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Natural Wastewater Processing Systems: Treatment Tanks using plants in Brazil's Izidora basin

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Abstract - *Disorderly urban expansion directly impacts city planning, a phenomenon that induces the settlement of vulnerable populations in areas lacking urban planning. Located in the northern sector of the city of Belo Horizonte (Brazil), the Izidora settlement has become established in the largest preserved fragment of the Atlantic Forest in the city, resulting in deforestation and degradation of riparian areas, affecting the region's watercourses. The Vitória Settlement, located in the Izidora region, is home to 4,500 low-income families. Due to the deficient urban infrastructure and buildings lacking a sewage system, domestic sewage is discharged directly into the watercourses, impacting the quality of aquatic ecosystems. In 2021, the Vitória Settlement was rehabilitated, aiming to restore the water bodies and their riparian forests. Among the recovery interventions, 12 Evapotranspiration Tanks (TEvaps), a nature-based and low-cost wastewater treatment system, were installed. These TEvaps promote the treatment of blackwater using microorganisms capable of decomposing organic matter, combined with plants that facilitate the elimination of water into the atmosphere through transpiration. This study evaluates the results of the TEvaps installed in the settlement through biological, physical, and chemical parameters of water samples collected from the region's watercourses.*

Keywords: TEvap, wastewater treatment, water conservation, pollutant removal, black water.

1. Introduction

The urban expansion process is marked by social inequality, which impacts various aspects of urban planning. With urban expansion, the poorer classes were unable to establish themselves in urbanized areas, forcing them to settle in the peripheric areas which largely lack a formal development planning [1]. The Izidora settlement (Fig. 1) located in Belo Horizonte city (Brazil) is the largest urban settlement in South America was constructed within a watershed tributary of the São Francisco River. The area constitutes the largest preserved fragment of the Atlantic Forest biome within the city of Belo Horizonte (19°48'53.58"S, 43°54'52.09"W), covering 950 hectares with around 280 springs. However, this region has faced the establishment of an informal settlement by low-income populations, resulting in deforestation and degradation of this region. In consequence, there occurred the degradation of riparian areas and severe impact to the watercourses. [2].

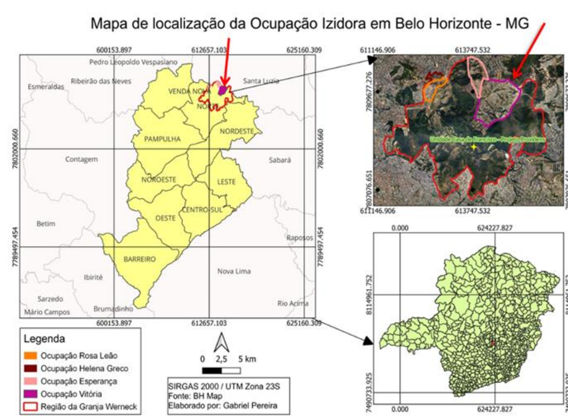

Figure 1. Location Map of the Izidora Occupation in Belo Horizonte

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The Vitória Settlement is located within the Izidora area, hosting around 4,500 low-income families. This settlement is connected to four main watercourses that are tributaries of the Macacos Stream (Fig. 2). Due to the deficient urbanization process, poorly planned buildings, and lack of sewage systems, waste is being directly discharged into the watercourses, which directly impacts the quality of the aquatic ecosystem. According to the sanitation data provided by the BHMap, the region most lacking in sewage systems are the northern areas of the city, including the Izidora Stream Basin [3].

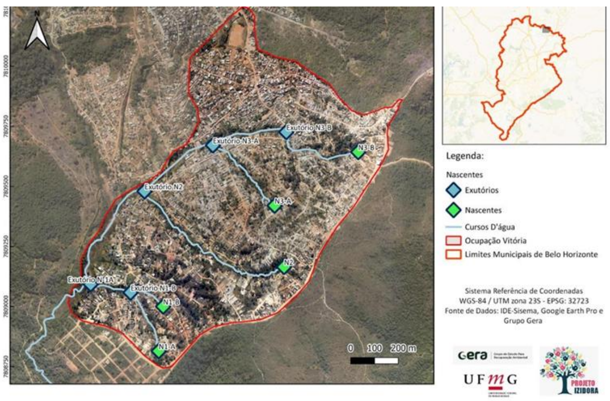

Figure 2. Location Map of the Vitória Settlement

According to the joint monitoring programme for water supply and sanitation (JMP), 4.5 billion people currently are not provided with managed sanitation [4]. Within this context, the separation of blackwater (BW) and greywater at the source is a wise choice. Blackwater is the fraction of domestic sewage originating from the toilets. Despite it is produced in a much lower volume, it contains the highest fraction of pathogens and nutrients than the greywater [5]. The total amount of faeces excreted by a human along one year was estimated in 25 to 50 kg, containing in average 550 g of nitrogen, 180 g of phosphorus and 370 g of potassium [6]. The urine produced by an adult was estimated 400 L of urine per year, containing 4 kg of nitrogen, 400 g of phosphorus and 900 g of potassium. Considering that the Vitória Settlement hosts 4.500 families or around 8.000 people, the sewage load carried by blackwater may be considered very high.

Managing wastewater is a significant environmental challenge, especially in regions where conventional sewage systems are impractical or unavailable. A possible solution to address the lack of sanitation measures provided by the government is the implementation of nature-based alternative sewage systems, such as septic tanks and soak ways, Residential Wastewater Treatment Plants, or Evapotranspiration Tanks (TEvap). Historically, the Evapotranspiration Tank (ETank) is a system for treating and reusing nutrients from toilet effluent. This system was created by permaculturist Tom Watson in the USA, under the name "Watson Wick" and was adapted by several Brazilian permaculturists (Fig. 3) and by the public company EMATER-MG.

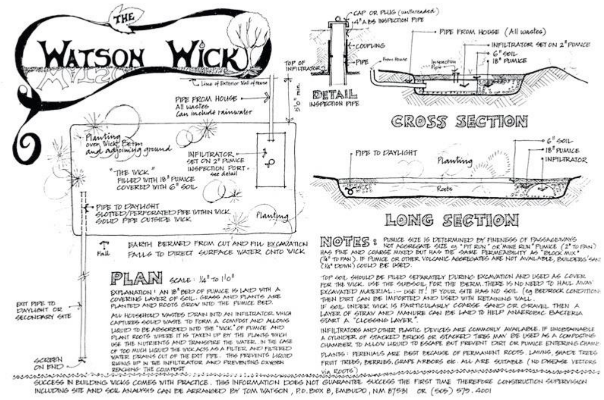

Figure 3. Diagram showing the Watson Wick System design
Source: WATSONWICK. In: Oasis Design, 2023 [7]

Evapotranspiration tanks are an innovative solution used in wastewater treatment, especially in areas where conventional systems may not be viable. They provide an ecological and cost-effective alternative to traditional septic systems, reducing reliance on water-intensive sewage treatment processes and minimizing the risk of groundwater contamination [8]. The evapotranspiration tank (TEvap) is a simplified treatment system, aiming at zero liquid discharge, which can be used for blackwater treatment at household level. It is a soil and plants-based system. TEvap are concrete chambers that receive sanitary sewage directly from the toilet. This tank is filled with one or more layers of different substrates as tires, stones, bricks, sand, gravel, and soil in a sealed and impermeable system. In the upper layer, banana plants are planted (Fig. 7). Microorganisms in the fecal organic matter are confined within the system, and in this anaerobic environment, the decomposition of all organic matter occurs. The mineralized nutrients are absorbed by the plant roots, as well as the sewage water. Through plant transpiration, all the sewage water is used and exchanged into the atmosphere [9]. Thus, nutrients are incorporated into the plant biomass and the water is eliminated through evapotranspiration, without runoff. As a result, there is no soil pollution or risk of soil contamination [10].

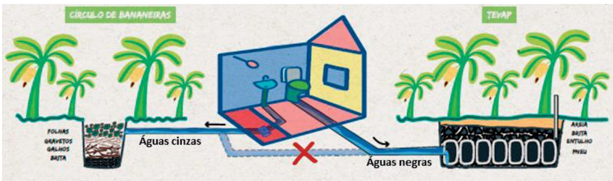

Figure 4. Treatment System using Evapotranspiration Tank (TEvap) Source: EMATER-MG, 2016 [11]

As shown in Figure 4, the primary structure of the TEvap [12] consists of a durable and waterproof tank made of reinforced concrete or polyethylene. This tank is divided into two compartments: a sedimentation chamber for the initial treatment of wastewater and a treatment chamber where the evapotranspiration process occurs. The construction includes, in addition to stones and tires, a system of perforated pipes to evenly distribute wastewater throughout the soil layer. This ensures that all areas of the tank are utilized in the treatment process. On the top of this structure, it is placed the following materials:

1) A soil layer composed of a selected soil mixture with a good water retention capacity and drainage properties to facilitate the evapotranspiration process. The soil layer typically consists of a mix of clay and sand to optimize moisture balance.
2) A gravel Layer installed to improve drainage and support the soil, preventing blockages and ensuring the distribution of wastewater.
3) Hydrophytic Plants: these plants are crucial for the transpiration process, where they absorb water through their roots and release it into the atmosphere through their leaves.

The design of the TEvap is adapted to local conditions, including climate, soil type, and the volume of wastewater generated. The size of the tank and the depth of the soil and gravel layers are calculated based on these factors. The tank is usually installed underground or partially buried, with its upper surface integrated into the landscape [5]. The regular monitoring of the system is essential to ensure its proper functioning which includes checking the plant health, soil moisture levels, and the integrity of the distribution pipes. Maintenance activities may involve replanting vegetation, adding soil, or unclogging pipes as needed

In 2021, the rehabilitation of the Vitória settlement was performed aiming at re-constructing the degraded drainage systems and the riparian forests [2]. Among the recovery interventions, 12 TEvaps (Fig. 8) were constructed in the N1 area (Fig. 8). In this study, we aim to evaluate the effectiveness of these TEvaps on the quality of water in the recovered drainage systems.

2. Material and Metods

21. Construction of TEvaps

The installation of 12 TEvaps was carried out along the reconstructed watercourse and the recovered riparian forest of N1, both on the right and left margin of the drain. The following criteria were used:

1) Selection of Benefited Residences along the N1 Drain: Houses located outside the Permanent Preservation Areas (PPA), since the Brazilian Forest Code [13] prohibits the construction of facilities less than 15 meters from the watercourse. These houses should have a low slope to facilitate the excavation and installation of the TEvap, and the local resident should be interested in installing it.
2) Sizing and Excavation of the Tanks: for the excavation, a useful volume of $2m^3$ per tank was adopted for each residence, considering 4 adults per house. The dimensions of the tank were 2 meters in width, 1 meter in depth, and 4 meters in length.

Figure 5. Construction of the septic system using an excavator

3) Construction Technique: Cemented chamber providing greater structural resistance with a waterproofing additive and concrete at the bottom, ensuring the containment of effluent in the system. Inclusion of tires in the anaerobic

chamber covered with stones. Additionally, a piezometer was installed, penetrating the tire chamber, and a 50mm diameter drainage pipe was placed 10cm below the soil at the tank's outlet to prevent overflow. Layers of 10cm gravel, 10cm sand, and 35cm soil were then added up to the upper limit.

Figure 6. Evapotranspiration System (TEvap) construction process.

4) Banana Plants: 3-4 small banana plant seedlings were planted in each system.

Figure 7. Evapotranspiration System (TEvap) using concrete chambers filled with stones, tires, sand and soil that receive the sanitary sewage. Banana plants (Musa sp.) are responsible for nutrient absorption and water transpiration.

Next, in Table 1, we list the materials needed to build twelve ETanks for 5 people:

Table 1. List of services and materials for ETank construction.

Service and Input Description	Unit	Total Quant.
BACKHOE	PHC	12
MEDIUM SAND	M^3	0.28
CRUSHED STONE N. 1 (9.5 to 19 MM)	M^3	1
HAND STONE OR RIPRAP FOR RETAINING WALL	M^3	3.7
POZZOLANIC PORTLAND CEMENT CP IV-32	KG	50
SOLID CERAMIC BRICK "5 X 12 X 24" CM (W X H X L)	UN	224
PVC SLIP COUPLING, DN 100 MM, FOR BUILDING SEWAGE	UN	1
WATERPROOF ADHESIVE WITH NORMAL SETTING FOR PVC	ML	2.5
MORTARS	Lt	11.5
PVC SEWER PIPE, JE, DN 100 MM (NBR 7362)	M	4.5
PVC ELBOW, WELDABLE, PB, 90 DEGREES, DN 100 MM, FOR SEWAGE	UN	2
CAP, MALE THREAD, DN 1"	UN	2
PVC LONG CURVE 90 DEGREES, DN 50 MM, FOR BUILDING SEWAGE	UN	1
SANITARY REDUCING TEE, PVC, DN 100 X 50 MM	UN	1
FACADE MESH IN POLYETHYLENE, ROLL 3 X 100 M (W X L)	M^2	94
WHITE EVA GLUE	ML	1000
PVC SIMPLE COUPLING, WELDABLE, DN 100 MM	UN	1
PVC ELBOW, WELDABLE, PB, 45 DEGREES, DN 100 MM - SEWAGE	UN	1
PVC ELBOW, WELDABLE, PB, 45 DEGREES, DN 100 MM - SEWAGE	UN	1
REDUCING TEE WITH THREAD, PVC, 90 DEGREES, 3/4 X 1/2" - WATER	UN	1
GALVANIZED IRON CAP, WITH BSP THREAD, 1/2"	UN	12
GEOTEXTILE FABRIC OF POLYAMIDE AND POLYPROPYLENE	M^2	1
ORNAMENTAL TREE PLANT	UN	1
GRAVEL PATH 10 (M)	M	10

3. Assessment of the effectiveness of the installed TEvaps

The effect of installing the 12 evapotranspiration tanks on the recovered drainage in area N1 (Fig. 8 - arrow) was assessed through water quality. Water samples were collected from both the preserved and impacted sections of the Macacos stream, the latter having a significant sewage inflow at the confluence with the Stream Izidora. These preserved and impacted sections were used as positive and negative controls, respectively. Analyses were conducted during both dry and rainy seasons. One year after the installation of the TEvaps, water samples were collected upstream and downstream the N1watercourse where the tanks were installed (Fig. 8) which were analyzed in triplicate. Sample collection, handling, and preservation, as well as analyses, were carried out according to the methods specified in the "Standard Methods for the Examination of Water and Wastewater," edited by the American Public Health Association [13].

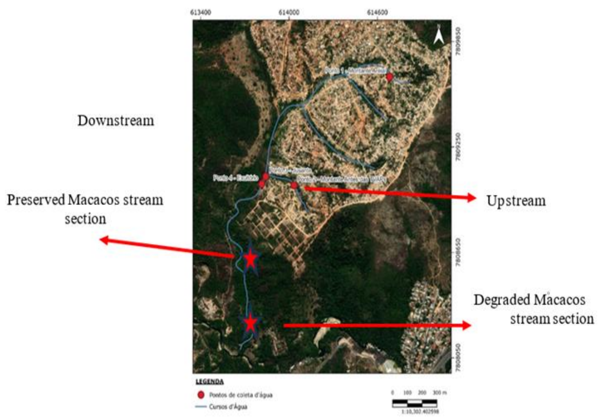

Figure 8. Sampling areas on restored water course upstream and downstream

For the assessment of water quality, the physicochemical variables were determined., pH, temperature (oC), conductivity, Phosphorus (PO4-), total nitrogen (total N), Ammonium, biochemical oxygen demand (BOD) and total Coliforms.

4. Results

The results presented in Table 2 show that the main parameters affected by sewage were BOD (Biochemical Oxygen Demand), phosphorus, and total coliforms, which showed a significant increase with sewage discharge compared to the preserved area. The biochemical oxygen demand indicates an increase in microbiota with aerobic respiration expected to be present in the sewage, as confirmed by the increase in coliforms number.

Temperature tends to rise during the summer, a phenomenon exacerbated by climate changes caused by anthropogenic actions. Such a phenomenon directly impacts the proliferation capacity of microorganisms in aqueous environments. The table 2 showed also a strong effect of season, especially in the dry season. In the rainy season, the dilution effect reduced the concentration of Phosphorus and the microbial population.

Table 2. Error rates for four different trials.

Local		**Preserved Macacos Stream**		**P21 – Impacted Macacos stream (near Izidora River)**	
Season		**Dry**	**Rainy**	**Dry**	**Rainy**
pH		7,98	7,20	7,50	6,90
Conductivity	µS/cm	246,5	335,5	509,5	429,5
BOD	mg O2/L	4,36	3,00	45,80	24,36
Temperature	ºC	16,35	22,80	19,55	23,15
Phosphorus	mg /L	350	220	1865	285
Nitrate	mg /L	180	300	20	810
Total coliform	MPN/100mL	$2,4x10^5$	$2,4x10^5$	$9,8x10^5$	$15x10^5$

Table 3. Water Quality analysis of N1 water course at upstream and downstream of TEvaps.

	Upstream Areial	Upstream – N1 water course	Downstream - N1 water course - 1	Downstream - N1/ Macacos stream - 2
pH	6,99	6,00	6,38	7,82
Condutivity (µS/cm)	234	237	309	294
BOD (mg O2/L)	19	42	6	58
Temperature (o C).	22,5	22,5	22,4	22,7
Phosphorus	< 0,3 mg/L	1,41 mg/L	< 0,3 mg/L	< 0,3 mg/L
Nitrate	20,7 mg/L	52,5 mg/L	< 2,0 mg/L	< 2,0 mg/L
Thermotolerant coliforms (MPN)	<1,8 /100 mL	2,7 x 103/100 mL	< 1,8 /100mL	< 1,8 /100mL
Total Coliforms (MPN)	17 x 105 /100mL	1,6 x 105 /100mL	0,11 x 105 /100mL	1,6 x 105 /100mL

5. Discussion

The Izidora Project encompasses the installation of 12 ETank units in the Vitória Community, strategically distributed among family homes. These installations, representing over 50% of the registered homes along stream N1, aim to address significant water quality concerns in the area.

Prior water quality assessments revealed critical indicators of fecal contamination, including elevated levels of coliforms, Biochemical Oxygen Demand (BOD), phosphorus, and nitrate, all directly linked to sewage discharge. The environmental impact of these contaminants is particularly concerning, as phosphorus enrichment can significantly degrade plant communities, including both higher plants and algae, by disrupting their competitive balance. This disruption creates a cascade effect throughout the ecosystem, compromising the entire trophic chain. Similarly, high nitrate levels indicate persistent fecal contamination, which not only promotes microbial growth but also impacts plant and algal communities.

Encouragingly, the ETank system has demonstrated its effectiveness, showing significant reductions in BOD, total coliforms, and phosphorus levels within one year of installation, corroborating findings from Paulo et al. (2019)'s four-year study. However, water quality deterioration near the Macacos stream (samples N1/2) suggests additional sewage inputs from this tributary require attention.

To maintain and verify the system's continued effectiveness, a comprehensive monitoring protocol has been established. This includes quarterly water quality assessments at monitoring points P-12 and P-12, measuring key parameters such as dissolved oxygen, pH, and electrical conductivity using a multiparameter probe. This systematic monitoring approach will help evaluate the long-term impact of the ETank installations on water quality improvement.

6. Conclusion

1) In developing nations, the implementation of alternative and nature-based wastewater management solutions should be prioritized, particularly given their cost-effectiveness, environmental sustainability, and adaptability to local conditions. These solutions often present more viable options than conventional infrastructure, especially in regions with limited resources and challenging terrain.

2)- The preliminary results from this study demonstrate compelling evidence of the TEvap system's effectiveness in mitigating water fecal contamination. Through systematic monitoring and analysis, significant reductions in key contamination indicators have been observed, validating the system's capability to improve local water quality standards.

3)- The Evapotranspiration Tank (TEvap) represents an innovative and highly effective sustainable solution for blackwater management, particularly valuable in regions where traditional sewage infrastructure is impractical or unfeasible. Its distinguishing feature lies in its ability to operate independently of extensive water resources or complex infrastructure networks. The system's natural processing approach not only effectively treats wastewater but also enhances local biodiversity through strategic vegetation integration, creating a symbiotic relationship between waste treatment and ecosystem development.

4)- The TEvap construction methodology demonstrates remarkable simplicity in its technical requirements and implementation process, making it readily transferable to settler communities. This accessibility enables local communities to participate in both the installation and maintenance processes, fostering a sense of ownership and sustainability.

5)- The economic advantage of TEvaps is significant, with installation costs substantially lower than conventional sewage systems. This cost-effectiveness extends beyond initial installation to include minimal operational and maintenance expenses, making it particularly attractive for resource-constrained communities.

6)- Based on comprehensive analysis, the TEvap system emerges as a highly recommended and promising alternative to traditional sewage treatment methods. Its adaptability to various climatic conditions and environmental contexts, coupled with its sustainable operational model, positions it as an ideal solution for diverse implementation scenarios. However, successful implementation requires:

-Meticulous planning and design considerations

-Careful selection of appropriate plant species and soil compositions

-Precise tank and distribution system design tailored to local conditions

-Implementation of regular monitoring protocols

-Establishment of consistent maintenance schedules

These requirements, while essential, are manageable within the context of community-based implementation and support the system's long-term sustainability and effectiveness.

References

[1] H. Lefebvre, La production de l'espace. Paris: Anthropos, 2000.

[2] M. T. Fonseca, S. L. L. Silva, J. P. Ferreira, R. S. Nunes., H. L. M. Paula, J. F. Cruz, A. Antão, I. N. R. Santos, J. Cordeiro, L. A. I. Saenz, M. Vieria, R. M. P. Coelho, M. R. Scotti, "Environmental impact of an informal settlement on a headwater area at high risk of erosion in Brazil," in Proceedings of the 8th World Congress on New Technologies (NewTech'22), Prague, CZE, 2022.

[3] PREFEITURA DE BELO HORIZONTE, "BHMap - Portal de Mapas de Belo Horizonte." Available:

https://bhmap.pbh.gov.br/v2/mapa/idebhgeo. [Accessed: 25-08-2024].

[4] World Health Organization (WHO) and United Nations Children's Fund (UNICEF), Progress on Drinking Water, Sanitation and Hygiene: 2017 Update and SDG Baselines. Licence: CC BY-NC-SA 3.0 IGO, Geneva, 2017. [Online]. Available: http://www.who.int/mediacentre/news/releases/2017/launch-version-report-jmp-watersanitation-hygiene.pdf. [Accessed: Apr. 16, 2018].

[5] P. L. Paulo, A. F. Galbiati, F. J. C. Magalhães Filho, F. S. Bernardes, G. A. Carvalho, and M. Á. Boncz, "Evapotranspiration tank for the treatment, disposal and resource recovery of blackwater," Resources, Conservation and Recycling, vol. 147, pp. 61-66, Aug 2019.

[6] S. Esrey, J. Gough, D. Rapaport, R. Sawyer, M. Simpson-Hébert, J. Vargas and U. Winblad, Ecological Sanitation, . Stockholm: Swedish International Development Cooperation Agency (SIDA), 1999.

[7] Oasis Design, "Watson Wick - a septic system that works." [Online]. Available: https://oasisdesign.net/compostingtoilets/watsonwick.htm. [Accessed: Jan. 3, 2025].

[8] G. Tchobanoglous, F. L. Burton, and H. D. Stensel, Wastewater Engineering: Treatment and Reuse, 4th ed. New York, NY, USA: McGraw-Hill, 2004.

[9] [1] L. A. S. Isla, R. M. P. Coelho, A. R. N. Júnior, and E. P. da Silva, "O esgotamento sanitário no Projeto Izidora: Tratamento alternativo com Tanques de Evapotranspiração," in Recuperação de Florestas e Águas em Ambientes Urbanos: Projeto Izidora, Belo Horizonte - Brasil, 2024, pp. 202-231.

[10] C. S. Cabral, "Avaliação de fatores para implementação de sistema de evapotranspiração para tratamento de efluentes," Bachelor's Monograph, Institute of Exact Sciences, Universidade Federal Fluminense, Volta Redonda, RJ, 2022.

[11] EMATER-MG; COPASA; FUNDAÇÃO BANCO DO BRASIL. Fossa Ecológica-TEvap: Manual de Tecnologia Social. Belo Horizonte, MG: Fundação Banco do Brasil, 2016. 14 p. [Online]. Available: www.fbb.org.br/tecnologiasocial. [Accessed: Dec. 13, 2024].

[12] D. K. Todd and L. W. Mays, Groundwater Hydrology, 3rs ed. New Jersey: John Wiley & Sons, 2004.

[13] Brazilian Forest Code, Law No. 14.285, Dec. 29, 2021.