Assessment of the sustainability of water and sanitation systems in rural villages through indicators. An experience of conceptual design and applied software in Peru

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Abstract. **The main objective of the present research was to apply the sustainability approach to the management of sanitation systems carried out by community-based organizations (JASS) in rural villages with the support of the district municipality. Given the limited capacity of rural district municipalities to supervise, monitor and provide technical assistance to these community organizations, a proposal for municipal technical assistance (MTA) was developed based on an index for the evaluation of the sustainability of rural sanitation systems (IESSSR). Such index allowed to evaluate not only the sustainability, but also to identify the deficient and unsustainable aspects of each system, which was crucial to develop improvement plans for each JASS.**

A first measurement of the sustainability of the two intervened systems was made – of the rural population centres of Palmira and Dos de Mayo, both located in the district of Leymebamba –, a general sustainability index (IGS) for JASS Palmira of 3.010 (Stable) and for Dos de Mayo of 2.997 (Unstable) were obtained. In the second measurement, using 5 dimensions, 18 factors, 48 variables and 66 indicators, the IGS of JASS Palmira was 3.179 (Stable) and that of Dos de Mayo was 3.233 (Stable). The reliability of the index was analysed using the test-retest method by comparing the May and December measurements of each JASS, obtaining a Pearson correlation index of 0.631 for Palmira and 0.602 for Dos de Mayo.

Finally, the index was developed into a software application to facilitate the storage, processing, monitoring, evaluation and presentation of the information, and is currently being tested in the municipality of Leymebamba.

Keywords: assessment, rural, sanitation, **sustainability.**

I. INTRODUCTION

In rural areas, the sustainability of water and sanitation systems is not duly considered in the management carried out by community organizations known as the Sanitation Services Administration Board (JASS), nor in the technical assistance plans of district municipalities, due to the lack of technical capacities, human resources, management tools and training materials**.** Likewise, in rural areas there is a 24.7% gap in access to water, while the quality gap is 96.8%, and only 3.2% of the rural

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population consumes water with an adequate level of chlorine [1].

Thus, the drinking water offered by most community organizations is not healthy, safe, continuous, or of full social access; there is no adequate solid waste management, wastewater is not treated, and the natural sources that provide this resource are not protected, so the integral sustainability of these systems is not ensured According to current regulations, district municipalities are responsible for providing technical assistance, training, and supervision to the JASS in the management of water and sanitation services to the population in their jurisdiction. However, the fulfillment of these functions requires a comprehensive proposal that is currently lacking and, therefore, there is no comprehensive and sustainable management of rural sanitation systems [2].

Taking this context into account, this research proposed to develop a municipal technical assistance model. The rural sanitation systems selected for intervention were those of the towns of Palmira and Dos de Mayo, rural localities whose combined population is equivalent to 49% of the district's inhabitants and 76% of the rural inhabitants. The model consisted of an instrument to identify and evaluate the sustainability of the main factors, variables and indicators of the systems in their Social, Economic, Environmental, Environmental, Social, Economic and Environmental dimensions.

This model has been called the Index for the Evaluation of the Sustainability of Rural Sanitation Systems (IESSSR). Based on the results obtained, we expect to formulate improvement plans for each system. We applied the index in both systems in May and December 2022 and the results were compared. Finally, to operationalize the use of the index and carry out the technology transfer, the IESSSR was digitally developed in a software prototype that is installed in the municipality of Leymebamba [3].

The methodological contribution of this research consists in the conceptualization and operationalization of sustainability through the generation of a set of dimensions, factors, variables, indicators and rubrics that concretize these concepts of sustainability in observable and measurable aspects on which it can act with improvement plans, technical assistance and training. The IESSSR will help the municipality to periodically evaluate the JASSs in its area and, according to the results, identify, prioritize and organize technical assistance and training to design and implement improvement plans with all its JASSs. On the other hand, it will also serve the community organizations as a technical and comprehensive guide to the aspects to be considered in integrated and sustainable management.

II. MATERIALS AND METHODS

The research was carried out in the district of Leymebamba, province of Chachapoyas, department of Amazonas. Leymebamba has an estimated total population of 3,620 inhabitants, 36% of whom live in urban areas and 64% in rural areas, distributed among 57 villages. The Palmira JASS, which provides services to approximately 646 inhabitants, and the Dos de Mayo JASS, which serves a population of 1,132 inhabitants, were selected as the rural sample. Both populations serve 49% of the district's inhabitants and 76.7% of rural inhabitants [1].

The research was carried out using a quasi-experimental methodological design in which the IESSSR was applied twice in each of the sanitation systems intervened. The first version of the index was developed based on bibliographic research and the review of the monitoring and registration instruments of the governing bodies such as the Ministry of Housing, Construction and Sanitation (MVCS) and the National Superintendence of Sanitation Services (SUNASS). This first index, which considered 120 indicators, was validated by expert judgment and allowed the selection of the clearest, most coherent and relevant indicators according to the weighting given on a Likert scale from 0 to 3. As a result of this expert judgment, the content and construct validity of the instrument was confirmed, taking the average 2.4 as the minimum score to maintain an indicator, the number of dimensions remained at 5, but the number of factors was adjusted to 18, the number of variables decreased to 55 and the number of indicators dropped to 76. This first version was applied in May 2022 in both JASS [3].

The final version of the index was applied in December 2022, also in both systems, it considered 66 indicators, being constituted as follows:

- Social Dimension: 3 factors (Satisfaction of basic needs of the population, Perception of the population on the service and Health behaviors of families), 9 variables and 14 indicators.
- Economic Dimension: 3 factors (Economic profitability of the system, Economic situation of the users and Financing of the system), 6 variables and 6 indicators.
- Environmental Dimension: 3 factors (Natural availability of water resources, Natural quality of water resources and Threats and impacts to the system and biodiversity), 8 variables and 9 indicators.
- Technical Dimension: 6 factors (system productivity, water and sanitation system infrastructure, drainage and sewerage system infrastructure, supply system operation, drainage, sewerage and WWTP system operation, and system maintenance), 11 variables and 23 indicators.
- Institutional dimension: 3 factors (community participation in the management, Sanitation service provider and Governance and institutional articulation), 14 variables and 14 indicators.

To evaluate the sustainability of each of the indicators, a rubric was developed on an increasing scale from 1 to 5, where the lowest number -1- means less sustainability and the highest number -5- means more sustainability. The index allows the values obtained in each of the indicators to be averaged according to factor and dimension. The sustainability scale proposed by Sepúlveda (2008) was used to classify sustainability, so that, obtaining between 0-1 means a state of collapse; obtaining between 1.1 and 2

means a critical state; obtaining between 2.1 and 3 indicates a situation of instability; obtaining between 3.1 and 4 shows stability; finally, obtaining between 4.1 and 5 means an optimal state of sustainability, as shown in Table 1. [4]-[5].

TABLE 1. SUSTAINABILITY LEVELS

0.0 - 1	1.1 - 2	2.1 - 3	3.1 - 4	4.1 - 5
Collapse	**Critical**	**Unestable**	**Sstable**	**Optimal**

The reliability of the IESSSR was estimated using the test-retest method and Pearson's coefficient to compare whether the results are equivalent at the two points in time when the index was applied and its results can be considered reliable. In the case of JASS Palmira, the Pearson correlation index comparing the two moments in which it was applied (May 2022 and Dec 2022) and calculated with the EXCEL program was: Pearson 0.631. This value indicates an average positive reliability of the index applied in Palmira and a correlation of this type can be plotted. In the case of JASS Dos de Mayo, the Pearson correlation index calculated with the EXCEL program was: Pearson 0.602, which also indicates an average positive reliability of the index applied in Dos de Mayo.

In addition to the IESSSR, two instruments were developed to collect and process information from the JASSs involved: a survey of the population and a structured interview with the leaders of the Palmira and Dos de Mayo JASSs. In the case of the population survey instrument, validity was obtained from expert judgment, since the instrument consisted of a survey that - based on the indicators linked to the social dimension and institutionalism - turned them into a 19-question survey whose options were similar to the Likert scale used in the index, taking MODA as a representative trend. The reliability of this instrument was verified by comparing the application carried out in Palmira with that carried out in Dos de Mayo, which, being populations with very similar characteristics, yielded very similar results. The responses obtained were subjected to Pearson's correlation coefficient, obtaining a value of 0.952830642, very close to 1, which indicates a high correlation and therefore a high reliability in the results of its application.

In the case of the structured interview instrument for the JASS leadership, validity was also obtained from expert judgment, since the instrument consisted of a survey that - taking the indicators of the index - converted them into a structured interview of 47 questions, from whose answers the information for entering the IESSSR was obtained.

The reliability of this instrument was verified by comparing the application in Palmira with that carried out in the reliability of this instrument was verified by comparing the application carried out in Palmira with that carried out in Dos de Mayo, which, being populations with very similar characteristics, yielded very similar results. The responses obtained were subjected to Pearson's correlation coefficient, obtaining the following coefficient 0.86652830642, quite close to 1, which indicates a high correlation and therefore a good reliability in the results of its application.

III. RESULTS AND DISCUSSION

The evaluation of the two intervened systems, using the IESSSR in the Palmira and Dos de Mayo systems, is shown in Table 2 below.

In the case of the two-stage evaluation carried out in Palmira, in the first stage an IGS of 3.010 was achieved, reaching the STABLE level, but with several factors at the UNSTABLE level and even two of them at the CRITICAL level. The averages of values by factors allow us to elaborate the following radial graph, shown in Fig. 1.

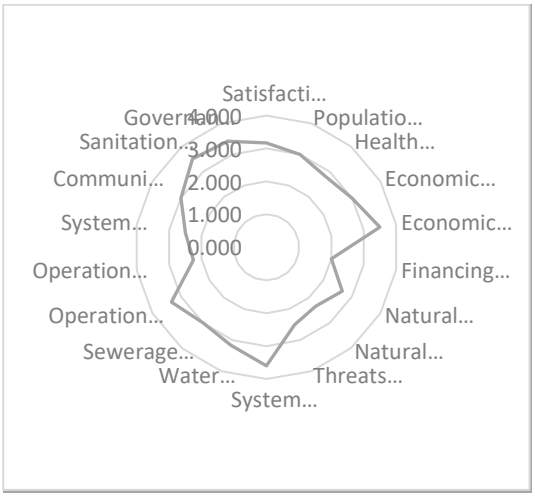

Fig 1. 1st IESSSR assessment in Palmira.

In a second evaluation, carried out 7 months later, the values obtained were quite similar, since an IGS of 3.179 was achieved, reaching the STABLE level, but with several factors in the UNSTABLE level and even one of them in the CRITICAL level. the STABLE level, but with several factors in the UNSTABLE level and even one of them in the CRITICAL level; and whose averages of values by factors allow to elaborate the following radial graph, shown in fig. 2.

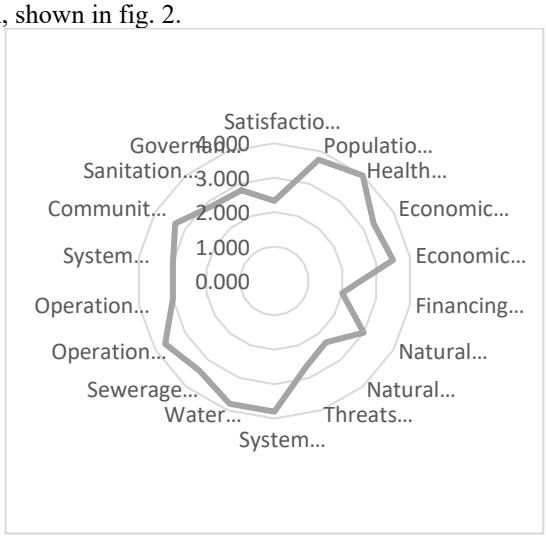

Fig 2. 2nd IESSSR evaluation in Palmira.

TABLE 2. RESULTS OF ASSESMENT SUSTAINABILITY WITH IESSSR

Factor	Jass Palmira			Jass Dos de Mayo		
	1ra Eval.	*2da Eval.*	*Level Sustainability*	*1ra Eval*	*2da Eval.*	*Level Sustainability*
Satisfaction of basic needs of the population	2.833	2.333	Unstable	2.833	2.833	Unstable
Population's perception of the service	2.75	3.75	Stable	2.75	3.75	Stable
Health behaviors of families	3.5	4	Stable	3.5	4	Stable
Economic profitability of the system	2.75	3.333	Stable	2.75	3	Stable
Economic situation of users	3	3.5	Stable	3	3.5	Stable
Financing of the system	2	2	Critical	2	2	Critical
Natural availability of water resources	3.333	3	Stable	3.333	3	Stable
Natural quality of water resources	2.333	2.333	Unstable	2.333	2	Critical
Threats and impacts to the system and biodiversity	2.333	2.667	Unstable	2.333	2.333	Unstable
System productivity	3.4	3.8	Stable	3.4	4	Stable
Water supply infrastructure	3.5	3.8	Stable	3.5	4	Stable
Sewerage and wastewater treatment infrastructure	3.167	3.4	Stable	3.167	3.4	Stable
Operation of the drinking water supply system	3.667	3.667	Stable	3.667	4	Stable
Operation of the drainage, sewerage, and WWTP systems	2.5	3	Stable	2.5	4	Stable
System maintenance	2	3	Unstable	2	3	Unstable
Community participation in management	3.333	3.333	Stable	3.333	3	Unstable
Sanitation service provider	3.167	2.833	Unstable	3.167	3.167	Stable
Governance and institutional articulation	3.571	2.806	Unstable	3.571	2.861	Unstable
General Sustainability Index (ISG)	3.01	3.179	Stable	2.997	3.233	Stable

There are variations in the values of some factors, but their ratings are not modified and are rather confirmed in the second measurement. This is also explained by the fact that in the second measurement the two instruments designed (population survey and structured interview with JASS) were used to better collect the information. It can be seen that steeper valleys indicate lower sustainability and higher peaks indicate higher sustainability.

In the case of Dos de Mayo, evaluations were also carried out at two points in time, in the first of which an IGS of 2.997 was achieved, falling very slightly in the UNSTABLE level, with several factors in the UNSTABLE level and even two of them in the CRITICAL level; and whose averages of values by factors allow the following radial graph to be drawn up, shown in fig. 3.

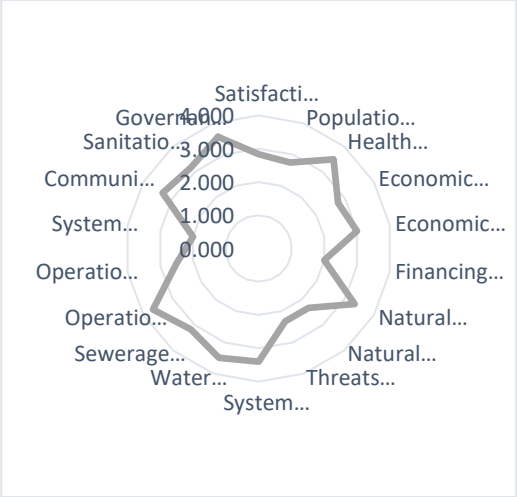

Fig 3. 1st IESSSR evaluation in Dos de Mayo.

In a second evaluation, carried out 7 months later, the values obtained were slightly higher, since an IGS of 3.233 was achieved, reaching the STABLE level, but with several factors in the UNSTABLE level, and even two of them in the CRITICAL level; and whose averages of values by factors allow to elaborate the following radial graph, shown in fig. 4.

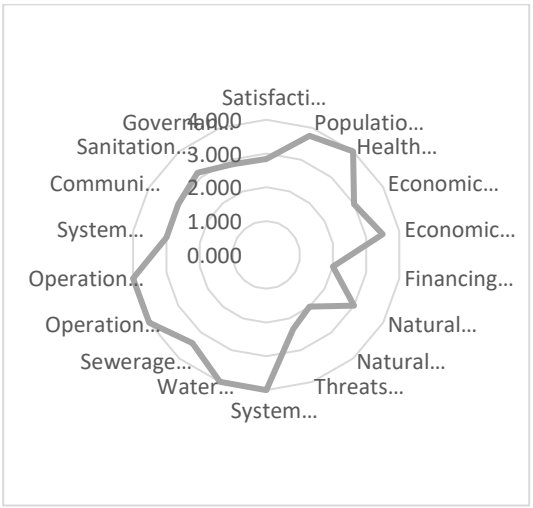

Fig. 4. 2nd evaluation of Dos de Mayo.

Variations are observed in the values of some factors, but in general their scores are not modified and are rather confirmed in the second measurement, confirming the reliability we obtained by applying Pearson.

The identification and measurement of these less sustainable factors makes it possible for the municipality to provide technical assistance on which factors and variables have been identified as the most at risk in terms of their sustainability and, consequently, to formulate improvement plans with the JASSs to remedy the deficiencies. From time to time, an overall measurement can be made and it can be observed whether the improvement plan has yielded results or not. In this way, the proposed technical assistance model contributes to the integrated and sustainable management of the rural sanitation systems under the responsibility of the JASSs.

It is important to highlight that the IESSSR designed makes it possible to introduce the sustainability approach in the supervision and technical assistance functions that the rural district municipality of Leymebamba should fulfill. This index proposes conceptual and methodological constructs and instruments that focus directly on the integrality and sustainability of rural systems. Thus, by using this index, the municipality will fulfill its function and contribute to implement the sustainability approach at the local level. Likewise, the JASS can learn to use it and it can serve as a training tool in the integrated and sustainable management of sanitation systems [6]-[7].

Likewise, with the IESSSR it was possible to diagnose the situation of the systems and their management in their social, economic, environmental, technical and institutional dimensions, thus responding to the characteristics of integrality that characterize the sustainability approach. However, we found some differences with respect to our precedents, such is the case of Burkina Faso and Niger [8], which in their analysis of 71 urban and rural systems, do not explicitly include the social dimension. On the other hand, Tonilli [9], proposes a multidimensional and systemic methodology emphasizing the need to achieve a measurement that contributes to make the concept more tangible based on valid and solid indicators that have heuristic value on the results; however, it is also noted that there are no universally used indicators nor a unique way to obtain them [7]-[9].

The Pan-American Center for Sanitary Engineering and Environmental Sciences- CEPIS proposes an index with 3 factors: System Status, Management and Operation and Maintenance, and about 20 indicators distributed among them. This research took the category "factor" and integrated it into the hierarchical scheme of the index created, but expanded the proposal by incorporating a hierarchical scheme consisting of dimension, factor, variable, indicator, rubric [10].

At the national level, there is an applied software that the Ministry of Housing, Construction and Sanitation-MVCS has called Diagnosis of Rural Water Supply and Sanitation - DATASS. This software collects information on access to sanitation services, sanitation infrastructure, quality of service, organizational management, cleaning, operation, maintenance and chlorination of the drinking water system, economic and financial management, and technical assistance and training to provide general reports on coverage and access to service [11].

In addition, the research proposed to complement this technological aspect of monitoring by developing the IESSSR in a prototype of computer software with which to operationalize and generalize the recording, analysis and evaluation of information evaluation indicators and

the use of this information in the development and implementation of improvement plans. A search of the Peruvian patent database found no record of any index, software or method for evaluating the sustainability of sanitation services [12]. The same occurred when reviewing the PATENTSCOPE databases of the World Intellectual Property Organization (WIPO) and the ESPACENET database of the European Union, where indexes or evaluation methods were found for various activities but not for sanitation services [13]-[14].

Then, progress was made towards technology transfer through the development of a software prototype that can be installed in any municipality for permanent monitoring and periodic evaluations of the JASS and the systems under its responsibility. Thus, the Sustainability Approach is embodied in a technological instrument that operationalizes and integrates this paradigm in the management of the operators and supervisors of the sanitation systems.

IV. CONCLUSIONS

A conceptual instrument was constructed to measure and evaluate the sustainability of rural sanitation systems called the Index for the Evaluation of the Sustainability of Rural Sanitation Systems (IESSSR), which makes it possible to evaluate in the Social, Economic, Environmental, Technical and Institutional dimensions whether the sustainability of a system is in a situation of COLLAPSE, CRITICAL, UNSTABLE, STABILITY and OPTIMAL.

The sustainability of the sanitation systems involved was evaluated not only at a general level but also by factors and dimensions, which made it possible to identify the critical and unstable points of both systems and to plan measures to improve the situation.

Progress was made in the technological transfer of the IESSSR's conceptual proposal by developing this index in a computer program that enables the timely, efficient and systematic management of the large amount of information required to monitor the operation and sustainability of rural sanitation systems.

Finally, the implementation of interventions on the technical platform that supports the management of rural sanitation systems, such as the one carried out by this research, is a way of making the sustainability approach more tangible and operationalizing it for the population, civil society and the public entities responsible for guaranteeing timely and quality water and sanitation services.

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REFERENCES

[1] INEI – PERÚ, "Censos nacionales 2017: XII de Población, VII de Vivienda y III de Comunidades Indígenas". Instituto Nacional de Estadística e Informática. 2017. Recuperado en https://censos2017.inei.gob.pe/redatam/.

[2] T. Burnstein-Roda, "Reflexiones sobre la gestión de los recursos hídricos y la salud pública en el Perú". Rev. perú. med. exp. salud publica vol.35 no.2 Lima abr./jun. 2018. DOI: http://dx.doi.org/10.17843/rpmesp.2018.352.3641

[3] H. Fujishima, "Aplicación de un índice para la evaluación de la sustentabilidad de sistemas de saneamiento rural en Leimebamba-Amazonas". Rev. Espacio y Desarrollo, (39), 1-27. PUCP 2022. Recuperado a partir de https://revistas.pucp.edu.pe/index.php/espacioydesarrollo/article/view/25552

[4] S. Sepúlveda, "Biograma: metodología para estimar el nivel de desarrollo sostenible de territorios". Sergio Sepúlveda S. San José, C.R.: IICA, 2008. 132 p. Recuperado de http://repiica.iica.int/docs/B0664e/B0664e.pdf

[5] J. Ramírez, A. Sigarroa, and R. Del Valle, "Characterization of Cocoa (Theobroma cacao L.) Farming Systems in the Norte de Santander Department and Assessment of Their Sustainability". Rev. Fac. Nac. Agron. Medellín 67(1):7177-7187. 2014. DOI: http://dx.doi.org/10.15446/rfnam.v67n1.42635

[6] S. Jones and C. Silva, "A practical method to evaluate the sustainability of rural water and sanitation infrastructure systems in developing countries" DOI: https://doi.org/10.1016/j.desal.2008.05.094

[7] L. Seghezzo, "Un índice de sustentabilidad para la evaluación integral de los sistemas de gestión del agua y el saneamiento". Rev. Avances en Energías Renovables y Medio Ambiente, Vol. 14, 2010. Recuperado de http://sedici.unlp.edu.ar/handle/10915/9936

[8] J. Debus, "Sustainability Index of Rural Water Services: Burkina Faso and Niger". Global Water Initiative programme in West Africa 2008-12. august 2014. Recuperado de https://pubs.iied.org/g03983

[9] A. Tonolli, "Propuesta metodológica para la obtención de indicadores de sustentabilidad de agroecosistemas desde un enfoque multidimensional y sistémico" Revista de la Facultad de Ciencias Agrarias. 51. 381-399. Recuperado de https://www.researchgate.net/publication/339165206_Propuesta_metodologica_para_la_obtencion_de_indicadores

_de_sustentabilidad_de_agroecosistemas_desde_un_enfoque_multidimensional_y_sistemico/citation/download

[10] COSUDE, "Acceso al agua y saneamiento. Desde la mirada de la Gestión Integrada de los Recursos Hídricos". Agencia Suiza para el Desarrollo. 2010. Recuperado de https://www.cooperacionsuiza.pe/categoria_de_publicacion/agua-institucionales/

[11] MVCS PERÚ, "Diagnóstico sobre el abastecimiento de agua y saneamiento en el ámbito rural – DATASS". Ministerio de Vivienda, Construcción y Saneamiento. 2023 recuperado de https://www.gob.pe/880-diagnostico-sobre-el-abastecimiento-de-agua-y-saneamiento-en-el-ambito-rural-datass

[12] INDECOPI PERÚ, "Base de datos de registros en dominio público". Instituto Nacional de Defensa del Consumidor y Propiedad Intelectual. Recuperado de https://indecopi.gob.pe/web/invenciones-y-nuevas-tecnologias/base-de-datos-de-patentes

[13] WIPO, "PATENTSCOPE, Date base of patents" World Intelectual Property Organization (2023). Recuperado de https://www.wipo.int/patentscope/en/

[14] European Patent Office, "ESPACENET. Date Base Patent search. 2023. Recuperado de https://worldwide.espacenet.com/patent/

[15] H. Fujishima, "Las organizaciones comunales y la gestión integral y sostenible del saneamiento rural en Leymebamba 2020. Tesis doctoral". Universidad Nacional Toribio Rodríguez de Mendoza. 2023 recuperado en: https://repositorio.untrm.edu.pe/bitstream/handle/20.500.14077/3530/Hugo%20Ramon%20Fujishima%20Martell%20-%20EPG.pdf?sequence=3&isAllowed