RGSA – Revista de Gestão Social e Ambiental
ISSN: 1981-982X
Data de submissão: 08/02/2022
Data de aceite: 12/06//2022
DOI: https://doi.org/10.24857/rgsa.v16n2-018
Organização: Comitê Científico Interinstitucional
Editora Chefe: Christian Luiz da Silva
Avaliação: Double Blind Review pelo SEER/OJS

FREE GEOTECHNOLOGIES APPLIED TO BASIC SANITATION MANAGEMENT: A CASE STUDY AT THE EMPRESA BAIANA DE ÁGUAS E SANEAMENTO

Helder Guimarães Aragão[1]
Vilmar Alves Pereira[2]
Rodrigo Florencio da Silva[3]

ABSTRACT

Objective: The general objective of this article is to study the implementation of free geotechnologies, based on free software, in basic sanitation management.

Theoretical benchmark: The research brings perspectives aiming to demonstrate that the implementation of geotechnologies, based on free and free software, in the management of basic sanitation can reduce the costs of implementing information technology, as well as assist the process of combating water losses and waste.

Method: This study consisted of exploratory research with application in a case study at the Bahia Water and Sanitation Company. To assess the hypotheses raised by the survey, data from the company's information systems were used, as well as the answers from the online questionnaire applied to professionals in the area of geotechnologies.

Results and conclusion: The results pointed out that the free geotechnologies, based on free and free software, implemented in the basic sanitation company allowed a better management of basic sanitation, being important for the specific process of combating water losses.

Research Implications: The research contributes with the literature review and practical application of free and free geotechnologies applied in the management of basic sanitation, which allow the economicity and scalability of technological projects of this nature.

Originality/value: The results obtained in the present study are unprecedented, innovative and relevant for the scientific community, in the context of the use of free and free geotechnologies, in the management of basic sanitation and its process of combating water losses.

Keywords: Geotechnologies, Free Software, Sanitation, Environment.

GEOTECNOLOGIAS LIVRES E GRATUITAS APLICADAS NA GESTÃO DO SANEAMENTO BÁSICO: UM ESTUDO DE CASO NA EMPRESA BAIANA DE ÁGUAS E SANEAMENTO

RESUMO

Objetivo: O objetivo geral deste artigo é estudar a implementação de geotecnologias gratuitas, baseadas em software livre, na gestão do saneamento básico.

---

[1] Universidad Internacional Iberoamericana. Puerto Rico. Estados Unidos. E-mail: helderaragao@gmail.com
Ordic: https://orcid.org/0000-0002-2889-9404
[2] Universidad Internacional Iberoamericana. Puerto Rico. Estados Unidos. E-mail: vilmar1972@gmail.com
Orcid: https://orcid.org/0000-0003-2548-5086
[3] Escuela Superior de Ingeniería Mecánica y Eléctrica (ESIME) - Unidad
Ticomán del Instituto Politécnico Nacional. Ciudad de México, CDMX, MX. E-mail: rflorencio@ipn.mx
Orcid: https://orcid.org/0000-0002-9644-7645

Referencial teórico: A pesquisa traz perspectivas visando demonstrar que a implementação de geotecnologias, baseadas em software livre e gratuito, na gestão do saneamento básico pode reduzir custos de implantação de tecnologia da informação, bem como auxiliar o processo de combate a perdas e desperdício de água.

Método: Este estudo consistiu em uma pesquisa exploratória com aplicação em um estudo de caso na Empresa Baiana de Águas e Saneamento. Para a avaliação das hipóteses levantadas pela pesquisa, foram utilizados os dados dos sistemas de informação desta empresa, bem como as respostas do questionário online aplicado aos profissionais da área de geotecnologias.

Resultados e conclusão: Os resultados apontaram que as geotecnologias gratuitas, baseadas em software livre e gratuito, implementadas na empresa de saneamento básico permitiram uma melhor gestão do saneamento básico, sendo importante para o processo específico de combate a perdas de água.

Implicações da pesquisa: A pesquisa contribui com a revisão de literatura e aplicação prática de geotecnologias, livres e gratuitas, aplicadas na gestão do saneamento básico, as quais permitem a economicidade e escalabilidade de projetos tecnológicos desta natureza.

Originalidade/valor: Os resultados obtidos no presente estudo são inéditos, inovadores e relevantes para a comunidade científica, no contexto de uso de geotecnologias livres e gratuitas, na gestão do saneamento básico e o seu processo de combate às perdas de água.

Palavras-chave: Geotecnologias, Software Livre, Saneamento Básico, Meio Ambiente.

1 INTRODUCTION

Water resources are elements of nature with an undisputed essentiality for human life. The water available on planet Earth can be studied under the socioeconomic and environmental dimensions. In recent years, anthropogenic actions on the environment have generated significant negative impacts that jeopardize the conservation of this natural resource. In the context of the activities dealing with water, certainly one of the most important for society, lies in basic sanitation (Constantiov, 2010).

Basic sanitation can be defined as the process of water treatment and distribution, sanitary depletion and proper disposal of solid waste. To provide these services, municipalities and states need to jointly invest in building complex physical structures involving large-scale engineering. The construction of water treatment plants, water distribution networks and sanitary depletion and aqueducts that conduct water miles away are necessary (Leoneti, Prado, & Oliveira, 2011). In order to manage this type of structure, it is essential to rely on various technologies, mainly Information Technology, which is present today in various industrial activities.

Among the technologies that can be useful in the management of basic urban services, such as sanitation, are the geotechnologies that are proper for dealing with complex problems, which involve the treatment of spatial and spatialized data (Longley, Goodchild, Mguire, & Rhind, 2005). In spite of being widely used and important, geotechnologies have a high cost. Companies need to invest their budgets for the purchase of equipment, such as *Global Positioning System* (GPS), *Plotter* printers, as well as the subscription (subscription) of licenses of *software*(Martin, 2019). The costs of these licenses are accounted for annually, and therefore will be present whenever *software* is in use by a particular company. This scenario does not allow most companies to invest adequately in the deployment of geotechnologies. The amounts spent by companies in implementation and in implementation also include investments in specialized teams and consultancies. An alternative to reduce this cost is the adoption of free *software*.

The *free software* is one that does not necessarily require costs for its use and allows some freedoms for the end user of the computer program (Barahona, 2021). Users can install them on as many computers as they want and use them as they see fit in the business context. However, there is still a bias involving the efficiency and economicity brought about by the choice of free *software*. This is no different in the area of geotechnology.

In this context, this article, which is derived from a doctoral thesis, aims to answer the following central question: are *free* software-based geotechnologies efficient for assisting the management of basic sanitation infrastructure by bringing economicity and allowing scale? The following question arises from this question: does the implementation of geotechnologies help in the specific process of reducing water losses in basic sanitation?

Depending on the questions raised in this research, two hypotheses were constructed, namely:

- H1 Geo-technologies based on free *software* are efficient and have functionalities to assist the management of basic sanitation infrastructure bringing economicity and allowing scale;
- H2 The implementation of geotechnologies, particularly the Geographical Information System (GIS), assists in the specific process of reducing water losses;

This research is limited to the application of free geotechnologies in the area of basic sanitation, not covering other areas of urban infrastructure, such as natural gas supply and electric energy. It is important to highlight, as a result and contribution of this research, the analysis of the results of the implementation of open and free geotechnologies based on free software, in the process of basic sanitation management.

The results presented in this study demonstrate that free geotechnologies, based on free software, allow for scalability and economicity in the area of sanitation, contributing, in addition, to the important process of reducing water losses. As a consequence of this, the companies that manage basic sanitation will be able to direct, the investments saved, in their own shares of the business, which will impact on the improvement of important processes, such as those referring to combating water losses. This article is composed of this introduction, the theoretical reference, the methodology, the analysis and discussion of the results, the final considerations and, finally, the references used in the work.

2 THEORETICAL FRAME

In this section, the importance of water resources and basic sanitation will be addressed, as well as the themes concerning geotechnologies and free software, subjects that formed the basis for the work presented in this article.

2.1 Water Resources

Water resources, a fundamental part of the environment, are essential for society. Despite being abundant on the surface of planet Earth, the availability of these resources for human consumption is small. Water can be found in rivers, lakes, seas, glaciers and oceans. Saltwater, which is present in the oceans, covers about 75% of the surface of our planet. For non-drinking fresh water, approximately 3% are fit for human consumption (Sekyere, Davis, Fiagbe, & Amoo, 2020). This small percentage of available fresh water needs to be treated so that it can be consumed and used by society. It is worth noting that the water that can be used, i.e. drinking water, is not available to everyone equally (Galindo, 2009).

The rational use of the available water resources depends on the actions of various players: citizens, governments and companies that carry out the management of basic sanitation. Economic development and the growing population of the world increase the demand for drinking water every year. This scenario makes water scarce and less accessible to society. Water is a finite commodity and its scarcity has been studied for a long time due to the great concern of the authorities about the survival of future generations (Sekyere, Davis, Fiagbe, & Amoo, 2020).

The 20th century was marked by advances in the processes of making use of water resources. At the beginning of this century, the use of these natural resources ceased to be something local, being exploited intensively and by various sectors of society. This created a crisis over water use in the late 20th century and society matured understanding of its multiple uses, bringing to light the concept of sustainability. Significant investment in basic and urban infrastructure, including those related to water use and exploitation, was made after World War II. In this period, there was a growing industrialization and urbanization of the countries, bringing a series of consequences for the environment, which ended up generating an environmental crisis at the end of this century (Tucci, 2001; Galindo, 2009). The degradation of natural resources and the living conditions of the population began to intensify.

In the 1970s, society began to discuss and consider the rational use of natural resources. A social mobilization, in favor of the proper use of water resources, has come to be present in the daily life of many people. This kind of mobilization was supported by several developed countries, bringing about the approval of the first environmental legislation. Understanding of the relationship between the use of natural resources, including water and the global impact, began in the following decade, that is, in the 80s (Tucci, 2001). Brazil approved its environmental legislation during this period, determining for the Brazilian states principles, guidelines, instruments and attributions about the environment. Law number 6.938/81 instituted the so-called National Environment Policy, which created the National Environment System (SISNAMA) (Moura A. M., 2016).

The global view about the use of water resources was maturing and, in the 90s, the world authorities, together with society, started to discuss sustainable development with a view to environmental conservation. This maturation brought the need for reflection on the better use of water in an integrated and multifinalitarian way (Moura A. M., 2016).

Water resources are closely linked to the environment and to the dignity of the person. The preservation of these resources is essential and should always aim to not compromise the survival of future generations (Ribeiro & Rolim, 2017). The scientific community has been studying for several years trying to understand the global and social impact of the absence of water and water sources preservation, as well as the unbridled exploitation of this natural resource. The work of (Li, et al., 2018) describes that understanding the environment and the consequences of human activities on it is fundamental to knowing what influence society and its activities have on nature. The environment when preserved promotes development in a sustainable way and reduces poverty (Xiang, Li, Khan, & Khalaf, 2021).

(Romeiro, 2012) addresses the theme of sustainable development in his work and states that this concept emerges from a need to consider a balance of ideas between the developmentists and the defenders of zero growth. Scientists and authorities, who advocate zero growth, warn of the present environmental limits, pointing out that the current reality can generate environmental disasters, more and more frequent, should this economic model of development, from the richer and capitalist countries, continue in an unbridled manner over the next few years. The authors (Hickel & Kallis, 2020) question, in their study, the possibility of balancing the growing economic development in line with the preservation of the environment of our planet. There is a group that believes in this possibility while there is another group that disputes it.

(Hickel & Kallis, 2020) state that, by analyzing relevant studies of history and future model-based projections, there is no evidence that it is possible to balance the preservation of natural resources on a global scale with unlimited economic growth. They conclude that it is unlikely that the reduction in carbon emissions will in fact be achieved at acceptable rates and in a rapid manner, avoiding global warming above 1.5º or 2º.

(Machado, et al., 2022) conclude that the occupation of the Atlantic Rain Forest biome, with a focus on industrial activities, without promoting the preservation of the environment, is causing several environmental problems in that region. Amongst these problems, the lack of conservation of riparian forest stands out, which directly impacts on the water quality of the river. The conservation of the Environmental Protection Areas (APA) and the water sources need to be part of the discussions about the exploitation of water resources. Water sources are the elements that will guarantee future water sustainability.

The subject of water management is still present today. In 2015, the United Nations (UN), which is concerned about this management, created the so-called Agenda 2030, which sets the objectives for global sustainable development in the world, including the theme of water and sanitation. This was a worldwide commitment made by the 192 signatory countries among them Brazil (United Nations Brazil, 2022) (Borelli, 2020) (Miranda, Mendonça, Melo, & Melo, 2021).

Agenda 2030 established 17 key objectives for global sustainable development, which were called Sustainable Development Goals (SDGs) (Zimpier, Stefani, & Dias, 2022). These objectives are:

1. poverty eradication;
2. zero hunger and sustainable agriculture;
3. health and well-being;
4. education and quality;
5. gender equality;
6. drinking water and sanitation;
7. clean and affordable energy;
8. Decent work and economic growth;
9. industry, innovation and infrastructure;
10. reducing inequalities;
11. sustainable cities and communities;
12. responsible consumption and production;
13. action against global climate change;
14. Life in water;
15. terrestrial life;
16. effective peace, justice and institutions;
17. partnerships and means of implementation.

Among the Agenda 2030 SDGs, number 6 refers to drinking water and sanitation given the importance for global development (Miranda, Mendonça, Melo, & Melo, 2021). In SDG 6, the goals are described, which aim to ensure access to quality drinking water through the development of basic sanitation. These targets are accompanied by indicators to be measured with the intention of knowing whether any given objetive is being met or not. In order to meet the goals of SDG 6, it is necessary for countries to invest in basic sanitation, a theme addressed below.

2.2 Basic Sanitation

The fresh water available on our planet is not in a condition for human consumption and should be submitted to a complex and costly treatment process, depending on the pollution of the environment and its water resources. Domestic sewage, untreated industrial effluents and the intensive use of chemical inputs for agribusiness activities are among the major vectors of water pollution (Ferreira & Cunha, 2005). In this context, a key industrial activity for life in society is the basic sanitation industry.

Basic sanitation means the appropriate water treatment, the process of sanitary depletion and the treatment of solid waste. This concept has been expanded beyond proper water treatment and potability. The essential conditions for the provision of this basic infrastructure are complex and must include the abstraction of water from water sources, the treatment of this water and its distribution to people. In addition, the complete structure is necessary for the management of the sanitary depletion (Sobrinho, 2012). As an activity essential to human life, countries, above all the more developed ones, seek to create public policies aimed at their implementation and the possible reduction of environmental damage, with some requirements in relation to developing countries. In some situations, in keeping with the environmental agendas, this generates some tensions that are not always followed by the two parties.

In Brazil, most of the companies responsible for providing basic sanitation are public companies linked to a federal state. In order to provide treated water for human consumption, these companies need to make major investments and manage complex infrastructure, which include water treatment plants, sewage treatment plants, water distribution networks and sewage treatment plants.

Sewerage companies are faced with several challenges for the realization of their infrastructure management. Among these challenges is combating water losses, which in a water supply system can be divided into two types: real and apparent (Nephew, 2012). Real water losses occur in the distribution of water through supply networks. Water leaks are the greatest example of a real loss. The apparent losses, on the other hand, are those related to the lack of payment for the service provided or for clandestine connections, and are therefore also a socio-economic problem (Costa & Périco, 2021).

In addition to the challenge of combating water losses, disorderly occupation in urban areas contributes to increasing the complexity of water availability in large urban centers. This is because, historically, many areas of the cities were occupied without proper urbanization and proper public policies, which promoted the absence of basic infrastructure such as energy and sanitation.

In Brazil, there is a historical deficit in relation to the lack of investments in basic sanitation services. Unrestricted access to this service is essential to promote an egalitarian society and the preservation of the environment. It should be noted that there is interest in the inclusion of private companies in the sanitation market in this country. In 2020, the Legal Framework for Sanitation was approved, which aimed at a greater participation of private companies in this area, to the detriment of public investments (Sousa, 2020).

Understanding the factors that provide such a situation is fundamental to change this reality, besides investigating less costly alternatives for the implementation of sanitation. Information Technology is one of the areas that has become strategic in various industries. This is no different in the context of sanitation. However, many widely available computing tools have a high development and deployment cost, often requiring consultancy services that are prohibitively valuable to most organizations. Among the Information Technologies available for the area of urban infrastructure management, the highlight is geotechnologies, which are specific to addressing problems involving large spatially dispersed urban structures (Martin, 2019).

2.3 Geotechnologies and *Free* Software

Geotechnologies can be defined as a set of technologies that aim to store and process spatial data. This set of technologies can be used in several areas, such as municipal management, environment, agribusiness, public sanitation services, electrical energy and telecommunications (Longley, Goodchild, Mguire, & Rhind, 2005). Among the technologies in the context of geotechnologies, the following stand out:

- *Global Positioning System* (GPS) is a system that allows the capture of coordinates of the Earth's surface. This equipment is fundamental for the production of digital cartography;
- Remote Sensing: is a technology that allows the sensing of the Earth's surface in a remote way, enabling the imaging of the Earth. Satellite images, which have become popular through tools such as Google Maps, fit this type of technology (GoogleMaps, 2022)
- Geographical Information Systems (GIS) and spatial databases: are geotechnologies that perform the processing and manipulation of geospatial data for subsequent availability of analyzes and visualizations of digital maps.

Geotechnologies can assist professionals at the operational, tactical and strategic level. Specifically in the strategic area, managers benefit from them for decision-making. They can perform complex spatial analyzes that other computing solutions do not allow, and in this way it is possible to generate answers to questions such as: where are my consumers concentrated? Where is my urban infrastructure? Only geotechnology solutions are able to provide tools to answer questions involving geographic space, because they bind tabular data with an associated spatial view (Longley, Goodchild, Mguire, & Rhind, 2005).

Although it is a recognized technology that is indispensable for companies that need to manage complex and geographically scattered infrastructure, such as basic sanitation, geotechnologies are expensive and often prohibitive for a large part of companies. Even larger companies, with a budget *dedicated to IT projects, feel the cost impacts from consulting to licensing* annual *software*.

As a result, deployment is often timely and non-scalable. The cost invested in *software* licensing, that is, the cost of paying for the use of a given computer program, corresponds to a good part of the value of the deployment (Martin, 2019). This cost also interferes with the continuity of the projects for the implantation of geotechnologies, because today they are offered in the modality of signature, forming themselves into an annual cost. An alternative to this scenario is the adoption of free geotechnologies based on free *software*.

A free *software* is a computer program that allows the user to run, access, and modify their source code without necessarily having to bear licensing costs. The redistribution of free *software* is a feature of this type of program, which makes it possible to adopt it massively and to democratize information technology. A great example of free *software* is the Linux operating system that makes the computer more accessible and cheaper for companies that adopt it (Barahona, 2021).

Adopting free *software* means having the freedom to develop new projects derived from the original product. A *software* of this type may even charge some value, or financial donations, however, such a practice is not common. The fact is that for a computer program to be classified as free, it need not necessarily be free, but allow the freedom to know the source code and to be able to redistribute it (Barahona, 2021). Among the main advantages of free *and* free software, they are: the knowledge of how it was developed, the freedom of use and the scalability of the computational projects, since there is no cost with the licensing, the user has the possibility to install on as many computers as he wishes.

Free *software* emerged and gained notoriety in the computer world in the 1980s. In 1983, system developer Richard Stallman announced the GNU project with the goal of creating a Unix-based operating system. From this, this type of program gained popularity as a function of the universities and the advance of the Internet (Barahona, 2021).

The free *software* movement in the context of geotechnologies is very mature and this is measured by the tradition of existing developer and project communities. There are several free and free projects that allow the construction of geotechnologies such as the GIS and the geographical database. Among the existing projects, Mapserver, QGIS and PostgreSQL with POSTGIS stand out. Mapserver is a type of map server that makes it possible to build GIS in a web environment (Kropla, 2005). QGIS is a *desktop* tool, that is, installed on the user's machine for manipulating spatial data (QGIS, 2022). Finally, PostgreSQL is a database that allows the use and processing of spatial data.

2.4 Geotechnologies for the management of basic sanitation

Geotechnologies can be used in various areas, such as public safety, the environment, education and sanitation. In the latter area, some works describe the effective use of geotechnologies. (Candido, 2008) shows the use of SGIs for carrying out spatial analyzes of interventions in the water supply in the city of Belo Horizonte, the capital of Minas Gerais in Brazil. In the work, the researcher assessed the number of savings achieved, that is, the extent of interruptions in the supply, as well as the volume of water impacted. Second (Cançada, 2008), only a system with spatial vision allows the analysis of interruptions through mathematical assumptions and space operation.

(Kereyu, 2013) addresses the implementation of the GIS for the evaluation of water quality. This work carried out complex spatial and temporal studies, which allowed the evaluation of the impacts of this quality on human activities. The study also analyzed the efficiency of water distribution and management. According to the author, the GIS helped to assess the quality of the water, making it possible to associate the studies with other data, such as land use and demography, which contributed towards an interpretation and clarification of the causes of possible contaminants.

(Moura & Procopiuk, 2020) carried out work with the aim of having a view of the geographical distribution of the basic sanitation service. The study of this research was carried out in the state of Paraná, Brazil, with data collected from the years 2000, 2010 and 2016. This data possessed the temporal distributions and spatial patterns of basic sanitation. In this way, the GIS allowed the spatial visualization of the changes in the rates of this service over time.

(Kennedy, 2019) shows the application of the use of GIS to combat water losses, a challenge faced by sanitation companies. According to the researcher, the GIS made it possible to find the leaks, which are responsible for a major part of the physical losses of water in a distribution network. Therefore, it was possible to know where the water losses were occurring, which helped the distribution network maintenance teams in the correction of water leaks, thus avoiding water waste. (Kennedy, 2019) describes in his research that significant changes in water loss levels were observed after the implementation of geotechnology.

3 METHOD

This study can be classified as applied because it aimed to produce knowledge for practical applications with the focus on solving a given problem. As to the objective, the present article is of the exploratory type as a function of the bibliographical reviews carried out for later application in a case study (Sant Ana & Lemos, 2020; Sampieri, Collado, & Lucio, 2013).

A case study can be considered as the description and analysis of some case that presents a particular characteristic, aiming to extrapolate, for other similar cases, the results achieved (Pereira, Shitsuka, Parreira, & Shitsuka, 2018) (Menezes, Duarte, Carvalho, & Souza, 2019).

To achieve the goals of the research presented in this article, it was necessary to divide it into phases. The first phase was to carry out in-depth bibliographic research on the related themes, starting from theoretical references of works such as dissertation, doctoral theses, books and articles at renowned conferences. This bibliographic research focused on the theme's framing in the area of geotechnologies, based on free and free software, applied in the management of basic sanitation (Menezes, Duarte, Carvalho, & Souza, 2019).

The second phase was the study of the implementation and application of geotechnologies, based on free and free software, at Empresa Baiana de Águas e Saneamento (EMBASA), a public company of mixed economy of the state of Bahia, responsible for the provision of basic sanitation services for the majority of the municipalities of that state. It was created in 1971 by State Law 2929. In 1975, it was incorporated into two other companies until then responsible for the provision of water supply and sanitary depletion services of Salvador and the interior of the state of Bahia (EMBASA, 2021). In addition, the second phase was able to count on an electronic questionnaire application, whose questions aimed to validate or refute the hypotheses described in the introductory section of this article.

The questions of the electronic form were elaborated using the Likert scale of six points. This type of scale was chosen because it is the one that best represents the degree of agreement with respect to a given assertive. Thus for each statement presented in the questionnaire, the participants were able to present their opinion in a gradation that was from 1 (total disagreement) to 6 (total agreement).

In the third phase, the data were collected from the company's information systems as well as from the *Microsoft Forms* electronic questionnaire platform. Finally, in the fourth and final phase, the data underwent an analysis and the answers to the questionnaire were tabulated in *Microsoft Excel*, with the objetive of recording the results of the research. In this article, the results of two of the three hypotheses were addressed, as it is the partial results of a doctoral thesis.

4 RESULTS AND DISCUSSIONS

For the validation of the hypotheses H1 and H2 addressed in the introductory section of this article, some variables were analyzed. Specifically in the H1 hypothesis, a quantitative variable on the projected cost was calculated, which the case study company would have if perhaps the free, free *software* were not adopted. Currently, the geotechnologies implemented at EMBASA have 1706 registered users, which represent almost 40% of the company's employees. Therefore, the company allows 1706 users to use the SIGs and all their functionality without any *software* license costs. If the company wants to add new users over time and serve the entire workforce of the company, there is no hindrance, because all technologies are free. Thus, it is observed that the adoption of free *software* makes it possible for the project to be scalable.

To contemplate the question of economy addressed, also, in H1, a comparison was made, if the *proprietary software* ArcGIS *was adopted*, which has a cost of around 100 dollars a year, per license (ArcGIS price, 2022). In other words, the company would have to pay the amount of 100 dollars per user per year so that it could enjoy the functions of the GIS if it opted for ArcGIS.

In this case, the company would have to bear a cost of approximately $170,600 per year to serve the 1,706 users currently using free geotechnologies. Whereas free geotechnologies based on free, free *software* at EMBASA have been deployed since 2007, the projected economy is $2,559,000 over these 15 years. This saved value could, therefore, be directed towards updating the technology park, as well as to meet other demands of the technology area, or even to carrying out investments in the basic sanitation infrastructure itself.

Also in the validation of H1, electronic questionnaires were applied to 101 professionals, aiming to measure the perception of the professionals, who use the geotechnologies at Embasa, with respect to the efficiency of these technologies. The total number of responses was 70 and the respondents were users of the geotechnologies implemented by the company or knew something about them.

When asked whether they considered *free software*-based geotechnologies to be efficient in assisting the management of urban sanitation infrastructure, the results shown in Figure 1 showed that:

- 4.3% said they did not know how to respond;
- 24,30 % of respondents agree with the statement;
- 68.60 % said they fully agree with the statement.

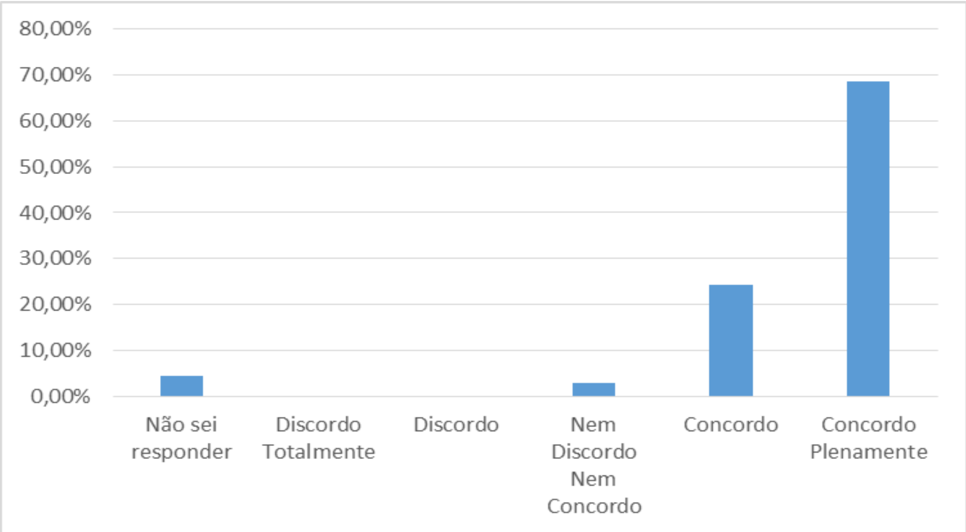

Figure 1: Answers to the statement, I consider that *free* software-based Geotechnologies are efficient for assisting the management of urban sanitation infrastructure. Elaborated by the author himself.

The survey participants, when asked whether they considered that there were no limitations in the features of the geotechnologies adopted by the company, such as Geoweb (corporate geographic information system) and QGIS, because they were developed with *free* software, obtained the following results, demonstrated in Figure 2:

- 4.3% said they did not know how to respond;
- 7.1% disagreed with the statement;
- 4.30% said they neither agreed nor disagreed;
- 34,30 % of respondents agreed with the statement;
- 50.00 % said they fully agreed with the statement.

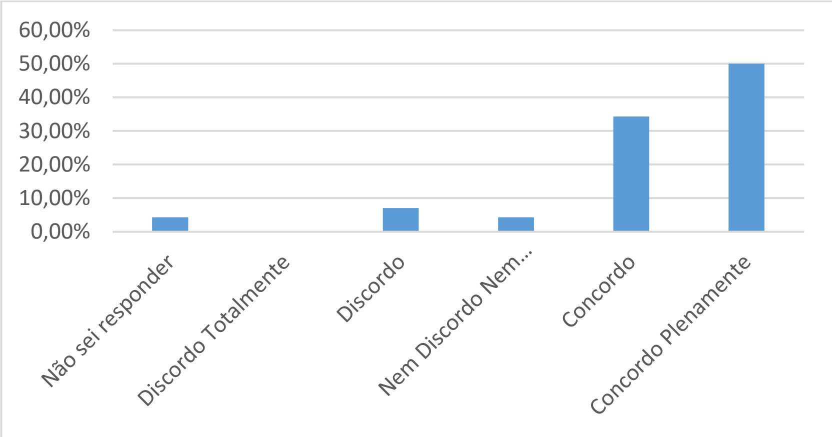

Figure 2: Answers to the statement "I consider that there were no limitations in the functionalities of the Geotechnologies adopted by the company, such as *Geoweb* and QGIS, as they were developed with free software". Elaborated by the author himself.

Finally, the respondents to the electronic questionnaire had to agree on the following assertion: "I believe that *free* software-based Geotechnologies bring cost savings and allow scalability, that is, the growth of the number of users and functionality". For this question, as shown in Figure 3, the following results were found:

- 4.3% said they did not know how to respond;
- 28,60 % of respondents agreed with the statement;
- 67,10 % said they fully agreed with the statement.

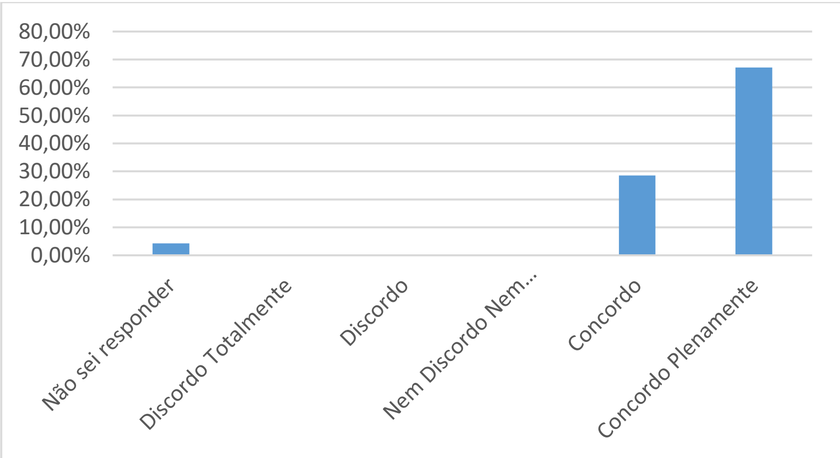

Figure 3: Answers to the statement "I consider that free software based Geotechnologies bring cost savings and allow scalability, that is, the growth of the number of users and functionality." Elaborated by the author himself.

On the basis of the results, it can be observed that the users of free and free geotechnologies, used at EMBASA, understand that there is no limitation of functionalities and that they allow the economicity and scalability of the projects.

To verify the H2 hypothesis, the geotechnologies applied to a given supply zone of the city of Salvador, capital of the State of Bahia, Brazil, were studied. A supply area is defined as a well-defined operational area, which is intended to serve a group of consumers. The supply zones at EMBASA are identified by numbers and the chosen one for the present study was zone number 41, as shown in Figure 4.

A number of thematic maps have been implemented in the corporate GIS called Geoweb in order to allow, in the supply zone 41, several geographical analyzes fundamental for combating water waste. In Figure 4, one can observe a thematic map showing the consumers who had the last consumption of water accounted for outside their usual average over the last 6 months. In this way, the company's professionals can carry out, in the field, actions to check if there have been leaks and consequent waste of water. This analysis can be done before going into the field.

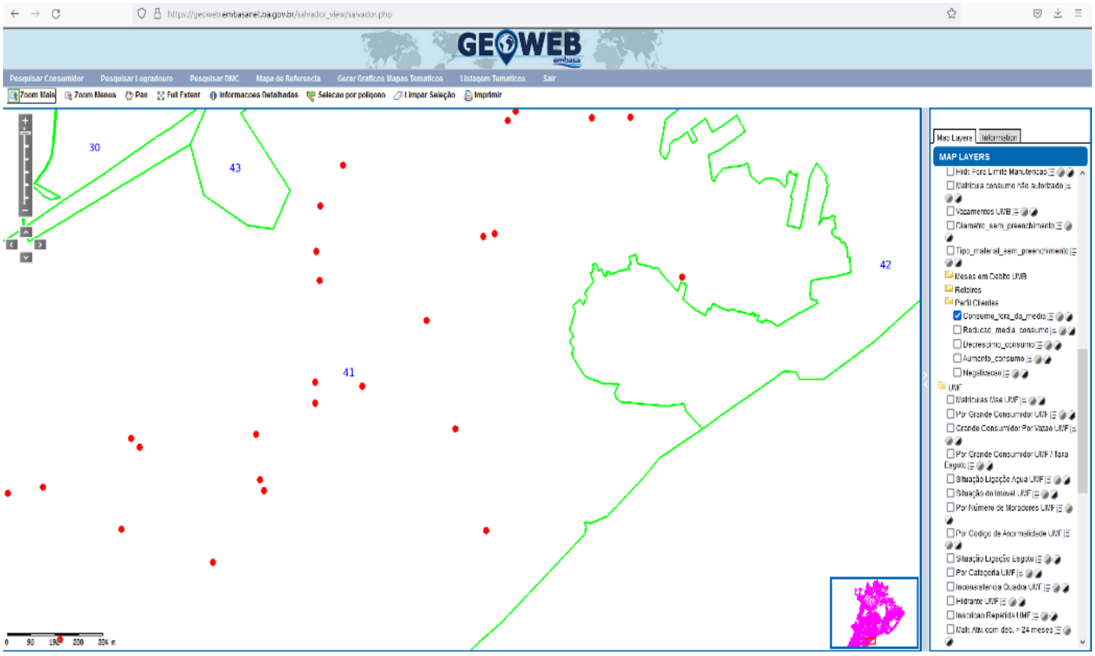

Figure 4: *Geoweb* image with supply zone 41 showing consumers with consumption outside the average of the last 6 months. Elaborated by the author himself.

Company managers may use spatial data in GISs to view consumers and their related data. It is possible to group consumers, geographically, according to their characteristics, such as residential or industrial. In addition, it is possible to visualize the entire water supply network network mesh of supply zone 41, which allows to have a spatial and operational view as shown in Figure 5. In this Figure, you can see points in red, which represent the location of each consumer in the company and lines in blue, which are the water supply networks. In addition, the system user can view orthophotos, that is, georeferenced photos with high precision which enriches the spatial view of the data.

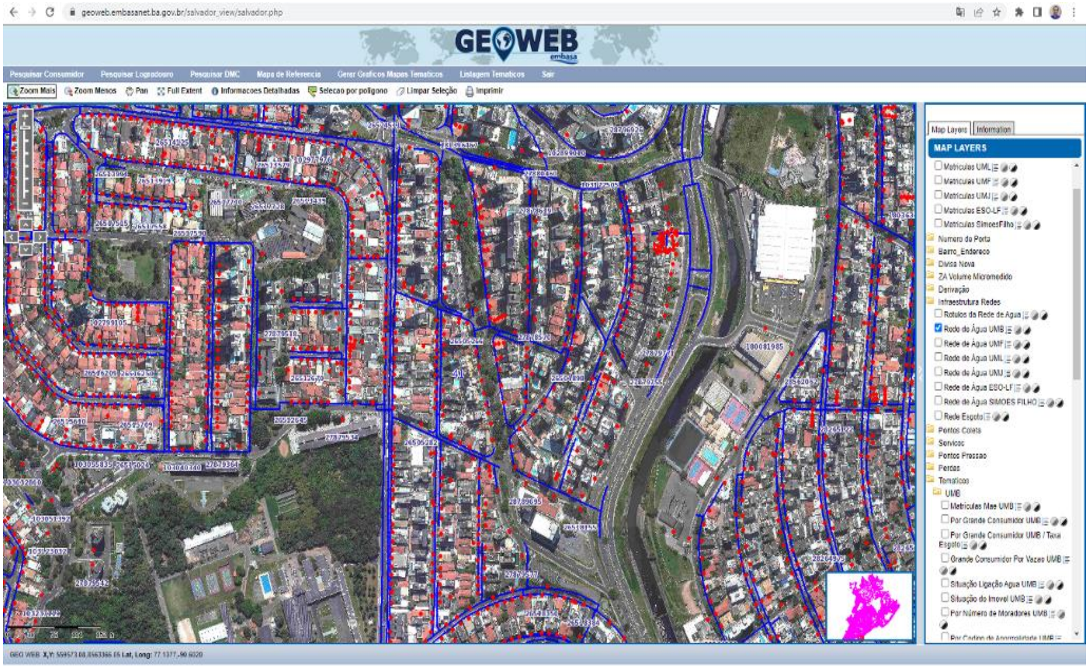

Figure 5: *Geoweb* image of water supply networks and consumers. Elaborated by the author himself.

By clicking on each line in blue, the user can have access to operational data from the water supply networks such as diameter, material and extension. It can be seen in Figures 4 and 5 that the use of geotechnologies allows a better operational management of the company, above all, for combating water losses. This may have contributed to this specific supply area having a low loss rate of 23.0%, below the national average of 39.2% (SNIS, 2019). This supply area consists of 29 344 consumers of drinking water. The period from August 2021 to July 2022 was taken into account for measuring the loss index.

The results of this research show that the investment in free and free geotechnologies and in technical and operational registration, can have a positive effect on the management of basic sanitation, above all, in the process of reducing water losses. This is because, as has been described in this work, decision-makers are able to carry out more assertive actions to combat leaks and fraud because they know in advance the exact location of both consumers and water supply networks.

5 FINAL CONSIDERATIONS

In response to the hypotheses advocated in the present study, it is possible to state that the implementation of free and free geotechnologies allowed the development of solutions in the area of Information Technology, aiming to optimize the management of basic sanitation without adding costs to the company.

In relation to the first hypothesis, it was observed that, in respect of the cost of *software* licenses, the result in the economy was significant, making it possible for the company to make the geotechnologies scalable and accessible in an unrestricted manner for the company's employees and managers. Considering the results obtained from the questionnaires applied to EMBASA professionals, it was observed that the majority of respondents considered that, depending on the adoption of free *and* free *software*, there was no harm in the question of efficiency of geotechnologies.

Analyzing the results for the confirmation of the H2 hypothesis, it was found that geotechnologies are fundamental for maintaining the loss indices at acceptable levels. The supply zone used in the study had an average index of 23.0%, below the national average, as described in the results and discussion section.

The results of the research showed that free and free geotechnologies bring economicity and efficiency in the management of basic sanitation. It is also concluded that this type of Information Technology is fundamental to help in the process of combating real water losses. In this way, sanitation companies can improve their management by reducing water waste and contributing to the environment.

This research was limited to the application of free and free geotechnologies in the area of basic sanitation. Therefore, other urban infrastructure services were not addressed. For future work, it is recommended to use the technologies described in this article in utility companies that are responsible for the service of the supply of electricity and natural gas that present challenges similar to those of sanitation companies. This future work will bring comparative results to see if the models apply to other business contexts.

REFERENCES

ArcGIS price. (2022). ArcGIS Price. https://www.esri.com/pt-br/arcgis/products/arcgis-online/buy#para-indiv%C3%ADduos.

Barahona, J.G. (2021). A Brief History of Free, Open Source Software, and its communities. *Open source expanded*.

Borelli, E. (2020). Basic sanitation policy in Brazil versus Agenda 2030. *Semicolon Magazine*.

Constantin, G. N. (2010). New Paradigms of Environmental Credits. *Environmental law: the environment in contemporary times.*, 1-491.

Costa, M. M., & Périco, A. E. (2021). *Basic Sanitation and Regulatory Agency: a case study.* Dialectic.

EMBASA. (03 of 12 of 2021). *EMBASA*. Source: www.embasa.ba.gov.br

Ferreira, A., & Cunha, C. (2005). Environmental sustainability of the water consumed in Rio de Janeiro, Brazil. *Rev Panam Salud Publica/Pan Am J Public Health*.

Galindo, E.F. (2009). *Cities and their waters: the interface urban management / water resources management for environmental sustainability*. [Doctoral Thesis, Federal University of Pernambuco].

GoogleMaps. (03/02/2022). Source: https://www.google.com.br/maps

Hickel, J., & Kallis, G. (2020). Is Green Growth Possible? *New Political Economy*.

Kennedy, R. (2019). The Impact of Application of GIS Technology on non-revenue water levels: a case study of Narok water and sewerage services company.

Kereyu, D.D. (2013). A GIS based water quality management - a case study of water supply for the city of Nairobi.

Kropla, B. (2005). *Beginning Mapserver: Open Source GIS Development.* Hurry.

Leoneti, A. B., Prado, E., & Oliveira, S. (2011). Basic sanitation in Brazil: considerations about investments and sustainability for the 21st century. Journal of Public Administration.

Li, X., Cheng, G., Ge, Y., Li, H., Han, F., Hu, X., . . . Fall, X. (2018). Hydrological Cycle in the Heihe River Basin and Its Implication for Water Resource Management in Endorheic Basins. *Advancing Earth and Space Science*.

Longley, P. A., Goodchild, M. F., Mguire, D. J., & Rhind, D. W. (2005). *Geographic Information System.* John Wiley & Sons.

Machado, P. P., Contarini, L. d., Rocha, L. S., Junior, J. L., Milaneze, L. A., Silva, M. P., & Rodrigues, B. D. (2022). Geoprocessing applied to the environment area: a case study based on digital image processing and remote sensing. *Brazilian Journal of Development*.

Martin, G. (2019). *Water Industry GIS Capabilities Survey Results.* Source: https://spatialvision.com.au/wp-content/uploads/2019/04/2018-19-GIS-in-Water-Industry-Report-SPATIALVISION-V1.pdf.

Menezes, A. N., Duarte, F. R., Carvalho, L. R., & Souza, T. S. (2019). *Scientific Methodology Theory and Application in Distance Education.* Publisher of Univasf.

Miranda, D. L., Mendonça, A. T., Melo, M. C., & Melo, E. D. (2021). Environmental Education from the agenda 2030: experiences of awareness and rational use of water in a municipal school of Varginha (MG). *Brazilian Journal of Environmental Education*.

Moura, A.M. (2016). Trajectory of the Federal Environmental Policy in Brazil. In *Environmental Governance in Brazil: institutions, actors and public policies.* Ipea.

Moura, E. N., & Procopiuk, M. (2020). GIS-based spatial analysis: basic sanitation services in Parana State, Southern Brazil. *Environmental Monitoring and Assessment*.

Nephew, R.A. (2012). Management of Water and Energy Losses in Water Supply Systems of Embasa: a study of factors intervening in RMS [Master's Dissertation, Federal University of Bahia).

Pereira, A. S., Shitsuka, D. M., Parreira, F. J., & Shitsuka, R. (2018). *Scientific Research Methodology*. NTE.

QGIS. (02 of 03 of 2022). Source: QGIS: www.qgis.org

R.D. (2008). Spatial Analysis of Interruptions in the Water Supply of Belo Horizonte: exploratory approach using GIS [Doctoral Thesis, Pontifical Catholic University of Minas Gerais].

Romeiro, A. R. (2012). Sustainable development: an economic and ecological perspective. *Advanced Studies*.

Sant Ana, W. P., & Lemos, G. C. (2020). Scientific Methodology: qualitative research in the views of Lüdke and André. *Electronic Scientific Journal Interdisciplinary Teaching*.

Sekyere, C. K., Davis, F., Fiagbe, A., & Amoo, R. (2020). Techno-Economic Assessment of Non-Revenue Water: A Case Study at AER, GWCL. *Journal of Water Resource and Protection*.

SNIS. (2019). SNIS Report. http://www.snis.gov.br/downloads/diagnosticos/ae/2019/Diagnostico-SNIS-AE-2019-Capitulo-08.pdf.

Sousa, A. A. (2020). What to expect from the new landmark of sanitation? *Public Health Notebooks.*

Tucci, C.M. (2001). *Overview of Water Resources.* Ministry of Science and Technology / Center for Management and Strategic Studies.

United Nations Brazil. (2022). Recovered at https://brasil.un.org/pt-br/sdgs.

Xiang, X., Li, Q., Khan, S., & Khalaf, O.I. (2021). Urban water resource management for sustainable environment planning using artificial intelligence techniques. *Environmental Impact Assessment Review*.

Zmpier, M., Stefani, S., & Dias, B. (2022). **Sustainable development goals - SDG, in the context of the covid-19 pandemic in cooperatives.** Journal of Social and Environmental Management.