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CHEMICAL WASTE MANAGEMENT IN EDUCATIONAL INSTITUTIONS

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Abstract

Green universities and Education for Sustainable Development have an important role in reaching a sustainable society. However, there is many gaps in this area. This study aimed to report the implementation and the results of the Chemical Waste Management Program (CWMP) of the Federal University of Lavras (UFLA). The CWMP have been implemented in 2009 to solve the existing environmental problem of inadequate disposal of chemical waste generated in UFLA's laboratories. In order to carry out the CWMP actions, the Chemical Waste Management Laboratory (CWML) was created in 2009, with the function of collecting, treating, and giving a final destination to the chemical waste generated by UFLA's teaching, research, and service laboratories. The treatments applied to chemical waste are adsorption, precipitation, distillation, drying and composting. Another important action of the CWMP was the realization of training courses and seminars, in addition to a graduate discipline, to raise awareness of the academic community about the importance of the correct disposal of chemical waste. The development of sustainable treatment methods, using recycled and low-cost materials allowed an increase of 400% in the amount of waste treated in the CWML. From 2009 to 2019, the CWML increased the number of solvents recovered from the waste and the amount of Chemical Waste Exchange (CWE). The CWMP contributed for UFLA to apply the concept of green chemistry daily. The results from these actions have contributed for the university to reach the second position among most sustainable universities in Latin America. Despite the increase in the amount of treated waste, it is necessary to develop new sustainable treatment methodologies to meet the university's growing demand.

Keywords: Chemical waste; Educational Institutions; Greening of campuses; Green University; Waste management.

1. Introduction

At the beginning of the 90s, with the adoption of the concept of sustainable development, there was a search for alternatives that avoided or minimized the production of waste, to the detriment of the concern with the treatment of waste in the final processes. This new direction on the issue of reducing the impact of chemical activity on the environment is called "green chemistry", or clean chemistry, environmentally benign chemistry, or self-sustainable chemistry.

As in industries, the universities start to worry about the wastes generated in their teaching and research activities, since they are composed by a great variety of substances, potentially toxic and harmful, which should go through adequate treatment before being disposed, aiming to avoid environmental problems and contamination of living beings (Mora et al., 2016; Moreira et al., 2018; Tancharoen & Rachakornkij, 2018). Many universities from the United States of America have institutionalized waste management programs, which are considered one of the most relevant approaches for waste reduction (Armijo de Vega et al., 2008). In 2010, institutions such as the Georgetown University and Rutgers University obtained a high annual index of recycling as a direct result of their waste management actions (Blackburn, 2016; Ebrahimi & North, 2017; Sallaku et al., 2020).

The need for sustainable development has become increasingly evident during the last decades, implying that universities are expected to prepare students to develop the ability to integrate social, environmental and economic considerations in future decision making (Sammalisto et al., 2015). Several, research institutions and laboratories around the world have been working on the implementation of good chemical waste management practices in order to reduce the risks of accidents and human and environmental contamination (Fernandes et al., 2019; Ho & Chen, 2018; Pourzamani et al., 2019). Brazilian Higher Education Institutions started to worry about the chemical waste generated from the teaching and research activities of their laboratories after the beginning of the 90s, when these institutions started to be seen as important generating units of this type of material (da Paz et al., 2015; Marinho et al., 2011; Moreira et al., 2018; Ramm et al., 2018; Santos & Lima, 2019).

In Brazil, the National Policy of Solid Waste (PNRS), implemented on 23rd of October (2017) and established by the Federal Law n. 12.305/2010, which has been regulated by the Decree nº 9.177, determined changes related to solid waste management, bringing together a set of principles, objectives, instruments, guidelines, goals, and actions to be implemented by the companies under cooperation regimes with public authorities, aiming an integrated environmental management of solid waste and establishing a shared responsibility for product's useful life (Maiello et al., 2018; Temer, 2017; Velázquez, 2018). It establishes that every waste generator, whether an individual or legal entity, is responsible for its waste, and must therefore take the actions needed to minimize the environmental impact caused by their disposal, being also responsible for the damage that may be caused due to the inadequate management of this material (Gonçalves & Leme, 2018).

Thus, Higher Education Institutions, public or private, have the challenge of promoting the sustainable development at the center of their actions, whether in the teaching, research, or extension programs, and enforcing the legal determination related to the solid waste management (management (Arana & Bizarro, 2018; Borges et al., 2016; Fagnani & Guimarães, 2017; Ramos et al., 2015). In this sense, UFLA's administration has always been concerned with environmental issues. Starting with isolated actions carried out by professors from different knowledge areas, the Environmental Plan was created, which aims to solve existing environmental problems and prevent future ones, placing UFLA as a sustainable environmentally friendly university (Scolforo et al., 2014).

The initiative came from the administration of the university, through the Pro-Rectory of Planning and Management (PROPLAG), which created the Environment Board, with the mission of managing the Environment Plant and planning goals for the future. Initially, the Environment Board was composed by six different committees, one for each coordination, and six different sectors: the Sanitation Coordination (Sewage and Water Treatment sectors), the Natural Resources Coordination, the Waste Coordination (Chemical Waste, Biological Waste, and Recycling sectors), the Energy Planning and Management coordination, the Endemic Prevention Coordination, and the Fire Prevention and Control Coordination (Fire Brigade Sector). Each coordination has a team, composed by professors, administrative technicians, and students, and is responsible for several actions of the Environmental Plan.

The Environment Plan included actions such as the implementation of a Chemical Waste Management Program (CWMP). In 2006, the treatment of waste generated during practical classes conducted at UFLA's Chemistry Department (UFLA) began, and in 2008, a survey of the passive and active waste generated in the laboratories from all the different departments of UFLA was performed. In addition, in 2008, UFLA invested on the construction of the Chemical Waste Management Laboratory (CWML), with the aim of providing an adequate destination for the laboratory waste generated in the university campus, enabling to recover the waste or decrease their toxicity, or sending they to industrial landfills, contributing to the environment preservation.

UFLA's CWML started its activities in August 2009, being one of a kind among the Federal Universities of the Minas Gerais state at the time, and had the aim of collecting, treating, and giving an adequate final destination for the chemical waste generated in the laboratories of UFLA's departments. The waste collected is first segregated according to the treatment type (precipitation, distillation, and neutralization). The recovered waste (solvents) returns to the laboratories of the university for the utilization in various different applications. Acidic and basic solutions that do not contain heavy metal are neutralized.

Environment education is a fundamental instrument for raising community awareness to any work or project directed to the environment (Araujo et al., 2019). Therefore, in 2009, a training course for all laboratory technicians from UFLA was carried out, allowing that all questions and concerns about the waste management in their laboratories to be clarified, integrating them to the CWMP. Lectures were also held in the Graduate Programs from the university, within the Seminar discipline, in order to guide and reinforce the integration and knowledge of the CWMP with the students, contributing to the consolidation of the program (Oliveira Júnior et al., 2014).

In the first half of 2010, every laboratory of the university was inspected for their adequacy towards chemical safety and waste management, according to the CWMP directions. In the same year, the CWML started to work through a Service Order (SO) system, in which the activities to be performed were first registered at the Campus Administrative department.

Since 2012, UFLA participates of the UI GreenMetric World University Ranking, which evaluates items such as green areas, water treatment, transportation within the academic campus, energy consumption, and waste management. Since its first participation in the ranking, UFLA has risen 41 positions, reaching the 29th position in 2019, highlighting the work developed by the CWMP, which treats the research waste from 200 laboratories.

In this context, the aim of this study was to report the CWMP implementation, and the results obtained from it at UFLA, focusing on the reduction preventive actions, waste reuse, and adequate final disposal of the waste generated from the teaching, research and extension activities; training courses for all technicians; disciplines and seminars for students, aiming the CWMP dissemination.

2. Methods

Educational institutions have several teaching laboratories in different areas of knowledge. Thus, different institutions produce different chemical waste, so each institution must make its own CWMP in order to classify the chemical residues produced in its laboratories (Ramm et al., 2018). The Federal University of Lavras (UFLA) is located in the city of Lavras, southern state of Minas Gerais, Brazil (Figure 1).

Figure 1. Location of Federal University of Lavras

Since 2010, the chemical waste generated in UFLA's laboratories are daily collected and taken to the CWML, where they are weighted, identified, and separated according to the type of chemical treatment. Figure 2 shows the workflow performed by the CWML from collecting the chemical waste in the laboratories until its destination.

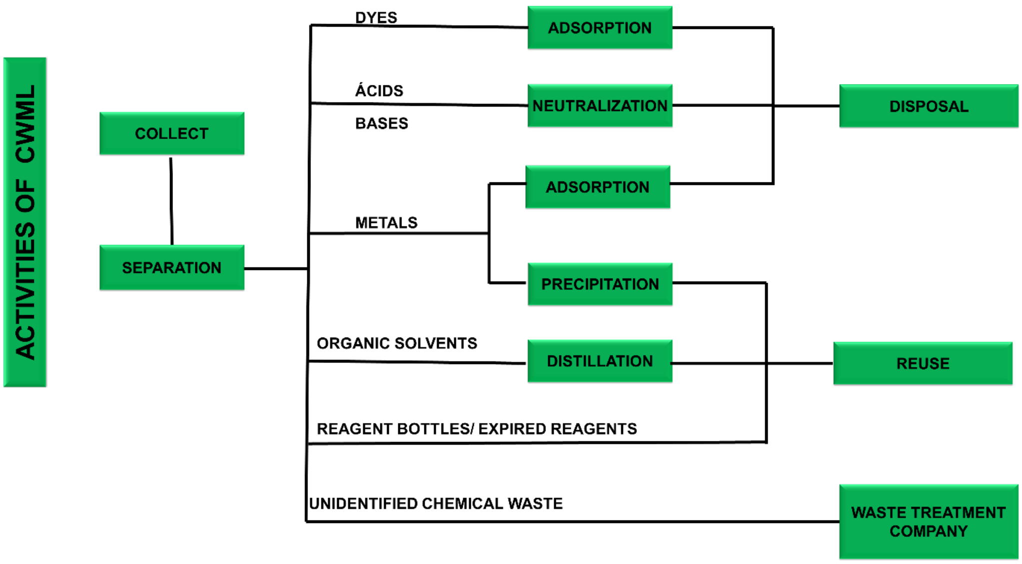

Figure 2. Workflow performed by CWML

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The following treatment types are employed at the CWML: adsorption, neutralization, precipitation, composting (waste not containing heavy metals), and drying, with the waste not having a treatment option being sent to final destination by a specialized company. The adsorption method consists of removing the pollutant from the aqueous medium by means of an adsorbent solid, controlling the pH, temperature and contact time between the residue and the adsorbent, the most common adsorbents being activated carbon, kaolinite and vermiculite (Magriotis et al., 2014).

Waste containing heavy metals or dyes are treated through adsorption. The most commonly used adsorbents at the CWML are activated carbon, kaolinite, and vermiculite. In the neutralization process, waste is treated by adjusting the pH to values from six to eight, and the following waste materials are treated through this process: inorganic acids, basic solutions that do not contain heavy metals, acid and basic salts, and waste containing toxic compounds (<0.1 mg L^{-1}). The precipitation process is used for treating waste containing solubilized heavy metals that can be conversed to their insoluble form through chemical reaction (Vogel & Svehla, 1982).

Solutions not presenting heavy metals are sent to the university's composting sector. In the distillation process, solvent containing waste are submitted to heating at controlled temperatures and the recovered solvents return to laboratories to be reused. Waste that do not have any treating option go through a drying process in a solar distiller developed by the CWML team, thus reducing the waste volume to be sent to specialized companies. The solar distiller is also used to dry the solids obtained from the precipitation process. The waste recovered and expired reagents are made available in a reagent bank to the academic community.

3. Results and Discussions

Initiating with the chemical waste generated from practical classes of the Chemistry Department, chemical waste treatment at UFLA started in 2006. In 2008, a survey of the passive and active waste generated in all laboratories the different university departments was conducted, and the CWML started to be build. In the following year, CWML began its activities of collection, treatment, and final disposal of the waste generated by UFLA's laboratories, thus institutionalizing the CWMP.

The UFLA's CWMP followed the pollution prevention hierarchy proposed in Pollution Prevention Act (PPA) by U.S. Environmental Protection Agency: (1) Source elimination or reduction, (2) Recycling or reuse, (3) Treatment and (4) Disposal (Goh et al., 2020). During the first year of operation, 12 tons of chemical waste, collected from UFLA's laboratories, and approximately 14 tons of chemical waste, stored in a concrete pit (deactivated after its emptying), were sent to destination. From this first action, the periodic collection of the chemical waste generated by the laboratories started at the university. Figure 3 shows the amount of chemical waste collected and treated by the CWML from 2010 to 2019.

The increase in the chemical waste collected between 2010 and 2012 resulted from the increased awareness of the academic community, obtained through training courses for laboratory technicians and lectures for the graduate students, who acted as disseminators of the knowledge acquired. In 2013, a decrease in the amount of the chemical waste collected and treated could be observed, which occurred in response to the expansion process of the CWML facilities. From 2016 to 2019, the 60 % increase in the collection of the chemical waste was attributed to the increase in the number of students of the university and the increased awareness of the academic community towards the importance of correctly disposing the chemical waste generated. Since the implantation of the CWMP there has been an increase academic community, in 2010 it was approximately 8,000 and currently has a population of 15,000 people, during this period CWMP enabled the correct disposal of 71,423 kg of solid and liquid chemical waste.

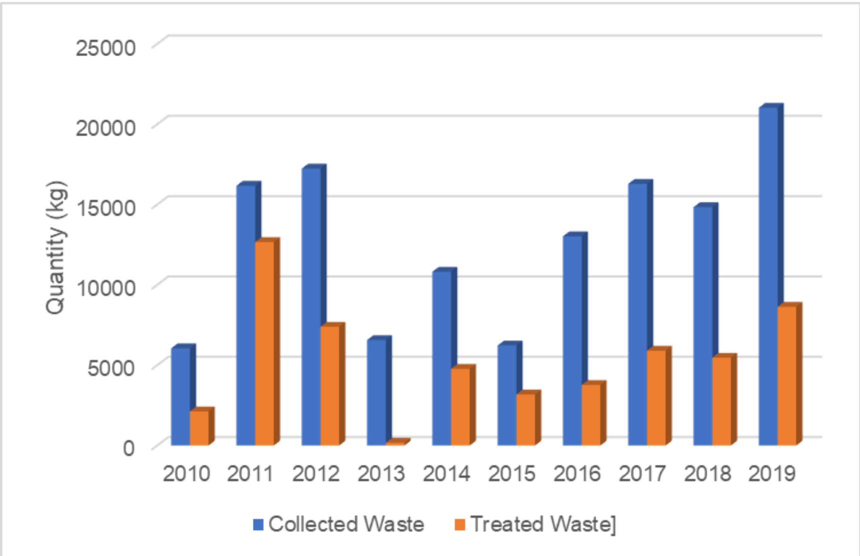

Figure 3. Amount of waste collected and treated between 2010 and 2019

The increase in treated waste, however, was due to the greater adhesion of the university community to the CWMP, as a result of the training actions and laboratory visits to instruct the correct segregation and identification of the waste. The development of new treating techniques by CWML team have also helped to increase in the amount of treated waste, since they enabled more efficient, faster, cheaper, and environmentally friendly treatment processes. The different chemical waste collected may be submitted to the treatments of neutralization, adsorption, precipitation, distillation, composting, or they can have their volume reduced through evaporation. The weighted of the treated waste by each of these treatment options can be observed in Figure 4.

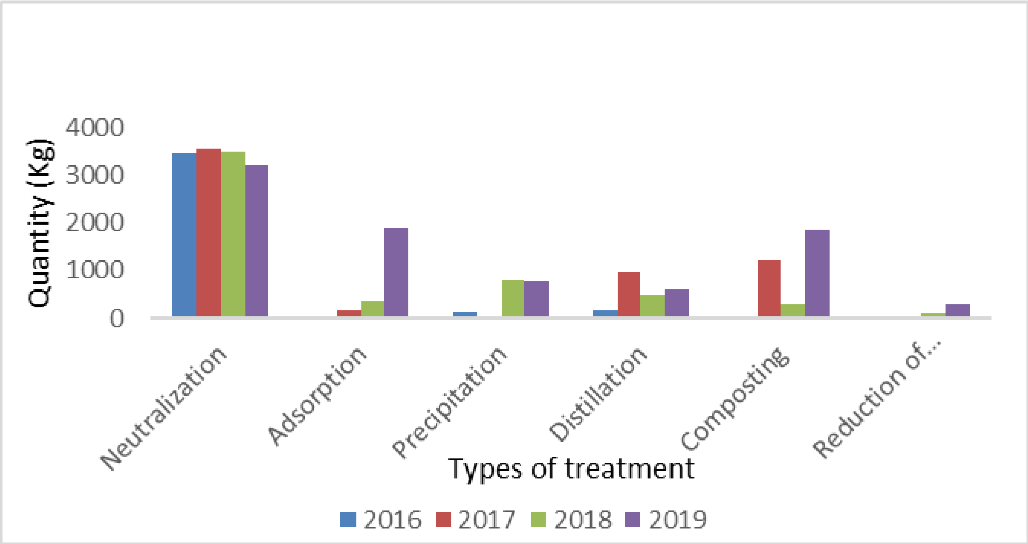

Figure 4. Amount of waste treated by type of treatment

Figure 4 shows that there was an increase in the amount of waste treated through adsorption, composting, and weight reduction through the years of analysis. The adsorption process, used to remove dyes and heavy metals, started in 2017, and 148 L of waste was treated through this technique. In the same year, more sustainable methods could be developed, which resulted in an increase of 400 % in the amount of adsorption treated waste. Among the new methods developed, the construction of adsorption (Figure 5A) and a filter (Figure 5B) column stand out, enabling the treatment of large volumes of waste by using recyclable materials that were previously not in use.

Waste containing essential metals such as Calcium, Magnesium, and Cupper, are sent to the organic matter composting system, and the compost originated from this treatment is used by the academic community. This treatment type started in 2017 and an increase of 52 % in the amount of the waste treated through this method could be observed in 2019 (Figure 4).

Aqueous waste, generated in large quantities and that do not have any defined treating method, have their volumes reduced before being sent to final disposal. Until 2018, this material used to be sent to final destination without any treatment, generating high cost for the university. After the adoption of waste drying in 2018, allowing the evaporation of the waste in the solar distiller, waste volumes could be significantly reduced with a low cost, representing savings for institution. The average volume reduction enabled through this treatment ranges from 90 % to 95 %, and this process is also used to concentrate heavy metals residues that are treated through precipitation. However, the drying process can only be used for treating thermally stable waste, which do not change under sunlight.

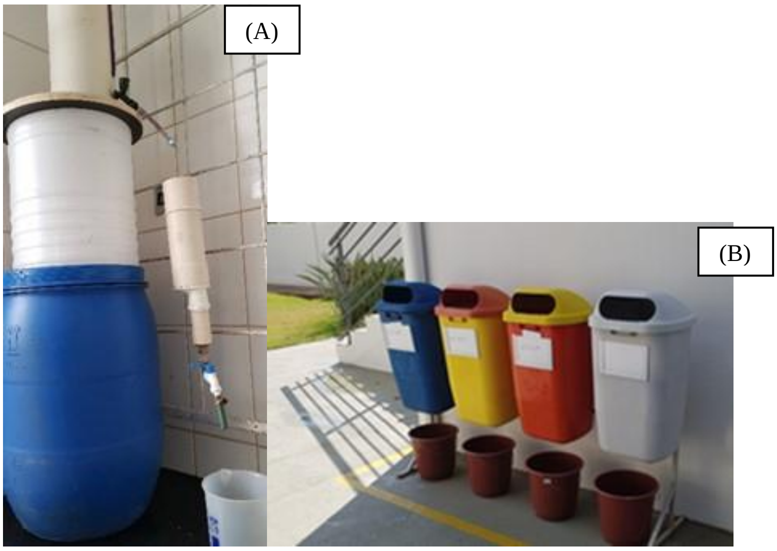

Figure 5. (A) Adsorption system and (B) Filtration system

On the other hand, the amount of waste treated through neutralization, precipitation, and distillation did not significantly change from 2016 to 2019, despite the increase in total waste amount produced in the university. This result comes from the fact that until 2016, the neutralization, precipitation, and distillation processes were basically the only waste treatments options available at UFLA, and the increase in the amount of chemical waste was thus compensated by the development and improvement of new treatment options, such as composting, adsorption, and volume reduction, which reduced the cost and dangerousness of the previously used treatments.

The chemical waste generated in universities can be very complex, considering that they often contain many different chemical substances on their composition, which complicates, and can even prevent, its treatment (Ho & Chen, 2018; Ramm et al., 2018). With the university expansion in the last years there was an increase of these residues generated, part of the chemical waste collected from UFLA's laboratories do not have an adequate treatment yet, and they cannot go through volume reduction processes because they contain volatile or potentially dangerous substances, or their treatment is very costly, both financially and environmentally.

For these types of waste, CWML has conducted studies with the aim of developing new treatment and recovering methodologies. However, for those waste materials that still do not have any treatment option, sending to destination by a specialized company is the alternative adopted by the university. In addition, waste that are not correctly identified during their generation processes, which prevents their treatment, are also sent to destination. In order to reduce the amount of waste sent to destination, CWML has intensified the training actions alongside the academic community, raising their awareness about the importance of carrying out the correct segregation and identification of the waste during its generation processes.

In addition to treating the waste, on-site monitoring of waste generation is also an important action conducted by the CWMP. It could be observed that the main waste producers are those department that, besides carrying out teaching, research, and extension activities, also provides services to the community outside the academic environment. CWMP actions in these departments have significantly improved the segregation of the waste, facilitating their treatment.

The waste treatment conducted through distillation have an important aspect to be considered: the organic solvent recovered in this case returns to the university laboratories to be reused in several applications, reducing the environment impacts caused by them and resulting in financial savings for the university. Comparing distillation and incineration treatments, distillation is environmentally more sustainable and about 8 times more economical than incineration (Coletti et al., n.d.; Hwang et al., 2017). The recovered solvents are analyzed through chromatographic techniques to access the quality and purity of the final product.

Another action that results in financial savings to UFLA is the implementation of Chemical Waste Exchange (CWE), a management tool that aims to make available internally chemical reagents with expired dates, which would be discarded (Barbosa et al., 2020). The CWML make available a bank of expired reagents, which are collected and stored at the CWML. These reagents are then distributed to the academic community and can be used during practical classes and initial tests in scientific studies, generating savings for the university considering that it prevents sending the reagent to final destination and the purchase of new reagents. From 2016 to 2019, UFLA has redistributed 4,362 kg of expired reagents. The Ezequiel Dias Foundation, a public institution of the Department of Health of Minas Gerais State implemented the CWE, in 7 years the internal economy was US$16,700.70 and for external institutions it was US$62,633.11 (Barbosa et al., 2020).

One of the crucial elements for the success of a chemical waste treatment program is the awareness of the academic community about the importance of the correct conditioning, segregation, and identification of the waste generated. Environmental education displays a fundamental role in raising community awareness of any work or project focused on the environment (Jardim, 1998).

In 2009, a training course offered for all laboratory technicians was conducted in order to present the program for them and integrate these important members of the academic community to the CWMP. This training course was the embryo for the professional master degree course of Environmental Technologies and Innovations, training UFLA professionals, government agencies, and environmental professionals. After the training course was given, the CWML team visited all laboratories in order to adjust their chemical safety and chemical waste management. In addition, from 2009 to 2012, lectures for UFLA’s graduate programs were given with aim of guiding and reinforcing the integration and knowledge of the CWMP with the students, contributing for the consolidation of the program. In 2013, the discipline entitled “Laboratory Safety: Legislation and Emergency Procedures”, which presents contents related to the CWMP and chemical safety, was created and started being offered for the graduate courses that carry out research activities in laboratories.

Despite the global training actions for the academic community, time is needed for training waste producers in the workplace. This training is enabled through laboratory visits for analyzing experimental conditions and explaining how to correctly dispose waste materials. The Waste Management System adopted by CWML has been a reference for Brazilian universities that seek ways to improve their chemical waste management. Over the years, management techniques have been improved, which has increased the efficiency of waste collection and treatment procedures. Process flows have been developed, establishing all the criteria to be observed from the waste generation stage to the treatment or final disposal stage. In addition, indicators are also constantly improved, always seeking the best evaluation of the work done at CWML.

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An important step for a university to become greener is the implementation of the Chemical Waste Management Plan. One of the most important ranking of green universities is the UI Green Metric World University Ranking on Sustainability that has ranked the greenest universities in the world since 2010. The CWML actions have certainly contributed for UFLA's score in the Green Metric ranking. Table 1 shows UFLA's position in the Green Metric ranking since its first participation in 2012 (Greenmetric (World University Rankings), 2020).

UFLA has risen 41 positions in the Green Metric ranking from 2012 to 2019, reaching the 29th position of the ranking that had the participation of 780 institutions in 2019. Until 2016, UFLA has occupied the first position of the ranking among the Latin America universities and, since 2017, the university is ranked in second position. In every year of analysis, the waste score of the university was among the best of the ranking.

Table 1. UFLA score in Green Metric between 2012 and 2019

Year	2012	2013	2014	2015	2016	2017	2018	2019
Ranking position	70	42	26	39	38	35	38	29
Total score	5516	6205	6771	6047	6422	6279	7475	7975
Infrastructure	501	511	605	809	1098	867	1375	1250
Energy and climate change	1195	1520	1295	1060	1139	1134	1300	1425
Waste	1500	1500	1725	1350	1125	1452	1425	1425
Water	1000	1000	1000	925	745	883	700	750
Transportation	650	1050	1150	841	1040	913	1225	1375
Education	670	624	996	1062	1275	1030	1450	1750

4. Conclusion

UFLA's Chemical Waste Management Program, carried out by the CWML, significantly contributes with the local community and the environment, since it reduces the environmental impacts caused by UFLA's teaching, research, and extension activities. Since its creation in 2009, the CWMP enabled the correct destination of 71,423 kg of solid and liquid waste, displaying a fundamental role for UFLA's good position in the Green Metric ranking, and contributed to the training of professionals committed to environment preservation through actions developed within the university, turning UFLA into a greener university. The CWMP cannot be static, because as the university's research areas increase, new residues can be produced, which implies developing new forms of treatments. Chemical Waste Management Program is an important tool for the universities to become “Green Universities” that have an important role in reaching a sustainable society. Moreover, the development and implementation of a CWMP in the universities contributes directly toward the professional qualification of the students and stimulate environmental awareness.

Author Contribution

The whole authors are contributed with conceptualization and validation. Also, to writing and review original draft articles.

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