comparisons, compare communities with different levels or degrees of ecosystem degradation, validate the indices identified in independent samples, and also incorporate measurements that consider dietary intake in greater detail, anthropometry, biomarkers, and environmental assessment in the field. They should also examine mediation or trajectory models when sample size permits, to verify whether occupational changes are linked to health through dietary transformations or other intermediate pathways.

Taken together, the study provides household-scale evidence for a relationship that is often analyzed in aggregate: the link between ecosystem degradation, reorganization of life systems, and health3,4. In Uru Vilañeque, diet appeared to be the dimension most consistently associated with symptomatic vulnerability, while occupation and environment showed different patterns. This heterogeneity supports the idea that the health effects of ecological change are not distributed through a single pathway and that understanding them requires integrating structural processes, everyday practices, and territorial conditions.

Conclusions

In the Uru Vilañeque community, food transformation was the socioecological dimension most consistently associated with symptomatic family vulnerability. The ITA showed a significant bivariate association with IVE-S and retained this relationship in the multivariate models, including the final reduced Beta regression. In contrast, occupational transformation and the current environmental risk indicator did not show statistically significant independent associations in the selected specification. These results indicate that, within the differences observed among the families studied, changes in dietary patterns constituted the component that best distinguished the levels of reported symptoms.

Comparing dimensions makes it possible to introduce nuance into the relationship between ecosystem degradation and health. Occupational changes may be part of a structural reorganization of livelihoods without translating directly into detectable symptomatic differences, whereas the dietary dimension is closer to everyday practices of provisioning and consumption. In turn, the behavior of ITAmb-R showed that a high and relatively homogeneous presence of plastic and disposable materials does not necessarily explain variability in health among households. The separation between historical environmental transformation and current exposure also demonstrates the need to generate indicators conceptually aligned with the research question.

From a practical perspective, the knowledge gained explicitly corroborates the inclusion of food systems in socioecological adaptation and community health techniques. The restoration of livelihoods in environmentally degraded contexts must include not only productive dimensions but also food diversity, access to healthy foods, the promotion of local production, food autonomy, and cultural significance. In the case of indigenous communities that maintain an economic and cultural history closely related to the specific ecosystem, food may become the dimension that combines public health, food security, local development, and socioecological restoration actions.

The conclusions presented below must remain confined to one study characterized by its cross-sectional design and retrospective nature. This is an identification of associative relationships rather than a demonstration of causal relationships. The greatest value of this research lies in accounting for a direction of analysis that merits being diagnosed in longitudinal designs, comparative samples, validation of indices, nutritional objectives, and specific environmental measures. Delving deeper into these lines will allow a more accurate determination of how changes in occupation, diet, and environmental exposure interact after processes of ecosystem degradation have been triggered and which interventions can contribute more effectively to reducing health vulnerabilities of Indigenous populations.

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CONFLICT OF INTEREST

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