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Research Article

Quantitative assessment of urban sustainability perceptions in Lurin, Peru

Ruth Ojeda-Zaga[‡], Vinicio Moya-Almeida[§], Natalia Alvarado-Arias[|], Diana Zuleta-Mediavilla[|]

‡ Escuela de Postgrado, Universidad César Vallejo, Lima, Peru
§ Centro de Investigaciones Aplicadas y Mejoramiento de la Productividad Empresarial (SAPIENS), Facultad de Ingeniería, Universidad Hemisferios, Paseo de la Universidad, 300, 170147, Quito, Ecuador
| Facultad de Arquitectura y Urbanismo, Universidad UTE, Quito, Ecuador

Corresponding author: Vinicio Moya-Almeida (viniciom@uhemisferios.edu.ec), Natalia Alvarado-Arias (nathalia.alvarado@ute.edu.ec)

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Abstract

In the current context, urban centres in Latin America are facing fundamental challenges in their endeavour for Sustainable Development. The focus of this study is the meticulous assessment of the perception of urban sustainability within the Lurín District of Peru. It introduces a system based on urban sustainability indicators, derived from social surveys and implements this system through linear regression models to discern their interrelations. The objective of the research is to quantify and evaluate essential elements linked to the management of natural resources, air and water quality, the advancement of sustainable mobility, education and the well-being of urban residents. By delineating these mathematical and statistical correlations amongst variables pertinent to urban sustainability, this study provides a robust framework for quantitative decision-making in the urban sphere. A methodology for the development of univariable and multivariable models has been demonstrated. Amongst the most important findings, it has been discovered that the variable Environmental Education System (SEA) is perceived as the least important and even negligible within the multivariable models. However, we believe this effect occurs because the impacts of education are perceived in the long term. This article contributes significantly to the academic discourse by providing a more nuanced understanding of the social perception of urban sustainability and its influence on policy formulation and decision-making processes in Latin America.

Keywords

social perception, linear regression model, survey-based studies, sustainable urban development

Introduction

The Sustainable Development Goals (SDGs) advocated by the United Nations (UN) have garnered considerable worldwide attention, particularly in the discourse surrounding the progress of cities in Latin America. These urban areas grapple with intricate issues, including swift population increase, unchecked urban sprawl and the continuous strain on natural resources. Evaluating urban sustainability is imperative to tackle these challenges and guide development towards a more sustainable and equitable future. This entails furnishing decision-makers with quantitative tools, amongst other measures, to facilitate informed choices in pursuing a more equitable and environmentally conscious trajectory. Tackling the SDGs entails promoting a society marked by innovation while fulfilling essential societal needs in harmony with environmental conservation and the well-being of the populace.

Growing cities in Latin America encounter extraordinary challenges in pursuing sustainable development. These urban centres grapple with constrained resources and rapid demographic expansion, placing them at a pivotal juncture. Choices regarding planning and resource distribution wield substantial influence over the well-being of residents and the conservation of the natural environment. As these cities expand and evolve, their impact extends beyond administrative boundaries. These urban zones play a crucial role in the flow of energy and materials within ecosystems. Swift and uncontrolled urbanisation (Mori and Christodoulou 2012) can result in effects that contribute to the depletion of natural assets (Bithas and Christofakis 2006).

The concept of sustainable development is characterised by its commitment to equity, habitability and viability (Tanguay et al. 2010). Certain authors propose embracing a tiered hierarchical approach that recognises the Earth's biophysical boundaries as a comprehensive parameter, encompassing both social and economic dimensions (Fischer et al. 2007, Mori and Christodoulou 2012, Verma and Raghubanshi 2018). Indeed, social sustainability holds considerable importance as well (Moldan et al. 2012). The paramount goal is to fulfil the current and future needs and aspirations of humanity. In this context, sustainable development offers a broad framework for assessing and rationalising urban policies (Pupphachai and Zuidema 2017).

Additionally, the concept of a "comfortable urban environment" is crucial for fostering sustainability. According to Bakaeva et al. (2020), this concept encompasses components that align with the principles of harmonious human development in symbiosis with the natural environment. Their research presents a conceptual model of urban environment comfort, providing a formal description that underscores the importance of integrating human and environmental considerations in urban planning. This model can be instrumental in constructing indicators that measure not only sustainability, but also the quality of urban life.

Progress towards sustainable development is assessed through the utilisation of indicators (Cutaia 2016). These indicators span metrics ranging from Gross Domestic Product (GDP) per capita to more intricate measures, such as childhood immunisation against infectious diseases. They play a crucial role in evaluating sustainability across all its dimensions, furnishing essential information to gauge progress in environmental, economic and social aspects (Böhringer and Jochem 2007). Indeed, some authors highlight that indicators assist policy-makers in comprehending the current state of the environment and identifying priority areas (Pupphachai and Zuidema 2017).

In recent years, numerous studies have focused on the development and application of urban sustainability indicators. For example, Paredes Morán (2023) designed a system of environmental sustainability indicators for urban conservation in the canton of Arenillas, employing qualitative methodologies and the Pressure-State-Response model to identify key issues in public services and urban management. Similarly, Díaz Muñoz et al. (2007) developed a system of indicators to evaluate urban mobility and transportation sustainability in Alcalá de Henares using GIS and surveys. Sotelo et al. (2012) emphasised the importance of harmonised methodologies for the comparability of sustainability indicators, highlighting challenges in using national survey data for regional indicators. Martínez Vitor (2019) evaluated urban indicators' influence on sustainable development in Huancayo, Peru, utilising multiple methodologies to assess population density changes and urban stability. Jacob (2018) analysed urban sustainability in Neuquén through quality of life indices, combining primary and secondary data to gauge economic, social and environmental dimensions. Aerni (2016) discussed urban policies' dynamic nature, advocating for sustainable urban expansion that accommodates migrants and fosters inclusivity. These studies provide essential background and underscore the significance of using indicators to guide urban sustainability efforts.

This article centres on examining "Urban Sustainability Indicators" and their application within the specific context of a developing city in Latin America, namely the District of Lurin in Lima, Peru. To fulfil this objective, the study employs the "Linear Regression Model" based on surveys, representing an innovative approach to urban sustainability research. The selection of indicators should be conducted with a focus on the priorities and goals of stakeholders, including policy-makers, citizens and experts (Huang et al. 1998). Composite indices, amalgamating various indicators, are commonly employed in assessing urban sustainability. Nevertheless, they encounter barriers such as a scarcity of available data, political apathy, governmental resistance to implementation, a lack of consensus on standard indicators and a shortage of comparative analyses spanning diverse disciplines and different urban areas (Moldan et al. 2012). However, the selection and weighting of these indices are of paramount importance and emerge as critical aspects of this process (Tran 2016). It is crucial to bear in mind that the weighting of indicators is subjective and varies based on the priorities of the involved parties (Ahvenniemi et al. 2017). Hence, this article implements a system of indicators based on social surveys, wherein the civilian population participated by evaluating their perception of sustainability in Lurin across various rating categories, facilitating the construction of these metrics.

The "Linear Regression Model" is introduced as a mathematical tool that aids in quantifying data gathered through surveys, serving as inputs for urban sustainability indicators. This model allows for the examination of the relationship between the perception of urban sustainability (dependent variable) and various independent variables, including socioeconomic, demographic or environmental factors. Its utilisation in social surveys within urban environments is notable for its innovation and ability to offer a more profound understanding of how diverse factors influence the population's perception of urban sustainability.

Developing cities in Latin America confront distinctive challenges and opportunities in their journey towards urban sustainability. They grapple with rapid population growth, unplanned urbanisation, inadequate infrastructure and substantial environmental pressures. Effectively addressing these challenges is crucial, not only for current well-being, but also for the well-being of future generations. Urban sustainability emerges as a cornerstone to ensure that these cities offer a high quality of life without depleting their natural resources or degrading their environment.

Surveys play a crucial role in studying social perception in developing cities as they enable the direct collection of data from the local population, capturing their opinions, attitudes and values regarding sustainable urban development. By comprehending the population's perception, planners can formulate policies and strategies that align with the community's needs and desires. Moreover, surveys can assist in identifying disparities in perception amongst different demographic groups, which is essential for fostering more inclusive and equitable planning. The survey-based method has been effectively employed in other similar works in the Latin American context (Alvarado-Arias et al. 2023).

At this juncture, it is important to emphasise that the equations and results presented in this study primarily aim to delineate the relationships as perceived by the respondents, rather than providing a deterministic formula for the relationships under examination.

In summary, the contribution of this article lies in underscoring the importance of urban sustainability indicators and quantifying their perception through the application of a Linear Regression Model, based on survey data in the context of developing cities in Latin America, with a specific focus on Lurin, Peru. This amalgamation of methods and approaches aims to offer a deep understanding of the social perception of urban sustainability and its impact on decision-making and urban policies. Notably, this study stands out as one of the few contributions in the Latin American region that establishes mathematical and statistical relationships between sustainability variables at the urban level

Sustainability indicators

Urban sustainability, an all-encompassing concept that touches on various aspects of city life, requires a comprehensive strategy that considers legal, environmental, economic and social factors. In their work, Leigh and Blakely (2016) explore the significant impact of local regulations on the development of cities, emphasising the role of effective planning and law-making as drivers of urban growth and rejuvenation. This perspective highlights the importance of adaptable policies that respond to evolving urban contexts and foster sustainable methods, from managing urban spaces to conserving cultural and natural assets.

Effective urban legislation is crucial not just for meeting present needs, but also for equipping cities to face future challenges. It strives to maintain harmony amongst economic advancement, social welfare and the protection of the environment (Wu 2013).

The current analysis delves into the methodological structure centred on the sustainable urban development of the Lurin District in Peru. It focuses on the selection and relevance of specific variables, intending to illuminate the interconnected complexity of environmental urban management and its inherent connection to sustainable development.

The chosen variables for this study arise from a comprehensive analysis of Lurin's contextual particularities, considering its challenges and potential opportunities. The selection of variables, including the municipal legal framework, environmental education system, urban management tools and sustainable development, responds to the necessity for a holistic and systemic understanding of urban sustainability (Huang et al. 2015).

In Table 1, detailed information on the studied variables is presented, including their respective dimensions, indicators and, ultimately, sub-indicators.

Independent Variables: Environmental Urban Management Systems

Municipal Legal Framework (Castro Pozo 2007): The municipal legal base, comprising laws and ordinances, sets the normative context for environmental management. The consistency of these norms ensures a coherent regulatory framework, while their continuous updating reflects adaptability to changing dynamics. The responsible use of resources, as a sub-indicator, underscores the importance of promoting sustainable and environmentally conscious practices. In the realm of ordinances, their effectiveness is measured not only by their existence, but by their actual impact. Citizen participation, deemed a fundamental pillar, is directly linked to the legitimacy and effectiveness of these regulations. Constant updating of ordinances is crucial for staying aligned with environmental dynamics and community needs.

Environmental Education System (Castro Pozo 2007): Environmental culture is built through effective educational programmes that aim not only to impart knowledge, but also to foster an active and conscious relationship with the environment. Institutional collaboration, another key indicator, highlights the importance of partnerships between educational entities and relevant stakeholders to strengthen environmental education. Critical awareness of environmental issues, as a sub-dimension, reflects the commitment to a deep understanding of environmental challenges. Student participation, addressing key topics and the development of collective environmental consciousness are essential aspects of this dimension.

Urban Management Tools (Castro Pozo 2007): Urban planning, as a tool, not only provides information on environmental management, but also addresses urban integration as an integral part of sustainable development. Promotion and development tools consider the environment in projects, aiming not just for economic growth, but also for equity in the distribution of benefits. The redistribution of costs and benefits, through strategic resource allocation, fosters citizen participation and promotes transparency and accountability. These tools constitute a complex network that seeks to balance urban progress with environmental preservation and active community participation.

Dependent Variables: Sustainable Development

Social Dimension (UN: WCED 1987, Sen 1999, Chen and Feeley 2014, Bermejo 2014, Miletzki and Broten 2017, Alvarado-Arias 2023): Quality of life, a central aspect of sustainable development, is broken down into various indicators. Urban environmental quality, as a sub-dimension, assesses the physical environment in the district, including green spaces and infrastructure and their contribution to improving the quality of life. Solid waste management, essential for environmental health, becomes a crucial marker of community well-being. Meeting basic needs, focused on access to services and decent and affordable housing, is integrated as an essential component of this dimension. Public policies and development programmes, evaluated for their effectiveness, guide the path towards sustainable and equitable quality of life. Health, as another social dimension, addresses equitable access to health services, the suitability of infrastructure and health education and awareness. These aspects are vital for ensuring the population's health and its ability to contribute to sustainable development.

Economic Dimension (Newman and Jennings 2008): Economic development, a key component of sustainable development, is assessed through public policies and programmes aimed at improving the community's economic situation. The generation of dignified and well-paid jobs, a crucial aspect, intertwines with the promotion of entrepreneurship and the creation of micro-enterprises. Activities and occupations, focused on training and labour formation, corporate social and ethical responsibility and economic contribution to sustainable development, constitute the district's economic fabric. Production with environmental criteria, a subset, ensures that these activities are not only economically viable, but also environmentally responsible.

Table 1.

Studied sustainability variables with their respective dimensions, indicators and sub-indicators.

Sustainability Variables	**Dimension**	**Indicators**	**Sub-indicators**	**Related Studies**
Urban Environmental Management Systems (Independent Variable) (UEMS)	Municipal Legal Framework (OJM)	Municipal Regulations	Consistency of regulations	Castro Pozo (2007), Barton and Grant (2013), Madreimov and Li (2019)
			Regulatory updating	
			Responsible Resource Use	
		Bylaws	Effectiveness of Bylaws	
			Citizen participation	
			Ordinance updates	
	Environmental Education System (SEA)	Environmental Culture	Effectiveness of educational programmes	
			Institutional collaboration	
			Promotion of environmental education	
		Critical Awareness of Environmental Issues	Student involvement	
			Key addressed issues	
			Awareness of environmental problems	
	Instruments of Urban Management (IGU)	Planning Instruments	Information on environmental management	
			Information on management plans	
			Urban integration	
		Instruments for Promotion and Development	Consideration of the environment in projects	
			Equity in benefit distribution	
			Job creation and opportunities	
		Instruments for Cost and Benefit Redistribution	Allocated resources	
			Citizen participation and consultation	

Sustainability Variables	Dimension	Indicators	Sub-indicators	Related Studies
			Transparency and accountability	
Sustainable Development (Dependent Variable) (SD)	Social (DSO)	Quality of Life	Urban environmental quality	UN: WCED (1987), Sen (1999), Kuzmin and Yusin (2011), Chen and Feeley (2014), Bermejo (2014), Miletzki and Broten (2017)
			Solid waste management	
			Public policies and development programmes	
		Satisfaction of Basic Needs (Urban Infrastructure)	Access to basic services	
			Access to decent and affordable housing	
			Public policies and development programmes	
		Health (Urban Infrastructure)	Access to health services	
			Health infrastructure	
			Health education and awareness	
	Economic (DE)	Economic Development	Public policies and development programmes	UN: WCED (1987), Newman and Jennings (2008), Bouton et al. (2012), Bermejo (2014), Ilyichev et al. (2015), Rodrigues and Franco (2020)
			Decent and paid employment	
			Entrepreneurship and micro-enterprises	
		Activities and Occupations (Sustainable Economic Development)	Training and labour education	
			Corporate social responsibility and ethics	
			Economic contribution to sustainable development	
		Production with Environmental Criteria	Sustainable management of natural resources	
			Corporate responsibility and transparency	

Sustainability Variables	Dimension	Indicators	Sub-indicators	Related Studies
			Eco-innovation and clean technologies	
	Environmental-Ecological (DAE)	Climate Change	Knowledge of environmental management plans	Beatley (2000), Holden et al. (2017), Ilyichev et al. (2018), Bokov (2019)
			Climate change mitigation	
			Collaboration in climate change	
		Natural Resources	Protection of natural resources by tourism	
			Coordination amongst tourism authorities and actors	
			Planning and regulation of natural resources	

Environmental-Ecological Dimension (Beatley 2000, Holden et al. 2017, Ilyichev et al. 2018, Bokov 2019): The environmental-ecological dimension stands as an essential pillar of sustainable development. In the face of climate change, the community's knowledge and the effectiveness of measures to mitigate its effects are evaluated, along with effective collaboration between different sectors to tackle this global challenge. Sustainable management of natural resources, as a central element, addresses the responsible use of resources like water and materials. Corporate responsibility and transparency concerning environmental and social impact, along with the promotion of eco-innovation and clean technologies, complete this crucial dimension.

This in-depth analysis highlights the importance of these variables and dimensions in assessing sustainable development in the Lurin District. The interconnection between independent and dependent variables reveals the complexity of factors influencing the path towards sustainable development. This multidimensional approach provides not only a detailed snapshot of the current state, but also serves as a strategic guide for future policies and practices that drive sustainability and improve the quality of life in this region. The detailed analysis of each variable and sub-variable offers a comprehensive understanding that will be crucial for informed decision-making and designing effective strategies for the future sustainable development of the Lurin District.

Lurin District: Introduction to the Case Study

The Lurin District, nestled in the heart of Metropolitan Lima, stands as a microcosm where environmental, cultural and urban aspects of significant importance converge. Its strategic geographical position, marked by the interaction of four distinctive ecosystems, sea, hills, valley and deserts, endows this region with a unique environmental and landscape richness (Velásquez Hidalgo et al. 2023). This distinctive blend of characteristics in Lurin renders it an optimal environment for exploring urban sustainability, following the evolving discourse on globally emphasised sustainable urban development (Keith et al. 2023).

Lurin is not only a witness to ecosystem diversity, but also a custodian of culturally significant historical heritage, epitomised in the sanctuary dedicated to the God Pachacamac. This site holds not only a deep spiritual meaning rooted in local tradition, but is also a tangible testament to the connection between nature and the community's worldview (Municipalidad Distrital de Lurín 2023).

However, this idyllic image of Lurin is threatened by disordered urban expansion, a phenomenon that has triggered a series of critical issues. The loss of environmental and cultural landscapes emerges as a direct consequence of transforming agricultural lands into urbanised areas. This urbanisation process, though potentially indicative of development, has resulted in significant environmental deterioration in Lurin. Specifically, the difficulties in managing water resources within the Lurin River Basin, a crucial source for Lima, exemplify the complex sustainability issues faced by the region (Anonymous 2018).

The research undertaken in this district becomes crucially relevant as it addresses specific critical problems and challenges that impact not only the inhabitants' quality of life, but also the integrity of the natural and cultural resources defining the region's identity.

Critical Problems in Lurin

Deterioration of Natural Resources: Disordered urban expansion has led to the loss of green areas and the degradation of natural ecosystems, affecting biodiversity and environmental quality.

Challenges in Basic Infrastructure: Unplanned growth has put pressure on basic infrastructure, resulting in deficiencies in essential services like water, sanitation and transportation.

Conversion of Agricultural Lands: The transformation of agricultural lands into urban areas not only compromises food security, but also threatens the traditional agricultural practices rooted in the community's history.

Justification for the research in Lurin

Preservation of Cultural and Environmental Heritage: The research aims to highlight the importance of preserving Lurin's cultural and environmental heritage. A detailed understanding of these elements is essential for designing sustainable development strategies that do not compromise the region's unique identity.

Development of Sustainable Solutions: The urgency to propose viable and sustainable solutions to Lurin's identified problems lies in the need to ensure a balance between urban development and environmental conservation. The research acts as a catalyst for creating policies and practices that comprehensively address the existing challenges.

Community Awareness and Participation: The research not only diagnoses problems, but also aims to actively involve the community in identifying solutions. Citizen participation is crucial for ensuring the feasibility and acceptance of proposed measures.

Model for Future Research: The Lurin case study can serve as a valuable model for other regions facing similar challenges in terms of urban development and environmental conservation. The findings and proposed strategies can be extrapolated and adapted to similar contexts, generating impact beyond the geographical confines of Lurin.

The research in the Lurin District presents itself as a critical and timely initiative. Addressing the specific issues of this region, it contributes not only to local improvement, but also to the advancement of knowledge in the field of sustainable urban development, offering valuable perspectives and solutions for a more equitable future in harmony with its natural and cultural environment.

Materials and Methods

Surveys

The methodology employed in surveying the inhabitants of Lurin to examine the relationships between the dependent variable and the independent ones, along with their indicators, reflects a rigorous and scientific approach. The questions posed are available in the Supplementary Files section (Suppl. material 1). The selection of a sample size of 180 individuals from a population of 89,195 inhabitants (Instituto Nacional de Estadística e Informática de Perú 2018), as of the year 2017, adheres to the criteria of a simple random sample.

This approach is appropriate for several reasons. Population and Sample Size: For large populations, a sample of 180 individuals is reasonable to generate statistically significant results, given that the sample is representative of the total population. Simple Random Sampling Formula: The formula employed to calculate the sample size is suitable for studies involving large populations; simple random sampling ensures that each member of the population has an equal probability of being selected, which is crucial for ensuring the validity and reliability of the results. Standard Normal Distribution: The assumption of a standard normal distribution is a common premise in many social and demographic research studies. Non-Probabilistic Samples: The utilisation of a sampling method that does not afford every individual in the population a known chance of inclusion. 95% Confidence Level: A standard confidence level in social and demographic research. (Hernández Sampieri et al. 2014).

The responses to the questions have been structured on a Likert scale ranging from 1 to 5, where 1 indicates total disagreement, 2 disagreement, 3 neither disagreement nor agreement, 4 agreement and 5 total agreement.

The outcomes of the survey will furnish valuable data for comprehending the interactions amongst the selected variables and will facilitate the formulation of pertinent conclusions and recommendations for the sustainable development of the district.

Statistical Tools

To quantify and identify the relationship between the studied variables, the Pearson sample correlation coefficient was used in its form described in Equation 1, where r_{xy} represents the Pearson coefficient, x_i and y_i represent each of the samples and $\bar{x}$ and $\bar{y}$ represent the means of the samples.

(Eq. 1)

$$r_{xy} = \left(\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})\right) \Big/ \left(\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2} \cdot \sqrt{\sum_{i=1}^{n}(y_i - \bar{y})^2}\right)$$

Pearson coefficients close to 1 indicate stronger positive correlations than those close to 0, whereas those close to -1 indicate stronger negative correlations (Bisquerra 1987).

To assess the feasibility of using parametric tests, Kolmogorov-Smirnov tests were applied to test the hypothesis of normality. The test statistic is the maximum difference between the sample and population distribution functions, as shown in Equation 2. A significance level of 5% ($p = 0.05$) was considered. Therefore, the null hypothesis (H_0) will be accepted when $p \geq 0.05$ and the alternative (H_1) when $p < 0.05$.

(Eq. 2).

$$D = \max_{1 \leq i \leq n} |F_n(x_i) - F_o(x_i)|$$

Subsequently, a linear regression analysis was conducted to determine the influence of the independent variables (X_i) on the dependent variable (Y), where β represents the coefficients of adjustment and m denotes the number of independent variables in the system, as shown in Equation 3.

(Eq. 3).

$$Y = \beta_o + \sum_{i=1}^{m} \beta_i X_i$$

Once each of the linear regression models for the different variables has been obtained and calculated, it is interesting to calculate the multiple regression for each dependent variable. This will allow us to obtain an equation as shown in Eq. 4:

(Eq. 4). $Y = \beta_o + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3$

Additionally, the VIF (Variance Inflation Factor) will be calculated. The VIF measures how much the variance of a coefficient increases due to collinearity. A VIF of 1 indicates no correlation between each combination of independent variables, 1 < VIF < 5 indicates a moderate, but generally acceptable correlation, VIF ≥ 5 indicates a high correlation that may suggest multicollinearity issues and VIF ≥ 10 indicates a very high correlation, which is problematic and generally unacceptable. The VIF helps identify multicollinearity problems amongst the independent variables, guiding us to decide whether to remove variables from the model, combine them or apply other solutions.

For statistical calculations, the Matlab® R2023b (MathWorks, Natick, MA, USA) software package was employed.

Studied Variables

In the initial phase of the study, a comparative analysis was conducted between the variables 'Urban Environmental Management System' (UEMS), serving as the independent variable and 'Sustainable Development' (SD), serving as the dependent variable. Subsequently, each of these variables was further decomposed into a series of study dimensions, each encompassing a set of indicators and sub-indicators.

The UEMS variable analyses the dimensions: Municipal legal framework, Environmental education system and Instruments of urban management.

The SD variable analyses the dimensions: Social dimension, Economic dimension and Environmental-ecological dimension.

Results and Discussion

Once the surveys were completed, a total of 180 records were obtained. The details of the participants' sociodemographic and socioeconomic characteristics are shown in Table 2.

Table 2.

Sociodemographic and Socioeconomic Characteristics of the Study Sample.

Characteristics		**Number of samples**	**%**
Age	18 to 25 years old	16	8.9
	26 to 35 years old	36	20.0
	36 to 45 years old	30	16.7
	46 to 55 years old	43	23.9
	Over 55 years old	55	30.6
	Total	180	100.0
Gender	Feminine	114	63.3
	Masculine	66	36.7
	Total	180	100.0
Education	Elementary or lower	24	13.3

Characteristics		Number of samples	%
	Secondary	68	37.8
	Technical or University	85	47.2
	Postgraduate	3	1.7
	Total	180	100.0
Income	Less than 2000 soles per month	146	81.1
	Between 2000 and 3000 soles per month	22	12.2
	Between 3000 and 4000 soles per month	5	2.8
	More than 4000 soles per month	7	3.9
	Total	180	100.0

There is a broad distribution amongst participants regarding their age; however, a significant difference is observed when considering gender, education level and income. On average, the participants are female, with secondary or technical university education and earning less than 2000 soles per month. For reference, the average bank exchange rate from May 2023 to May 2024 (1 year) has been 3.725219 soles per U.S. dollar, according to the Central Reserve Bank of Peru (Banco Central de Reserva del Perú 2024).

Descriptive statistics of the variable 'Urban Environmental Management Systems'

In Table 3, descriptive statistics for the data obtained for the variable 'Urban Environmental Management System' are presented, concerning each of its respective dimensions. The first row includes the statistics for the consolidated data. Fig. 1 illustrates data through graphical representation.

Table 3.

Descriptive statistics of the Urban Environmental Management System (UEMS) variable concerning its dimensions and indicators.

	Min	Max	Mean	Std
Dimensions				
Urban Environmental Management Systems (Consolidated Data)	1.857	4.714	2.673	0.4333
Municipal Legal Framework	1.333	4.833	2.731	0.6739
Environmental Education System	1.833	4.833	3.085	0.5186
Urban Management Tools	1.444	4.556	2.360	0.4607
Indicators				
Municipal Regulations	1.00	4.67	2.661	0.7858
Bylaws	1.00	5.00	2.800	0.7192
Environmental Culture	1.67	4.67	3.311	0.5374

	Min	Max	Mean	Std
Dimensions				
Critical Awareness of Environmental Issues	1.33	5.00	2.859	0.7614
Planning Instruments	1.33	5.00	2.430	0.5498
Instruments for Promotion and Development	1.00	4.33	2.317	0.5825
Instruments for Costs and Benefit Redistribution	1.00	4.33	2.333	0.6332
Abbreviations: Min: minimum value; Max: maximum value; Std: standard deviation.				

For the variable Urban Environmental Management Systems (UEMS), when consolidating the data, a standard deviation of 0.4333 is obtained, with a minimum value of 1.857, a maximum of 4.714 and a mean of 2.673. Upon analysing its dimensions independently, 'Municipal legal framework' and 'Urban management instruments' exhibit the highest and lowest standard deviations, with values of 0.6739 and 0.4607, respectively. Additionally, the 'Urban management instruments' dimension showed the highest number of outliers, all close to its maximum value.

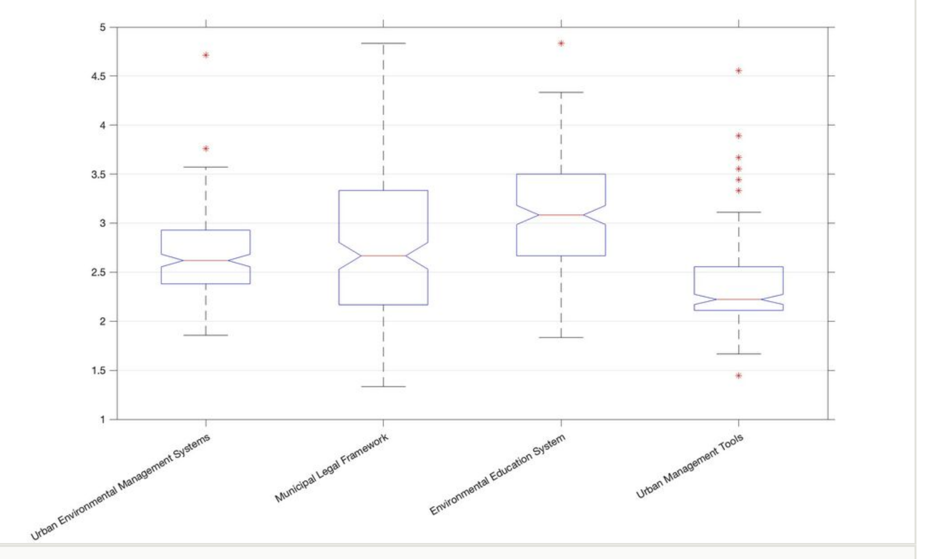

Figure 1.

Box and whisker plot of the Urban Environmental Management Systems variable and its respective dimensions.

With the presented data, it can also be mentioned that respondents consider 'Urban management instruments' to be the least performing, as it has the lowest mean and standard deviation amongst the dimensions studied. This implies unanimity in perceiving it as the most neglected dimension, demanding greater attention from decision-makers. In contrast, the 'Environmental education system' has the highest mean, while displaying an intermediate standard deviation. Consequently, respondents believe this dimension is in the best condition. Nevertheless, it is noteworthy that the difference in means between these two dimensions is 0.725 and the overall mean is 2.673. Thus, respondents agree that the UEMS variable is characteried by low performance.

It is also interesting to study the weight of each indicator on the UEMS variable. Table 3 displays the specific statistics for each indicator. Fig. 2 illustrates data through graphical representation.

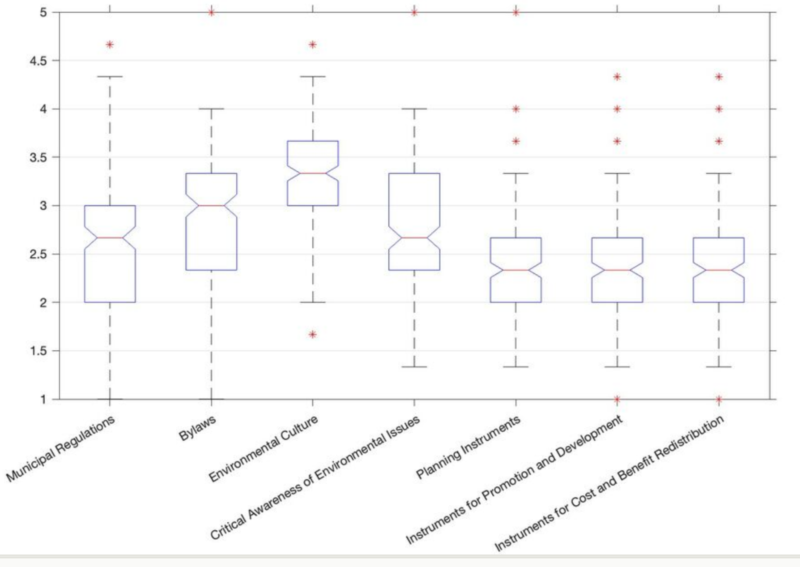

Figure 2.

Box and whisker plot of the indicators of the Urban Environmental Management Systems variable.

The indicator 'Environmental Awareness' has the highest mean (3.311) and the lowest standard deviation (3.311), indicating unanimous agreement amongst respondents that it is the indicator in the best condition. On the contrary, the indicators 'Planning instruments', 'Instruments for Promotion and development' and 'Instruments for Costs and Benefit Redistribution' have the lowest, albeit close, means (2.430, 2.317, 2.333, respectively) and their standard deviations (0.5498, 0.5825, 0.6332, respectively) are also amongst the lowest. Such unanimity illustrates that these three indicators are the least performing and, hence, merit greater attention from decision-makers.

Descriptive statistics of the variable 'Sustainable Development'

In Table 4, descriptive statistics for the data obtained for the variable 'Sustainable Development' are presented concerning each of its respective dimensions. The first row includes the statistics for the consolidated data. Fig. 3 illustrates data through graphical representation.

Table 4.

Descriptive statistics of the Sustainable Development (SD) variable concerning its dimensions and indicators.

	Min	Max	Mean	Std
Dimensions				
Sustainable Development (Consolidated Data)	1.458	3.750	2.269	0.5274
Social dimension	1.222	4.000	2.183	0.5872
Economic dimension	1.333	4.000	2.295	0.5953
Environmental-Ecological dimension	1.167	4.167	2.357	0.6076
Indicators				
Quality of Life	1.67	4.67	2.974	0.6773
Satisfaction of Basic Needs	1.00	3.67	1.850	0.6961
Health	1.00	4.67	1.726	0.7196
Economic Development	1.00	4.00	2.369	0.7302
Activities and Occupations	1.00	4.00	2.326	0.7474
Production with Environmental Criteria	1.00	4.00	2.191	0.6032
Climate Change	1.00	4.33	2.389	0.6077
Natural Resources	1.00	4.00	2.324	0.7691
Abbreviations: Min: minimum value; Max: maximum value; Std: standard deviation.				

For Sustainable Development (SD), when consolidating the data, a standard deviation of 0.5274 is obtained, with a minimum value of 1.458, a maximum of 3.750 and a mean of 2.269. Analysing the three dimensions independently, both means and standard deviations are very close, with relatively low values, indicating that the weights of each dimension contribute similarly to the total variable. Additionally, respondents unanimously consider that all three dimensions face issues.

It is also interesting to study the weight of each indicator on the Sustainable Development (SD) variable. Table 4 displays the specific statistics. Fig. 4 illustrates data through graphical representation.

Upon analysing the indicators independently, it is observed that 'Health' exhibits the poorest performance, having the lowest mean (1.726) and a significant accumulation of data below the score of 2. Following this, 'Satisfaction of Basic Needs' shows the lowest-performing data with a mean of 1.850. Subsequently, the indicators 'Economic income', 'Activities and Occupations', 'Production with Environmental Criteria', 'Climate Change' and 'Natural Resources' all display similar patterns, with most of their data falling between scores 2 and 3. This suggests a widespread dissatisfaction amongst respondents. Nevertheless, it is interesting to note that 'Quality of Life' has a relatively higher mean and accumulation of results compared to other indicators, indicating a potential sense of attachment to the location.

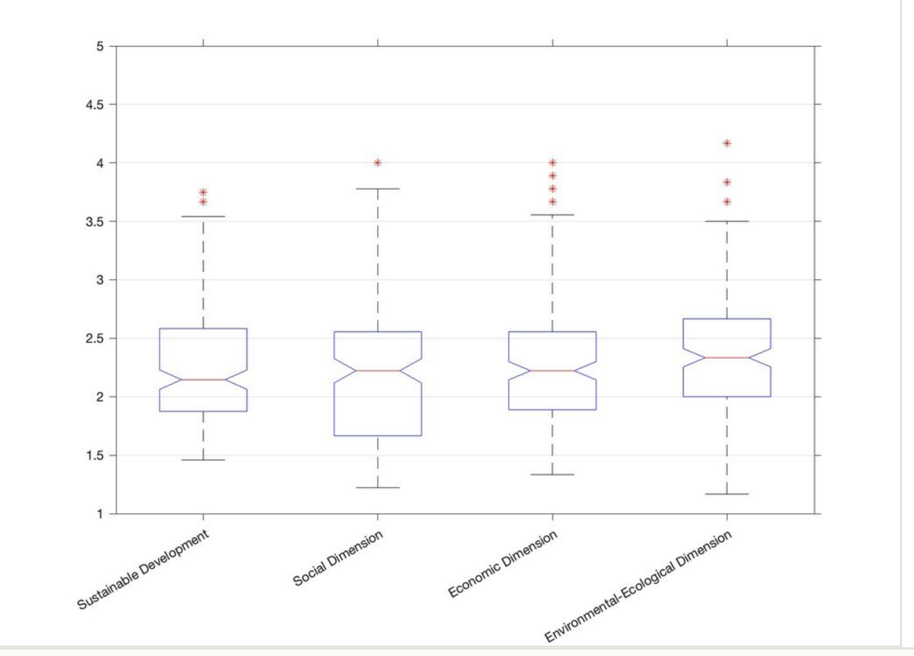

Figure 3.
Box and whisker plot of the Sustainable Development variable and its respective dimensions.

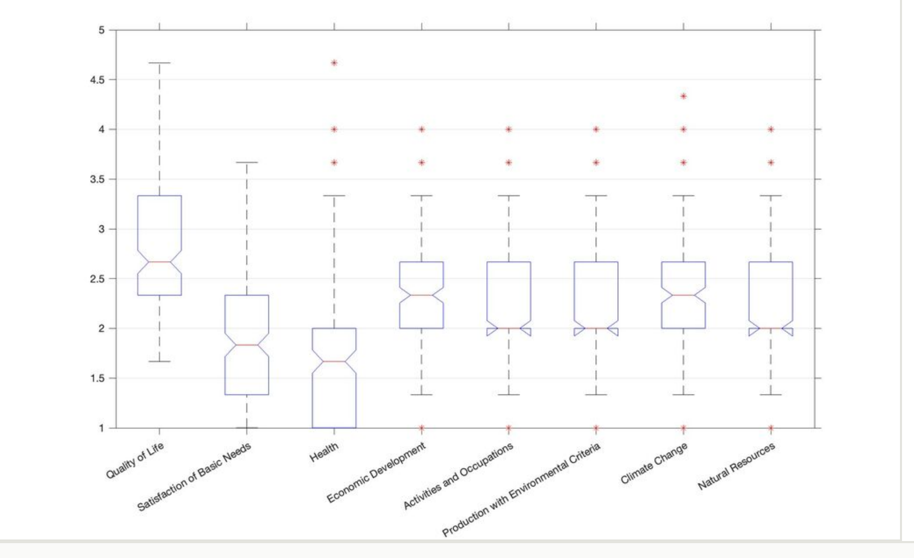

Figure 4.
Box and whisker plot of the indicators of the Sustainable Development variable.

Linear regression equation between the variables SD and UEMS

To analyse the use of the Pearson coefficient and linear regression, the Kolmogorov-Smirnov normality test was conducted. A p-value of 0.053 was obtained for the variable UEMS (Urban Environmental Management System) and a p-value of 0.066 for the variable SD (Sustainable Development). Thus, the null hypothesis, which posits that both variables follow a normal distribution, is accepted. Therefore, parametric tests are employed to determine the causal relationship between them.

Due to the presence of a single independent variable, Equation 3 takes the form of Equation 5, with β_0 representing the intercept and β_1 as the slope of the line.

(Eq. 5). $Y = \beta_o + \beta_1 X$

Subsequently, we aim to establish the relationships between the independent variable (UEM) and the dependent variable (SD). For this, we will begin with a hypothesis test where: Ho ($\beta_1 = 0$) states 'UEMS does not have a positive effect on SD in the Lurin District' and H1 ($\beta_1 \neq 0$) states 'UEMS has a positive effect on SD in the Lurin District', with a significance level of 5%.

Quantifying the correlation and coefficient of determination of the model yields the observed data in Table 5. Thus, it is inferred that there is a high positive correlation (R = 0.656) between the variables studied. Additionally, the predictor variable UEMS explains 43% (R^2 = 0.430) of the behaviour of the SD variable.

Table 5.

Correlation and coefficient of determination of the linear regression model.

Model	**R**	**R^2**	**$R^2_{adjusted}$**	**SE**
1	0.656[a]	0.430	0.427	2.974

[a] Predictors: (Constant), Urban Environmental Management System

Abbreviations: R: Pearson correlation coefficient; R^2: coefficient of determination; Max: maximum value; SE: standard error.

Table 6.

ANOVA between the variables UEMS and SD.

Model		**Sum of squares**	**df**	**Mean Square**	**F**	**Significance**
1	Regression	21.399	1	21.399	134.195	0.000
	Residual Total	28.384	178	0.159		
	Total	49.783	179			

[a] Dependent Variable: SD
[b] Predictors: (Constant), UEMS

Abbreviations: df: degrees of freedom.

Subsequently, it is important to determine if there is a linear dependency between both variables. To achieve this, an ANOVA is conducted to obtain the F-statistic and assess the significance value (p). If p = 0, it is concluded that there is a linear relationship between the dependent and independent variables. Upon performing the ANOVA analysis, as seen in Table 6, it is concluded that, with a significance value of 0.000, there is indeed a linear relationship between the variables and, therefore, it is appropriate to use the proposed linear regression model.

With this information, the simple linear regression model is performed, as detailed in Table 7, where it is inferred that β_0 = 0.187 and β_1 = 0.798. However, in the case of β_0, having a significance value of 0.469, this coefficient is excluded. Thus, the linear model relating the variables can be observed in Equation 6.

(Eq. 6).
$$SD = +0.798 * UEMS$$

With this equation, we can conclude that the implementation of a UEMS has a positive impact on SD in the Lurin District. In Fig. 5, the scatter plot of UEMS versus SD is shown, along with a comparison to the linear regression model given by Equation 6. The methodology could be extended to all other relationships between variables and indicators and their respective linear regression model equations, described later.

Table 7.

Statistics of the simple linear regression model.

Model		Unstandardised Coefficients		Standardised Coefficients	**t**	**Significance**
		B	**Standard Error**	**Beta**		
1	(Constant)	0.135	0.187		0.726	0.469
	UEMS	0.798	0.069	0.656	11.584	0.000
[a] Dependent variable: SD						

Linear regression equations between the indicators SD and UEMS

Following the method explained in the previous paragraphs, we proceeded to relate the variables UEMS and SD from the perspective of their respective indicators. Table 8 provides a summary of the linear regression models' equations, along with their respective coefficients of determination and Pearson correlation.

(Eq. 7).
$$DSO = 0.721 + 0.536 * OJM$$

(Eq. 8).
$$DE = 0.824 + 0.539 * OJM$$

(Eq. 9).
$$DAE = 1.114 + 0.444 * OJM$$

(Eq. 10).
$$DSO = 0.852 + 0.432 * SEA$$

(Eq. 11).
$$DE = 1.193 + 0.357 * SEA$$

(Eq. 12).
$$DAE = 1.781 + 0.187 * SEA$$

(Eq. 13).
$$DSO = 0.575 + 0.682 * IGU$$

(Eq. 14).
$$DE = 0.802 + 0.633 * IGU$$

(Eq. 15).
$$DAE = 1.116 + 0.526 * IGU$$

The summary of the linear regression model equations offers enlightening insights into the intersection between the analysed variables, the uniqueness of the Lurin environment and the challenges it faces on its path towards sustainable development. The combination of the Municipal Legal Framework (OJM), Environmental Education System (SEA) and Urban Management Instruments (IGU) reveals an intricate web of influences shaping the social, economic and environmental-ecological dimensions in this specific region.

Table 8.

Linear regression equations between the indicators.

Independent variable	**Dependent variable**	**R**	**R^2**	**SE**	**p-value**	**Regression model**
Municipal Legal Framework (OJM)	Social dimension (DSO)	0.615	0.378	0.464	4.36×10^{-20}	Eq. 7
	Economic dimension (DE)	0.610	0.372	0.473	1.03×10^{-19}	Eq. 8
	Environmental-ecological dimension (DAE)	0.492	0.242	0.530	2.2×10^{-12}	Eq. 9
Environmental Education System (SEA)	Social dimension (DSO)	0.381	0.145	0.544	1.29×10^{-7}	Eq. 10
	Economic dimension (DE)	0.311	0.097	0.567	2.12×10^{-5}	Eq. 11
	Environmental-ecological dimension (DAE)	0.159	0.025	0.602	0.0328	Eq. 12
Urban Management Instruments (IGU)	Social dimension (DSO)	0.535	0.286	0.498	1.06×10^{-14}	Eq. 13
	Economic dimension (DE)	0.490	0.240	0.521	3.06×10^{-12}	Eq. 14
	Environmental-ecological dimension (DAE)	0.398	0.159	0.559	3.04×10^{-8}	Eq. 15

Abbreviations: R: Pearson correlation coefficient; R^2: coefficient of determination; SE: standard error.

The high R^2 value in the social dimension (37.8%) suggests that the OJM plays a pivotal role in improving quality of life and meeting basic needs in Lurin. This outcome not only reflects the importance of a clear and effective legal framework, but also indicates that municipal policies significantly impact social cohesion and the overall well-being of the population. In the economic dimension, the OJM remains a crucial driving force, with an R^2 of 37.2%. The positive connection underscores the capacity of the legal framework to foster sustainable economic development in Lurin, highlighting the need for clear regulations that promote economic equity and efficiency. Regarding the environmental-ecological dimension, the R^2 of 24.2% underscores the MLF's contribution to the sustainable management of natural resources in the district. The positive relationship indicates that a robust legal framework can be a catalyst for more responsible environmental practices and biodiversity preservation.

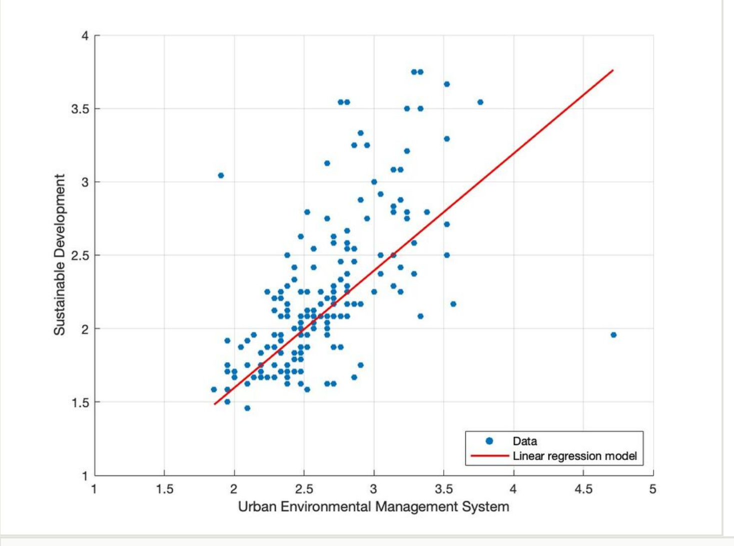

Figure 5.

Scatter Plot of UEMS vs. SD compared with the Linear Regression Model.

The analysis of the social dimension reveals that the SEA, with an R^2 of 14.5%, plays a vital role in enhancing the quality of life and social awareness in Lurin. The positive connection suggests that environmental educational programmes can positively influence perception and social cohesion, albeit more moderately than the OJM. In the economic dimension, the SEA shows a more subtle influence, with an R^2 of 9.7%. While the positive relationship indicates that environmental education can contribute to economic aspects, its direct impact may be overshadowed by other variables in Lurin's economic context. In the environmental-ecological dimension, the SEA, with an R^2 of 2.5%, appears to have a limited connection with sustainable practices in the region. Although the relationship is positive, the low R^2 proportion suggests that additional factors may be more significantly influencing this dimension.

In the social dimension, the IGUs exhibit considerable influence, with an R^2 of 28.6%. This finding highlights the importance of a comprehensive approach to urban management in improving social cohesion and quality of life in Lurin. The economic dimension reflects a substantial impact on the IGUs, with an R^2 of 24.0%. This underscores the effectiveness of urban management tools in driving sustainable economic development, advocating for urban projects that are not only efficient, but also equitable. In the environmental-ecological dimension, the IGUs show significant influence, with an R^2 of 15.9%. This highlights that effective urban management is directly linked to more sustainable practices, pointing towards urban planning that considers environmental impact.

Multiple regression of the dimensions of UEMS concerning each of DS

A multiple regression was subsequently performed, as observed in Equation 4, following the same methodology previously explained. The results obtained are shown in Table 9. The obtained equations correspond to Equations 16, 17 and 18.

(Eq. 16). $DSO = 0.098 + 0.395 \cdot OJM + 0.031 \cdot SEA + 0.386 \cdot IGU$

(Eq. 17). $DE = 0.460 + 0.451 \cdot OJM - 0.065 \cdot SEA + 0.340 \cdot IGU$

(Eq. 18). $DAE = 1.096 + 0.420 \cdot OJM - 0.207 \cdot SEA + 0.319 \cdot IGU$

Table 9.

Statistics of Multiple Regression Models.

		Estimate	SE	t	p-value (per variable)	VIF	Adjusted R^2	p-value (multivariable model)
DSO Eq. 16	(Intercept)	0.098	0.221	0.443	0.658		0.442	8.71×10^{-23}
	OJM	0.395	0.061	6.491	9.392×10^{-10}	1.561		
	SEA	0.031	0.075	0.413	0.682	1.415		
	IGU	0.387	0.083	4.648	6.555×10^{-6}	1.364		
DE Eq. 17	(Intercept)	0.460	0.230	2.00	0.047		0.413	6.98×10^{-21}
	OJM	0.451	0.063	7.135	2.425×10^{-11}	1.561		
	SEA	-0.065	0.078	-0.828	0.409	1.415		
	IGU	0.341	0.086	3.939	1.180×10^{-4}	1.364		
DAE Eq. 18	(Intercept)	1.096	0.259	4.236	3.661×10^{-5}		0.286	1.87×10^{-13}
	OJM	0.420	0.071	5.897	1.853×10^{-8}	1.561		
	SEA	-0.207	0.088	-2.352	1.853×10^{-8}	1.415		
	IGU	0.320	0.097	3.282	1.853×10^{-8}	1.364		

All VIF values are close to 1.5, indicating that there are no significant multicollinearity issues amongst the independent variables in these models. This allows us to assume that the coefficient estimates are reliable and not unduly inflated by strong correlations between the predictor variables.

In Fig. 6, we can observe the graphical representation of the experimentally obtained data versus the data predicted by the regression model for the variable DSO (Eq. 16). In Suppl. materials 2, 3, the graphical representation for DAE and DE variables is shown. A y=x reference line has been added for better understanding.

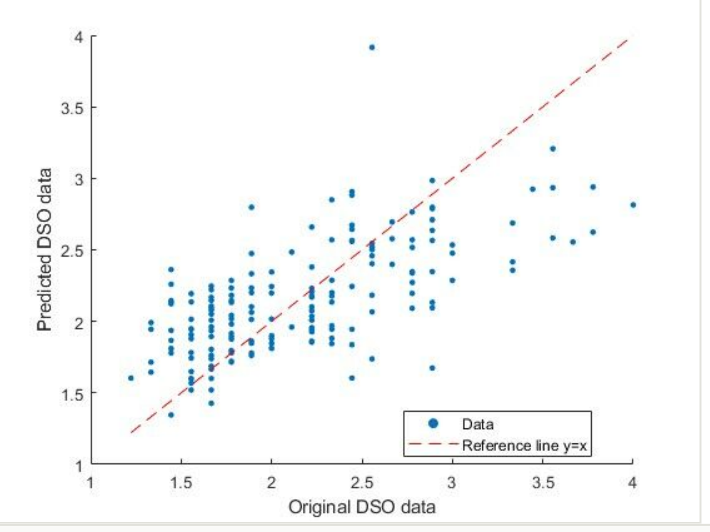

Figure 6.

Comparison graph between experimental data and predicted data through multiple regression model for the dependent variable DSO.

From the observations in Table 9 for the variable DSO, we can conclude that, since the p-value for Environmental Education Systems (SEA) is 0.681, it is not statistically significant. Therefore, its influence on the Social Dimension (DSO) of Sustainable Development is less than that provided by Urban Management Instruments (IGU) and Municipal Legal Framework (OJM). Consequently, it can be concluded that SEA can be removed from the model without detriment.

Upon closer analysis, it is striking, yet not surprising, that the inhabitants of Lurin consider the investment in education to be of lesser influence compared to investments in urban management and legal framework. The latter yield more visible short-term results, whereas educational investments, although necessary, take longer to show their best outcomes. Considering this and despite the statistical evidence, we believe that other indicators should be taken into account in future studies to reinforce the weight of SEA within the model.

Despite those mentioned earlier, as the p-value of the multivariable model is 8.71×10^{-23}, thus the model can be considered valid. Additionally, the adjusted R^2 was chosen because it better represents the accuracy of multivariable models. For DSO, 0.442 is considered acceptable since R^2 values tend to be relatively low in social perception studies.

For the variable DAE, we observe that OJM and IGU behave similarly to the previous case for DSO. However, for SEA, it is within the 5% significance level in this instance, albeit with a negative trend.

When we analyse the model corresponding to DE, a similar case to that found in DSO arises, as the p-value of SEA is 0.409, making it not statistically significant for the model. However, we emphasise that, since this concerns educational topics, the effects introduced by this variable into the model may become apparent in the long term. Therefore, the current perception is severely diminished or undervalued by the respondents.

In general, for all models, we recommend seeking and including more potentially relevant variables that may help explain greater variability in the model.

Conclusions

The dynamic interrelation between sustainability variables and the dimensions of sustainable development in Lurin reveals a series of key implications that can guide future actions and development policies in the district.

Need for Inter-Institutional Coordination: The significant influence of the Municipal Legal Framework underscores the importance of coordinating efforts between government entities and civil society to strengthen and update municipal regulations. Effective collaboration amongst various institutions, including those related to education and urban management, can maximise the positive impact on social, economic and environmental dimensions.

Relevance of Tailored Environmental Education: Despite its moderate impact, the Environmental Education System remains crucial for improving quality of life and social awareness. Tailoring educational programmes to address the district's specific needs and environmental challenges is recommended. Innovative strategies, such as active student involvement in identifying local environmental issues, can strengthen the connection between education and critical awareness.

Integrated Urban Management for Sustainable Development: The effectiveness of the Urban Management Instruments highlights the importance of comprehensive urban planning. The implementation of policies that promote equity in benefit distribution, environmental consideration in projects and citizen participation is suggested. Coordination amongst urban stakeholders and transparency in resource allocation are critical aspects for ensuring the success of integrated urban management.

Challenges and Opportunities for Sustainable Development: The loss of environmental and cultural landscapes in Lurin underscores the need to balance urban growth with the preservation of natural and cultural heritage. The conversion of agricultural lands to urban areas presents significant challenges, but also opens opportunities for implementing sustainable development practices that protect and restore natural resources.

Importance of Community Participation: Citizen participation emerges as a crucial component for the success of the analysed variables. Encouraging active community collaboration in decision-making and policy implementation is recommended to ensure diverse perspectives are represented.

Future Perspectives: The path towards sustainable development in Lurin requires a comprehensive and long-term approach. Conducting periodic assessments to measure progress and adjust strategies as necessary is suggested. Additionally, seeking external funding and partnerships can strengthen the implementation of sustainable projects and address specific challenges identified in this study.

In summary, this analysis provides a solid framework for informed decision-making in Lurin, outlining key strategies for advancing towards a future where sustainability is the pillar of its identity and prosperity.

Author contributions

Conceptualisation, R.O.Z., V.M.A. and N.A.A.; methodology, R.O.Z., V.M.A. and N.A.A.; software, V.M.A.; validation, R.O.Z. and V.M.A.; formal analysis, R.O.Z., V.M.A., N.A.A. and D.Z.M.; investigation, R.O.Z., V.M.A.; resources, R.O.Z., V.M.A. and N.A.A.; data curation, R.O.Z., V.M.A., N.A.A. and D.Z.M.; writing—original draft preparation, V.M.A., N.A.A.; writing—review and editing, V.M.A., N.A.A. and D.Z.M.; visualisation, V.M.A.; supervision, R.O.Z. and V.M.A.; project administration, V.M.A.; funding acquisition, V.M.A. and N.A.A. All authors have read and agreed to the published version of the manuscript.

Conflicts of interest

The authors have declared that no competing interests exist.

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Supplementary materials

Suppl. material 1: Details of questions regarding the surveys conducted for the research doi

Authors: ROZ
Data type: Questions Surveys
Brief description: Detailed description of each of the questions asked, including their indicators, sub-indicators, scales etc. Since this is original information, it is provided in Spanish, the original language of the work.
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Suppl. material 2: Comparison graph between experimental data and predicted data (DAE) doi

Authors: VAMA
Data type: image
Brief description: Comparison graph between experimental data and predicted data through a multiple regression model for the dependent variable DAE.
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Suppl. material 3: Comparison graph between experimental data and predicted data (DE) doi

Authors: VAMA
Data type: image
Brief description: Comparison graph between experimental data and predicted data through a multiple regression model for the dependent variable DE.
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